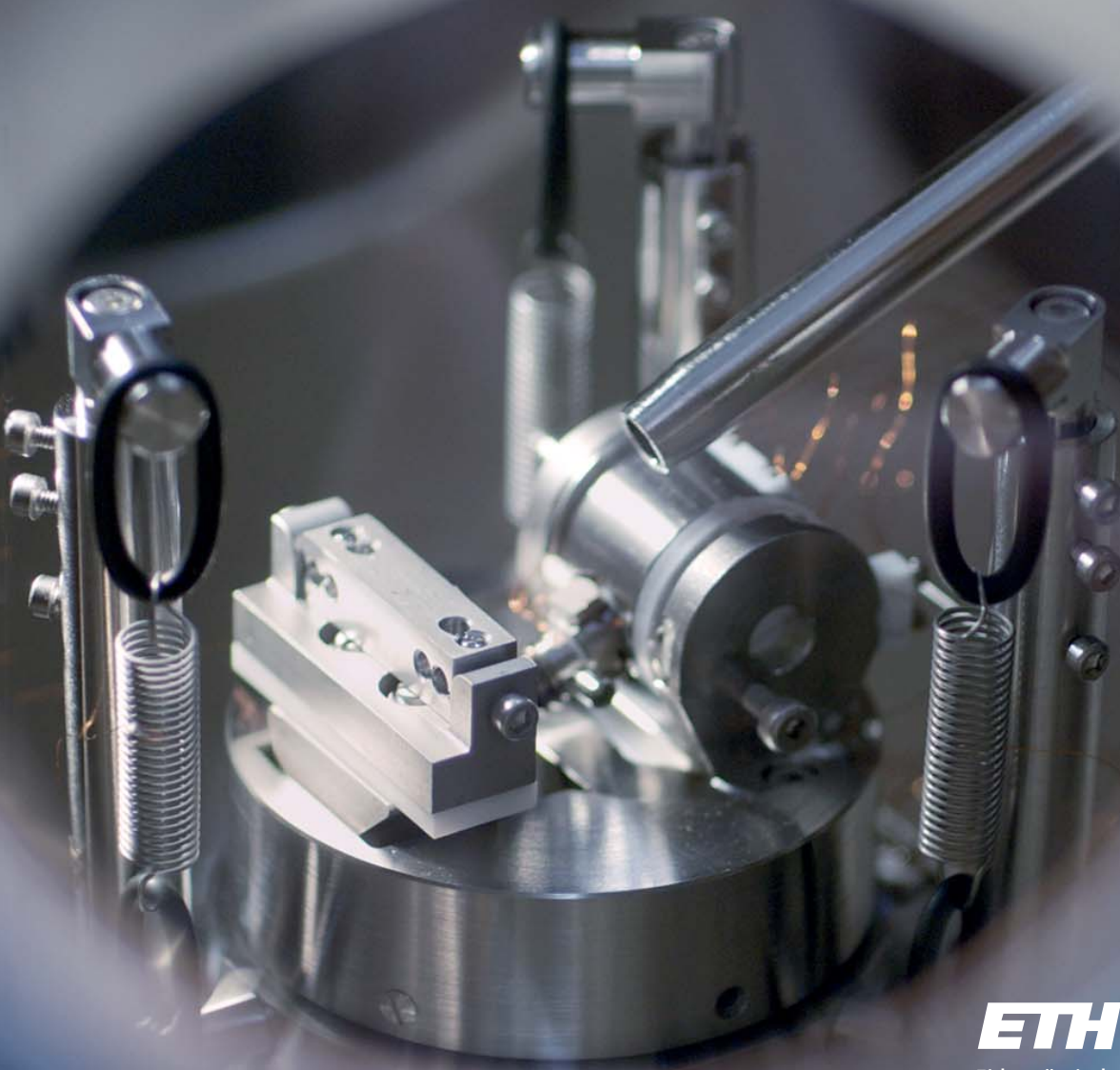


LABORATORY FOR SOLID STATE PHYSICS

ETH Zurich
Department of Physics

Annual Report 2008



ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Cover page:

Scanning Tunneling and Force Microscope in a vacuum chamber. This device is part of the Microstructure Research Lab of Prof. Danilo Pescia.

This annual report was edited by Philip Moll

PREFACE

In this Annual Report the Laboratory for Solid State Physics at ETH Zurich presents the research highlights that mark a productive and successful year 2008. Numerous scientific publications and presentations at international meetings reflect the wide variety of topics pursued. Exploring new areas in solid state physics at the highest levels is highly gratifying and also serves as training ground for educating new generations of scientists.

In the past year we had the pleasure to welcome two colleagues in the Laboratory: Prof. Joël Mesot and Prof. Andreas Vaterlaus. Prof. Mesot has been appointed director of the PSI, and holds a professorship at ETH-Z and at EPFL. At the Laboratory for Solid State Physics he will pursue solid state NMR, in addition to the neutron scattering and ARPES research at PSI. Prof. Andreas Vaterlaus' research interests in solid state physics focus on the dynamics of magnets on the femto-second time scale. The experimental technique of time and energy resolved laser induced photo-electron spectroscopy is being developed and employed at ETH and at the new free-electron laser facilities. In addition, Prof. Vaterlaus works on the pedagogy of physics and has assumed a central role in the physics teacher education. The Physics Department has considered high quality science teacher education to be of great importance, and we are now very glad to have this position filled by such a highly esteemed colleague. We wish both colleagues all the best in their endeavors. The search for additional professors is well underway and close to successful completion.

Members of the Laboratory continue to be committed to all levels of physics education for students in the Physics Department and in other ETH departments. Introductory level courses, laboratory courses, and numerous courses up to the doctoral level have been taught.

The many experimental research programs are made possible by the highly-developed infrastructure provided by our Laboratory, the Physics Department and ETH Zurich in general. We would like to thank all the many people for their technical and administrative expertise and dedicated services.

As in the past years, we express our sincere appreciation and thanks to the ETH Schulleitung for the broad and unwavering support, to the Swiss National Science Foundation, to KTI, to our partners in industry, and to all the other sources of support.

For preparing this Annual Report, we would like to thank Mr. Ph. Moll, Prof. L. Degiorgi and Mrs. H. Hediger.

Zürich, May 2008

Der Vorsteher

A handwritten signature in black ink, reading "Bertram Batlogg". The signature is fluid and cursive, with the first name "Bertram" and the last name "Batlogg" clearly distinguishable.

Prof. Dr. B. Batlogg

Contents

1	Physics of new materials	7
1.1	Quinoid heteropentacenes as promising organic semiconductors for field-effect transistor applications	9
1.2	Oxygen-related traps in pentacene thin films: Energetic position and implications for transistor performance	10
1.3	Stable complementary inverters with organic field-effect transistors on Cytop fluoropolymer gate dielectric	11
1.4	Na_xCoO_2 : Switching magnetic ground states by inducing different Sodium arrangements	12
1.5	Fermi surface gapping and magnetic long-range order in Na_xCoO_2 for $x > 0.75$	13
1.6	Spin fluctuations in Na_xCoO_2 , ($x=0.6 - 0.75$), probed by Muon Spin Rotation	14
1.7	Magnetoresistance in Iron Arsenide Superconductors in micro-cut crystals	15
1.8	Single crystals of $\text{LnFeAsO}_{1-x}\text{F}_y$ ($\text{Ln}=\text{La, Pr, Nd, Sm, Gd}$)	16
1.9	Single crystals of Rb-substituted BaFe_2As_2	18
1.10	Bulk single crystal growth of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ from solution in gallium under high pressure	19
2	Physics of mesoscopic structures, semiconductor nanostructures	21
2.1	Tunable quantum dots in nanostructured graphene	23
2.2	Scanning gate microscopy measurements on a superconducting single electron transistor	24
2.3	Charge detection in graphene quantum dots	25
2.4	Observation of excited states in a graphene quantum dot	26
2.5	Self-aligned charge read-out for InAs nanowire quantum dots	27
2.6	Observation of excited states in a p-type GaAs quantum dot	28
2.7	Detecting terahertz current fluctuations in a quantum point contact using a nanowire quantum dot	29
2.8	Time-resolved detection of single-electron interference	31
2.9	Statistical electron excitation in a double quantum dot induced by two independent quantum point contacts	32
2.10	Spin-orbit interaction and spin relaxation in a two-dimensional electron gas	34
2.11	Dynamics of coupled spins in quantum dots with strong spin-orbit interaction	35
3	Microstructure research	37

3.1	Low-Voltage Field Emission Scanning Electron Microscope	38
3.2	Co deposition onto icosahedral Al-Pd-Mn quasicrystals	40
3.3	Adsorption of oxygen on the decagonal Al-Co-Ni quasicrystal	40
3.4	Nanometer-size alumina substrates on quasicrystal surfaces	41
3.5	Simulation of structure formation on quasicrystals	41
4	Thin-Film Physics Group	43
4.1	Epitaxial IV-VI narrow-gap semiconductor layers and mid-IR devices	45
4.2	Thin-film Cu(In,Ga)Se ₂ and CdTe compound semiconductors solar cells	47
5	Optical Spectroscopy	51
5.1	Evidence for coupling between charge-density-wave and phonons in two-dimensional rare-earth tri-tellurides	53
5.2	Pressure-induced quenching of the charge-density-wave state observed by x-ray diffraction	55
6	Quantum Device Lab	59
6.1	Observing the $\sqrt{n}$ Nonlinearity in a Cavity QED System	61
6.2	Measuring the Lamb Shift in an Electrical Circuit	62
6.3	Coplanar Waveguide Resonators for Circuit Quantum Electrodynamics	64
7	Publications	67
8	Presentations	77

Chapter 1

Physics of new materials

(<http://www.pnm.ethz.ch/>)

Head

Prof. Dr. Bertram Batlogg

Academic Staff

Dr. B. Alloing
J. Kanter
P. Moll

Dr. P. Cristea
L. Kreuzer
PD Dr. H. von Känel

W. Kalb
T. Mathis

Technical Staff

K. Mattenberger

Administrative Staff

G. Strahm

Academic Guest

Prof. Dr. Yoshihiro Kubozono, Research Laboratory for Surface Science, Okayama University, Okayama (Japan)

Diploma & Master Theses

S. Bäuerle	FS 2008
M. Gantert	FS 2008
J. Kanter	SS 2007 - FS 2008
S. Klemmt	SS 2008 - FS 2009
P. Moll	FS 2008
T. Morf	HS 2007 - FS 2008
M. Portmann	FS 2008
R. Scherwitzl	HS 2008
V. Wittwer	FS 2008

High Pressure Materials Synthesis Group

Head

Dr. Janusz Karpinski

Academic Staff

A. Belousov

Dr. Z. Bukowski

Dr. S. Katrych

Dr. N. Zhigadlo

Academic Guests

Dr. Roman Puzniak, Polish Academy of Sciences, Warsaw (Poland)

Dr. Krzysztof Rogacki, Polish Academy of Sciences, Wroclaw (Poland)

Jan Jun, Institute of High Pressure Physics, Warsaw (Poland)

1.1 Quinoid heteropentacenes as promising organic semiconductors for field-effect transistor applications

W. L. Kalb, A. F. Stassen, B. Batlogg in collaboration with U. Berens, B. Schmidhalter, F. Bienewald, A. Hafner (Ciba Speciality Chemicals Inc., Group Research, Basel, Switzerland) and T. Wagner (Novartis Institutes for BioMedical Research, Basel, Switzerland)

The performance of organic field-effect transistors is getting closer to fulfilling the requirements for applications: high field-effect mobility, near zero threshold voltage, steep subthreshold swing, low current at zero applied gate bias and high electrical and environmental stability. Moreover, the organic transistors should be inexpensive, i.e. low-cost synthesis, purification and processing of all involved materials are required.

The semiconductor material plays an important role for the performance of an organic field-effect transistor. Consequently, intense research efforts are currently being undertaken to synthesize improved organic semiconductors. Pentacene derivatives and heteropentacenes are promising classes of materials and are synthesized with the aim to mimic the excellent transport properties of the benchmark material pentacene but to have improved properties, such as a better stability or solubility.

Both single crystal and thin-film transistors were fabricated with the new quinoid heteropentacene

7,14-Diphenyl-chromeno[2,3-b]xanthene (DPCX, inset in Fig. 1.1). Field-effect mobilities of $0.16 \text{ cm}^2/\text{Vs}$ and $0.01 \text{ cm}^2/\text{Vs}$

were achieved respectively in single crystal and thin-film devices with this p-type small molecule material. In addition, the devices show favourable properties such as near zero onset/threshold voltages and a small current hysteresis (Fig. 1.1). X-ray diffraction experiments show the molecules to be arranged in slipped stacks and to have a flat backbone in the crystals. A comparison of DPCX thin films on octadecyltrichlorosilane (OTS)-treated and bare SiO_2 gate dielectrics provides clear evidence that the OTS surface treatment leads to organic thin films with a better structural order. The low-cost synthesis and purification of DPCX along with the improved processability and the good electrical characteristics suggest that quinoid heteropentacenes are promising materials for organic field-effect transistors.

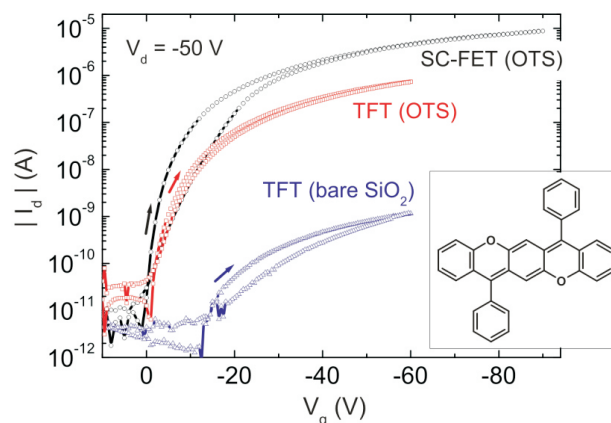


Figure 1.1: Transfer characteristic from a DPCX single-crystal transistor (SC-FET) with OTS-treated SiO_2 ($\mu = 0.16 \text{ cm}^2/\text{Vs}$). Also shown are the transfer characteristics from a DPCX thin-film transistor (TFT) with OTS ($\mu = 0.01 \text{ cm}^2/\text{Vs}$) and with a bare SiO_2 gate dielectric ($\mu = 2 \times 10^{-5} \text{ cm}^2/\text{Vs}$). Remarkable is the near zero onset voltage V_{on} and the small current hysteresis. Depending on the type of device, the field-effect mobility spans five orders of magnitude. This highlights the importance of structural order to obtain high field-effect mobilities.

1.2 Oxygen-related traps in pentacene thin films: Energetic position and implications for transistor performance

W. L. Kalb, K. Mattenberger, and B. Batlogg

Charge carrier mobilities in organic field-effect transistors are comparable to the mobilities in hydrogenated amorphous silicon transistors and are adequate for many applications. Critical issues, however, are electrical and environmental stability. The electrical stability of both n- and p-type organic semiconductor transistors has recently been shown to be very high if suitable gate dielectrics are used. The environmental stability of the organic semiconductor, thus, is an urgent issue to be addressed. It is crucial to understand in detail the way in which an oxidation of the organic semiconductor impedes the charge transport and thus degrades the transistor characteristics.

We studied the influence of oxygen on the electronic trap states in a pentacene thin film. This was done by carrying out gated four-terminal measurements on thin-film transistors as a function of temperature and without ever exposing the samples to ambient air. Photooxidation of pentacene is shown to lead to a peak of trap states centered at 0.28 eV from the mobility edge, with trap densities of the order of 10^{18} cm^{-3} (Fig. 1.2). These trap states capture gate-induced charge and cause a reduction in the number of free carriers. Moreover, the exposure to oxygen reduces the mobility of the charge carriers above the mobility edge. We correlate the change of these transport parameters with the change of the essential device parameters, i.e. subthreshold performance and effective field-effect mobility. The experiments support the assumption of a mobility edge for charge transport, and contribute to a detailed understanding of an important degradation mechanism of organic field-effect transistors: Deep traps in an organic field-effect transistor reduce the effective field-effect mobility by reducing the number of free carriers and their mobility above the mobility edge.

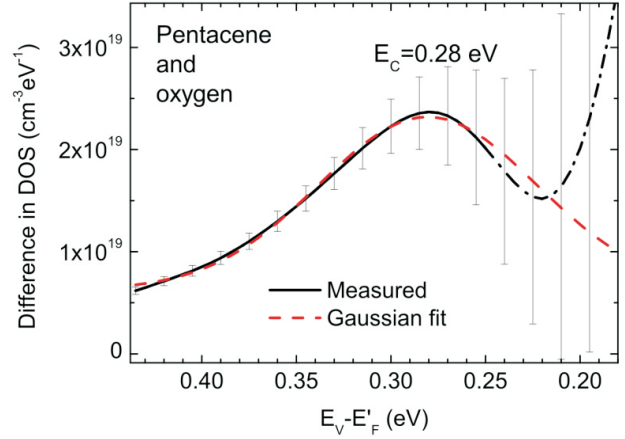


Figure 1.2: Measured difference of the DOS prior to and after the oxygen exposure (full and dash-dotted black line). The oxygen exposure leads to a broad peak of trap states centered at $E_C = 0.28 \text{ eV}$. A Gaussian fit for energies $\geq 0.25 \text{ eV}$ (dashed red line) gives good agreement with the measured curve.

1.3 Stable complementary inverters with organic field-effect transistors on Cytop fluoropolymer gate dielectric

M. P. Walser, W. L. Kalb, T. Mathis, T. J. Brenner and B. Batlogg

Intense efforts in research on organic semiconductors have lead to new organic materials with p- or n-type conduction, being ready for the integration in low-cost large area electronics and electronics on flexible foils and transparent substrates. A major challenge to the application of organic electronics is to realize complementary circuits. Charge transport in organic thin-film transistors is mainly confined to the interface between the organic semiconductor and the gate dielectric. The tendency for organic semiconductors to show p-type conduction, but rarely n-type conduction, was attributed to the semiconductor-dielectric interface: electrons are trapped at the interface by hydroxyl groups, present in the form of silanols in the case of the commonly used SiO₂ dielectric. Thus the key in promising material combinations for complementary organic circuits is a gate dielectric that (1) allows for both p- and n-type conduction with the adjacent semiconductors, (2) provides for chemical and electrical stability, (3) can be easily processed and (4) leads to highly reliable devices.

As a result of the present study we have come up with a promising materials combination for organic thin film transistors. We have deposited ultrathin perfluorinated cyclic polymer (7-9 nm, Cytop) layers as dielectric on n⁺⁺-Si/SiO₂ substrates used as convenient bottom-gate. As p-type semiconductor we used pentacene and as n-type semiconductor N,N'-ditridecylperylene-3,4,9,10-tetracarboxylicdiimide (PTCDI-C13). Typical transfer characteristics for PTCDI-C13 with Cr electrodes and pentacene with Au electrodes are shown in Fig. 1.3. Due to the very low density of 'slow' traps, the hysteresis in transfer characteristics is very small and output characteristics exhibit no hysteresis at all. Particularly remarkable for PTCDI-C13 on Cytop is the very steep onset, a near zero onset and a subthreshold swing as low as 0.6V/decade. To fabricate complementary inverters, the basic elements of complementary logics, we combined pentacene and PTCDI-C13 thin-film-transistors (Fig. 1.4). The hysteresis is as low as 0.2V and reflects the very small hysteresis of the combined transistors. The symmetry in the static response indicates that neither n- nor p-type conduction is dominant. The maximal gain dV_{out}/dV_{in} is very high, with a maximum around 250. Inverters still worked after 6 months in He atmosphere despite several days of contact to air. The devices are almost unaffected by repeated gate bias stress.

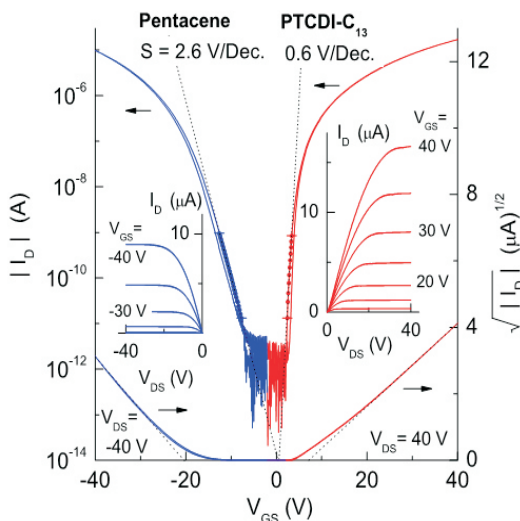


Figure 1.3: Transfer- and output characteristics of the combined p- and n-type TFT's. Forward- and reverse-sweep are shown in all panels. A very small hysteresis is visible only in the subthreshold regime.

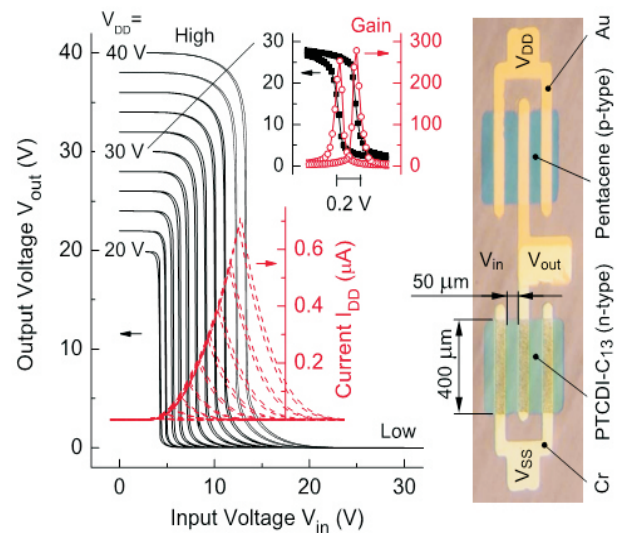


Figure 1.4: Static inverter characteristics for a complementary pentacene/PTCDI-C13 inverter with a 8nm thick Cytop dielectric and a common n⁺⁺-Si/SiO₂ bottom-gate. The dimensions of the device are given in the photograph.

1.4 Na_xCoO_2 : Switching magnetic ground states by inducing different Sodium arrangements

J. Kanter, S. Petitjean, K. Mattenberger and B. Batlogg

The sodium cobaltates (Na_xCoO_2) have emerged as an interesting candidate to study correlated electron phenomena. The layered structure of this compound and the mobile dopant ions render Na_xCoO_2 a model system to study a possible coupling between the spatial modulation of electronic states and sodium vacancy orderings. The rich phase diagram as a function of sodium content, including superconductivity (when hydrated), a metal-insulator-transition, one of the highest known Seebeck coefficients, and various magnetic orderings underline the subtle dependence of the Co-O derived electronic states on the sodium concentration. In recent experiments we could show that different sodium arrangements can be induced by defined cooling protocols, resulting in distinct magnetic transitions at low temperatures. Applying a newly developed cooling technique we could show that these magnetic transitions can be linked to a sodium reordering transition around 280 K. These findings allow studying the influence of the sodium ordering on the Co-3d electrons at one sodium concentration and may lead to a better understanding on how the sodium ordering influences the spatial modulation of electronic states.

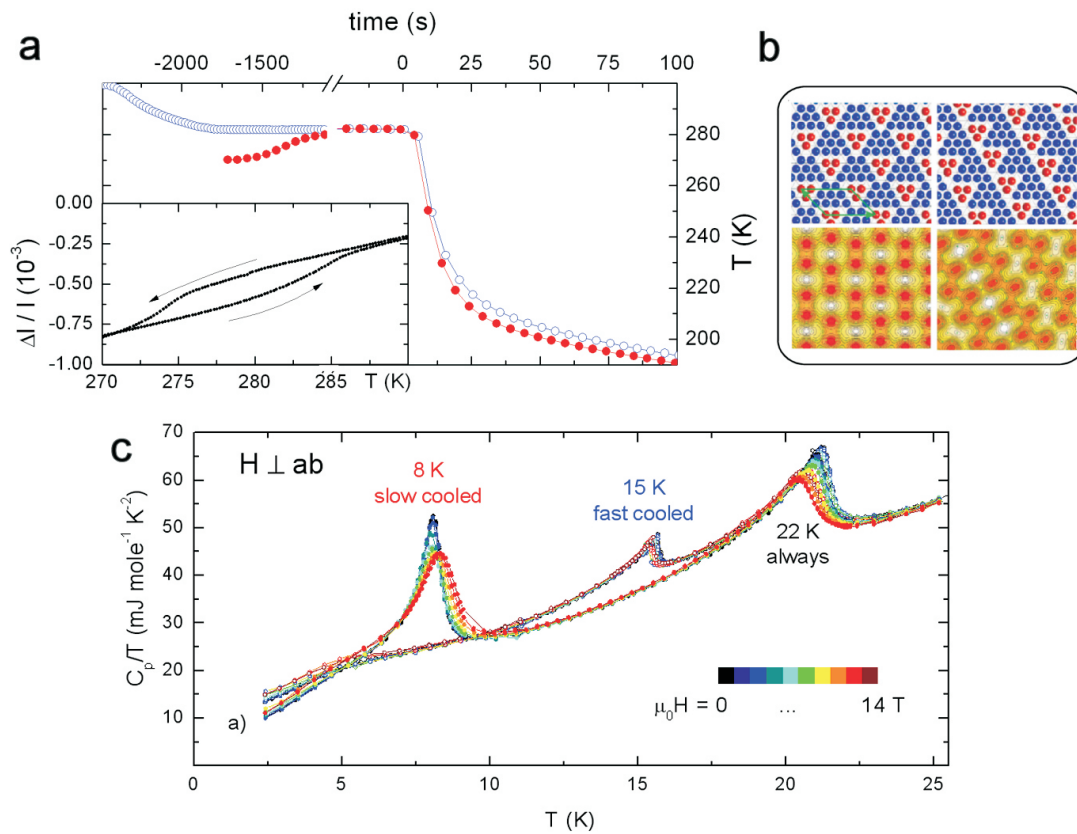


Figure 1.5: **a)** Temperature vs. time of the defined cooling protocol. Exploiting the hysteresis of the 280 K transition, the different low temperature magnetic signatures could be linked to the sodium reordering transition. The same initial temperature was chosen for the quenching process, once approached from above (preparing the configuration above the transition temperature) and once from below (configuration below transition temperature). The inset shows the dilatation signature of the transition, the broad hysteresis can be seen. **b)** Sodium ordering pattern below (left) and above (right) the transition temperature and the corresponding Coulomb potential landscape in the CoO layers. Figure credit: Morris *et al.*, PRB **79**, 100103(R) (2009) **c)** Field dependence of the specific heat for the different magnetic transitions.

1.5 Fermi surface gapping and magnetic long-range order in Na_xCoO_2 for $x > 0.75$

T. F. Schulze, M. Brühwiler, P. S. Häfliger, S. M. Kazakov, K. Mattenberger, J. Karpinski and B. Batlogg

The layered transition-metal oxide Na_xCoO_2 combines high thermopower and metallic conductivity, making it a promising candidate for thermoelectric energy conversion. The discovery of superconductivity in hydrated compounds and other types of ordered electronic ground states for higher sodium content have intensified the interest and raised questions related to Fermi surface instabilities. Itinerant electrons moving on the CoO_2 triangular lattice and the ability to control the filling of the narrow Co-O derived bands through the sodium content x render it an appealing model system in the field of correlated electron physics. It is especially interesting to address the low-energy electronic excitation density as it is both a measure of correlation effects and an indicator of collective ground states. In order to explore the magnetic and thermodynamic properties of the electronic system in this context in detail, we studied the heat capacity of a large number of both polycrystalline and single-crystalline samples.

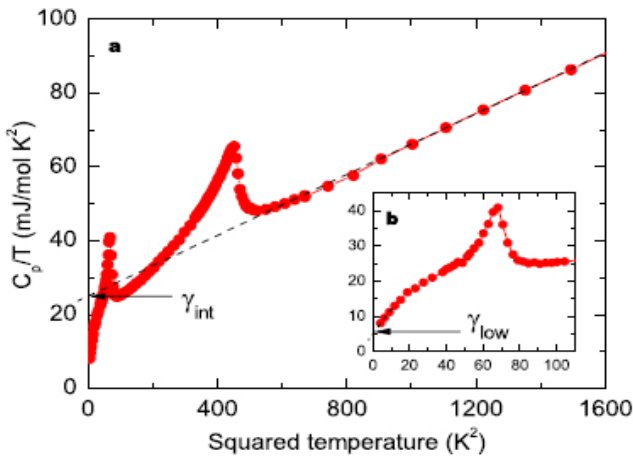


Figure 1.6: **a)** Typical specific-heat data for a slowly cooled $\text{Na}_{0.85}\text{CoO}_2$ single crystal with two transitions into a long range ordered magnetic state (at 22 K and 8 K). **a)** The electronic density of states at intermediate temperatures γ_{int} (above any Fermi surface instabilities) is determined by a linear fit to the C_p/T vs T^2 data. **b)** The residual low-T DOS γ_{low} is determined from a linear extrapolation of the low-T data to $T \rightarrow 0\text{ K}$.

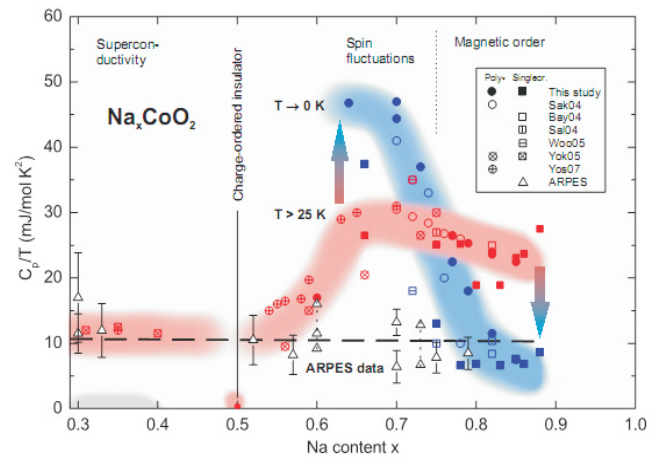


Figure 1.7: Phase diagram of the various electronic ground states in $\text{Na}_{0.85}\text{CoO}_2$. The diagram contrasts the low-energy electronic excitation density as measured via the specific heat at lowest temperatures (blue symbols) and intermediate temperatures (red symbols) with the ARPES-measured values (open triangles) and the approximate LDA band-structure trend (dashed black line). Together with our data (filled symbols) numerous previous results by other groups are shown (open symbols). All specific-heat data on single crystals are marked with square symbols while polycrystals are represented by circles. The colored arches are guides to the eye.

The interpretation of our heat-capacity and muon-spin rotation data provides a consistent picture of the Na_xCoO_2 low-energy electronic excitation density for both intermediate and low temperatures over a large sodium concentration range and for both single and polycrystals. New insight is gained from our in-depth analysis of both γ_{int} and γ_{low} (Fig. 1.7): Our field-dependent heat-capacity measurements in quantitative comparison with ARPES and LDA results reveal a rich and complex picture, which renders spin fluctuations to be only one out of two coexisting low-energy excitation density enhancement mechanisms for $x \approx 0.6$. For the whole x range the high-energy band dispersion as measured by ARPES yields a density of states consistent with LDA band-structure calculations (DOS around 10 mJ/mol K^2). However, the low-energy excitation spectrum ($< 100\text{ K}$) as measured by specific heat reveals distinctly richer phenomena: For $x > 0.6$ the intermediate-T DOS is two to three times higher (25-30 mJ/mol K^2). In the range $0.6 < x < 0.75$ the low-temperature excitation density is dominated by spin fluctuations that can be suppressed in a magnetic field and cause even stronger renormalization of γ as compared to the intermediate-temperature range, but no magnetic long-range order is present. A variety of magnetically ordered states is then observed for $x \approx 0.75$, including an 8K transition in addition to the previously studied SDW-like 22K transition. In the light of the low DOS

derived from ARPES and LDA calculations and the existence of a second DOS enhancement mechanism seen in the excitation density phase diagram the question whether Fermi surface gapping caused by magnetic ordering is present in the high- x range is not trivially answered by a loss of low- T DOS as compared to intermediate- T DOS. Here, our nuclear heat-capacity analysis provides important additional evidence based upon which it can be concluded that the magnetic order involving the itinerant electrons indeed causes the disappearance of part of the Fermi surface.

1.6 Spin fluctuations in Na_xCoO_2 , ($x=0.6 - 0.75$), probed by Muon Spin Rotation

T. F. Schulze, M. Brühwiler, P. S. Häfliger, K. Mattenberger, S. M. Kazakov, J. Karpinski and B. Batlogg

In collaboration with Ch. Niedermayer, PSI Villigen

The central observation in this region of the phase diagram is the absence of any magnetic LRO, which can be deduced from the heat-capacity. Shown in Fig. 1.8 are zero-field muon-spinrotation spectra taken on $x=0.64$ and $x=0.7$ polycrystals. These SR data do not show any LRO down to 1.7 K, which would result in an oscillatory part in the positron emission asymmetry. While mu-SR experiments reveal important information on the static magnetism they cannot elucidate on the possible presence of spin fluctuations with a time scale shorter than the order of 10^{-10} s. On the other hand, from specific heat we get strong indications of low-energy magnetic excitations: we note the absence of any sign of a phase transition in C_p for $x=0.6-0.75$, which confirms the mu SR results. However, the low-temperature C_p trend shows some peculiarity: C_p distinctly increases below $T = 10$ K, not inconsistent with a $T \log(T)$ behavior, indicating an increasing excitation density at lowest temperatures. The contribution of the nuclei to the heat capacity has been subtracted for clarity. Dependent on x , values as large as $47 \text{ mJ/mol } K^2$ are reached for $T \rightarrow 0$ K. In an external magnetic field, these additional excitations are significantly suppressed. Upon application of a 14 T external field, $\gamma(T \rightarrow 0 \text{ K})$ decreases to $31 \text{ mJ/mol } K^2$. In the H range accessible with our magnet there is an indication of a saturation of γ_{low} toward the value of γ_{int} , which is $25-30 \text{ mJ/mol } K^2$ for $x=0.6-0.75$. Here (and also for higher x), γ_{int} is significantly higher than in the $x < 0.5$ range. Obviously, compared to the strong renormalization of the electronic excitation density is present only at a low excitation energy scale. This behavior is consistent with a magnetic origin of the apparent mass enhancement for $x=0.6-0.75$, which is likely to be spin fluctuations that arise due to the proximity to magnetic ordering. This conclusion is in good agreement with NMR and neutron-diffraction data that provide evidence for ferromagnetic (FM) in plane fluctuations being present in Na_xCoO_2 with $x=0.7-0.75$. Additional support comes from theoretical studies yielding the onset of FM fluctuations for higher x assisted by charge disproportionation or band-structure effects.

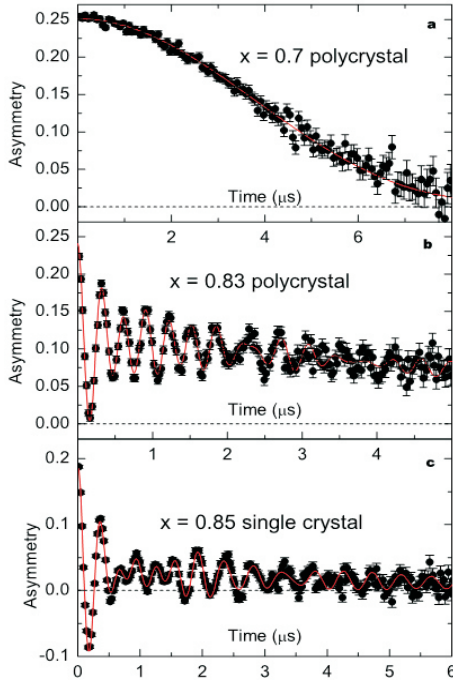


Figure 1.8: Muon-spin-rotation data taken on Na_xCoO_2 polycrystals and single crystals contrasting the low-T magnetic state for a sample with spin fluctuations and two with magnetic order. **a)** The absence of any oscillatory contribution in the positron decay asymmetry corresponds to the absence of static magnetic LRO for a $x=0.7$ polycrystal. **b)** In the $x=0.83$ polycrystal, the entire sample volume is magnetically ordered (within experimental limits of $\pm 5\%$). **c)** The same is true for the $x=0.85$ single crystal.

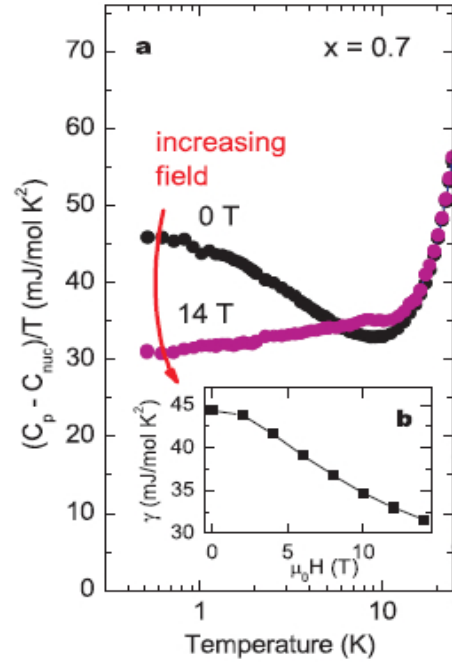


Figure 1.9: Specific heat measured on Na_xCoO_2 polycrystals. The low-T DOS ($T < 10$ K) is enhanced due to spin fluctuations for $0.6 < x < 0.75$. The nuclear contribution to the specific heat has been subtracted.

1.7 Magnetoresistance in Iron Arsenide Superconductors in micro-cut crystals

P. Moll, J. Karpinski, Z. Bukowski, N. Zighadlo and B. Batlogg, in collaboration with K. Kunze, P. Gasser (Electron Microscopy ETH Zurich)

We grow crystals from two classes of the newly discovered iron arsenide superconductors ("1111" : Lanthanide-FeAs(O,F), "122" : $BaFe_2As_2$) in high pressure synthesis. While the "122" materials grow as macroscopic crystals (1 mm), the "1111" crystals grow as thin ($\approx 10 \mu m$) platelets with typical diameters of less than $100 \mu m$. This size is suitable for magnetization measurements in our SQUID magnetometer, but it is too small for conventional electric measurements which provide indications for possible applications in superconducting wires and magnets. To reliably contact samples of these dimensions for four-point and Hall-effect measurements, we use a Focused Ion Beam (FIB). The ion beam is highly focused (nm^2) and consists of 30kV Ga^{2+} ions which are used to cut materials on a nanoscopic scale in a process akin to atomic sandblasting. Furthermore, it is possible to precisely deposit Platinum onto the sample by ion-assisted chemical vapor deposition (IA-CVD). A Pt-precursor gas is introduced into the vacuum chamber that decomposes upon ion beam irradiation into a Pt atom and lighter organic substances. In this way, electric leads can be attached to the sample by controlled irradiation of the desired current path. This technique allowed us to study electric transport of the iron-pnictide superconductors in great detail. A typical sample after FIB processing is shown in Fig. 1.10: the crystal itself (blue) is glued to a substrate with photolithographically prepared Au electrodes, and electric contact is made by Pt leads (red). We have studied the broadening of the superconducting transition with increasing magnetic field and found both $SmFeAs(O,F)$ and $(Ba,Rb)Fe_2As_2$ to be surprisingly resistant to magnetic fields indicating strong pinning (Fig. 1.11). Keeping in mind that the derivation of upper critical fields from resistance measurements depends on the criterium to define H_{c2} because the transition is broadened by fluctuations and vortex motion. We define T_c at 50 % of the normal state resistivity and evaluate $H_{c2}^{50\%}$ as an indicator for the broadening

in magnetic fields. $Hc_2^{50\%}$ depends linearly on temperature, and we find a slope $dHc_2^{50\%}/dT$ of 1.9 T/K for magnetic fields in the FeAs-planes and 7.9 T/K perpendicular to the planes, which leads to a surprisingly small upper critical field anisotropy $\gamma = 4.2$. These high upper critical fields and the reasonably low anisotropy are very promising for applications of Iron-Pnictides in superconducting wires and magnets.

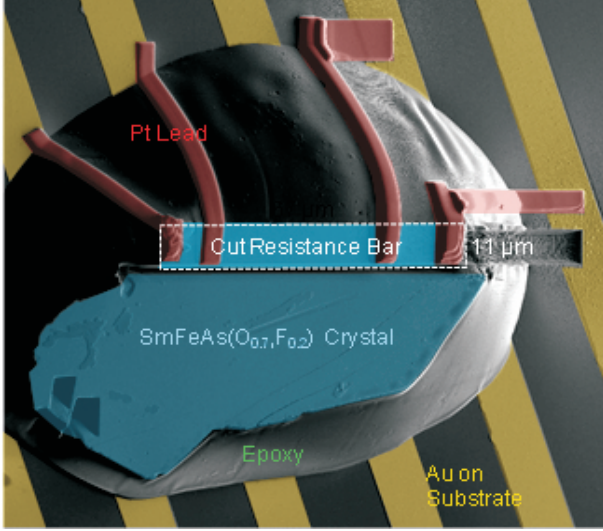


Figure 1.10: SmFeAsO_{0.7}F_{0.25} single crystal (blue) glued onto a photolithographically prepared gold structure (yellow) on a SiO₂ substrate. The FIB was used to connect the crystal to the gold by deposition of platinum leads (red) and to cut it into rectangular shape (lighter blue) to optimize the current geometry.

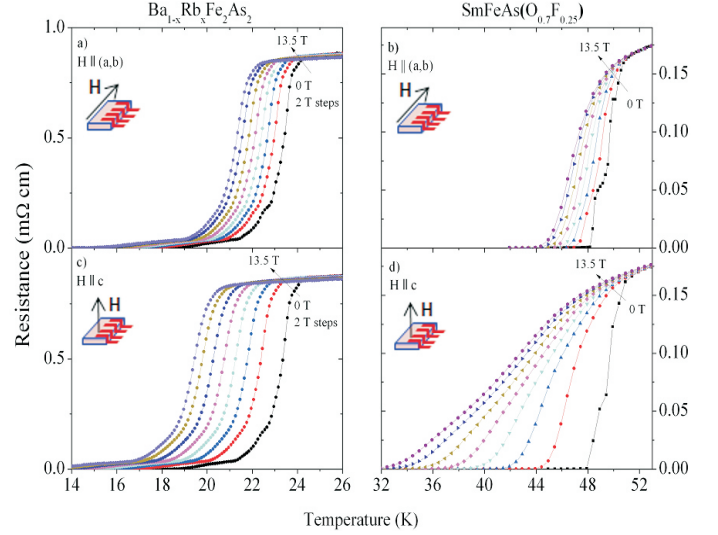


Figure 1.11: Superconducting transition of SmFeAsO_{0.7}F_{0.25} and Ba_{0.9}Rb_{0.1}Fe₂As₂ for two magnetic field alignments (H orthogonal to or in the FeAs-planes) and fields from 0 T to 13.5 T (2T steps)

1.8 Single crystals of LnFeAsO_{1-x}F_y (Ln=La, Pr, Nd, Sm, Gd)

N.D. Zhigadlo, S. Katrych, P. Moll, Z. Bukowski, J. Karpinski and B. Batlogg

We have successfully grown single crystals of LnFeAsO_{1-x}F_y (Ln=La, Pr, Nd, Sm, Gd) at high pressure. The crystals (Fig. 1.12) were grown in NaCl/KCl flux at 30 kbar and 1350-1450 °C using a cubic anvil high-pressure system and we performed structural, electrical, magnetic and spectroscopic measurements. These studies revealed systematic changes of the structural parameters and the superconducting transition temperature T_c with rare-earth substitution. A typical magnetic susceptibility of SmFeAsO_{1-x}F_y in 1 mT is shown in Fig. 1.13. The lower branch shows the perfect Meissner-diamagnetism when the magnetic field is applied after cooling the crystal in zero-field below T_c . In contrast, the upper branch shows almost no diamagnetic signal because of vortex trapping. The sharp transition to the superconducting state is characteristic for the good quality of this single crystal. It shows a transition temperature of 52 K indicating that the doping is close to optimal doping levels in SmFeAsO_{1-x}F_y which reach transition temperatures of 55 K. The influence of the rare-earth element was investigated in a detailed substitution study, which yielded a clear dependence of T_c on the used element (Fig. 1.14). The maximal T_c of 52 K was reached in the SmFeAsO_{1-x}F_y system, while the LnFeAsO_{1-x}F_y system showed the lowest T_c of 26 K.

Our single crystals were studied on a four-circle X-ray diffractometer equipped with a CCD detector (Mo K α radiation, X-calibur PX, Oxford Diffraction). We found well-resolved reflection patterns indicating a high quality of the crystallographic structure. From the structure refinement (space group P4/nmm) of the LnFeAsO_{1-x}F_x crystals we found the lanthanide contraction to lead to a systematic reduction of the lattice parameters across the series upon rare-earth substitution (Fig. 1.15). The absolute value of the Ln-O distance ($d_{Ln-O} \sim 2.28-2.34$ Å) is close to the sum of covalent radii of the elements ($\sim 2.27-2.35$ Å for Gd-La series) indicating covalent bonding in the Ln-O planes.

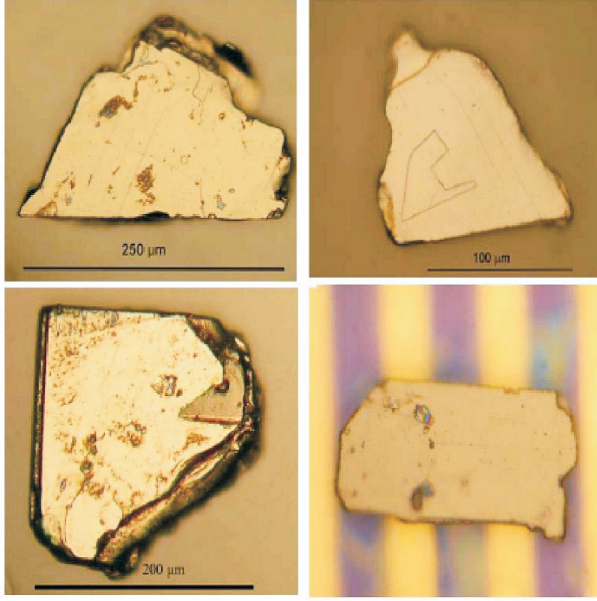


Figure 1.12: $\text{SmFeAsO}_{0.7}\text{F}_{0.25}$ single crystals grown from NaCl/KCl flux at high pressure

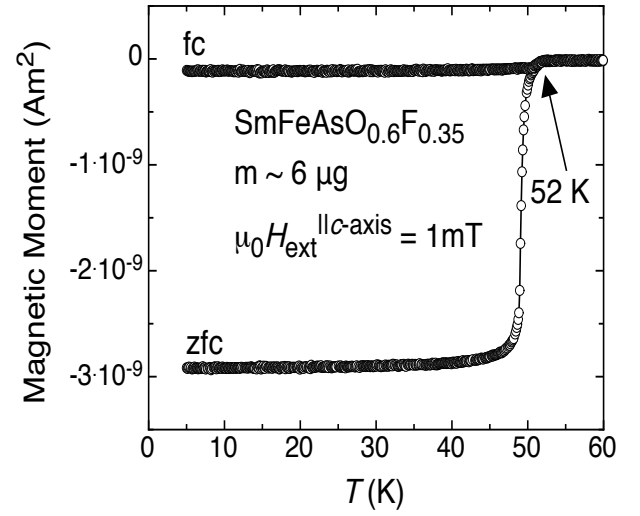


Figure 1.13: Temperature dependence of magnetic moment measured on $\text{SmFeAsO}_{0.6}\text{F}_{0.35}$ single crystal in an applied field of 1 mT.

The planes are mainly ionically bound as can be seen from the sum of the covalent radii of the Ln and As atoms ($r_{\text{cov,Ln}} + r_{\text{cov,As}} \sim 2.82\text{-}2.90 \text{ \AA}$ for Gd-La series), that is smaller than the measured distances between these atoms ($d_{\text{Ln-As}} \sim 3.24\text{-}3.34 \text{ \AA}$) indicating ionic bonding. But we also found more than 10 % vacancies on the O(F) indicating the difficulty to dope the material with Fluorine.

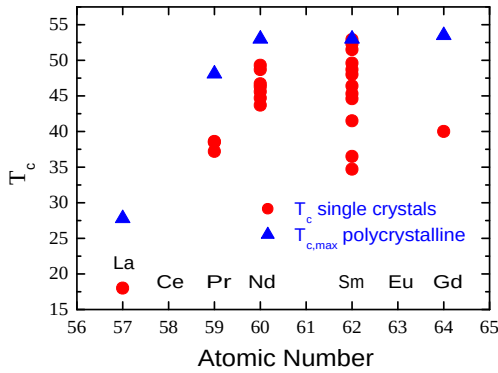


Figure 1.14: Variation of T_c upon rare-earth substitution for polycrystalline samples and single crystals from SQUID measurements.

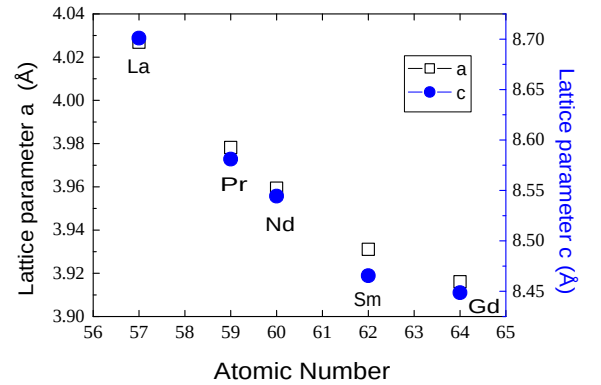


Figure 1.15: Cell parameters as a function of the atomic number for $\text{LnFeAs}(\text{O,F})$ ($\text{Ln}=\text{La, Pr, Nd, Sm, Gd}$). Squares show a- and circles represent c-lattice parameters.

1.9 Single crystals of Rb-substituted BaFe_2As_2

Z. Bukowski, S. Katrych, N.D. Zhigadlo, P. Moll, J.Karpinski and B. Batlogg

Single crystals of $\text{Ba}_{1-x}\text{Rb}_x\text{Fe}_2\text{As}_2$ with $x = 0.05-0.1$ were grown from Sn flux and found to be bulk superconductors with T_c up to 23 K. The single crystals of $\text{Ba}_{1-x}\text{Rb}_x\text{Fe}_2\text{As}_2$ grow in a plate-like shape with typical dimensions (1-3) x (1-2) x (0.05-0.1) mm³ (Fig. 11). Depending on the starting composition, the crystals displayed a broad variety of properties from nonsuperconducting to superconducting with sharp transitions to the superconducting state. The crystals studied by XRD reveal good quality, and no additional phases (impurities, twins or intergrowing crystals) were detected by examining the reconstructed reciprocal space sections (Fig. 12).

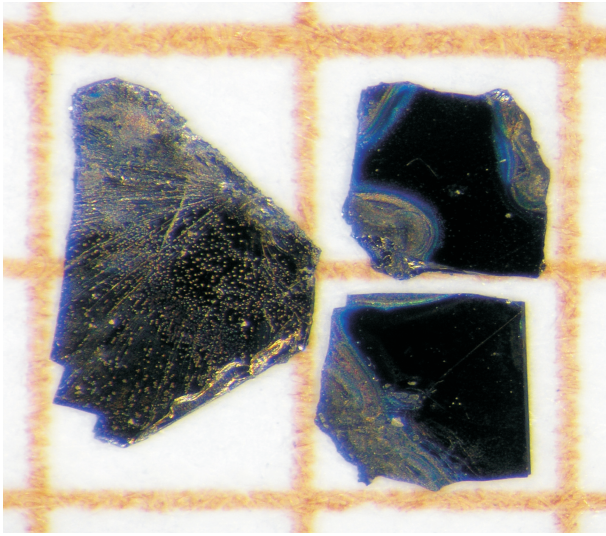


Figure 1.16: Three single crystals of $\text{Ba}_{0.9}\text{Rb}_{0.1}\text{Fe}_2\text{As}_2$ on a millimeter grid.

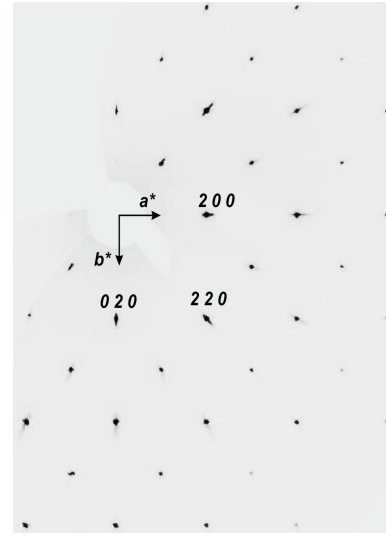


Figure 1.17: The $hk0$ reciprocal space section of the $\text{Ba}_{1-x}\text{Rb}_x\text{Fe}_2\text{As}_2$ crystal.

The crystal structure was refined by X ray diffraction analysis. Sn is found to substitute for $\sim 5\%$ of Ba and is displaced by 1.1 Å from the Ba site (Fig. 1.18, 1.19). The upper critical field deduced from resistance measurements is slightly anisotropic with slopes of 7-7.3 T/K ($H \parallel ab$ -plane) and 3.9-4.3 T/K ($H \parallel c$ -axis). The deduced upper critical field anisotropy, around 3 close to T_c , was found to be in good agreement with estimations from magnetic torque measurements. This is indicative of significantly more isotropic electronic properties in the doped BaFe_2As_2 compound compared to the LnFeAsO family. The in-plane critical current density at 5 K exceeds 10^6 A/cm^2 , which suggests the iron-pnictides to be suitable for high-current superconductor applications.

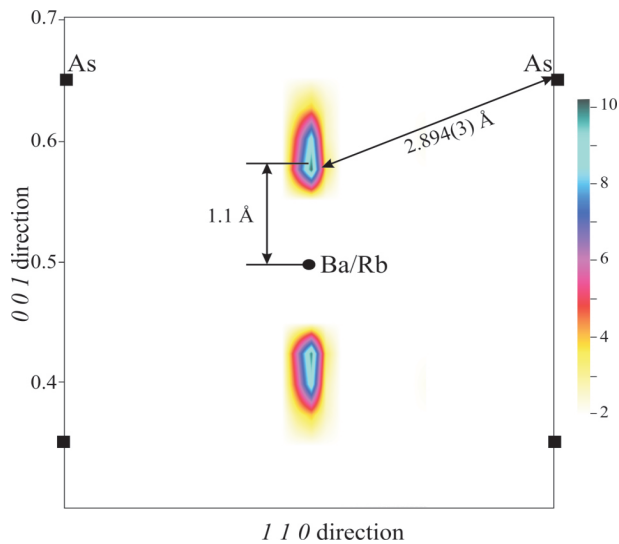


Figure 1.18: (1 1 0) section of the F_0-F_c difference Fourier map. The enhanced electron density reveals the location of Sn atoms, shifted by 1.1 Å towards the (Fe_2As_2) - layers. The black spot shows the Ba/Rb position and black squares mark As positions.

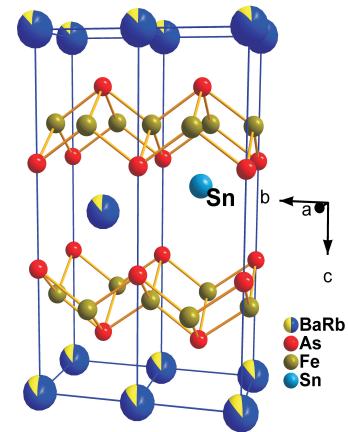


Figure 1.19: Schematic illustration of two unit cells of Rb and Sn substituted BaFe_2As_2 . A possible Sn location is shown, for clarity on one site only.

1.10 Bulk single crystal growth of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ from solution in gallium under high pressure

A. A. Belousov, S. Katrych, J. Jun, J. Karpinski and B. Batlogg

Single crystals of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ with an Al content from 50 % to 90 % were successfully grown from solution in Ga using a high pressure nitrogen gas autoclave. A crystal growth rate of up to 0.1 mm/day was achieved, a rate comparable to the growth of GaN from solution or by the ammonothermal method. As a source of Al the previously synthesized polycrystalline $\text{Al}_y\text{Ga}_{1-y}\text{N}$ was used.

To grow $\text{Al}_x\text{Ga}_{1-x}\text{N}$ single crystals, the previously sintered pellet of $\text{Al}_y\text{Ga}_{1-y}\text{N}$ was placed in Ga in the upper part of a graphite crucible and this assembly was introduced into the gas pressure chamber (Figure 1.20). By applying a thermal gradient of about 20 K/cm at constant temperature for 6-7 days, $\text{Al}_x\text{Ga}_{1-x}\text{N}$ crystals grew in the colder part of the crucible. The crucible had an internal diameter of 14 mm and was 70-mm long.

The grown crystals were up to $0.8 \times 0.8 \times 0.8 \text{ mm}^3$ in size and were colorless, of a hexagonal habit, and of wurtzite structure. The morphology of the crystals depends on the nitrogen pressure, temperature and temperature gradient.

Two methods have been employed to determine the composition: laser ablation mass spectrometry and a structure refinement based on the X-ray diffraction data. No twinning or intergrowth could be detected. As the laser ablation drilled a small hole into the crystals, the depth profile of the composition was monitored. Accordingly, the Ga/Al ratio was found to be constant ($\pm 0.5\%$) inside the crystals. There was satisfactory agreement between the composition determined by these two methods.

In order to study the pressure-temperature (p-T) equilibrium of the (Al,Ga)N system, several experiments were per-

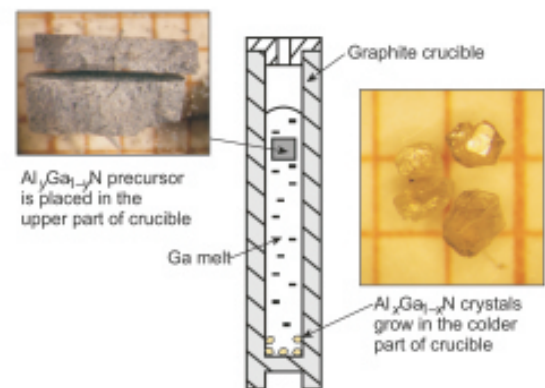


Figure 1.20: Schematic illustration of the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ crystal growth crucible. Pre-reacted pellets (left) and $\text{Al}_{0.86}\text{Ga}_{0.14}\text{N}$ crystals (right) are shown on a 1 mm grid.

formed at 5 to 10 kbar nitrogen pressure and at a temperature of 1490-1780 °C. The symbols in Figure 1.21 mark the p-T parameters for which crystals of a particular composition were grown. The dashed lines are tentative lines for constant Al composition, guided by the shape of the well-established equilibrium line for GaN. With increasing Al content, growth of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ crystals takes place at lower pressures than that required for GaN at the same temperature. By choosing the appropriate pressure and temperature conditions, $\text{Al}_x\text{Ga}_{1-x}\text{N}$ crystals with a particular Al composition could be grown. For example, to grow crystals with $x = 0.62$, the required conditions are 8.4 kbar and 1540 °C. By decreasing the pressure to approx. 2.54 kbar and maintaining almost the same temperature of 1550 °C, crystals with $x = 0.85$ could be synthesized.

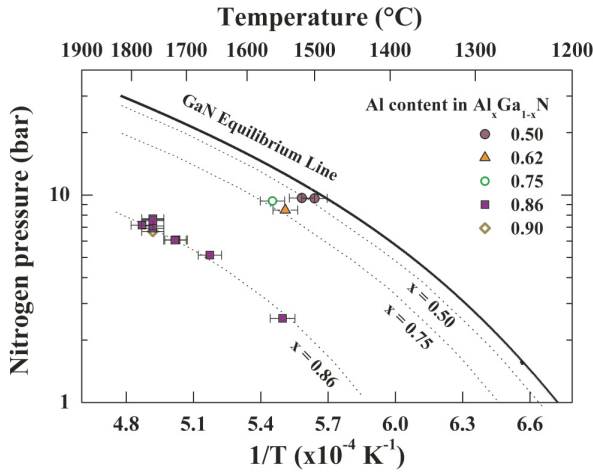


Figure 1.21: Equilibrium pressure of N_2 over GaN and $\text{Al}_x\text{Ga}_{1-x}\text{N}$ estimated experimentally for various Al ratios as a function of the temperature. Each symbol is derived from a separate growth experiment. Dashed lines are guides to the eye for constant composition x .

Chapter 2

Physics of mesoscopic structures, semiconductor nanostructures

(<http://www.nanophys.ethz.ch>)

Head

Prof. Dr. Klaus Ensslin

Prof. Dr. Thomas Ihn

Prof. Dr. René Monnier

Academic Staff

Dr. I. Blatter

T. Choi

Dr. M. Csontos

S. Dröscher

U. Gasser

S. Gustavsson

J. Güttinger

M. Hübner

A. Jacobsen

Y. Komijani

B. Küng

C. May

F. Molitor

T. Müller

A. Pfund

P. Roulleau

E. Ruh

S. Schnez

Dr. I. Shorubalko

Dr. C. Stampfer

M. Studer

Technical Staff

C. Barengo

P. Studerus

Administrative Staff

C. Vinzens

Academic Guests

Prof. Yigal Meir, Ben-Gurion University, Israel, 16-18. 6. 2008

Prof. Michael Hilke, Montreal University, Canada, 1.4.-31.8.2008

Prof. Thomas Heinzel, Düsseldorf University, Germany, 1.10.2008-31.3.2009

Diploma & Master Theses

Ch. Charpentier (FS 2008)

S. Hellmüller (HS 2008)

O. Pfäffli (HS 2008)

T. Choi (HS 2008)

K. Interbitzin (FS 2008)

E. Schurtenberger (FS 2008)

T. Frey (FS 2008)

A. Jacobsen (HS 2008)

J. Wernery (HS 2008)

2.1 Tunable quantum dots in nanostructured graphene

J. Güttinger, F. Molitor, E. Schurtenberger, C. Stampfer, T. Ihn, and K. Ensslin

Graphene is a promising material to investigate mesoscopic phenomena in two dimensions (2D). Unique electronic properties, such as massless carriers, electron-hole symmetry near the charge neutrality point, and weak spin orbit coupling makes graphene interesting for high mobility electronics, for tracing quantum electrodynamics in 2D solids, and for the realization of spin qubits. While diffusive transport in graphene and the anomalous quantum Hall effect have been investigated intensively, graphene quantum dots are still in their infancy from an experimental point of view. This is mainly due to difficulties in creating tunable quantum dots in graphene because of the absence of an energy gap. Also, phenomena related to Klein tunneling make it hard to confine carriers laterally using electrostatic potentials.

The nanodevice shown in Fig. 2.1 has been fabricated from graphene, which has been extracted from bulk graphite by mechanical exfoliation onto 300 nm SiO₂ on n-Si. Raman imaging is applied to verify the single-layer character of the investigated devices. PMMA (polymethylmethacrylate) is then spun onto the samples and electron-beam lithography is used to pattern the etch mask for the graphene devices. Reactive ion etching based on an Ar / O₂ plasma is introduced to etch away unprotected graphene. The scanning force microscope image of the etched graphene structure after removing the residual PMMA is shown in Fig. 2.1. Finally, the graphene device is contacted by e-beam patterned 2 nm Ti and 50 nm Au electrodes.

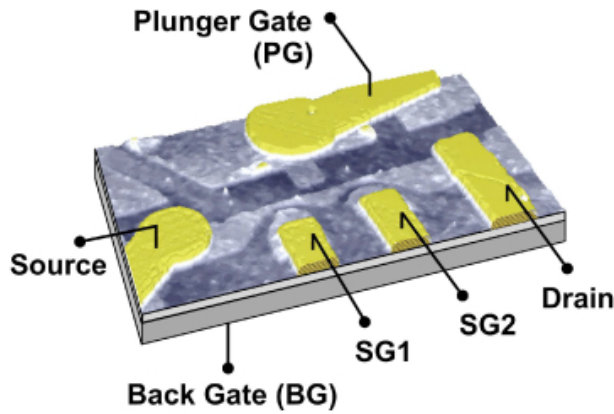


Figure 2.1: Scanning force microscopy image of the graphene single electron transistor after RIE etching. The gold contacts to the various parts of the graphene devices are indicated in yellow. The current flows from source to drain contact. The back gate is used to tune the overall Fermi level in the system. Side gates SG1 and SG2 allow to tune the tunnel barriers and the plunger gate PG is used to tune the charge on the island.

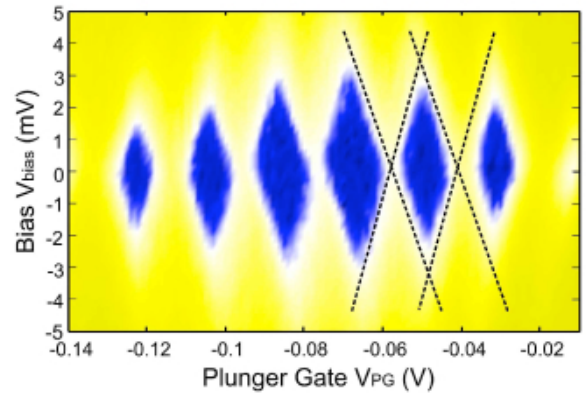


Figure 2.2: Coulomb diamonds in differential conductance represented in a logarithmic color scale plot. Dark regions represent low conductance. A dc bias with a small ac modulation is applied symmetrically across the dot, and the current through the dot is measured.

Transport measurements have been performed in a variable temperature He cryostat at a base temperature of 1.7 K. Before the cool down, the sample has been baked in vacuum at 135 °C for 12 h. We have measured the two-terminal conductance through the dot by applying a small symmetric dc or ac bias voltage V_{bias} . At high bias, the backgate characteristics clearly reveal the charge neutrality point of the graphene material. Such measurements are used to adjust the useful range of the back gate voltage. By sweeping the side gate voltages V_{SG1} and V_{SG2} to a regime where the back ground current is significantly suppressed, the plunger gate V_{PG} can be used to trace Coulomb resonances.

Coulomb diamond measurements, i.e., measurements of the differential conductance as function of symmetric bias voltage V_{bias} and plunger gate voltage V_{PG} , are shown in Fig. 2.2. The elevated background at the left and right sides is due to barrier dependent conductance modulations. Please note that within the swept plunger gate voltage range, no charge rearrangements have been observed. From the extent of the diamonds in bias direction, we estimate

the charging energy of the graphene dot to be about 3.5 meV. This charging energy corresponds to a capacitance of the dot $C = 45.8$ aF in agreement with estimates based on its geometrical size.

2.2 Scanning gate microscopy measurements on a superconducting single electron transistor

M. Huefner, C. May, R. Monnier, K. Ensslin, and T. Ihn, in collaboration with M. Hilke, McGill University, Canada; K. Suter and N. de Rooij, EPFL, Switzerland; U. Staufer, TU. Delft, The Netherlands

In semiconductor quantum dots there are two dominant energy scales, namely, the charging energy, which depends on the capacitance and therefore the geometry of the dot and its gate electrodes including the tip, and the single-particle level spacing arising from the quantum mechanical confinement of the system. In metallic single electron transistors (SETs) the single-particle level spacing is orders of magnitude too small for being observable. For superconducting single electron transistors new energy scales enter the problem, namely, the energy gap Δ of the superconductor, and the Josephson energy E_J .

Here we present scanning gate measurements performed on a superconducting SET. Spatial images of the differential conductance give insight into the interaction potential between the tip and the electrons in the SET. We investigate in detail how the charging energy as well the superconducting gap of the SET island depend on tip position and the voltage applied to the tip.

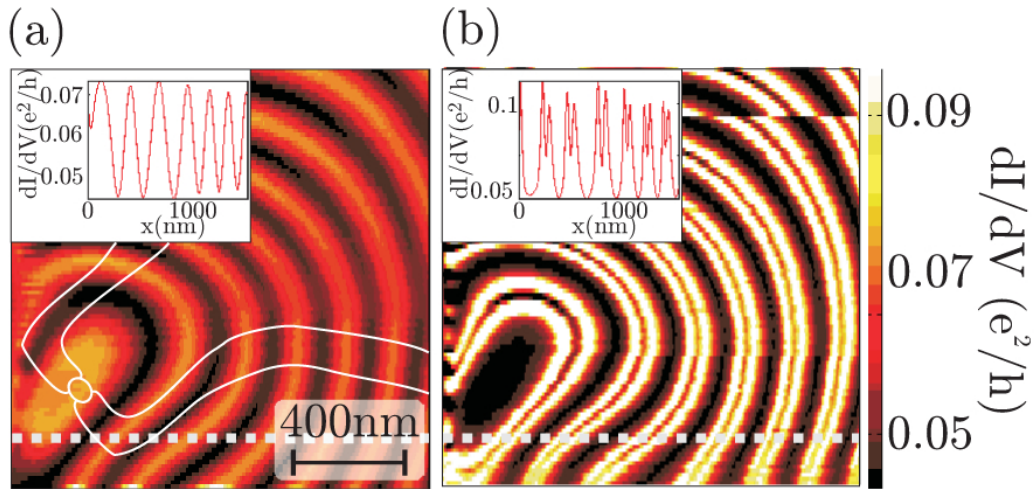


Figure 2.3: Scanning gate measurements for different magnetic fields. The tip sample distance is around 50 nm, $V_G = 0$ V and $V_{SD} = 1.5$ mV. The scanned area is $1.51 \mu\text{m} \times 1.51 \mu\text{m}$ (a) at $B = 0.5$ T and (b) at $B = 0$ T. The insets show crosssections at the position of the grey dotted line. The white lines in (a) mark the approximate position of source, drain and SET of the structure.

Fig. 2.3 shows scanning gate measurements taken at two different magnetic fields. Let us start by discussing the SET in the normal conducting state. Fig. 2.3 (a) shows a scanning gate image taken at a magnetic field of $B = 0.5$ T which drives Al into the normal conducting state. We observe concentric ring-shaped features. The island itself is expected to be located at the center of the concentric rings. The inset shows a cross-section through the scanning gate image taken along the dashed line in Fig. 2.3 (a). Fig. 2.3 (b) shows a scanning gate measurement of the same scan frame as in Fig. 2.3 (a) but in the situation where the SET is in the superconducting state. Since the two measurements have been carried out one right after another and no charge rearrangements were observed, we can assume the SET to be in the same now superconducting state until the clearly visible charge rearrangement in the last quarter of the measurement in the superconducting state takes place. The signature of superconductivity at this source drain voltage is the splitting of the resonance rings. Every single ring splits up into two when the SET is scanned in the superconducting state.

This finding is consistent with the features observed in the Coulomb diamonds. Since the number of features as well as their spacing is the same for the superconducting and normal conducting state, we know that we can controllably load single electrons onto the SET by scanning the tip.

2.3 Charge detection in graphene quantum dots

J. Güttinger, C. Stampfer, S. Hellmüller, F. Molitor, T. Ihn, and K. Ensslin

By etching graphene it is possible to make tunable graphene nanodevices, as it has been shown by the fabrication of graphene nanoribbons, interference devices, and graphene quantum dots. For semiconductor systems electrostatically coupled quantum systems have been realized. The capacitive coupling between neighboring systems can be used to perform a read-out of the charged state of one system (typically a quantum dot) with another system (typically a quantum point contact). Here we set out to realize a similar quantum circuit in an all graphene system.

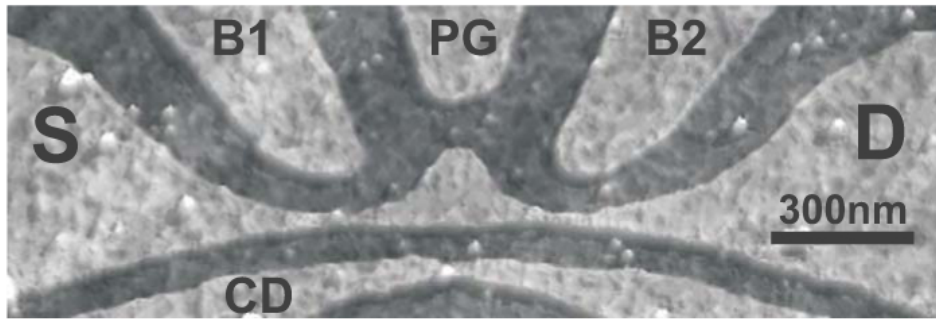


Figure 2.4: Scanning force micrograph of the measured device. The central island is connected to source S and drain D contacts by two constrictions. The diameter of the dot is 200 nm and the constrictions are 35 nm wide. The graphene nanoribbon acts as charge detector (CD). Three lateral gates B1, B2, and PG are used to tune the devices.

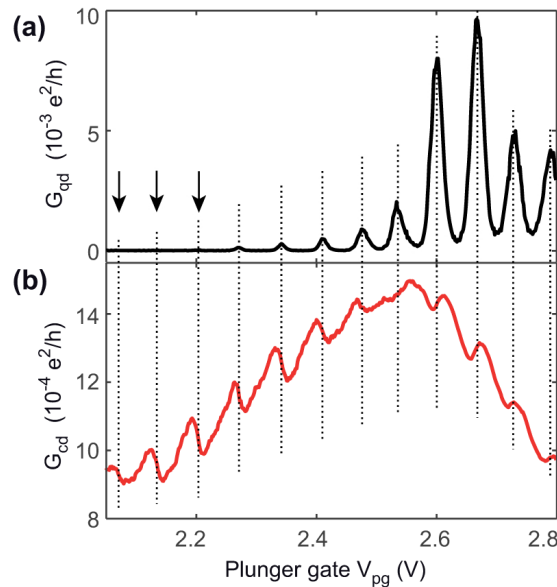


Figure 2.5: (a) Dot conductance G_{qd} and (b) charge detector conductance G_{cd} as a function of plunger gate voltage V_{pg} for a fixed back gate voltage $V_{BG} = 6.5$ V. The arrows indicate Coulomb blockade resonances that can be hardly measured by conventional means because the current levels are too low. (b) However, they can be detected by the charge detector (CD).

Fig. 2.4 shows a scanning force microscope image of the all graphene structure. The quantum dot device consists of two 35 nm wide graphene constrictions separating source (S) and drain (D) contacts from the graphene island with a

diameter of 200 nm. The constrictions and the island are electrostatically tuned independently by two barrier gates (B1) and (B2), and a plunger gate (PG), respectively. The highly doped silicon back gate (BG) allows to adjust the overall Fermi level. In addition, we placed a 45 nm wide graphene nanoribbon 60 nm next to the island, which acts as a charge detector (CD), as shown below.

Fig. 2.5 (a) shows almost equidistantly spaced Coulomb blockade resonances as a function of plunger gate voltage V_{pg} . The strong modulation of the conductance peak amplitudes is due to superimposed resonances in the graphene constrictions defining the island.

In Fig. 2.5 (b) we plot the simultaneously measured conductance through the nearby CD for the same plunger gate voltage range. On top of the peak-shaped charge detector resonance we observe conductance steps that are well aligned (see dotted lines) with single charging events on the nearby quantum dot. The conductance step is related to a shift in the charge detector resonance with respect to the plunger gate voltage.

Here we demonstrated the functionality of an integrated graphene CD based on a nanoribbon nearby a graphene QD. We confirm the detection of charging events in regimes where Coulomb blockade resonances can hardly be resolved because the current levels are too low, see e.g., arrows in Fig. 2.5 (a). In contrast to state-of-the-art quantum-point contact charge detectors, we do not make use of slopes between quantized conductance plateaus. We rather use local resonances in the graphene nanoribbon to detect charging. We anticipate that this technique will play an important role for the investigation of the electron-hole crossover and spin states in graphene QDs.

2.4 Observation of excited states in a graphene quantum dot

S. Schnez, F. Molitor, C. Stampfer, J. Güttinger, I. Shorubalko, T. Ihn, and K. Ensslin

The identification of individual orbital quantum states, well established in GaAs quantum dot devices, has so far remained on the wish list of physicists aiming at quantum information processing with graphene.

The experiments were carried out in a dilution refrigerator at a base temperature of 40 mK. Coulomb diamond measurements, i.e., plots of the differential conductance as a function of the quantum dot bias voltage and plunger gate voltage are shown in Fig. 2.6. Within this plunger gate voltage range, no charge rearrangements were observed and the sample was stable for more than two weeks. We extract a typical energy scale of the order of 10 meV.

Excited states appear in Fig. 2.6 (a) as distinct lines of increased conductance running parallel to the edge of the Coulomb diamonds. Fig. 2.6 (b) showing a closeup of Fig. 2.6 (a) allows to extract an excitation energy 1.6 meV as marked by the white arrow. A line cut (dashed line) presented in the left panel of Fig. 2.6 (b) shows the peak of the excited state at finite bias. The broadening of the peak significantly exceeds thermal broadening and might be due to the energy dependent coupling of the excited state to the graphene leads. Fig. 2.6 (c) shows two Coulomb diamonds at lower plunger gate voltage, where more than one excited state is observed as a function of increasing energy, as shown by pairs of dashed lines. These excitations are found at energies of around 1.6 and 3.3 meV (black dashed lines) and 2.1 and 4.2 meV (white dashed lines), respectively. The observation of excitations at finite source-drain voltage finds support by the detection of inelastic cotunneling onsets at lower bias. Inside the upper Coulomb diamond of Fig. 2.6 (c), we distinguish between regions of suppressed and slightly elevated conductance separated by the dotted line. The edge of this conductance step is aligned with the first excited state outside the diamond at an energy of 1.6 meV as highlighted by an arrow.

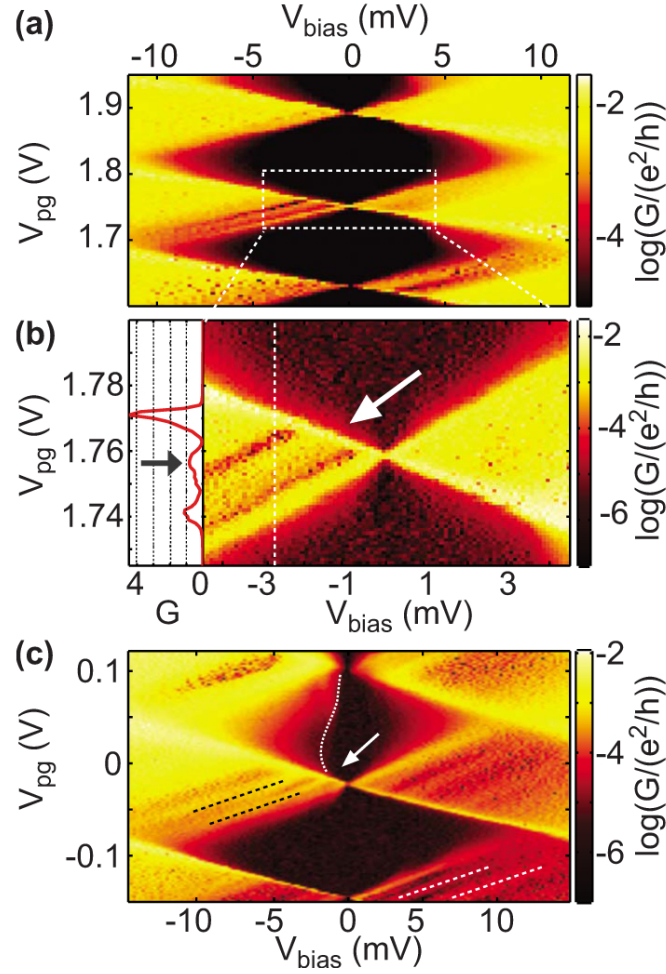


Figure 2.6: (a) Differential conductance as a function of source-drain voltage V_{bias} and plunger gate voltage V_{PG} . (b) The right panel is a zoom of the framed area in (a). An excited state is clearly visible (white arrow). A cut along the dashed line at $V_{bias} = -2.87$ mV is shown in the left panel. (c) Stability diagram at different plunger gate voltages. Several excited states are visible as shown by dashed lines. In the upper diamond, regions of higher conductance (in the left part of the diamond) can be seen. This is interpreted as a signature of cotunneling in a graphene quantum dot (see arrow).

2.5 Self-aligned charge read-out for InAs nanowire quantum dots

I. Shorubalko, R. Leturcq, A. Pfund, D. Tyndall, R. Krischek, T. Ihn, and K. Ensslin, in collaboration with S. Schön, FIRST lab, ETH Zurich

The control and measurement of individual charges via transport experiments through semiconductor quantum dots (QD) have been complemented by so-called charge detection via a nearby quantum point contact (QPC). These devices are typically realized in two-dimensional electron gases in AlGaAs/GaAs heterostructures. The QPC is placed in close vicinity to the QD giving rise to a strong capacitive coupling between the two systems. The QPC is tuned to a regime where its conductance is a steep function of a gate voltage.

QDs in InAs nanowires represent another fascinating avenue to realize high quality electronic nanostructures. The bandstructure of InAs gives rise to strong spin-orbit interactions and large confinement energies caused by the small effective mass of the conduction band electrons. This makes QDs in InAs nanowires excellent candidates for spin qubits especially in view of electric field-induced spin manipulation.

We set out to realize a charge read-out for QDs in InAs nanowires with optimized coupling and sensing ability. An InAs nanowire is deposited on top of a shallow 2DEG. The QD in the InAs nanowire and the QPC in the underlying

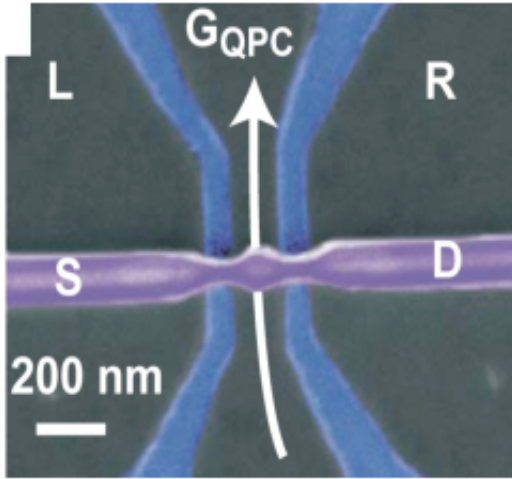


Figure 2.7: Scanning electron microscope image of the etched sample structure. The white bar has a length of 200 nm. The top nanowire (colored magenta between S and D) is reduced in width in the center where the QD forms between two barriers. The blue lines define insulating barriers in the underlying electron gas. Contacts S and D are source and drain contacts of the nanowire. Contacts L and R are the lateral gates to tune the electronic width of the QPC.

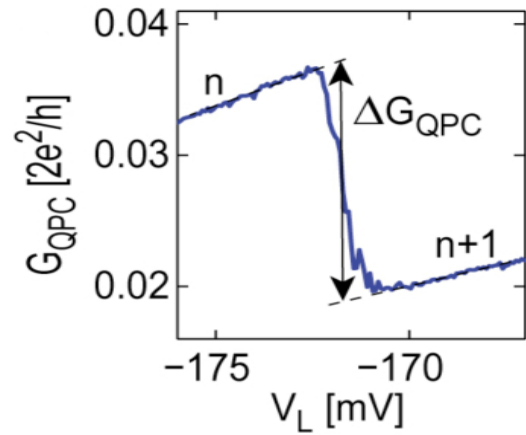


Figure 2.8: Conductance of the quantum point contact in the parameter regime where one electron is added to the InAs nanowire quantum dot.

2DEG are defined in a single-etching step. This way the alignment of the two devices is guaranteed and strong coupling is ensured.

The sample structure looks as shown in Fig. 2.7. The etching parameters are carefully optimized such that the constrictions in the nanowire form tunnel barriers suitable for operation of the dot while the etched trenches in the 2DEG underneath are deep enough to act as laterally insulating barriers.

The conductance of the QPC G_{QPC} is shown in Fig. 2.8. For each additional electron entering the quantum dot, the QPC current changes by about 20-50%. This extraordinarily strong signal is useful for time-resolved measurements and for studies of back action between the two quantum devices.

2.6 Observation of excited states in a p-type GaAs quantum dot

Y. Komijani, M. Csontos, T. Ihn, K. Ensslin, D. Reuter, and A. D. Wieck, in collaboration with D. Reuter, and A. D. Wieck, Univ. of Bochum, Germany

Quantum dots implemented in GaAs heterostructures represent promising candidates for the experimental realization of quantum computation, as well as various spintronic devices. However, research based on electronic transport through such small conducting islands has been, so far, almost exclusively focused on quantum dots defined on n-type GaAs heterostructures. The recently emerging interest in low-dimensional hole-doped systems arises primarily from the fact that spin-orbit as well as carrier-carrier Coulomb interaction effects are more pronounced in such systems compared to the more established n-doped systems. The main reason for this is that holes have a much higher effective mass than electrons, and thus a smaller Fermi energy. This enables the investigation of novel regimes with much higher relative interaction strength.

The sample was patterned in the 2DHG by local anodic oxidation lithography. The bright oxide lines displayed in Fig. 2.9 (a) are created on the wafer surface by using the charged tip of an atomic force microscope (AFM) in a humid environment. Oxide lines as high as 15 nm are able to locally deplete the 2DHG situated 45 nm below the surface separating the 2DHG into laterally disconnected regions which are individually connected to metallic leads. Voltages in the range of 200mV can be applied between separated regions without any significant leakage current across the

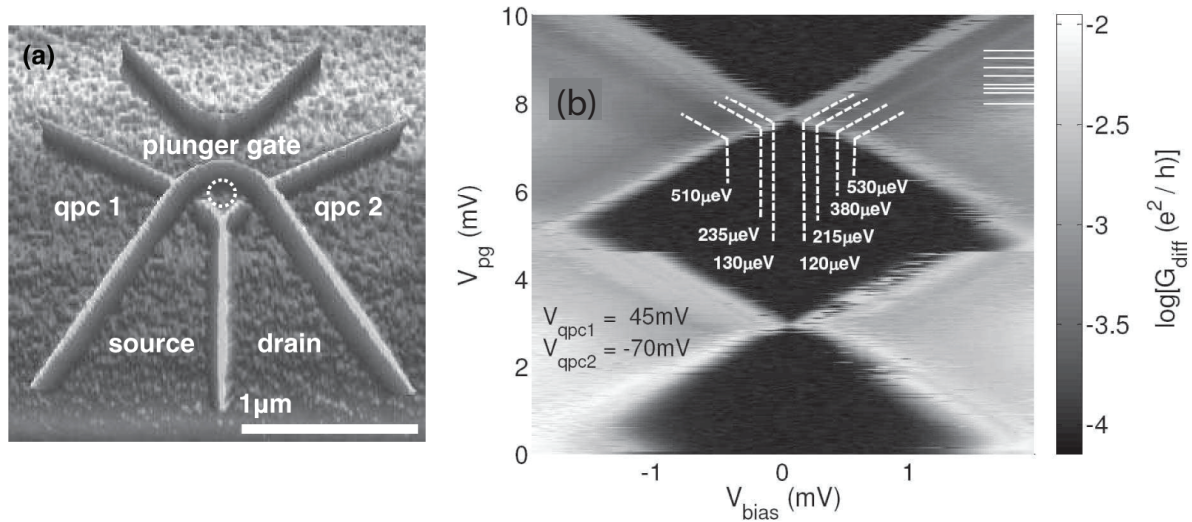


Figure 2.9: (a) AFM image of the sample topology. The 15nm high oxide lines are prepared by local anodic oxidation and create insulating barriers in the underlying 2DHG separating it into electrically disconnected areas. The dashed circle indicates the location of the QD which is connected to source and drain contacts by two QPCs. The couplings of the dot to the leads are tuned individually by the in-plane gates qpc1 and qpc2 while the electrochemical potential of the dot can be varied by applying a voltage on the nearby plunger gate. (b) High-resolution scan of a Coulomb diamond. The parallel lines of higher conductivity outside the diamonds are attributed to sequential elastic tunneling through single-particle excited states of the dot. The corresponding excitation energies of the levels are also indicated.

oxide line. A small quantum dot is formed between the source (S) and drain (D) leads. The coupling of the dot to S and D through two quantum point contacts (QPCs) can be tuned individually by applying voltages on the nearby in-plane gates qpc1 and qpc2. The third in-plane plunger gate PG is used to align the electrochemical potential and thus the number of the confined holes in the dot with respect to the electrochemical potentials in S and D.

The transport experiments were carried out at 60mK base temperature of a standard dilution refrigerator. The two-terminal electrical conductance was measured by the simultaneous application of a symmetrical ac bias with an amplitude of $20 \mu\text{V}$ at 31Hz lock-in frequency and dc biases up to 2mV between S and D.

A refined Coulomb diamond scan was performed for the data presented in Fig. 2.9 (b). Apart from a small displacement due to a background charge rearrangement at $V_{pg} \approx 4.5\text{meV}$ the three diamonds in Fig. 2.9 (b) show outside the diamonds, parallel to the edges, lines of higher differential conductance. Apart from the missing left-side counterpart of the right-hand side line at $\approx 380 \mu\text{eV}$ which reveals the weak coupling of the excited states to the leads, the well-visible left-right symmetry of the line distribution excludes an alternative explanation in terms of resonances in the random potential landscape of the leads. One can, therefore, unambiguously attribute these lines to elastic sequential tunneling through the single-level excited states of the dot. The weak coupling of the excited states made the simultaneous detection of second-order current steps in the Coulomb blocked region, characteristic to inelastic co-tunneling via the excited states, difficult. However, a faint contrast in the middle of the Coulomb diamonds was found in the strongly coupled regime where the connecting excited-state lines outside the diamonds were no longer resolvable.

2.7 Detecting terahertz current fluctuations in a quantum point contact using a nanowire quantum dot

S. Gustavsson, I. Shorubalko, R. Leturcq, T. Ihn, and K. Ensslin, in collaboration with S. Schön, FIRST lab, ETH Zurich

Charge detection with single-electron precision provides a highly-sensitive method for probing properties of mesoscopic structures. If the detector bandwidth is larger than the timescale of the tunneling electrons, single-electron

transitions may be detected in real-time. The sample is the same as the one presented in Fig. 2.7.

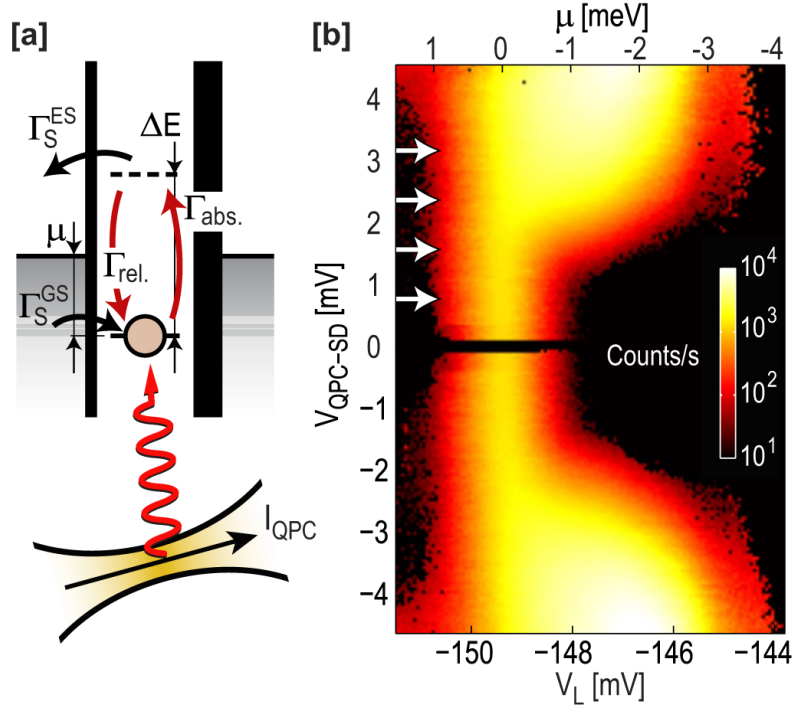


Figure 2.10: (a) Energy level diagram describing the absorption process. The electron in the QD is excited due to photon absorption, which allows it to tunnel out to the lead. (b) Quantum dot excitations, measured versus QPC bias voltage. The main peak at zero chemical potential is due to equilibrium fluctuations between the source lead and the QD. As the gate voltage V_L is increased, the electrochemical potential of the QD drops below the Fermi level of the lead and only tunneling processes involving QD excitations become possible. Photon absorption is only possible for QPC bias voltages higher than the QD level separation ΔE , giving rise to the shoulderlike features appearing at high V_{QPC} .

We discuss the QD configuration used for probing the radiation of the QPC. Since the QD level spectrum is not tunable, we can only drive transitions at fixed frequencies corresponding to excited states in the QD. Fig. 2.10 (a) shows the level configuration of the system, with the QD electrochemical potential below the Fermi level of the leads. The tunneling barriers are highly asymmetric, with the barrier connecting the QD to the drain lead being almost completely pinched off. We do not apply any bias voltage to the QD. The system is in Coulomb blockade, but by absorbing a photon the QD may be put into an excited state with electrochemical potential above the Fermi energy of the leads. From here, the electron may leave to the source contact, the QD is refilled and the cycle may be repeated.

In Fig. 2.10 (b) we plot the electron count rate versus QD potential and QPC bias. The peak at zero chemical potential is due to equilibrium fluctuations between the QD and the source contact, with the width set by the electron temperature in the lead. As the QPC bias is increased above 2.5 mV, a shoulder appears in the region of negative chemical potential. This is consistent with the picture in Fig. 2.10 (a). We need to apply a QPC bias larger than the single-level spacing for the photon-assisted tunneling to become possible. The width of the shoulder is set by $E = 2.5$ meV and is therefore expected to be independent of QPC bias. The apparent smearing of the features in Fig. 2.10 (b) is due to temperature and tuning of the tunneling rates. The picture is symmetric with respect to V_{QPC} , meaning that the emission and absorption processes do not depend on the direction of the QPC current. The lack of data points around $V_{QPC} = 0$ V is due to the fact that the low QPC bias prevents the operation of the QPC as a charge detector. Due to the asymmetric coupling of the QD to the source and drain lead, we could not make a direct confirmation of the existence of an excited state with $\Delta E = 2.5$ meV using finite bias spectroscopy. However, the value is consistent with excited states found in Coulomb diamond measurements in regimes where the tunnel barriers are more symmetric.

2.8 Time-resolved detection of single-electron interference

S. Gustavsson, M. Studer, R. Leturcq, T. Ihn, K. Ensslin, in collaboration with D. C. Driscoll and A. C. Gossard, University of California, Santa Barbara, USA

One of the cornerstone concepts of quantum mechanics is the superposition principle as demonstrated in the double-slit experiment. The partial waves of individual particles passing a double slit interfere with each other. The ensemble average of many particles detected on a screen agrees with the interference pattern calculated using propagating waves (Fig. 2.11 (a)). This has been demonstrated for photons, electrons in vacuum and more massive objects like C_{60} -molecules. The Aharonov-Bohm (AB) geometry provides an analogous experiment in solid-state systems. Partial waves passing the arms of a ring acquire a phase difference due to a magnetic flux, enclosed by the two paths (Fig. 2.11 (b)).

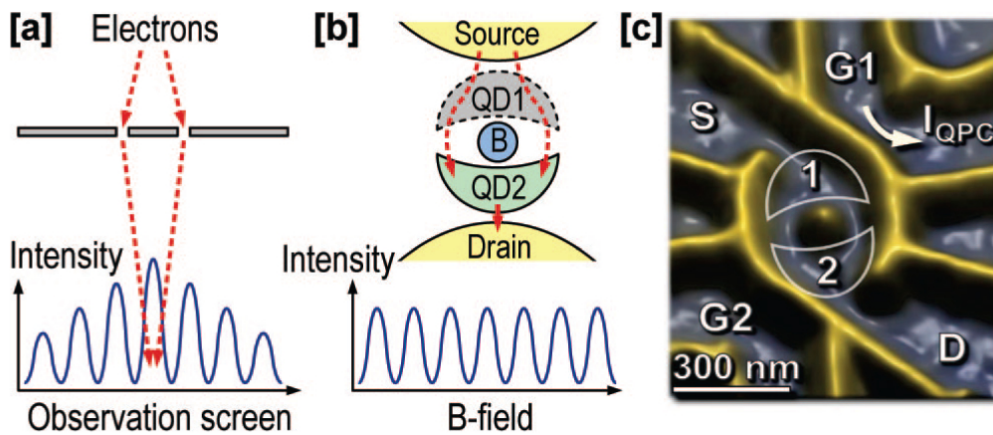


Figure 2.11: (a) Setup of a traditional double-slit experiment. Electrons passing through the two slits give rise to interference pattern on the observation screen. (b) Schematic drawing of the setup used for measuring single-electron Aharonov-Bohm interference. Electrons are injected from the source lead, tunnel through QD1 and end up in QD2, where they are detected. The interference pattern is due to the applied B-field, which introduces a phase difference between the left and right arm connecting the two quantum dots. (c) Double quantum dot used in the experiment. Yellow lines are written with a scanning force microscope on top of a semiconductor heterostructure and represent the potential landscape for the electrons. The QDs (marked by 1 and 2) are connected by two separate arms, allowing partial waves taking different paths to interfere. The current in the nearby QPC (IQPC) is used to monitor the electron population in the system.

The sample was fabricated by local oxidation of the surface of a GaAs/AlGaAs heterostructure containing a two-dimensional electron gas 34 nm below the surface. Following the sketch in Fig. 2.11 (b), electrons are provided from the source lead, tunnel into QD1 and pass on to QD2 through either of the two arms. Upon arriving in QD2, the electrons are detected in real-time by operating a near-by quantum point contact (QPC) as a charge detector. Coulomb blockade prohibits more than one excess electron to populate the structure, implying that the first electron must leave to the drain before a new one can enter. This enables time-resolved operation of the charge detector and ensures that we measure interference due to individual electrons.

The electrons travel one-by-one through the system but still build up a well-pronounced interference pattern with period 130 mT as seen in Fig. 2.12. This corresponds well to one flux quantum penetrating the area enclosed by the two paths. The visibility of the AB oscillations is higher than 90%, which is a remarkably large number demonstrating the high degree of phase coherence in the system. We attribute the high visibility to the short time available for the cotunneling process and to strong suppression of electrons being backscattered in the reverse direction, which is otherwise present in AB experiments. Another requirement for the high visibility is that the two tunnel barriers connecting the QDs are carefully symmetrized. The overall decay of the maxima of the AB oscillation with increasing B is probably due to magnetic field effects on the orbital wave functions in QD1 and QD2.

The dephasing of open QD systems is thought to be due to electron-electron interaction, giving dephasing rates that depend strongly on temperature. Fig. 2.12 shows the temperature dependence of the AB oscillations in our system. The amplitude of the oscillations remains almost unaffected up to ≈ 400 mK, indicating that the coherence is not

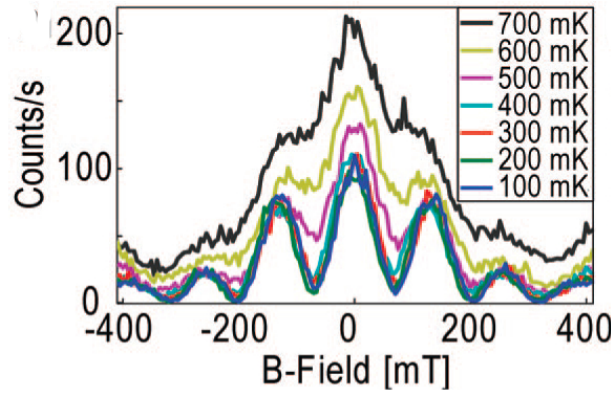


Figure 2.12: Aharonov-Bohm (AB) oscillations measured at different temperatures. At ≈ 400 mK, the visibility of the oscillations drops drastically.

affected by temperature until the thermal energy becomes comparable to the single-particle level spacing of the QDs. We conclude that the decreased visibility at higher temperatures is due to an increase in thermal fluctuations of the QD population.

We have demonstrated interference of single electrons in a semiconductor system. Such experiments have so far been limited to photons or massive particles in a high-vacuum environment to decouple the quantum mechanical degrees of freedom as much as possible from the environment. Our experiments demonstrate the exquisite control of modern semiconductor nanostructures which enables interference experiment at the level of single quasi-particles in a solid-state environment.

2.9 Statistical electron excitation in a double quantum dot induced by two independent quantum point contacts

U. Gasser, S. Gustavsson, B. Küng, K. Ensslin, T. Ihn, in collaboration with D. C. Driscoll and A. C. Gossard, University of California, Santa Barbara, USA

The application of a quantum point contact (QPC) as a source of energy to drive interdot electronic transitions in a double quantum dot (DQD) was recently realized. These experiments were explained in terms of acoustic phonon based energy transfer between the QPC and the DQD circuits.

The sample shown in Fig. 2.13 is based on a GaAs/AlGaAs heterostructure with a two-dimensional electron gas 2DEG 34 nm below the surface. It was fabricated by double layer local oxidation with a scanning force microscope (SFM). The 2DEG is depleted below the oxide lines written on the GaAs surface (white lines in Fig. 2.13 (a)). A 4 nm titanium film was evaporated and patterned by local oxidation to create mutually isolated top gates indicated by the dashed lines in Fig. 2.13 (a). The confinement potential produced by the top gates and the oxide lines is shown in the contour plot in Fig. 2.13 (b). It was calculated assuming a pinned surface model using the lithographic sizes of the gates measured after the sample was fabricated. It shows an approximately circular symmetry for the dots with the left quantum dot being slightly larger than the right one.

Fig. 2.14 shows the dot current versus detuning. The black data points in Fig. 2.14 (a) were taken with zero bias applied to the DQD as well as to QPC1 and QPC2. No measurable current above the noise level is detected. When a dc current of 50 nA is driven through QPC1, an asymmetric peak with a maximum of about 125 fA along the detuning line is observed (blue points in Fig. 2.14 (a)). This effect is strongly enhanced if the current through QPC1 is further increased to 75 (green points) and 100 nA (red points). A similar but significantly more pronounced effect is observed if QPC2 is driven, as shown in Fig. 2.14 (b). Moreover, for negative detuning a small negative DQD current is observed. QPC2 is more sensitive as a charge readout and it has a stronger effect on the DQD.

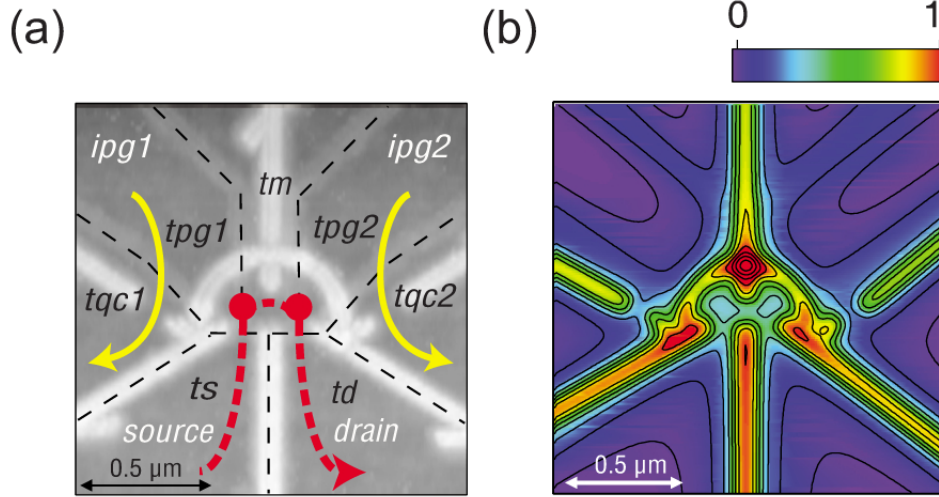


Figure 2.13: (a) SFM image of the sample. In-plane gates are defined by the thick white lines while titanium oxide lines are indicated by dashed lines. Top gates are labeled with black letters. The QDs are indicated with red circles. The yellow arrows indicate the positive direction of the current in the QPCs. (b) Calculated electrostatic potential in the 2DEG generated by the oxide lines and the top gates.

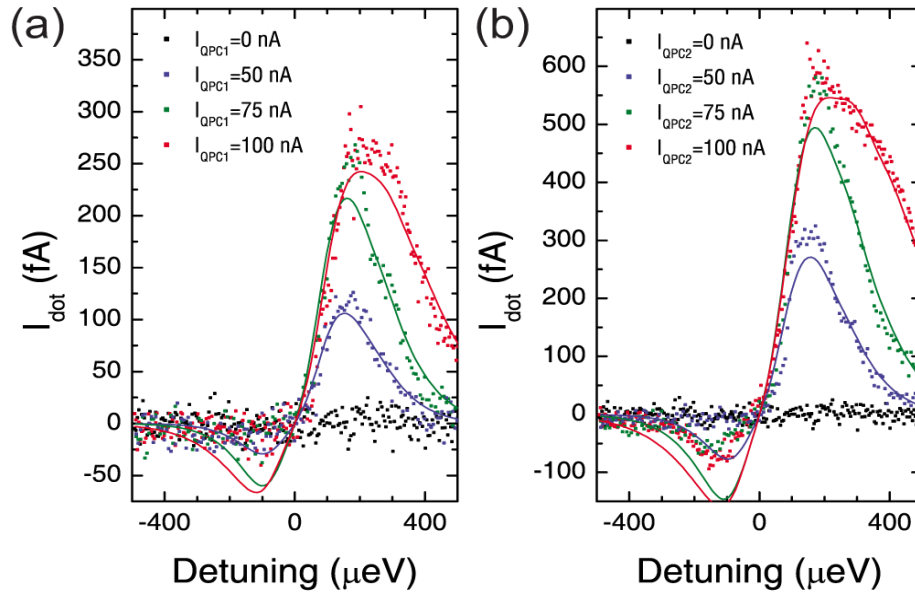


Figure 2.14: Current through the DQD along the detuning line: (a) for different QPC1 and (b) different QPC2 currents. Fits are plotted with solid lines.

The possible mechanisms of the pumping effect are coupling to acoustic or optical phonons, plasmons, photons, shot noise, or thermopower effect. Scattering with optical phonons is strongly suppressed as long as the relevant energy scales are smaller than the optical phonon energy. Coupling to plasmons can be ruled out as well. We can also exclude the shot noise as a source of the energy because during the experiment both QPCs were tuned to their first plateau.

We have established the possible dominant mechanism of energy transfer between the double quantum dot and the quantum point contact in the investigated regime. Driving current through the QPC leads to emission of energy that increases the temperature of the bosonic environment. We identify these bosons as acoustic phonons. To model the interaction of the phonons with the double quantum dot, we have assumed that their energy distribution is described by Bose-Einstein statistics. Another important point is a non-additive effect of both QPC currents. It is understood in terms of the temperature of the bosonic bath. We find that the DQD current is proportional to the power emitted by the QPCs.

2.10 Spin-orbit interaction and spin relaxation in a two-dimensional electron gas

M. Studer, and K. Ensslin, in collaboration with G. Salis, IBM Zurich, and S. Schön, FIRST lab, ETH Zurich

The possibility to manipulate spins in semiconductors is a requirement for future spin-based information processing. Using the spin-orbit interaction is a promising way to precisely control spin polarization because of its simple principle based on external gate electrodes.

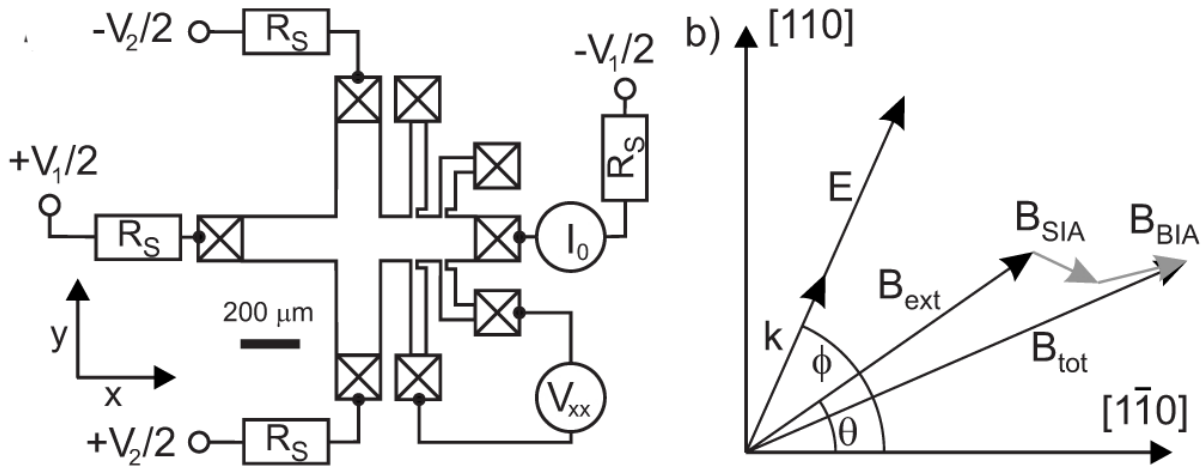


Figure 2.15: (a) The InGaAs/GaAs QW is shaped into a cross with 150 nm wide arms contacted by ohmic contacts. Additional contacts on one arm of the cross allow a four-point measurement of the voltage drop V_{xx} and the determination of electron sheet density and mobility. (b) θ and Φ are the angles of the magnetic and electric fields with respect to the $[1-10]$ axis. B_{tot} is the vector sum of the external magnetic field and the two SO effective magnetic field contributions.

The 2DEG we use in this work is located in an InGaAs/GaAs QW. Electrons are confined to a 20-nm thick InGaAs layer that is n-doped to ensure a small electron scattering time such that we are in the dirty limit of the SO interaction, where the frequency of spin precession about the SO fields is small compared with the momentum scattering rate.

We obtain the resistivity of the 2DEG during optical experiments by monitoring the ratio of the voltage drop V_{xx} and the current I_0 through one arm of the cross [Fig. 2.15 (a)]. An external magnetic field B_{ext} is applied in the direction Θ as seen in Fig. 2.15 (b). Because of the different angular dependencies of the Rashba and Dresselhaus spin-orbit fields, the two contributions can be distinguished.

We have measured the spin orbit interaction coefficients and found no significant temperature dependence. From the Rashba and Dresselhaus coefficients, the measured Hall mobility and the anisotropy in $1/T_2^*$, we estimate the contribution from Dyakonov-Perel spin dephasing and find that this mechanism alone cannot explain the measured $1/T_2^*$. From a linear increase in $1/T_2^*$ with B_{ext} , we identify an inhomogeneous broadening from a spread in the electron g factor. These effects do not account for all of the measured spin-dephasing rate. We speculate that Elliott-Yafet or an inhomogeneous spin-orbit field might induce an additional isotropic contribution. A more detailed study of the nature of the elastic and inelastic electron-scattering mechanisms involved might facilitate an exact attribution to the different decay mechanisms.

2.11 Dynamics of coupled spins in quantum dots with strong spin-orbit interaction

A. Pfund, I. Shorubalko, R. Leturcq, and K. Ensslin

Double quantum dots (DQDs) are considered as model systems for quantum bits (qubits) in spin-based solid-state quantum computation schemes.

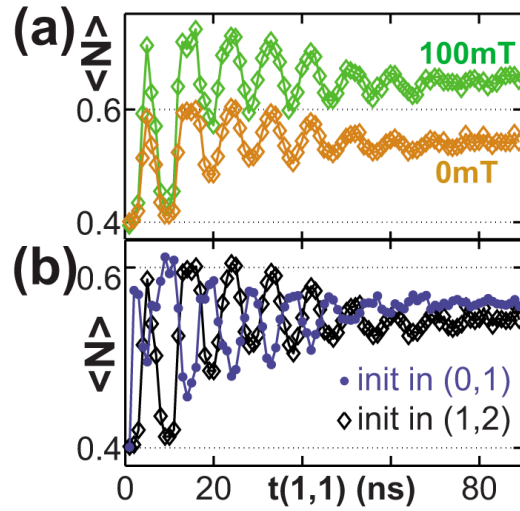


Figure 2.16: Number of pumped electrons per cycle as a function of the time spent in (1,1). (a) Dependent on the external field, the average number of electrons shows oscillations with a period 9.4 ns and characteristic decay time of 25 ns for 0 mT and 45 ns in 100 mT. (b) When changing the initialization state of the cycle, the phase of the oscillations changes by π .

We employ a charge pumping scheme to measure the time dependence of two-electron spin states by transport through the DQD. When the system contains two excess electrons, the Pauli exclusion principle suppresses certain transitions. This spin-blockade (SB) can be used to electrically determine the spin state.

We investigate a DQD formed by lithographically defined top gates on an epitaxially grown InAs nanowire. To probe the time evolution of the spin states, we use pumping cycles where single electrons are shuttled through the DQD. Fast ns pulses are applied to the gates in a loop around the (0,1), (-1,1), (-1,2)-triple point in the charge stability diagram. The pumped current is measured with zero bias across the device and is strongly reduced in the blocked direction compared to cycling in the opposite way, which reflects the spin transition rules leading to the SB.

The number of pumped charges is shown as a function of the time spent in the (1,1) state, see 2.16 (a). The total cycle time is constant (140 ns) in a regime, where the signal only depends on $t(1,1)$ [$t(0,2)=20$ ns] is fixed. The oscillation period does not vary with magnetic field, but the decay is changed. A purely exponentially decaying function cannot be fitted to the amplitude. Nevertheless it allows to estimate a decay time, which increases monotonically from 25 ns at 0 T to 45 ns at 100 mT. A detection of coherent oscillations in the pumping scheme would imply a selective state preparation. In 2.16 (b) we observe a striking dependence of the phase of the oscillations on the way the two-electron state is loaded. Moving the initial state from (0,1) to (1,2) in the charge stability diagram results in a phase shift of π . In both cases, the charge is pumped in the direction of spin blockade.

Chapter 3

Microstructure research

(<http://www.microstructure.ethz.ch>)

Head

Prof. Dr. Danilo Pescia
Prof. Dr. Mehmet Erbudak

Academic Staff

S. Burkard	O. Portmann	N. Saratz
T. Kirk	Dr. U. Ramsperger	Dr. A. Vindigni
Dr. A. Vaterlaus	Dr. M. Hochstrasser	

Technical Staff

Th. Bähler

Academic Guests

Prof. E. Özensoy	S. Manukyan	Dr. F. Cinti
Prof. S. Cannas	Dr. J. Cazaux	Prof. D. Stariolo

Diploma & Master Theses

L. De Pietro	HS 2008
A. Lichtenberger	FS 2008
Y. Riesen	HS 2008
O. Scholder	HS 2008
D. Sutter	FS 2008

3.1 Low-Voltage Field Emission Scanning Electron Microscope

T. Kirk, U. Ramsperger, D. Pescia

R. D. Young (R. D. Young, J. Ward, and F. Scire, *Rev. Sci. Instrum.* **37**, 43, 999 (1972)) was the first to employ a field emission (FE) current between a sharp metallic tip and sample to resolve surface features, as small as 400nm. In the experiment proposed by Young, a tip is brought in close proximity to the sample surface until the desired current is achieved. The tip is then rastered along the surface at the set current, which is maintained by a feedback controller that adjusts the vertical piezo voltage accordingly. The voltage applied is much larger than the work function of the emitting material, which results in an I-V relation consistent with Fowler-Nordheim field emission law. This primary beam of electrons impinges the surface at a well-defined area and undergoes elastic as well as inelastic collisions penetrating the top most layer of the surface (1nm). The ejected secondary electrons from the collisions were collected using an electron multiplier. The electron intensity from the electron multiplier signal displays the surface topography. Young was aware that decreasing the tip radius and the tip sample separation would increase the resolution; however Binnig and Rohrer were the first to implement these conditions in the MVM (metal-vacuum-metal tunneling) regime. The vertical motion of the tip in constant current mode, as described above, was used to determine surface topography instead of the secondary electron intensity, i.e. scanning tunneling microscope (STM) mode. Binnig and Rohrer achieved atomic resolution, which initiated the birth of scanning probe microscopy. The experiments involving Young's Field Emission Scanning Microscopy (FESM) are the most significant to the current project. These experiments show promising results as well as a variety of methods in the analysis of the secondary electrons which even led to patents in some cases (H.W. Fink, *Phys. Scripta* **38**, 260 (1988), B. Reihl and J. K. Gimzewski, *Surf. Sci.* **189/190**, 36 (1987), H.W. Fink, US patent 4954711, Frohn and Ibach, US patent 5099117, Kitamura, US patent 5438196, R. Palmer, US patent 6855926, G. Bednorz, US patent 4698502). A recent realization of the experiment by Young is described e.g. in F. Festy et al., *J. Appl. Phys. D*: **34**, 1849 (2001), which produced topographic images with 40 nm lateral resolution. This group went further by analyzing the energy of the backscattered electrons and thus were able to perform Electron Energy Loss Experiments with high spatial resolution. A study comparing scanning electron microscopy (SEM) and STM (Ph. Niedermann and O Fisher, *IEEE Transactions on Electrical Insulation*, **24**, 905 (1989)) exploits the benefits of near field FE-microscopy to bridge the gap between the two techniques. There are two previous attempts to use FESM with spin polarization analysis of the secondary electrons. The experiment by R. Allenspach at IBM measured a hysteresis loop with secondary electrons emitted by an STM tip FE-excitation (R. Allenspach and A. Bischof, *Appl. Phys. Lett.* **54** 54, 587 (1989)). First et al. at NIST (P.N. First, *J. Vac. Sci. Technol. B* **9** 531 (1991)) produced magnetic images using FESM and with a spatial resolution of about 50 nm. J.J. Saenz et al., *Appl. Phys. Lett.* **14** 65 (23) (1994) calculated the spatial resolution of an STM in field emission mode from geometrical arguments, which is on the order of $\approx \sqrt{(R + d) \cdot d}$, where R is the tip Radius and d the distance between tip and surface. Although the calculations do not take into consideration surface roughness or work function dependence, it predicts a lateral resolution of a few nanometers. Fink has already achieved 3nm lateral resolution on a polycrystalline gold surface by measuring the electron intensity from an electron multiplier. All these experimental results point out that, although FE-SEMPA will not achieve atomic resolution, it is potentially an attractive technique because it allows "good" spatial resolution in combination with large area scans, which are often important when both the spin configuration within a domain wall and within the interior of magnetic domains are investigated simultaneously. Second, it measures directly the magnetization and is conceptually very close to SEMPA – a fact that is important when distinguishing between topographic and magnetic contrast. In addition, it is contact free and, being performed with a non-magnetic tip, hence it cannot affect the magnetic state of the sample one seeks to image. Finally, it should offer a less cumbersome and inexpensive alternative to a conventional SEMPA instrument, which uses ad hoc developed UHV electron guns which are very rare and prohibitively expensive.

Taryl Kirk and U. Ramsperger have designed and constructed a working prototype of an FE-microscope (without spin analysis). This prototype is shown in Fig.1 schematically. An important improvement with respect to earlier designs is the use of very sharp Tungsten tips with high FE yield (we thank Prof. W. Fink for his essential help in developing these tips) and to the positioning of the scintillator in close proximity to the sample surface. The Tungsten tips are made by the standard electro-chemical etching process, and we estimate a nominal tip radius of approximately 2nm. We also took profit of the important fact (R. Palmer) that near field FE-excited electrons travel almost parallel to the

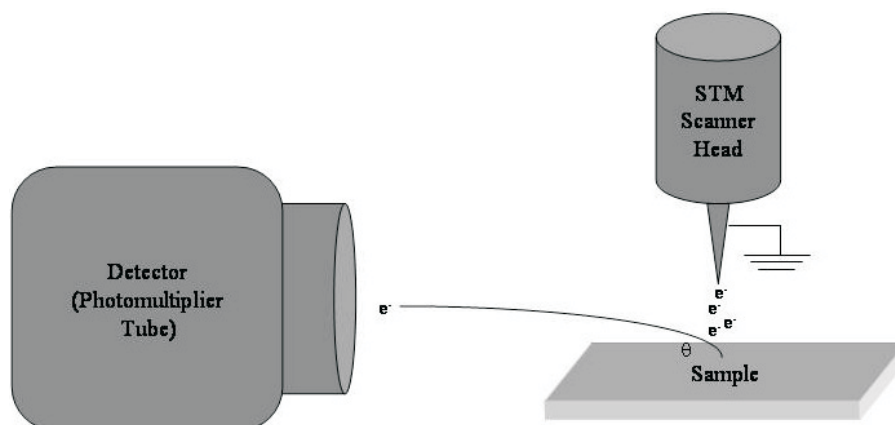


Figure 3.1: Schematic diagram of the near field emission microscope and secondary electron detector. A primary electron beam is produced via a STM-tip at energies ranging from 30 to 60 eV. The resultant secondary electrons are accelerated to the detector at glancing angles with respect to the sample surface

surface. The preliminary images taken with our own self-made device (Fig.2) are very encouraging, in our opinion. We are able to measure step edges 12-15nm wide, which is slightly larger than what we measure with the STM. We expect this new instrument to make magnetic imaging at nanometer resolution available to a larger community than presently. It represents a technological challenge that also have a high education value for those involved with it, as it encompasses a large amount of self-development of new technology and/or integration of well-developed technologies into one single innovative instrument.

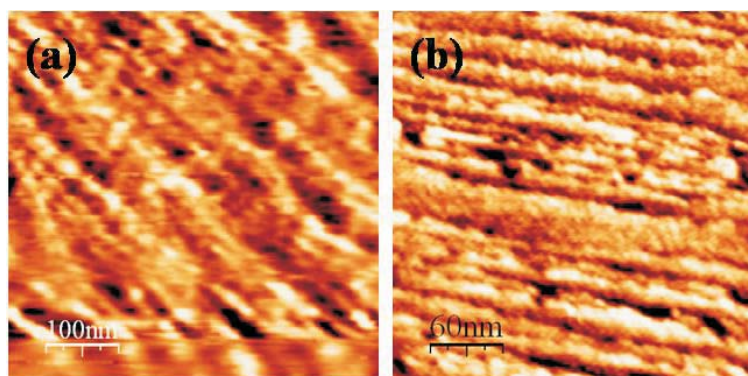


Figure 3.2: Micrograph of a single crystal Cu(100)-surface. (a) 500×500 nm topographic image from the electron intensity of secondary electrons. The primary beam energy was 47 eV with a field emission current of 50 nA, and the tip-sample separation was about 75 nm. The image was scanned at constant height mode. Frequent jumps occurred during the scan, due to adsorbate movement between tip and sample. (b) 300×300 nm topographic image from a STM with tunnel current of 0.1 nA and a bias of 200 mV. The two images show the similar, characteristic disordered step-like features.

3.2 Co deposition onto icosahedral Al-Pd-Mn quasicrystals

S. Burkardt, M. Erbudak, Y. Weisskopf

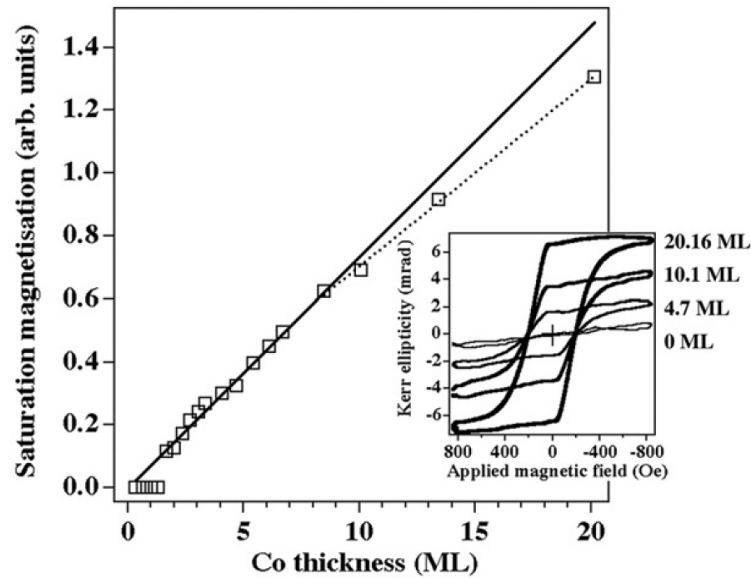


Figure 3.3: Dependence of the Kerr intensity on the Co deposit in monolayers.

We have evaporated Co onto the pentagonal surface of an icosahedral Al-Pd-Mn quasicrystal, kept at room temperature. For submonolayer (ML) Co deposits, the growth of five AlCo domains is observed exposing their (110) faces parallel to the surface and rotated azimuthally by 72° with respect to each other. For thicker layers, Co grows epitaxially on the AlCo domains in a novel body-centered cubic (bcc) structure. We extract the details of the growth resulting in ordered nanostructures from low-energy electron diffraction (LEED) investigations. The ordering at the atomic scale can be explained by a strain-relieved surface reconstruction of the Co film during growth. The hysteresis loops obtained in magneto-optical Kerr effect measurements for different Co deposits show that the coercive force, i.e., anisotropic magnetization, is not dependent on the film thickness, as seen in the inset of Fig. 3.3. This observation implies that the coupling of the magnetic moments is independent of the atomic coordination. The straight line in the figure is a linear fit to the data points recorded for deposits between 1.5 and 6.5 ML, and the dotted line is a fit to the magnetization values for 8.5 to 20 ML. The straight line passes approximately through the origin suggesting that no magnetically dead layer is present. Thus, the entire Co film deposited onto the bcc AlCo domains formed in the submonolayer regime is ferromagnetic.

3.3 Adsorption of oxygen on the decagonal Al-Co-Ni quasicrystal

S. Burkardt, M. Erbudak

We have detected an ordered formation of the oxygen layer upon high-temperature exposure of the decagonal surface of the Al-Co-Ni quasicrystal. Like on the (111) surface of Al, oxygen exists in a state of dissociative adsorption on this quasicrystalline surface even though the heat of formation is extremely large for Al_2O_3 . This observation complements those by other groups that have observed pseudomorphic growth for noble gases on the same surface. We also have determined conditions for which oxygen chemically binds to Al of the quasicrystal and forms ordered alumina layers. Measurements at different temperatures and oxygen doses show that alumina layers can be grown that are thicker than one single atomic layer, because the diffusion of Al becomes possible at elevated temperatures and

post-annealing of the surface layers establishes the crystalline order. We anticipate that these results may find some application in quantum electronics.

3.4 Nanometer-size alumina substrates on quasicrystal surfaces

S. Burkardt, M. Erbudak

We have grown thin Al-oxide layers on the pentagonal surface of the icosahedral Al-Pd-Mn quasicrystal by selective segregation epitaxy, in which Al segregates to the surface and is oxidized in a controlled way at a particular temperature. The formed ultra-thin oxide domains are only a few nanometers in size and especially attractive because of their thermodynamic stability, e.g. their chemical and mechanical robustness, they may act as nanosubstrates for the growth of material in a laterally restricted size. The fabrication of quantum dots may become feasible with substances that would otherwise not grow in the desired small size. We have tested this novel approach for the growth of low-dimensional systems using Al. LEED and secondary-electron imaging investigations show that Al nanocrystals grow in their natural face-centered cubic structure and show their (111) faces parallel to the pentagonal surface of the quasicrystal, while the in-plane orientation of the crystallites is random. Spot-profile analysis of the diffraction beams indicate that the Al nanocrystals grow in 3 nm large domains up to a deposition thickness of ~ 50 ML.

3.5 Simulation of structure formation on quasicrystals

S. Burkardt, M. Erbudak, M. Mungan

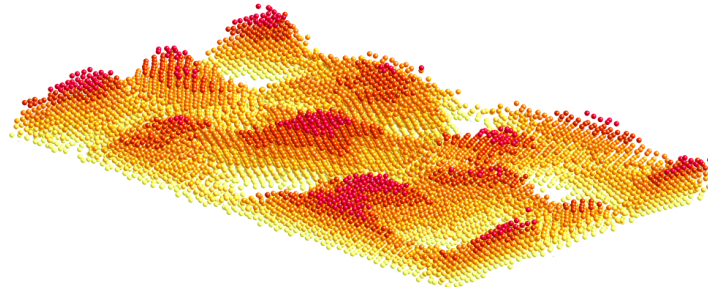


Figure 3.4: Overall adatom configuration at 3.5 ML coverage. Observe the different orientation of atom rows in the domains.

Using molecular dynamics simulations, we have studied the structure formation when atoms are deposited onto a substrate with a quasicrystalline order. Keeping the substrate atoms as a rigid template, we investigate the three dimensional adlayer growth up to a deposition that corresponds to ~ 3.5 ML. We consider the deposition process under conditions of very slow energy dissipation, leading to a large thermal relaxation time for the deposited atoms. The interaction between the adatoms, like that between the adatoms and the substrate atoms, the ratio of which is called η , is assumed to be pairwise and of Lennard-Jones type. For $\eta = 1$, our simulations show that the initial lateral distribution of atoms is homogeneous giving rise to layer-by-layer growth. Larger values of η will increase the probability for arriving new adatoms to be deposited on already present ones giving rise to a cluster-type growth. This is encountered even for $\eta = 1.2$ resulting in a configuration where the adlayer structure, while well ordered, is highly corrugated and does not fully cover the substrate. This configuration, shown in Fig. 3.4, exactly corresponds to what we have observed in the growth of material on different surfaces of Al-Pd-Mn as well as Al-Co-Ni quasicrystals.

Chapter 4

Thin-Film Physics Group

(<http://www.tfp.ethz.ch/>)

Head

PD Dr. H. Zogg

Academic Staff

Prof. Dr. A. N. Tiwari
Dr. Y. Romanyuk
A. Chirila
J. Perrenoud
R. Verma

Dr. D. Güttler
D. Brémaud
F. Felder
M. Rahim
D. Corica

Dr. S. Nishiwaki
S. Bücheler
M. Fill
S. Seyrling

Technical Staff

J. Däscher

O. Meier

Diploma & Master Theses

J. Perrenoud	HS 2007 - FS 2008
L. Inderbitzin	HS 2007 - FS 2008
P. Blösch	FS 2008
D. Boye	FS 2008
A. Fognini	FS 2008
R. Chati	HS 2008
S. Hänni	HS 2008
A. Khlar	HS 2008
R. Sauaia	HS 2008

4.1 Epitaxial IV-VI narrow-gap semiconductor layers and mid-IR devices

F. Felder, M. Fill, M. Rahim, D. Boye, A. Fognini, A. Khir and H. Zogg

Epitaxial narrow gap lead chalcogenide (IV-VI) layers like PbX , $\text{Pb}_{1-y}\text{Sn}_y\text{X}$, $\text{Pb}_{1-y}\text{Eu}_y\text{X}$ and $\text{Pb}_{1-y}\text{Sr}_y\text{X}$ ($\text{X} = \text{Te}$, Se) are investigated for applications and basic research. The band gaps of the active infrared layers range from < 0.1 to 0.4 eV (corresponding to wavelengths in the mid-IR range). Larger band gaps are realised with larger y values for the cladding $\text{Pb}_{1-y}\text{Eu}_y\text{X}$ and $\text{Pb}_{1-y}\text{Sr}_y\text{X}$ layers. All layers are grown by solid source molecular beam epitaxy (MBE) onto $\text{Si}(111)$ -substrates by employing a CaF_2 buffer layer, or onto $\text{BaF}_2(111)$ substrates. The layers are heavily lattice- and (for Si-substrates) thermal-expansion mismatched. Lead-chalcogenides are fault tolerant, and allow to realize high quality mid-infrared optoelectronic devices even with such mismatched layers.

In addition, epitaxial Bragg mirrors with very high reflectivity over a broad spectral range are easily obtained with a few quarter wavelength layers with alternating high and low refractive indices.

Vertical External Cavity Surface Emitting Laser (VECSEL)

VECSELs for the visible and near-infrared range are popular due to their easy fabrication, scalability, and good beam quality. We realized the first VECSELs emitting above $3 \mu\text{m}$ wavelength. The devices were grown on BaF_2 or Si substrates, optically pumped with a commercial $1.55 \mu\text{m}$ wavelength laser diode, and operated up to 175 K. The active layer was PbTe with emission wavelength around $5 \mu\text{m}$. Recently, we built the first mid-IR VECSEL operating up to above room temperature. A resonant design was chosen: The active part consists of a single 850 nm thick epitaxial PbSe gain layer. It is followed by a 2.5 pair $\text{Pb}_{1-y}\text{Eu}_y\text{Te}/\text{BaF}_2$ Bragg mirror and an Al heat spreader layer. No microstructural processing is needed. The device operates up to 45°C with 100 ns pulses and delivers 6 mW output power at 27°C heat-sink temperature. Compared to edge-emitting mid-IR lasers like type-W or quantum cascade lasers (QCL), the structure is remarkably simple, easily wavelength tunable and emission is into a narrow output beam cone only.

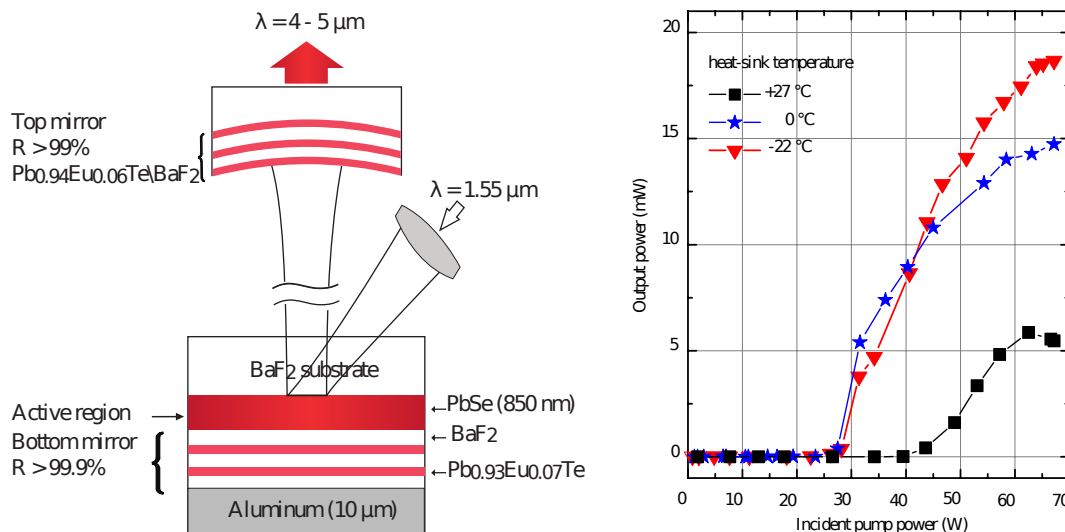


Figure 4.1: (left) Schematic representation of a PbSe -based IV-VI VECSEL. The curved Bragg mirror is used as output coupler. (right) Light-in/light-out characteristics at different temperatures.

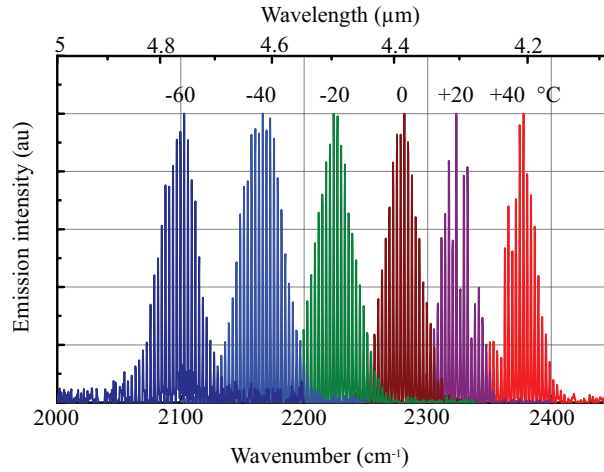


Figure 4.2: Normalized PbSe based VECSEL lasing spectra at different heat sink temperatures.

Resonant Cavity Enhanced Detector (RCED)

A resonant cavity enhanced detector (RCED) is an embedded absorber layer within a Fabry-Perot cavity. It is sensitive mainly at the resonance wavelengths, where it exhibits a high quantum efficiency. By changing the cavity length, wavelength tuning is possible. We realized a RCED with movable MEMS micromirrors. Due to alloying the bandgap of the $\text{Pb}_{0.98}\text{Sr}_{0.02}\text{Te}$ absorber layer is blue-shifted. The total tunable range is $\sim 0.5 \mu\text{m}$ wide.

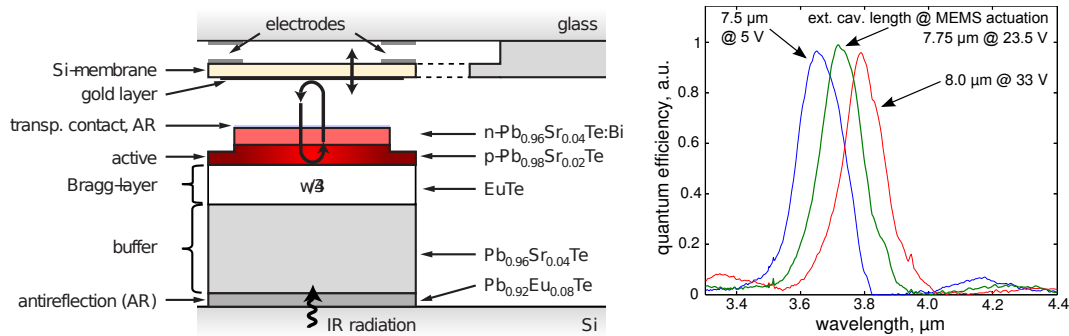


Figure 4.3: Schematics of a RCED and measured spectra for different MEMS actuation voltages.

PbTe quantum dots in a CdTe-layer on Si(111)

Quantum dot infrared photodetectors (QDIP) have high sensitivity limits and are especially suited to be employed in RCEDs. PbTe QDs are promising IV-VI candidates for this purpose. They may be embedded in a CdTe matrix. PbTe is nearly lattice matched with CdTe but has a different crystal structure: The lattice is rocksalt for PbTe, while it is zinkblende for CdTe. Coherent PbTe precipitates form since intermixing is avoided. PbTe QD in a CdTe matrix were studied on different substrates, for example on GaAs(100). Here we present the formation of self assembled PbTe QD in a CdTe matrix on Si(111). Fig. 2 shows the PL spectra of an ensemble of PbTe QD showing a blueshift with regard to bulk PbTe as well as the calculated energies for a specific QD size.

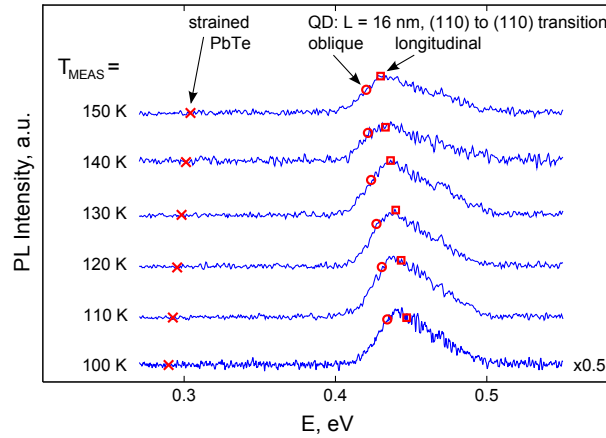


Figure 4.4: PL spectra of an annealed PbTe QD in CdTe sample strained PbTe, the calculated interband transitions for a QD size of 16 nm are shown.

4.2 Thin-film Cu(In,Ga)Se₂ and CdTe compound semiconductors solar cells

D. Bremaud*, S. Bücheler*, A. Chirila*, S. Seyrling*, R. Verma*, A.N.Tiwari* and H. Zogg

* Now at EMPA, Dübendorf, www.empa.ch/tfpv

Thin film solar cells based on Cu(In,Ga)Se₂ (CIGS) and CdTe have potential to provide cost effective solar electricity. Flexible and lightweight solar cells are interesting for a variety of terrestrial and space applications as they offer potentially lower production cost and new application possibilities where lightweight, rollability, portability and high specific power (kW/kg, ratio of output electrical power to the weight of the solar module) are desired.

Alternative buffer layers and deposition

State of the art high efficiency CIGS solar cells contain a thin cadmium sulphide buffer layer between cell absorber and front contact. This buffer layer deposited by chemical bath deposition has limitations due to optical absorption losses below 2.4 eV and is not ideal for continuous in-line manufacturability. Therefore alternative materials and deposition processes are investigated and the properties of layers, heterojunctions, devices and meta-stabilities are studied with various analytical tools.

Non-vacuum deposited indium sulfide layers are a promising low-cost option as alternative buffer layers in CIGS thin film solar cells. The indium sulfide layers were grown by an ultrasonic spray pyrolysis method. Chemical analysis of the sprayed In₂S₃ films by RBS and ERDA revealed Cl, O, N, and C impurities; their concentration decreases with increasing substrate temperature and S excess in the solution. A chemical treatment of the as-deposited In₂S₃ buffer layer on CIGS for 2 min in an aqueous solution containing cadmium acetate, thiourea, and ammonia showed an improvement of the solar cell performance. Two distinct effects were observed: an increase of the Voc and FF for middle-high efficiency cells and for low efficiency cells additionally an increase in the Jsc. The external quantum efficiency (EQE) measurements suggest that collection of charge carriers is drastically improved if the buffer layer is chemically treated in Cd containing solution. The figure shows the plan and cross-section of the polyimide/Mo/CIGS/(~ 30nm) In₂S₃ stack. It was observed that the In₂S₃ film only non-uniformly covers the rough CIGS surface, which resulted in limited cell efficiencies. Furthermore the presence of intermediate residual Na(F) layer could be identified between the CIGS and buffer layers, which originates from the NaF post deposition treatment after CIGS growth. The presence of this residual layer is detrimental and a surface treatment method is needed to improve the interface properties of the heterojunction. A best cell efficiency of 10.1% was achieved for the flexible CIGS cell with indium sulfide buffer layer. This is 76% of the CdS reference cell, which yielded an efficiency of 13.2%.

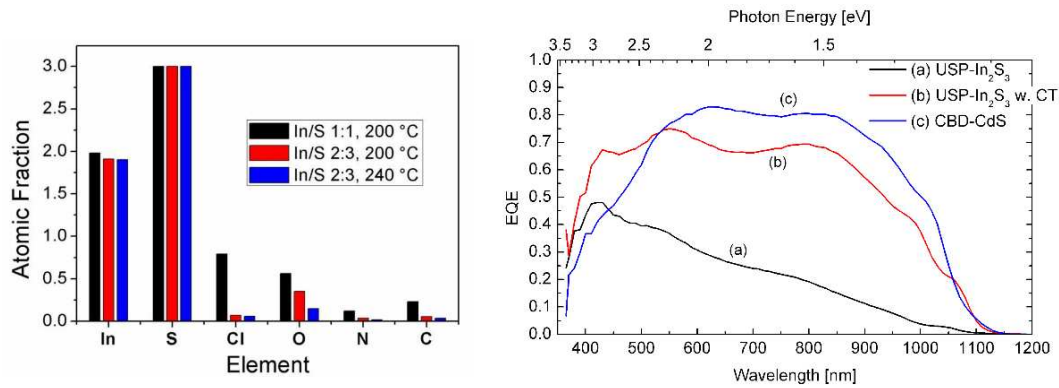


Figure 4.5: (left) Composition of layers on (111)-Si substrate deposited at different surface temperatures using solution of different In:S ratios as derived from ERDA measurements. (right) External quantum efficiency (EQE) of Cu(In,Ga)Se₂ based solar cells with different buffer layer: (a) sprayed In₂S₃, (b) sprayed In₂S₃ with 2 min chemical treatment (CT), and (c) CBD-CdS buffer reference cell.

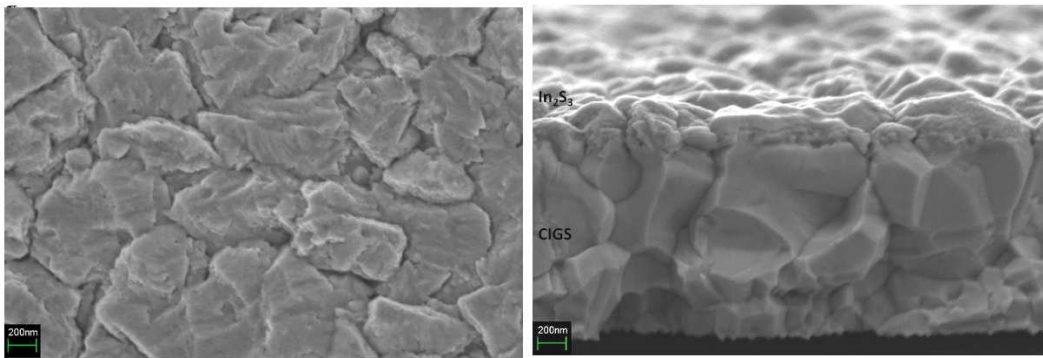


Figure 4.6: Surface morphology of the In₂S₃ film deposited on CIGS surface (a), and cross-section micrograph showing the presence of In₂S₃ buffer layer on CIGS film (b).

CdTe thin film solar cells by low-temperature deposition process

A highly resistive buffer layer between the front contact and the CdS layer in low temperature processed high vacuum evaporation (HVE)-CdTe/CdS thin film solar cells was implemented in order to reduce the optical absorption losses. An intrinsic ZnO layer, deposited by rf-magnetron sputtering, was used as high resistive transparent buffer layer. Substrate temperature as well as chamber pressure strongly influence grain structure, layer thickness and compactness. The growth rate of the layer increases with decreasing chamber pressure. X-ray diffraction revealed a preferred orientation in (002) direction with average grain size of 30 nm. The CdCl₂ layer thickness for the CdTe recrystallisation treatment was optimized to the new configuration. All solar cell parameters improved significantly with increasing CdCl₂ thickness and saturated with CdCl₂ thickness more than 400 nm. Best cell efficiency was 11.8%.

High growth rates for CIGS solar cells

We investigated the so-called three-stage vacuum evaporation process for the growth CIGS layers which yields the highest efficiencies up to date. In order to enhance the deposition rates the process steps were scaled down in time independently from each other. It was found that in each step very high deposition rates can lead to deterioration in solar cell performance. In the 1st stage the main problem is attributed to the selenium pressure which must be chosen appropriately high in order to avoid blisters forming due to stress relaxation. The 2nd stage was found to lead to degradation only at very high deposition rates. The 3rd stage proved to be crucial and we found that the selenium pressure needs to be extremely high in order to prevent the formation of copper whiskers which lead to shunts in the

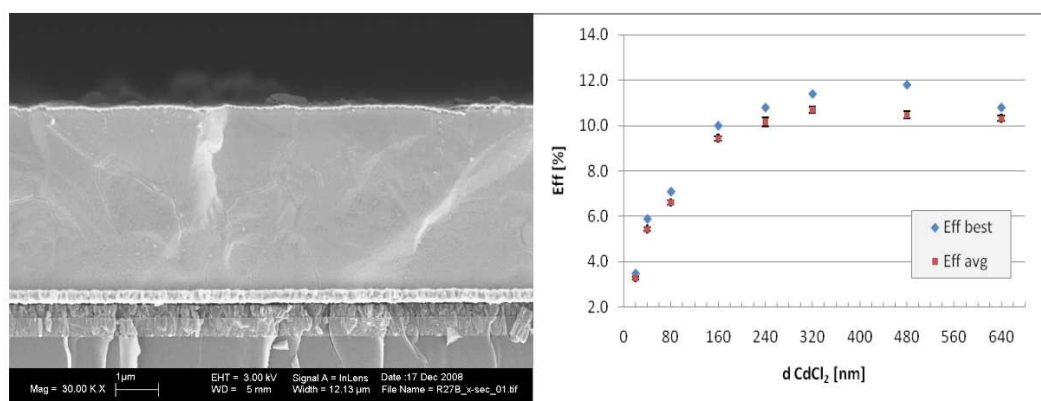


Figure 4.7: (left) SEM image of a CdTe thin film solar cell in superstrate configuration with highly resistive layer between the TCO and the CdS n-type junction partner. (right) Efficiency of CdTe solar cells versus the CdCl₂ layer thickness during the activation treatment.

devices. The microstructures of CIGS absorbers grown at high deposition rates are shown in the figure. Depicted are the above described phenomena as the development of blisters and whiskers. Plots of cell efficiencies versus deposition time show, that the deposition speed can be increased by a factor of ~ 3 -4 without a significant efficiency loss if the modified three-stage process can be optimized further.

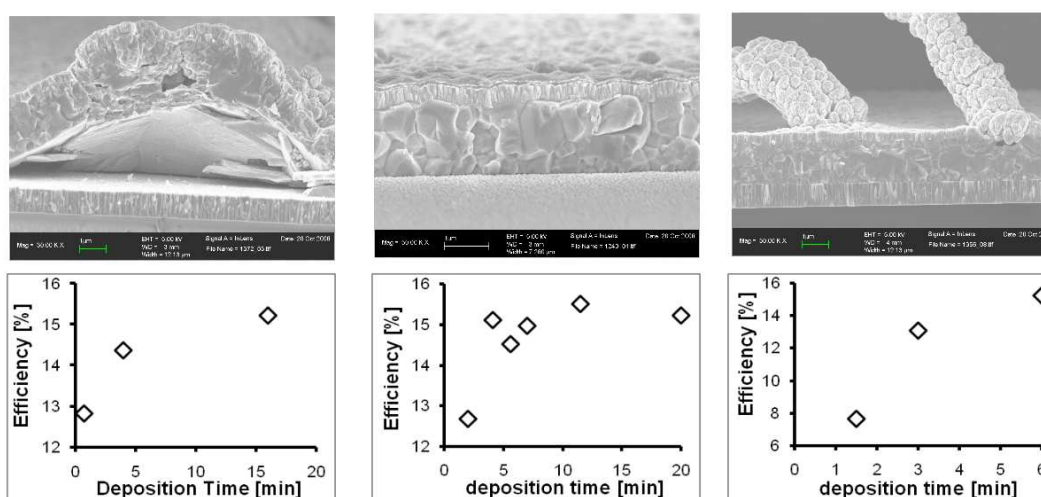


Figure 4.8: SEM micrographs (top) from CIGS films grown at high rates in the 1st stage (left), 2nd stage (middle) and 3rd stage (right) and solar efficiency dependence on the deposition time (bottom).

Chapter 5

Optical Spectroscopy

(<http://www.solidphys.ethz.ch/spectro/>)

Head

Prof. Dr. L. Degiorgi

Academic Staff

M. Lavagnini

F. Pfuner

Administrative Staff

I. Mettler

5.1 Evidence for coupling between charge-density-wave and phonons in two-dimensional rare-earth tri-tellurides

M. Lavagnini, A. Sacchetti, R. Monnier and L. Degiorgi

work in collaboration with M. Baldini, D. Di Castro and P. Postorino, Università “La Sapienza” Rome, Italy, B. Delley, PSI-Villigen, Switzerland, J.-H. Chu, N. Ru and I.R. Fisher, Stanford University, California, U.S.A.

The electron-phonon coupling is of fundamental relevance for the development of several types of charge ordering in solids, of which the charge-density-wave (CDW) state, first predicted by Peierls, is an interesting realization. Peierls argued that one-dimensional (1D) metals are intrinsically unstable, and that a new broken-symmetry ground state results from the selfconsistent rearrangement of the electronic charge density in response to the (static) modulation of the ionic positions. The new lattice periodicity leads moreover to the opening of a gap at the Fermi level. The consequences of this intimate connection between electronic properties and lattice dynamics have been intensively investigated in a number of prototype quasi-1D materials.

CDW's have been observed in transition metal di- and trichalcogenides, in the ladder compounds $\text{Sr}_{14-x}\text{Ca}_x\text{Cu}_{24}\text{O}_{41}$ and in some copper oxide high temperature superconductors (where they are known as “stripes”) as well, suggesting that similar effects are to be expected also in layered quasi-2D systems. A recent theoretical study confirms that this is indeed the case, and that two orthogonal CDW's may even combine to generate a checkerboard-like charge pattern. However, high temperature superconductors are bad candidates for a systematic study of the interplay between electronic and phononic degrees of freedom in quasi-2D materials, given the strongly correlated nature of the electrons in these systems. One class of quasi-2D compounds well suited to address this issue are the rare-earth (*R*) tri-tellurides. They host a CDW state already at 300 K and their structure consists of alternating double Te (*ac*) planes (where the CDW resides) sandwiched between *R*Te layer blocks and stacked along the long *b* axis in the weakly orthorhombic (pseudo-tetragonal) cell. In our first optical investigations, we have established the excitation across the CDW-gap and discovered that this gap is progressively reduced upon compressing the lattice either with chemical substitution (i.e., by changing *R*) or with externally applied pressure.

The formation of the CDW condensate in *R*Te₃ only partially gaps the Fermi surface and therefore these materials remain metallic even well below the critical temperature T_{CDW} at which the CDW appears. This prevents the investigation of the phonon modes and more generally of the impact of the lattice dynamics on the CDW state in an infrared absorption experiment, as the corresponding signals are overwhelmed by the metallic contribution. We therefore address the issue of the coupling between vibrational modes and CDW condensate in these prototype 2D systems from the perspective of the Raman scattering response.

We have reported on a Raman scattering investigation of *R*Te₃ (*R*= La, Ce, Pr, Nd, Sm, Gd and Dy) at ambient pressure, and of LaTe₃ and CeTe₃ under externally applied pressure. Figure 5.1(a) summarizes the Raman scattering spectra, collected for the whole *R*Te₃ series (i.e., chemical pressure). Four distinct modes at 72, 88, 98 and 109 cm^{-1} and a weak bump at 136 cm^{-1} (labelled P1-P5, respectively) can be identified in the La compound. The P1 mode slightly softens from La to Nd and slowly moves outside the measurable spectral range at ambient pressure (i.e., in SmTe₃ only its high frequency tail is still observable). The remaining modes weakly disperse and progressively disappear when going from the La to the Dy compound along the rare-earth series. Panels (b) and (c) in Fig. 5.1 display the Raman scattering spectra of LaTe₃ and CeTe₃, under increasing and decreasing externally applied pressure. The spectral range covered within the DAC is limited at low frequencies at about 75 cm^{-1} , while at ambient pressure it extends down to 65 cm^{-1} . Therefore, the lowest zero-pressure mode P1 cannot be clearly detected in the applied pressure experiment. As in the chemical pressure case, all other modes slightly disperse and disappear upon applying pressure. This qualitative equivalence between chemical and applied pressure is also supported by the fact that the peaks in LaTe₃ disappear at a slightly higher pressure than in CeTe₃. The pressure dependence is fully reversible since upon decreasing pressure the modes reappear again. The observed phonon peaks can be ascribed to the Raman active modes for both the undistorted as well as the distorted lattice in the CDW state by means of a first principles calculation.

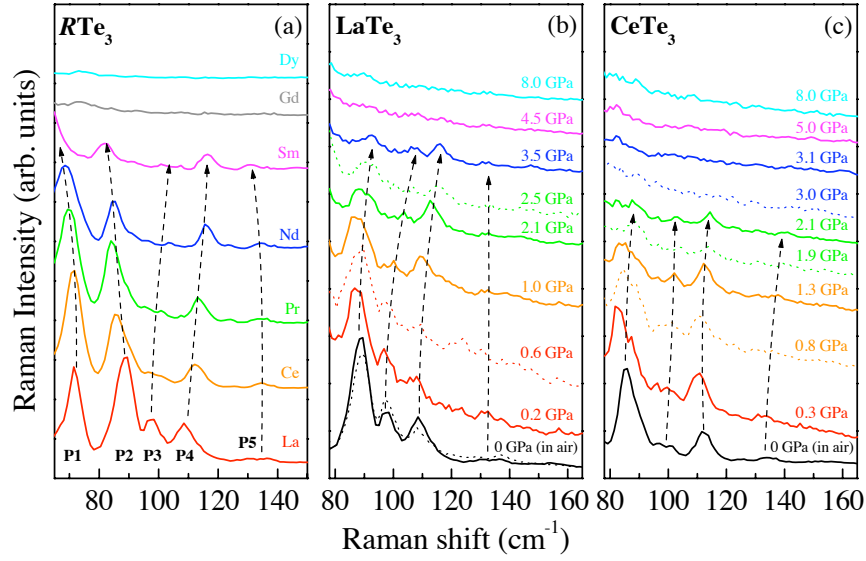


Figure 5.1: Raman scattering spectra at 300 K for the $R\text{Te}_3$ series at ambient pressure (a), and for LaTe_3 (b) and CeTe_3 (c) for increasing (continuous lines) and decreasing (dashed lines) pressure. All spectra have been shifted for clarity.

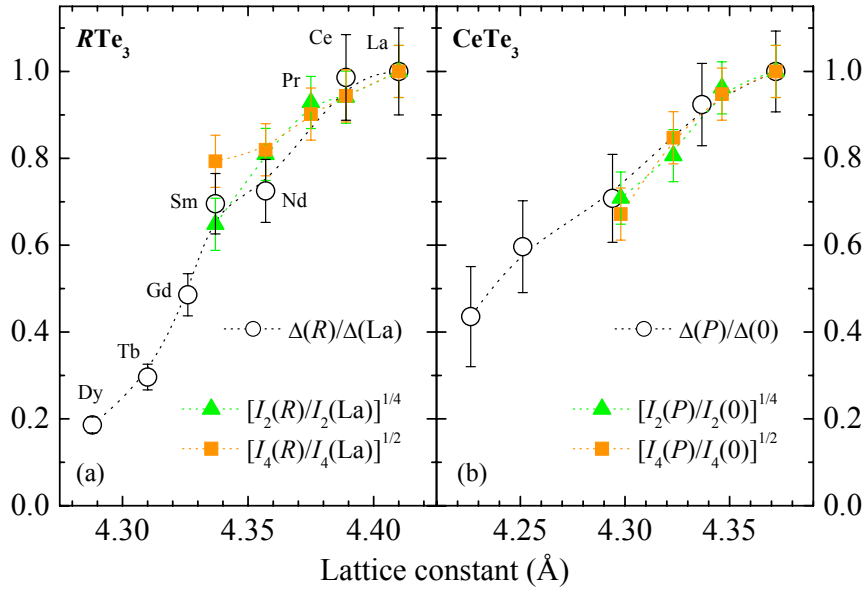


Figure 5.2: Comparison between the amplitude of the CDW-gap (open circles) and the integrated intensities (I) of the P2 (full triangles) and P4 (full squares) peaks, raised to 1/4 and 1/2, respectively (see text) as a function of the lattice constant for the $R\text{Te}_3$ series (a) and for CeTe_3 under pressure (b). All quantities are normalized to their starting values.

An important result of our experimental investigation is the observation of a systematic decrease of the integrated intensity (I) of the most prominent peaks P2 and P4 in the Raman spectra of Fig. 5.1 with pressure, which bears a striking similarity with the behaviour of the amplitude of the CDW-gap Δ (i.e., the order parameter) upon compressing the lattice, as obtained from the optical conductivity. One could first argue that these modes disappear because of an enhancement of their width and a concomitant decrease of their apparent amplitude due to the increase in free carrier concentration upon compressing the lattice. The modes' width remains, however, almost constant so that this possibility is rather unlikely. Our optical data also allow us to exclude the possibility that the phonon modes disappear due to an increase of the absorption coefficient at the laser frequency with decreasing lattice constant. Figure 5.2 shows that the intensities of the P2 and P4 peaks scale fairly well with Δ^4 and Δ^2 , respectively, suggestive

of a coupling between the lattice vibrational modes and the CDW condensate. This is not at all surprising, as our calculations predict these peaks only in the distorted structure. Furthermore, the specific behaviour ($I \sim \Delta^q$, $q=2$ or 4) is consistent with theoretical predictions for the intensity in the distorted phase of originally silent modes, obtained from a group theoretical analysis in the framework of Landau's theory of second order phase transitions.

In summary, we have been able to draw a consistent picture of the Raman response of the CDW rare-earth tri-tellurides, by combining experimental observations and numerical simulations. In particular, we have provided clear evidence for the tight coupling between the CDW-gap and the lattice degrees of freedom and have made a robust prediction (not shown) for the Kohn anomaly inducing the CDW phase transition. Therefore, the easily tuneable $R\text{Te}_3$ series provides a rather unique playground for a systematic study of the mechanism leading to CDW formation.

5.2 Pressure-induced quenching of the charge-density-wave state observed by x-ray diffraction

F. Pfuner; M. Lavagnini, A. Sacchetti and L. Degiorgi

work in collaboration with M. Baldini and P. Postorino, Università "La Sapienza" Rome, Italy, C.L. Condon, J.-H. Chu, M.F. Toney and I.R. Fisher, Stanford University, California, U.S.A., S.N. Gvasaliya and J. Mesot, PSI Villigen, Switzerland, M. Merlini and M. Hanfland, ESRF Grenoble, France

Low dimensionality plays an important role in condensed-matter physics owing to the observation of intriguing phenomena such as the formation of spin- and charge-density-waves (CDW), as well as non Fermi-liquid behavior of the electronic properties in a variety of materials. As pointed out above, a revival of interest in low-dimensional interacting electron gas systems, and in their wealth of astonishing properties, took place since the discovery of high-temperature superconductivity in the layered two-dimensional (2D) copper oxides. This furthermore led to the quest for prototype layered systems, allowing a systematic study of these phenomena. In this context, the already introduced rare-earth tri-tellurides ($R\text{Te}_3$, with $R=\text{La-Sm}$, Gd-Tm) were recently revisited and recognized as a paramount example of easily tunable 2D materials. The formation of the CDW condensate, hosted within Te-layers, is to a large extent driven by the nesting of the Fermi-surface (FS), which is thus gapped over a sizeable portion. Systematic x-ray diffraction (XRD) studies of the $R\text{Te}_3$ series revealed that the modulation vector $\vec{q} \approx (2/7)\vec{c}^*$ ($\vec{c}^*$ is the reciprocal lattice vector of the c axis) is almost the same for every member of this family, and that the CDW state is progressively suppressed as the lattice is chemically compressed (i.e., going from $R=\text{La}$ to $R=\text{Tm}$). The transition temperature T_{CDW} is 250 K for TmTe_3 , increases gradually up to 410 K in SmTe_3 , and is larger than 450 K in the tri-tellurides with lighter rare-earth elements ($R=\text{La-Nd}$).

We have presented a high-pressure XRD diffraction study on LaTe_3 and CeTe_3 , with the goal of monitoring the evolution of the CDW distortion with pressure. XRD patterns were collected at room temperature as a function of pressure for LaTe_3 and CeTe_3 single crystal and as a function of temperature for a LaTe_3 polycrystal at 6.0 ± 0.2 GPa. Representative areas of the diffraction patterns at selected pressures and temperatures are shown in Fig. 5.3. At low-pressure and at 300 K, several Bragg-peaks in both LaTe_3 and CeTe_3 display pairs of satellites, which are due to the modulated CDW lattice-distortion. Upon increasing pressure, the intensity of these satellite peaks is progressively reduced and they eventually disappear at high enough pressure (3 and 5 GPa in CeTe_3 and LaTe_3 , respectively) as shown in Fig. 5.3(a-d). At 6.0 ± 0.2 GPa the satellite peaks in LaTe_3 are recovered by cooling the polycrystalline specimen well below 300 K [see Fig. 5.3(e,f)]. This indicates that at this pressure the CDW transition occurs at a lower critical temperature T_{CDW} (i.e., < 300 K).

From the positions of selected Bragg peaks we obtained the lattice parameters and thus the unit-cell volume. The corresponding results for CeTe_3 under pressure at 300 K and for LaTe_3 as a function of temperature at 6.0 ± 0.2 GPa are shown in Fig. 5.4. The pressure experiment on LaTe_3 at room temperature provides similar results (not shown) as for CeTe_3 . At ambient pressure the slight orthorhombic distortion of the unit-cell results in a small difference between the in-plane lattice parameters a and c . Upon increasing pressure this difference between the a and c axes decreases and both lattice constants become nearly indistinguishable above 3 GPa in CeTe_3 [Fig. 5.4(a)]. A similar effect is observed in LaTe_3 at 5 GPa and was previously reported for $R\text{Te}_3$ with $R=\text{Sm-Tm}$ on crossing T_{CDW}

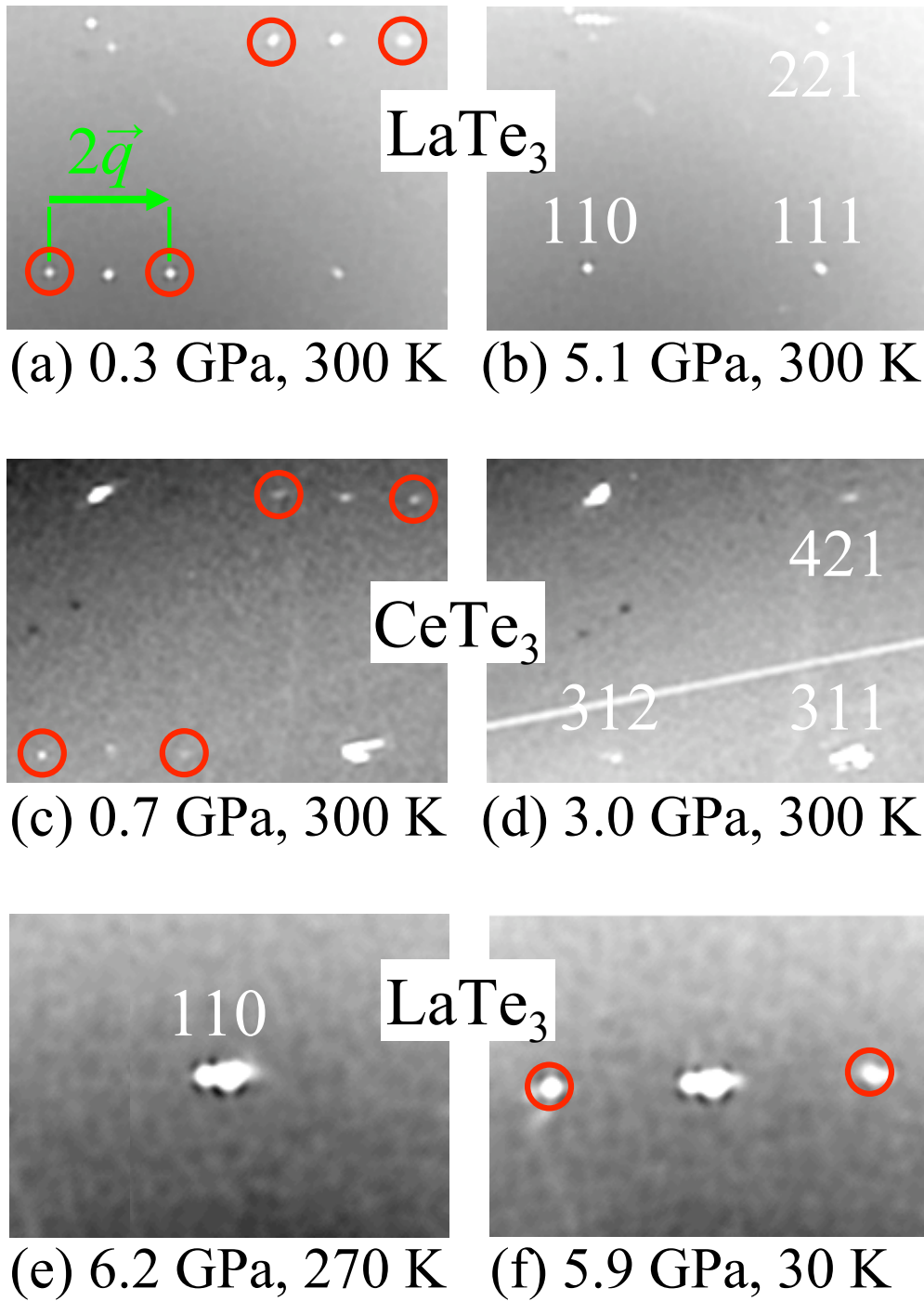


Figure 5.3: Selected 2D XRD patterns on single-crystals of LaTe_3 at 300 K and at 0.3 GPa (a) and 5.1 GPa (b), and of CeTe_3 at 300 K and at 0.7 GPa (c) and 3.0 GPa (d), and finally on polycrystalline LaTe_3 at 270 K and 6.2 GPa (e), and at 30 K and 5.9 GPa (f). Circles highlight the CDW satellite peaks. The modulation vector $\vec{q}$ is also shown in (a).

at ambient pressure. The unit-cell volume [Fig. 5.4(b)] decreases smoothly with pressure and follows the Birch-Murnaghan equation of state. A change in the temperature dependence of the c and a lattice constant is also observed when lowering the temperature below 180 K in LaTe_3 at 6 GPa [Fig. 5.4(c)]. While the scatter in the data is more pronounced than in the experiment as a function of pressure at fixed temperature, the tendency for a and c to diverge

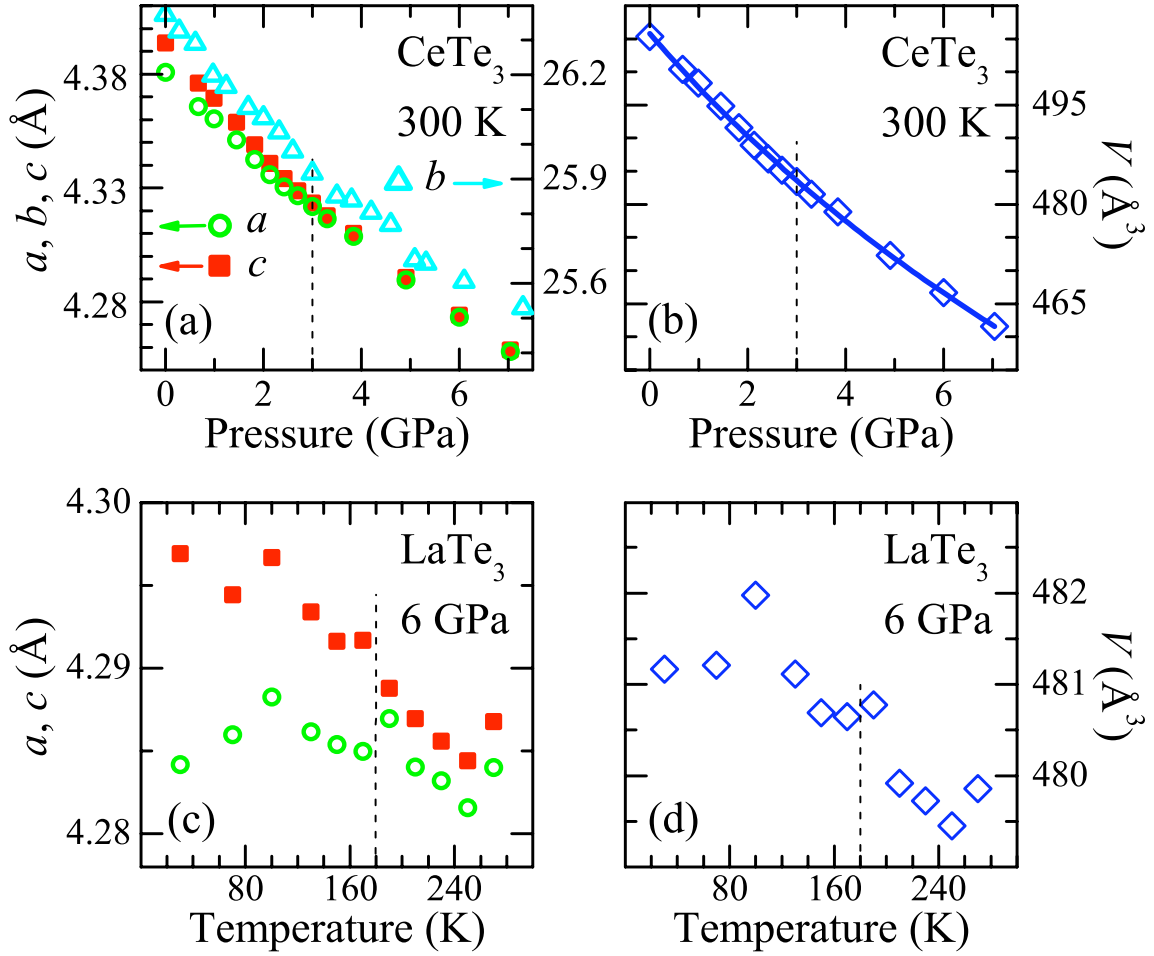


Figure 5.4: Lattice parameters (left panels) and unit-cell volume (right panels) for CeTe_3 at 300 K as a function of pressure (a,b) and for LaTe_3 polycrystal at 6.0 ± 0.2 GPa as a function of temperature (c,d). The solid line in (b) is the Birch-Murnaghan fit to the data. Vertical dashed lines indicate the pressure and temperature where the CDW satellite peaks (Fig. 5.3) disappear.

below 180 K is evident, like the weak discontinuity in the unit-cell volume [Fig. 5.4(d)]. The overall temperature dependence of the lattice parameters is very similar to that observed at ambient pressure in the heavy rare-earth tri-tellurides, suggesting an analogous impact of both chemical and applied pressure on the structural properties of $R\text{Te}_3$.

In summary, the pressure dependence of the in-plane lattice parameters is consistent with a pressure-induced reduction of the *pseudo*-tetragonal phase, i.e. of the lattice distortion accompanying the formation of the CDW condensate. This is similar to what has been observed upon cooling across the CDW transition in LaTe_3 at high pressure (present work), as well as at ambient pressure in the heavy rare-earth tri-tellurides. More striking evidence of the pressure-induced quenching of the CDW phase is provided by the intensities of the CDW satellite peaks (Fig. 5.3), which tend to zero with increasing pressure. Such observations support ideas based on the equivalence between chemical and applied pressure in $R\text{Te}_3$, put forward in our previous work.

Chapter 6

Quantum Device Lab

(<http://qudev.ethz.ch/>)

Head

Prof. Dr. Andreas Wallraff

Academic Staff

P. Arnold

Dr. S. Filipp

T. Frey

Dr. P. Leek

S. Schmidlin

M. Baur

J. Fink

M. Göppl

P. Maurer

L. Steffen

R. Bianchetti

A. Fragner

D. Henzen

G. Puebla-Hellmann

P. Studer

Technical Staff

H. Aeschbach

Administrative Staff

G. Strahm

Diploma theses

L. Steffen

A. Fragner

P. Maurer

P. Studer

FS 2008

SS 2008

SS 2008

SS 2008

6.1 Observing the $\sqrt{n}$ Nonlinearity in a Cavity QED System

J. M. Fink, M. Göppl, M. Baur, R. Bianchetti, P. J. Leek and A. Wallraff

in collaboration with A. Blais, Université de Sherbrooke, Canada

The already very active field of cavity quantum electrodynamics (QED), traditionally studied in atomic systems, has recently gained additional momentum by the advent of experiments with semiconducting and superconducting systems. In these solid state implementations, novel quantum optics experiments are enabled by the possibility to engineer many of the characteristic parameters at will. In cavity QED, the observation of the vacuum Rabi mode splitting is a hallmark experiment aimed at probing the nature of matter-light interaction on the level of a single quantum. However, this effect can, at least in principle, be explained classically as the normal mode splitting of two coupled linear oscillators. It has been suggested that an observation of the scaling of the resonant atom-photon coupling strength in the Jaynes-Cummings energy ladder, see Fig. 6.1 a, with the square root of photon number n is sufficient to prove that the system is quantum mechanical in nature.

We report a direct spectroscopic observation of this characteristic quantum nonlinearity. Measuring the photonic degree of freedom of the coupled system, our measurements provide an unambiguous, long sought for spectroscopic evidence for the quantum nature of the resonant atom-field interaction in cavity QED. We explore atom-photon superposition states involving up to two photons, using a spectroscopic pump and probe technique. The experiments have been performed in a circuit QED setup, in which ultra strong coupling is realized by the large dipole coupling strength and the long coherence time of a superconducting qubit embedded in a high quality on-chip microwave cavity.

We observe the quantum nonlinearity directly using a scheme similar to the one suggested by Thompson et al. by pumping the system selectively into the first doublet $|1\pm\rangle$ and probing transitions to the second doublet $|2\pm\rangle$, see

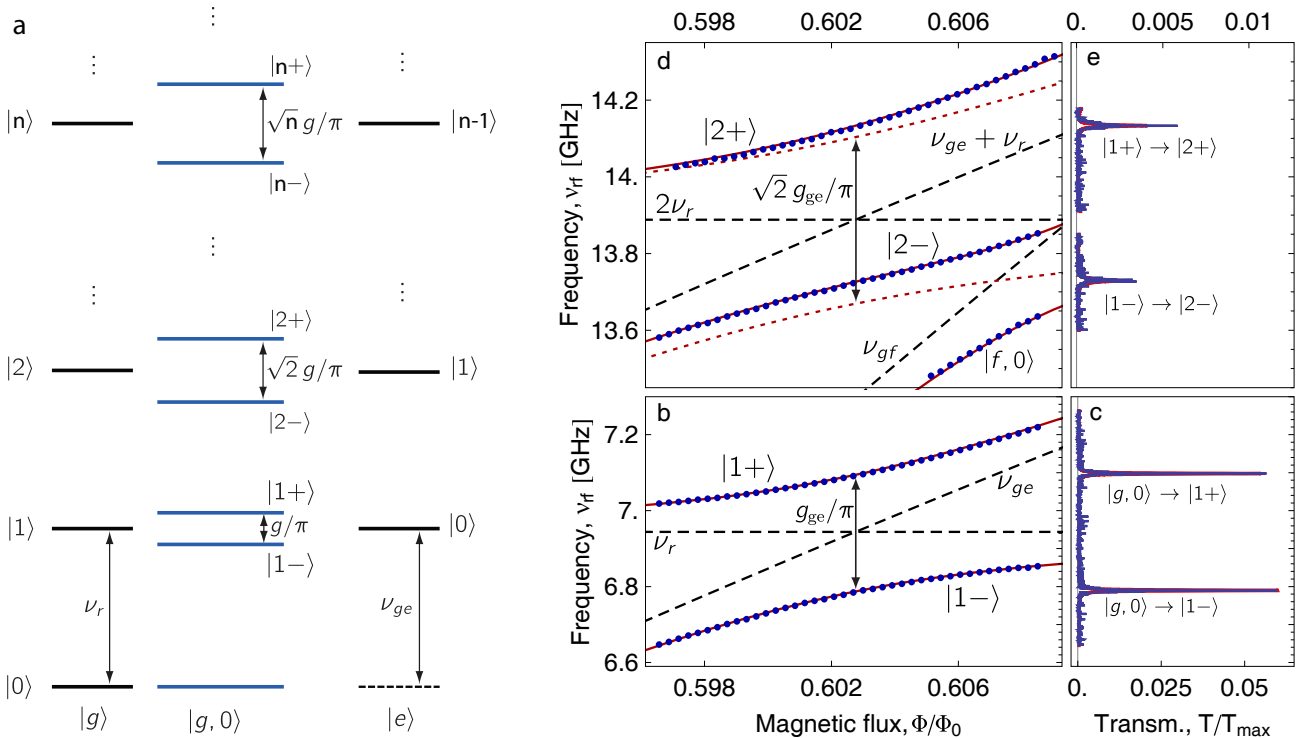


Figure 6.1: (a) Resonant ($\nu_r = \nu_{ge}$) Jaynes-Cummings energy ladder. Black bars indicate bare states of the cavity ($|0\rangle, |1\rangle, \dots, |n\rangle$) and the qubit ($|g\rangle, |e\rangle$) and blue bars indicate dipole coupled dressed states $|n\pm\rangle \equiv (|g, n\rangle \pm |e, n-1\rangle)/\sqrt{2}$. (b) Extracted (blue dots) and predicted (red lines) vacuum Rabi splitting versus applied flux bias in the presence of only one excitation. (c) Measured resonator transmission on resonance. (d) Extracted vacuum Rabi splitting in the presence of two photons. (e) Measured transmission spectrum on resonance offset by the applied pump tone frequencies.

Fig. 6.1 a. This technique realizes efficient excitation into higher doublets at small intra cavity photon numbers avoiding unwanted a.c. Stark shifts occurring in high drive and elevated temperature experiments.

First the system is prepared in its ground state $|g, 0\rangle$ by cooling it to temperatures below 20 mK in a dilution refrigerator. We then probe the energies of the lowest doublet $|1\pm\rangle$ measuring the cavity transmission spectrum T and varying the detuning between the qubit transition frequency ν_{ge} and the cavity frequency ν_r by applying a magnetic flux Φ . Measuring cavity transmission T as a function of flux bias Φ in the anti-crossing region yields transmission maxima at frequencies corresponding to transitions to the first doublet $|1\pm\rangle$ in the Jaynes-Cummings ladder as shown in Fig. 6.1 b. On resonance ($\Delta = 0$), we extract a coupling strength of $g_{ge}/2\pi = 154$ MHz, see Fig. 6.1 c.

In our pump and probe scheme we then apply a pump tone at the fixed frequency $\nu_{g0,1-}$ or $\nu_{g0,1+}$ to populate the respective first doublet state $|1\pm\rangle$. A probe tone of the same power is then scanned over the frequency range of the splitting. This procedure is repeated for different flux controlled detunings and the transmission at the pump and probe frequencies is spectrally resolved in a heterodyne detection scheme. Populating the symmetric state $|1+\rangle$, we observe an additional transmission peak at a probe tone frequency that varies with flux, as shown in Fig. 6.1 e. This peak corresponds to the transition between the symmetric doublet states $|1+\rangle$ and $|2+\rangle$ at frequency $\nu_{1+,2+}$. Similarly, when the antisymmetric state $|1-\rangle$ is populated we measure a transmission peak that corresponds to the transition between the two antisymmetric doublet states $|1-\rangle$ and $|2-\rangle$ at frequency $\nu_{1-,2-}$.

The energies of the first doublet $|1\pm\rangle$, split by g_{ge}/π on resonance, are in excellent agreement with the dressed states theory (solid red lines) over the full range of flux Φ controlled detunings, see Fig. 6.1 b. The absolute energies of the second doublet states $|2\pm\rangle$ are obtained by adding the extracted probe tone frequencies $\nu_{1-,2-}$ and $\nu_{1+,2+}$ to the applied pump frequencies $\nu_{g0,1-}$ or $\nu_{g0,1+}$, see blue dots in Fig. 6.1 d. For the second doublet, we observe two peaks split by $1.34 g_{ge}/\pi$ on resonance, a value very close to the expected $\sqrt{2} \sim 1.41$. This small frequency shift can easily be understood, without any fit parameters, by taking into account a third qubit level $|f, 0\rangle$ which is at a frequency ν_{gf} , just below the second doublet states $|2\pm\rangle$ for the transmon type qubit.

Our experiments clearly demonstrate the quantum non-linearity of a system of one or two photons strongly coupled to a single artificial atom in a cavity QED setting. Both symmetric and antisymmetric superposition states involving up to two photons are resolved by many tens of linewidths. We have also observed that higher excited states of the artificial atom can induce energy shifts in the coupled atom-photon states. The observed very strong nonlinearity on the level of single or few quanta could be used for the realization of a single photon transistor, parametric down-conversion, and for the generation and detection of individual microwave photons. Circuit QED systems also provide a natural quantum interface between flying qubits (photons) and stationary qubits for applications in quantum information processing and communication (QIPC).

6.2 Measuring the Lamb Shift in an Electrical Circuit

A. Fragner, M. Göppl, J. M. Fink, M. Baur, R. Bianchetti, P.J. Leek, A. Wallraff
in collaboration with A. Blais, Université de Sherbrooke, Canada

Quantum theory predicts that empty space is not truly empty. Even in the absence of any particles or radiation, that is in pure vacuum, virtual particles are constantly created and annihilated. In an electromagnetic field, the presence of virtual photons manifests itself as a small renormalization of the energy of a quantum system, known as the Lamb shift. We have experimentally observed the Lamb shift in a solid state system. The strong dispersive coupling of a superconducting electronic circuit acting as a quantum bit (qubit) to the vacuum field in a transmission line resonator leads to measurable Lamb shifts of up to 1.4 % of the qubit transition frequency. The qubit is also observed to couple more strongly to the vacuum field than to a single photon inside the cavity, an effect that is explained by taking into account the limited anharmonicity of the higher excited qubit states.

The concept of the vacuum field was originally invoked as an explanation for the natural linewidths of atoms in free

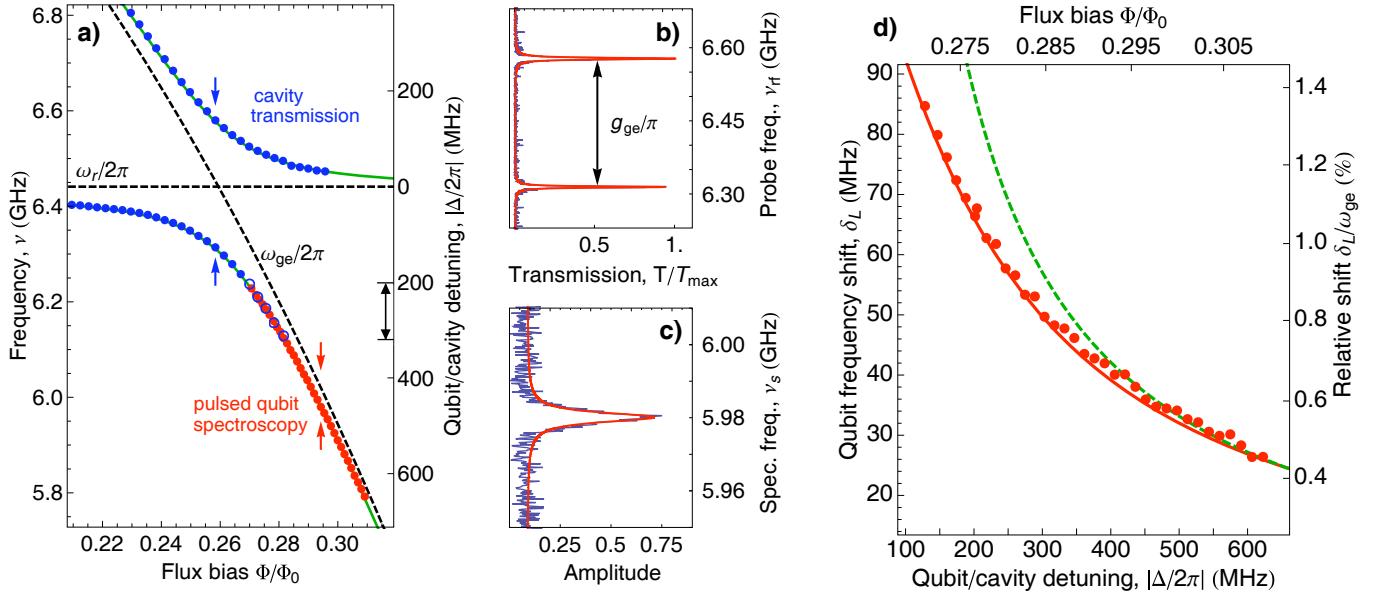


Figure 6.2: Spectrum of the coupled qubit/cavity system. (a) Measured transition frequencies of cavity (blue data points) and qubit (red data points) versus normalized flux bias Φ/Φ_0 . Dashed horizontal line is cavity transition frequency ω_r , dashed slanted line is calculated bare qubit transition frequency ω_{ge} . Green solid lines are numerically calculated eigenfrequencies of the coupled system. Overlap of resonator transmission (open blue) and qubit spectroscopy data (solid red points) is indicated by black arrows on detuning axis. See text for details. (b) Measured resonant vacuum Rabi mode-split cavity transmission spectrum T (blue line) vs. probe frequency ν_{rf} at flux bias indicated by blue arrows in (a). Solid red line is a fit to a double-peak Lorentzian. (c) Measured spectroscopic qubit line shape (blue line) vs. spectroscopy frequency ν_s at flux bias indicated by red arrows in (a). Solid red line is a fit to a Lorentzian. (d) Difference between measured qubit transition frequency $\tilde{\omega}_{ge}/2\pi$ dressed by the vacuum field fluctuations (red data points) and calculated bare qubit transition frequency $\omega_{ge}/2\pi$ vs. qubit-cavity detuning $\Delta/2\pi$ (bottom axis) and normalized flux bias Φ/Φ_0 (top axis). The right axis shows the Lamb shift as a percentage relative to the bare qubit transition frequency. Red line is predicted Lamb shift calculated using exact numerical diagonalization of the generalized Jaynes-Cummings hamiltonian, dashed green line is g_{ge}^2/Δ from a dispersive approximation of the hamiltonian.

space and given its physical interpretation in terms of virtual particles within the framework of quantum field theory. The electromagnetic vacuum leads to a number of observable effects, most notably the Casimir forces, which cause mechanical displacements of parallel conducting plates in vacuum, the Purcell effect, which governs the spontaneous emission of a quantum system coupled to a cavity field, and the Lamb shift, a radiative level shift first observed in hydrogen atoms. The Lamb shift has since been investigated in a number of experiments in the atomic domain where it is also being established as an ultra-high precision test of the theory of quantum electrodynamics (QED). The interaction with the vacuum fluctuations is the underlying reason for the spontaneous emission of radiation from any excited quantum system. The same effect also triggers the well-known process of vacuum Rabi oscillations in cavity QED. Quantum fluctuations have been demonstrated to determine the spontaneous emission lifetime of superconducting qubits and they also serve as a benchmark for amplifiers and squeezing of quantum noise at the quantum limit or for detecting the zero-point motion of nano-mechanical oscillators.

Here we observe the cavity enhanced Lamb shift, see Fig. 6.2, of an individual superconducting two-level system coupled to a high quality factor resonator with large vacuum field strength in an architecture known as circuit QED.

Our measurements have been carried out using a superconducting transmon-type qubit, a Cooper pair box with a large ratio of Josephson to charging energy E_J/E_C . The transmon qubit provides for both a large dipole coupling strength to the resonator and long relative coherence times, at the expense of limited anharmonicity in the energy level spectrum. The Lamb shift induced in a solid state quantum system by the vacuum fluctuations of the electromagnetic field in a resonator is observed spectroscopically. In resolving this effect we explicitly demonstrate the presence of dispersive vacuum field interactions in circuit QED and show that these can exceed the interaction with a photon populated field. The clear observation of vacuum fluctuations in this strongly coupled system should serve as a motivation for further experiments aimed at investigating other effects triggered by quantum fluctuations of electromagnetic or even nano-mechanical degrees of freedom in solid state systems.

6.3 Coplanar Waveguide Resonators for Circuit Quantum Electrodynamics

M. Göppl, A. Fragner, M. Baur, R. Bianchetti, S. Filipp, J. M. Fink, P. J. Leek, G. Puebla, L. Steffen and A. Wallraff

Superconducting coplanar waveguide (CPW) resonators find prominent applications in quantum optics and quantum information processing with superconducting electronic circuits and in single photon detectors and parametric amplifiers.

We have demonstrated that we are able to design and fabricate CPW resonators with well defined resonance frequency and coupled quality factors. The resonance frequency is controlled by the resonator length and its loaded quality factor is controlled by its capacitive coupling to input and output transmission lines. Strongly coupled (overcoupled) resonators with accordingly low quality factors are ideal for performing fast measurements of the state of a qubit integrated into the resonator. On the other hand, undercoupled resonators with large quality factors can be used to store photons in the cavity on a long time scale, with potential use as a quantum memory.

The planar geometry of a capacitively coupled CPW resonator is sketched in Figure 6.3 a. The resonator is formed of a center conductor of width $w = 10 \mu\text{m}$ separated from the lateral ground planes by a gap of width $s = 6.6 \mu\text{m}$. Resonators with various center conductor lengths l between 8 and 29 mm aiming at fundamental frequencies f_0 between 2 and 9 GHz were designed. These structures are easily fabricated in optical lithography while providing sufficiently large vacuum field strengths. The center conductor is coupled via gap- or finger capacitors to the input and output transmission lines. For small coupling capacitances gap capacitors of widths $w_g = 10$ to $50 \mu\text{m}$ have been realized. To achieve larger coupling finger capacitors formed by from one up to eight pairs of fingers of length $l_f = 100 \mu\text{m}$, width $w_f = 3.3 \mu\text{m}$ and separation $s_f = 3.3 \mu\text{m}$ have been designed and fabricated, see Fig. 6.3 a. Resonators are fabricated by evaporating a layer of $t = 200 \text{ nm} \pm 5 \text{ nm}$ aluminum on high resistivity, thermally oxidized silicon (oxide thickness $h_2 = 500 \text{ nm}$) or on pure sapphire two inch wafers which both have a thickness of $h_1 = 500 \mu\text{m}$. Figure 6.3 c shows optical microscope images of the final Al resonators with different finger and gap capacitors.

Altogether, more than 80 Al CPW resonators with fundamental frequencies from 2 to 9 GHz and loaded quality factors ranging from a few hundreds to a several hundred thousands reached at temperatures of 20 mK were realized and more than 30 of these devices were carefully characterized at microwave frequencies. Transmission spectra were measured and analyzed using both a lumped element model and a distributed element transmission matrix method.

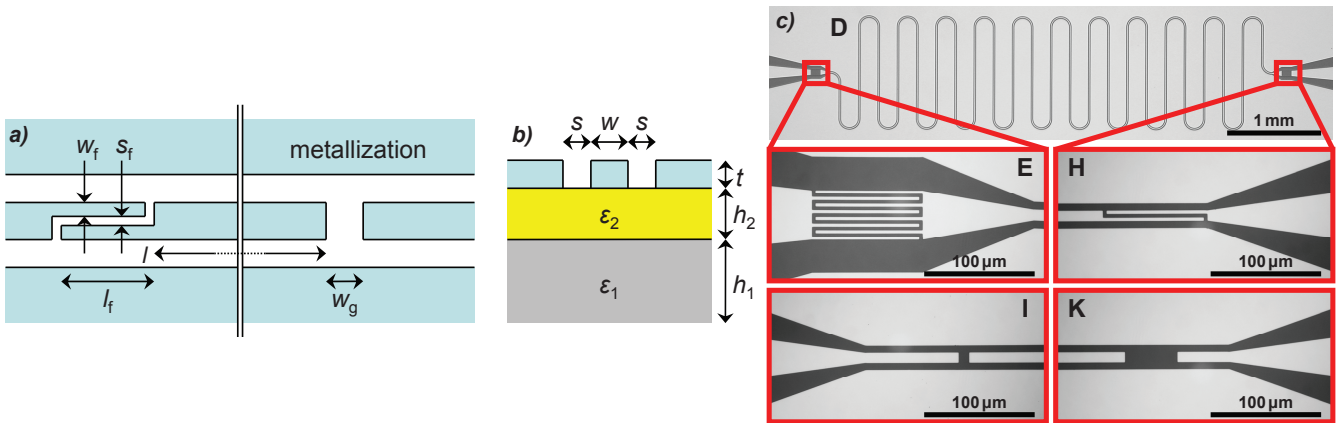


Figure 6.3: (a) Top view of a CPW resonator with finger capacitors (l.h.s.) and gap capacitors (r.h.s.). (b) Cross section of a CPW resonator design. Center conductor and lateral ground metallization (blue) on top of a double layer substrate (grey/yellow). Parameters are discussed in the main text. (c) Optical microscope images of an Al coplanar waveguide resonator (white is metallization, grey is substrate). The red squares in the upper image indicate the positions of the input/output capacitors. Also shown are microscope images of finger- and gap capacitor structures. The labels D, E, H, I, K refer to the device ID listed in Tab. 6.1.

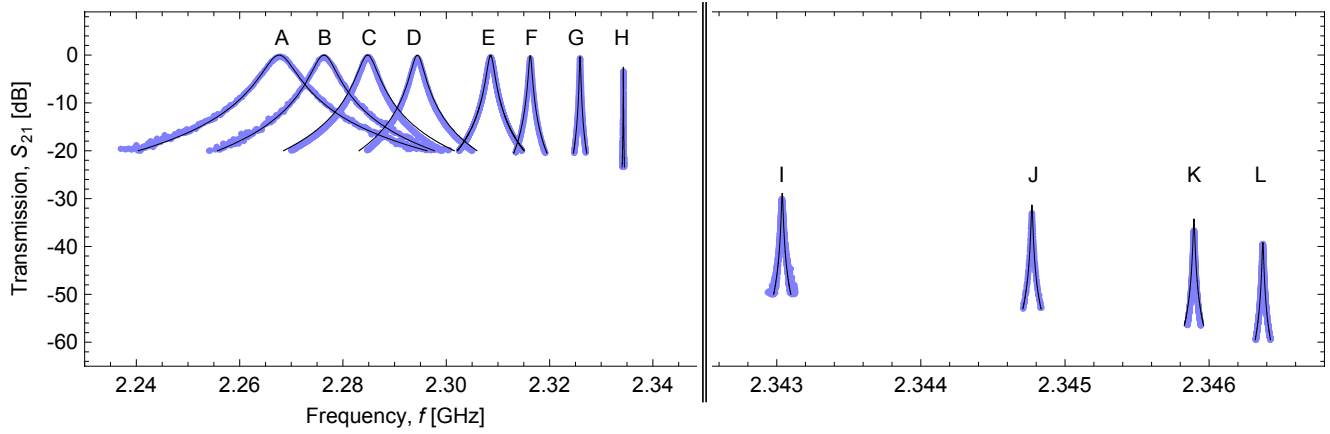


Figure 6.4: S_{21} transmission spectra of 2.3 GHz resonators, symmetrically coupled to input/output lines. The left part of the split plot shows spectra of finger capacitor coupled resonators whereas on the right hand side one can see spectra of gap capacitor coupled resonators. The data points (blue) were fitted (black) with the transmission matrix method.

To study the effect of the capacitive coupling strength on the microwave properties of CPW resonators, twelve 2.3 GHz devices, symmetrically coupled to input/output lines with different gap and finger capacitors have been characterized, see Table 6.1 for a list of devices. The measured transmission spectra are shown in Fig. 6.4. The left hand part of Fig. 6.4 depicts spectra of resonators coupled via finger capacitors having 8 down to one pairs of fingers (devices A to H). The right hand part of Fig. 6.4 shows those resonators coupled via gap capacitors with gap widths of $w_g = 10, 20, 30$ and $50 \mu\text{m}$ (devices I to L) respectively. The coupling capacitance continuously decreases from device A to device L. The nominal values for the coupling capacitance C_κ obtained from EM-simulations for the investigated substrate properties and geometry are listed in table 6.1. The resonance frequency f_0 and the measured quality factor $Q_L = f_0/\delta f$ of the respective device is obtained by fitting a Lorentzian line to the data, where δf is the full width half maximum of the resonance. With increasing coupling capacitance C_κ , Fig. 6.4 shows a decrease in the measured (loaded) quality factor Q_L and an increase in the peak transmission, as well as a shift of f_0 to lower frequencies. The experimentally determined resonance frequencies, quality factors and insertion losses are fully and consistently characterized by the two models for all measured devices [4].

ID	Coupling	C_κ (fF)	f_0 (GHz)	Q_L
A	8 + 8 finger	56.4	2.2678	$3.7 \cdot 10^2$
B	7 + 7 finger	48.6	2.2763	$4.9 \cdot 10^2$
C	6 + 6 finger	42.9	2.2848	$7.5 \cdot 10^2$
D	5 + 5 finger	35.4	2.2943	$1.1 \cdot 10^3$
E	4 + 4 finger	26.4	2.3086	$1.7 \cdot 10^3$
F	3 + 3 finger	18.0	2.3164	$3.9 \cdot 10^3$
G	2 + 2 finger	11.3	2.3259	$9.8 \cdot 10^3$
H	1 + 1 finger	3.98	2.3343	$7.5 \cdot 10^4$
I	10 μm gap	0.44	2.3430	$2.0 \cdot 10^5$
J	20 μm gap	0.38	2.3448	$2.0 \cdot 10^5$
K	30 μm gap	0.32	2.3459	$2.3 \cdot 10^5$
L	50 μm gap	0.24	2.3464	$2.3 \cdot 10^5$

Table 6.1: Properties of the different CPW resonators whose transmission spectra are shown in Fig. 6.4. C_κ denotes the simulated coupling capacitances, f_0 is the measured resonance frequency and Q_L is the measured quality factor.

Chapter 7

Publications

K. Bernot, J. Luzon, R. Sessoli, A. Vindigni, J. Thion, S. Richeter, D. Leclercq, J. Larionova, A. van der Lee
The canted antiferromagnetic approach to single-chain magnets
J. Am. Chem. Soc. **130**, 1619-1627 (2008)

L. Bogani, A. Vindigni, R. Sessoli, D. Gatteschi
Single-chain magnets: where to from here?
J. Mater. Chem. **18**, 4750-4758 (2008)

S. Buecheler, D. Corica, D. Guettler, A. Chirila, R. Verma, U. Müller, T. P. Niesen, J. Palm and A. N. Tiwari
Ultrasonically Sprayed Indium Sulfide Buffer Layers for Cu(In,Ga)(S,Se)₂ Thin-Film Solar Cells
Thin Solid Films (2008), doi:10. 1016/j. tsf. 2008. 10. 135

S. Burkardt, M. Erbudak, J.-N. Longchamp, Y. Weisskopf
Co nanocrystallites on an icosahedral Al-Pd-Mn quasicrystal
Phil. Mag. **88**, 2111-6 (2008)

S. Burkardt, M. Erbudak
Structure of Al deposits on nanometer-size islands of aluminum-oxide
Surf. Sci. **602**, 2915-2920 (2008)

S. Burkardt, S. Deloudi, M. Erbudak, A. R. Kortan, M. Mungan, W. Steurer
Bulk and surface structure of the clean and adsorbate covered decagonal Al-Co-Ni quasicrystal
J. Phys.: Condens. Matter **20**, 314006 (2008)

T. Calarco, Ph. Grangier, A. Wallraff, P. Zoller
Commentary: Quantum leaps in small steps
Nature Physics **4**, 2 (2008)

T. Calarco, Ph. Grangier, A. Wallraff, P. Zoller, D. Binosi
Small steps that will lead to Quantum leaps
eStrategies Projects **7**, 70 (2008)

S. Calnan, H. M. Uphadhyaya, S. Buecheler, G. Khrypunov, A. Chirila, A. Romeo, R. Hashimoto, T. Nakada, A. N. Tiwari

Application of high mobility transparent conductors to enhance long wavelength transparency of the intermediate solar cell in multi-junction solar cells

Thin Solid Films (2008), doi:10. 1016/j. tsf. 2008. 11. 007

D. Corica, S. Buecheler, D. Guettler, A. Chirila, S. Seyrling, R. Verma and A. N. Tiwari

Indium Sulfide Buffer Layer for Cu(In,Ga)Se₂ Thin-Film Solar Cells Deposited by Ultrasonic Spray Pyrolysis

Proc. 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, Sept 1-5, 2008

D. Daghero, D. Delaude, A. Calzolari, M. Tortello, G. A. Ummarino, R. S. Gonnelli, V. A. Stepanov, N. Zhigadlo, J. Karpinski, A. Palenzona

Point-contact Andreev-reflection spectroscopy in segregation-free Mg_{1-x}Al_xB₂ single crystals up to x=0.32

J. Phys.: Condens. Matter, **20**, 085225, (2008)

U. Del Pennino, V. Corradini, R. Biagi, V. De Renzi, F. Moro, D.W. Boukhvalov, G. Panaccione, M. Hochstrasser, C. Carbone, C.J. Milio, E.K. Brechin

Electronic structure of a Mn-6(S=4) single molecule magnet grafted on Au(111)

Phys. Rev. B, **77**, 085419 (2008)

C. Dubois, G. Santi, I. Berthold, N. Jenkins, A.P. Petrovic, A.A. Manuel, Ø. Fischer

Scanning Tunneling Spectroscopy in the Superconducting State and Vortex Cores of the Beta-Pyrochlore KOs₂O₆

Phys. Rev. Lett., **101**, 057004 (2008)

J. M. Fink, M. Goepl, M. Baur, R. Bianchetti, P. J. Leek, A. Blais, A. Wallraff

Climbing the Jaynes-Cummings ladder and observing its square root of n nonlinearity in a cavity QED system

Nature, **454**, 315-318 (2008)

A. Fragner, M. Goepl, J.M. Fink, M. Baur, R. Bianchetti, P.J. Leek, A. Blais, A. Wallraff

Resolving Vacuum Fluctuations in an Electrical Circuit by Measuring the Lamb Shift

Science, **322**, 1357-1360 (2008)

A.E. Gildemeister, T. Ihn, M. Sigrist, K. Ensslin, D.C. Driscoll, A.C. Gossard

Lever arm of a metallic tip in scanning gate experiments

Physica E **40**, 1640 (2008)

F. Giubileo, F. Bobba, A. Scarfato, A.M. Cucolo, A. Kohen, D. Roditchev, N.D. Zhigadlo, J. Karpinski

Local study of the Mg_{1-x}Al_xB₂ single crystals by scanning tunneling spectroscopy in magnetic field up to 3 T

Physica C, **468**, 828-31 (2008)

M. Goppl, A. Fragner, M. Baur, R. Bianchetti, S. Filipp, J.M. Fink, P.J. Leek, G. Puebla, L. Steffen, A. Wallraff

Coplanar Waveguide Resonators for Circuit Quantum Electrodynamics

Journal of Applied Physics, **104**, 113904 (2008)

B. Grbic, R. Leturcq, T. Ihn, K. Ensslin, G. Blatter, D. Reuter, A. D. Wieck

Hysteretic magnetotransport in p-type AlGaAs heterostructures with In/Zn/Au ohmic contacts

Phys. Rev. B, **77**, 245307 (2008) / arXiv:0711.0534

B. Grbic, R. Leturcq, T. Ihn, K. Ensslin, D. Reuter, A. D. Wieck
Aharonov-Bohm oscillations in p-type GaAs quantum rings
Physica E **40**, 2144 (2008) / arXiv:0711.0489

B. Grbic, R. Leturcq, T. Ihn, K. Ensslin, D. Reuter, A.D. Wieck
Strong spin-orbit interactions in carbon doped p-type GaAs heterostructures
Physica E **40**, 2144 (2008) / arXiv:0711.0492v1

B. Grbic, R. Leturcq, T. Ihn, K. Ensslin, D. Reuter, A. D. Wieck
Strong spin-orbit interactions and weak antilocalization in carbon doped p-type GaAs heterostructures
Phys. Rev. B **77**, 125312 (2008) / arXiv:0711.0492

J. Güttinger, C. Stampfer, F. Molitor, D. Graf, T. Ihn, K. Ensslin
Coulomb oscillations in three-layer graphene nanostructures
New J. Phys., **10**, 125029 (2008) / arXiv:0806.1478

J. Guettinger, C. Stampfer, S. Hellmueller, F. Molitor, T. Ihn, K. Ensslin
Charge Detection in Graphene Quantum Dots
Appl. Phys. Lett., **93**, 212102 (2008) / arXiv:0809.3904

S. Gustavsson, M. Studer, R. Leturcq, T. Ihn, K. Ensslin, D. C. Driscoll, A. C. Gossard
Detecting single-electron tunneling involving virtual processes in real time
Phys. Rev. B, **78**, 155309 (2008) / arXiv:0805.3395

S. Gustavsson, R. Leturcq, B. Simovic, R. Schleser, T. Ihn, P. Studerus, K. Ensslin, D. C. Driscoll, A. C. Gossard
Counting statistics of single electron transport in a semiconductor quantum dot
Advances in Solid State Physics **46**, 31 (2008) / arXiv:cond-mat/0510269v3

S. Gustavsson, R. Leturcq, M. Studer, T. Ihn, K. Ensslin, D. C. Driscoll, A. C. Gossard
Time-resolved detection of single-electron interference
Nanoletters **8**, 2547 (2008) / arXiv:0807.1881

S. Gustavsson, I. Shorubalko, R. Leturcq, T. Ihn, K. Ensslin, S. Schön
Detecting THz current fluctuations in a quantum point contact using a nanowire quantum dot
Phys. Rev. B, **78**, 035324 (2008) / arXiv:0805.1341

S. Gustavsson, I. Shorubalko, R. Leturcq, S. Schön, K. Ensslin
Measuring current by counting electrons in a nanowire quantum dot
Appl. Phys. Lett., **92**, 152101 (2008) / arXiv:0712.3634

S. Gustavsson, R. Leturcq, M. Studer, T. Ihn, K. Ensslin, D.C. Driscoll, A.C. Gossard
Time-resolved interference experiments in a solid state environment
Physica E **40**, 1044 (2008)

T. Ihn, D. Graf, F. Molitor, C. Stampfer, K. Ensslin
Phase-coherent transport in a mesoscopic few-layer graphite wire
Physica E **40**, 1851 (2008)

W. L. Kalb, K. Mattenberger, B. Batlogg

Oxygen-related traps in pentacene thin films: Energetic position and implications for transistor performance
Phys. Rev. B, **78**, 3, 035334 (2008)

J. Karpinski, N.D. Zhigadlo, S. Katrych, K. Rogacki, B. Batlogg, M. Tortello, R. Puzniak

MgB₂ single crystals of substituted with Li and with Li-C: Structural and superconducting properties
Phys. Rev. B, **77**, 21, 214507 (2008)

R. Khasanov, A. Shengelaya, J. Karpinski, A. Bussmann-Holder, H. Keller, K.A. Müller

s-Wave symmetry along the c-axis and s+d in-plane superconductivity in bulk YBa₂Cu₄O₈
J. Supercond. Nov. Magn., **21**, 81-85 (2008)

R. Khasanov, P.W. Klamut, A. Shengelaya, Z. Bukowski, I.M. Savic, C. Baines, H. Keller

Muon-Spin Rotation Measurements of the Penetration Depth of the Mo₃Sb₇ Superconductor
Phys. Rev. B, **78**, 0114502 (2008)

R. Khasanov, K. Conder, E. Pomjakushina, A. Amato, C. Baines, Z. Bukowski, J. Karpinski, S. Katrych, H.-H. Klaus, H. Luetkens, A. Shengelaya, N.D. Zhigadlo

Evidence of nodeless superconductivity in FeSe_{0.85} from a muon-spin-rotation study of the in-plane magnetic penetration depth
Phys. Rev. B, **78**, 22, 220510, 1-4 (2008)

Y. Komijani, M. Csontos, T. Ihn, K. Ensslin, D. Reuter, A. D. Wieck

Observation of excited states in a p-type GaAs quantum dot
Europhys. Lett., **84**, 57004 (2008) / arXiv:0809.1362

Y. Kubozono, S. Haas, W. L. Kalb, P. Joris, F. Meng, A. Fujiwara, B. Batlogg

High-performance C₆₀ thin-film field-effect transistors with parylene gate insulator
Appl. Phys. Lett., **93**, 3, 033316 (2008)

M. Lavagnini, A. Sacchetti, L. Degiorgi, A. Arcangeletti, L. Baldassarre, P. Postorino, S. Lupi, A. Perucchi, K.Y. Shin, and I.R. Fisher

Pressure dependence of the optical properties of the charge-density-wave compound LaTe₂
Phys. Rev. B, **77**, 165132 (2008)

M. Lavagnini, M. Baldini, A. Sacchetti, D. Di Castro, B. Delley, R. Monnier, J.H. Chu, N. Ru, I.R. Fisher, P. Postorino, and L. Degiorgi

Evidence for coupling between charge density waves and phonons in two-dimensional rare-earth tritellurides
Phys. Rev. B, **78**, 201101(R) (2008)

P. Legendre, Y. Fasano, I. Maggio-Aprile, Ø. Fischer, Z. Bukowski, S. Katrych, J. Karpinski

Unexpectedly Wide Reversible Vortex Region in Beta-pyrochlore RbOs₂O₆
Phys. Rev. B, **78**, 144513 (2008)

J.N. Longchamp

Thin films on icosahedral AlPdMn quasicrystal
Logos Verlag, Berlin, 2008; ISBN 978-3-8325-1781-6.

- R. Leturcq, S. Gustavsson, M. Studer, T. Ihn, K. Ensslin, D.C. Driscoll, A.C. Gossard
Frequency-selective single-photon detection with a double quantum dot
Physica E **40**, 1844 (2008)
- F. Maccherozzi, M. Sperl, G. Panaccione, R.J. Mina, S. Polesya, H. Ebert, U. Wurstbauer, M. Hochstrasser, G. Rossi, G. Woltersdorf, W. Wegscheider, C.H. Back
Evidence for a magnetic proximity effect up to room temperature at Fe/(Ga,Mn) interfaces
Phys. Rev. Lett., **101**, 267201 (2008)
- A. Manchon, S. Pizzini, J. Vogel, V. Uhler, L. Lombard, C. Ducruet, S. Auffret, B. Rodmacq, B. Dieny, M. Hochstrasser, G. Panaccione
X-ray analysis of oxygen-induced perpendicular magnetic anisotropy in Pt/Co/AlO_x trilayers
J. Magn. Magn. Mat., **320**, 1889 (2008)
- A. Manchon, S. Pizzini, J. Vogel, V. Uhler, L. Lombard, C. Ducruet, S. Auffret, B. Rodmacq, B. Dieny, M. Hochstrasser, G. Panaccione
X-ray analysis of the magnetic influence of oxygen in Pt/Co/AlO_x trilayers
J. of Appl. Phys., **103**, 07A912 (2008)
- A. Manchon, S. Pizzini, J. Vogel, V. Uhler, L. Lombard, C. Ducruet, S. Auffret, B. Rodmacq, B. Dieny, M. Hochstrasser, G. Panaccione
Analysis of oxygen induced anisotropy crossover in Pt/Co/MO_x trilayers
J. Appl. Phys., **104**, 043914 (2008)
- C. Martin, M.D. Vannette, R.T. Gordon, R. Prozorov, J. Karpinski, N.D. Zhigadlo
Effect of C and Li doping on the rf magnetic susceptibility in MgB₂ single crystals
Phys. Rev. B, **78**, 14, 144512, 1-6 (2008)
- A. Mattila, J.A. Soininen, S. Galambosi, T. Pylkkänen, S. Huotari, N.D. Zhigadlo, J. Karpinski, K. Hämäläinen
Electron-hole counts in Al-substituted MgB₂ superconductors from x-ray Raman scattering
Phys. Rev. B, **78**, 064517 (2008)
- L. Meier, G. Salis, E. Gini, I. Shorubalko, K. Ensslin
Two-dimensional imaging of the spin-orbit effective magnetic field
Phys. Rev. B, **77**, 035305 (2008) / arXiv:0712.1091
- M. Mezger, S. Schoder, H. Reichert, J. Okasinski, V. Honkimaki, J. Ralston, J. Bilgram, H. Dosch
Water and ice in contact with octadecyl-trichlorosilane functionalized surfaces: A high resolution x-ray reflectivity study
Journal of Chemical Physics, **128**, 24, 244705 (2008)
- Th. Michlmayr, N. Saratz, U. Ramsperger, Y. Acremann, Th. Bähler, D. Pescia
Magnetic field generation with local current injection
Journ. of Phys. D: Appl. Phys., **41**, 055005 (2008)
- F. Molitor, D. Graf, C. Stampfer, T. Ihn, K. Ensslin
Raman imaging and electronic properties of graphene
Advances in Solid State Physics **47**, 171 (2008) / arXiv:0709.3426v1

- K. Oganisian, K. Rogacki, C. Sulkowski, N.D. Zhigadlo, S. Katrych, J. Karpinski
Thermoelectric Power of MgB_2 single crystals doped with holes and electrons
Acta Physica Polonica A, **114**, 191-195 (2008)
- P. Parisiades, D. Lampakis, D. Palles, E. Liarokapis, N.D. Zhigadlo, S. Katrych, J. Karpinski
Two-mode behavior for the E_{2g} broad band in $\text{Mg}(\text{B}_{1-x}\text{C}_x)_2$
Physica C, **468**, 1064-9 (2008)
- K.P. Pernstich, B. Rössner, B. Batlogg
Field-effect-modulated Seebeck coefficient in organic semiconductors
Nature Materials, **7**, 4, 321-325 (2008)
- A. Pfund, I. Shorubalko, R. Leturcq, K. Ensslin
Pauli spin-blockade in an InAs nanowire double quantum dot
Physica E **40**, 1279 (2008)
- F. Pfuner, L. Degiorgi, H.R. Ott, A.D. Bianchi, Z. Fisk
Magneto-optical behavior of EuIn_2P_2
Phys. Rev. B, **77**, 024417 (2008)
- F. Pfuner, L. Degiorgi, K.Y. Shin, and I.R. Fisher
Optical properties of the charge-density-wave polychalcogenide compounds R_2Te_5 ($\text{R}=\text{Nd}$, Sm and Gd)
Eur. Phys. J. B, **63**, 11 (2008)
- N. Quack, S. Blunier, J. Dual, F. Felder, M. Arnold, H. Zogg
Mid-Infrared Tunable Resonant Cavity Enhanced Detectors
Sensors 2008, **8**, 9, 2008, pp. 5466-5478
- N. Quack, S. Blunier, J. Dual, M. Arnold, F. Felder, C. Ebnetter, M. Rahim, H. Zogg
Vertically Moving Micromirror for Detectors in the Mid Infrared
Sensors and Actuators A: Physical (2008)
- N. Quack, S. Blunier, J. Dual, M. Arnold, F. Felder, C. Ebnetter, M. Rahim, H. Zogg
Tunable Resonant Cavity Enhanced Detectors using Vertical MEMS Mirrors
Journal of Optics A: Pure and Applied Optics, **10**, 044015 (2008)
- M. Rahim, F. Felder, M. Fill, H. Zogg
Optically Pumped $5\ \mu\text{m}$ IV-VI VECSEL with Al-Heatspreader
Optics Letters, **33**, 24, pp. 3010-3012, 2008
- M. Rahim, F. Felder, M. Fill, D. Boye, H. Zogg
Lead chalcogenide VECSEL on Si emitting at $5\ \mu\text{m}$
Electronic Letters, **44**, 25, pp. 1467-1469, 2008
- K. Rogacki, G. Schuck, Z. Bukowski, N. D. Zhigadlo, J. Karpinski
Structural and superconducting properties of RbOs_2O_6 single crystals
Phys. Rev. B, **77**, 134514 (2008)

K. Rogacki, K. Oganisian, C. Sulkowski, N.D. Zhigadlo, S. Katrych, J. Karpinski
Transport properties of MgB_2 single crystals doped with electrons and holes
Journal Phys. Chem. Solids, **69**, 12, 3202-3204 (2008)

A. Romeo, S. Buecheler, M. Giarola, G. Mariotto, A. N. Tiwari, N. Romeo, A. Bosio, S. Mazzamuto
Study of CSS- and HVE-CdTe by different recrystallization processes Thin Solid Films (2008), doi:10. 1016/j. tsf. 2008. 10. 129

S. Schnez, K. Ensslin, M. Sigrist, T. Ihn
Analytical model of the energy spectrum of a graphene quantum dot in a perpendicular magnetic field
Phys. Rev. B, **78**, 195427 (2008) / arXiv:0810.3216

J. Schoenes, A.-M. Racu, K. Doll, Z. Bukowski, J. Karpinski
Phonons and crystal structures of the Beta-pyrochlore superconductors KOs_2O_6 and RbOs_2O_6 from micro-Raman spectroscopy
Phys. Rev. B, **77**, 134515 (2008)

T.F. Schulze, M. Brühwiler, P.S. Häfliger, S.M. Kazakov, Ch. Niedermayer, K. Mattenberger, J. Karpinski, B. Batlogg
Spin fluctuations, magnetic long-range order and Fermi surface gapping in Na_xCoO_2
Phys. Rev. B, **78**, 20, 205101 (2008)

T.F. Schulze, P.S. Häfliger, C. Niedermayer, K. Mattenberger, S. Bubenhofer, B. Batlogg
Direct link between low-temperature magnetism and high-temperature sodium order in Na_xCoO_2
Physical Review Letters, **100**, 2, 026407 (2008)

I. Shorubalko, R. Leturcq, A. Pfund, D. Tyndall, R. Krischek, S. Schon, K. Ensslin
Self-aligned charge read-out for InAs nanowire quantum dots
Nanoletters **8**, 382 (2008) / arXiv:0712.1705v

I. Singer-Loginova, H.M. Singer
The phase field technique for modelling multiphase materials
Rep. Progr. Phys., **71**, 106501 (2008)

C. Stampfer, E. Schurtenberger, F. Molitor, J. Güttinger, T. Ihn, K. Ensslin
Tunable Graphene Single Electron Transistor
Nanoletters **8**, 2378 (2008) / arXiv:0806.1475

C. Stampfer, J. Guettinger, F. Molitor, D. Graf, T. Ihn, K. Ensslin
Tunable Coulomb blockade in nanostructured graphene
Appl. Phys. Lett., **92**, 012102 (2008) / arXiv:0709.3799

V. H. Tran, W. Müller, Z. Bukowski
Observation of a Spin Gap in the Normal State of Superconducting Mo_3Sb_7
Phys. Rev. Lett., **100**, 137004 (2008)

V.H. Tran, Z. Bukowski
Synthesis and Characterization of the Superconductor Mo_3Sb_7
Acta Physica Polonica A, **114**, 73 (2008)

- V.H. Tran, E. Bauer, A. Galatanu, Z. Bukowski
Magnetoresistivity and Upper Critical Field in Superconductor Mo_3Sb_7
J. Optoelectronics and Advanced Materials, **10**, 1630 (2008)
- V.H. Tran, W. Miiller, Z. Bukowski
Low-Temperature Specific Heat of the Superconductor Mo_3Sb_7
Acta Materialia, **56**, 5694 (2008)
- V.H. Tran, A. D. Hillier, D.T. Adroja, Z. Bukowski
Muon Spin Rotation Study of the Superconducting Properties of Mo_3Sb_7
Phys. Rev. B, **78**, 172505 (2008)
- T. Uchihashi, U. Ramsperger, T. Nakayama, M. Aono
Nanostencil-fabricated electrodes for electron transport measurements of atomically thin nanowires in ultrahigh vacuum
Japn. J. Appl. Phys., **47**, 1797 (2008)
- R. Verma, S. Buecheler, D. Corica, A. Chirila, S. Seyrling, J. Perrenoud, D. Guettler, C. J. Hibberd and A. N. Tiwari
Cu(In,Ga)Se₂ Solar Cells with In₂S₃ Buffer Layers grown by Vacuum Evaporation and Chemical Spray Methods
Proc. 23rd European Photovoltaic Solar Energy Conference, Valencia, Spain, Sept. 1-5, 2008
- A. Vindigni
Statistics and game theory in single-chain magnet relaxation
Inorg. Chem. Acta, **361**, 3731-3739 (2008)
- A. Vindigni, N. Saratz, O. Portmann, P. Politi, D. Pescia
Stripe width and non-local domain walls in the two-dimensional dipolar frustrated Ising ferromagnet
Phys. Rev. B, **77**, 092414 (2008)
- P. Wachter
Cu, Pu and Fe high T_c superconductors: spin holes in antiferromagnetic clusters form nonmagnetic bipolarons
Physica C, **469**, 5-6 (2009)
- A. Wallraff
Quantenmechanik mit Schaltkreisen: Photonen und Qubits auf einem supraleitenden Mikrochip
Physik Journal, **7**, 39-45 (2008)
- S. Weyeneth, T. Schneider, N.D. Zhigadlo, J. Karpinski, H. Keller
Probing Superconductivity in MgB_2 confined to magnetic field tuned cylinders by means of critical fluctuations
J.Phys.: Condens. Matter, **20**, 135208 (2008)
- S. Weyeneth, T. Schneider, Z. Bukowski, J. Karpinski, H. Keller
3D-xy critical properties of $\text{YBa}_2\text{Cu}_4\text{O}_8$ and magnetic field induced 3D to 1D crossover
J. Phys. Condens. Matter, **20**, 345210 (2008)
- S. Wu, J. Zhang, A. Belousov, J. Karpinski, R. Sobolewski
Dynamic of intervalley transitions and propagation of coherent acoustic phonons in GaN single crystals studied by femtosecond pump-probe spectroscopy in Gallium Nitride Materials and Devices III
Proc. of III SPIE, **6894**, 68940K-1. (2008)

S. Wu, J. Zhang, A. Belousov, J. Karpinski, R. Sobolewski

Dynamics of intervalley transitions and propagation of coherent acoustic phonons in GaN single crystals studied by femtosecond pump-probe spectroscopy

Proceedings of the SPIE - The International Society for Optical Engineering v. 6894 , p. 68940K-1-13, 7 February 2008

N.D. Zhigadlo, J. Karpinski, S. Weyeneth, R. Kasanov, S. Katrych, P. Wägli, H. Keller

Synthesis and bulk properties of oxychloride superconductor $\text{Ca}_{2-x}\text{Na}_x\text{CuO}_2\text{Cl}_2$

Journal of Physics, **97**, 012121 (2008)

N.D. Zhigadlo, S. Katrych, Z. Bukowski, S. Weyeneth, R. Puzniak, J. Karpinski

Single crystals of superconducting $\text{SmFeAsO}_{1-x}\text{F}_y$ grown at high pressure

J. Phys.: Condens. Matter, **20**, 342202 (2008)

H. Zogg, M. Arnold, F. Felder, M. Rahim, M. Fill, D. Boye

Epitaxial lead-chalcogenides on Si for mid-IR detectors and emitters including cavities

Proc. SPIE, **7082**, 70820H (2008)

H. Zogg, M. Arnold, F. Felder, M. Rahim, C. Ebnetter, I. Zasavitskiy, N. Quack, S. Blunier, J. Dual

Epitaxial lead-chalcogenides on Si for mid-IR detectors and emitters including cavities

Journal of Electronic Materials, **37**, 9, 2008, pp. 1497-1503

Chapter 8

Presentations

(* = invited talk)

Batlogg, B.
Wieviel Technik verträgt der Mensch?
VLBG Dornbirn, Austria, 15.01.2008

Batlogg, B.
Wieviel Technik verträgt der Mensch?
Rotary Club Volketswil, Switzerland, 21.02.2008

★ Batlogg, B.
Electronic ground states and Na patterning in Na_xCoO_2
Winter school, Planneralp, Austria, 25.02.2008

★ Batlogg, B.
Electron correlation and unconventional superconductivity
Physik Colloquium, Technische Universität, Graz, Austria, 04.03.2008

Batlogg, B.
Direct link between low-T magnetism and high-T Na order in Na_xCoO_2
APS March Meeting, New Orleans, USA, 10.03.2008

Batlogg, B.
Gate voltage modulated Seebeck coefficient in organic FET structures
APS March Meeting, New Orleans, USA, 13.03.2008

★ Batlogg, B.
Correlated electrons and mobile Na in Na_xCoO_2
Nat. Inst. of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, 14.08.2008

★ Batlogg, B.
Correlated electrons and mobile Na in Na_xCoO_2
MDCL Special Seminar, ISSP, Tokyo, Japan, 18.08.2008

★ Batlogg, B.

Improved OFET performance: identify-quantify-eliminate traps

Int. Symposium on Organic Transistors and Functional Interfaces, Inst. for Materials Research Tohoku University, Sendai, Japan, 22.08.2008

★ Batlogg, B.

Physics and materials of organic field-effect devices: improved performance by controlling bulk and interface traps

Nat. Inst. of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, 22.09.2008

★ Batlogg, B.

Field effect devices: physics and materials

Int. Conference on Solid State Devices and Materials, Tsukuba, Japan, 24.09.2008

Buecheler, S.

Ultrasonically Sprayed In_2S_3 Buffer Layer for $\text{Cu}(\text{In,Ga})(\text{S,Se})_2$ Thin-Film Solar Cells

E-MRS Spring Meeting 2008, Strasbourg, France, 26.-30.5.2008

Buecheler, S.

Ultrasonically Sprayed Alternative Buffer Layers for CIGS Solar Cells

ATHLET general assembly, highlight session, Zurich, Switzerland, 10.-11.1.2008

Bukowski, Z.

Single crystal growth and properties of the intermetallic compounds T_3X_7 (T=Mo, Pd, Pt, Os; X=Sb, Ga, In, Sn) isostructural to superconducting Ir_3Ge_5

Swiss Physical Society Meeting, Geneve, Switzerland, 26.03.2008

Burkardt, S.

Al nanostructures on a well-ordered, ultrathin Al_2O_3 film grown on icosahedral AlPdMn quasicrystal

14th Int. Conf. Solid Films and Surfaces, Dublin, Ireland, 29.6.2008

Burkardt, S.

Nanostructures on a well-ordered oxidized pentagonal surface of an icosahedral AlPdMn quasicrystal

10th Int. Conf. Quasicrystals, Zurich, Switzerland, 10.7.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave rare-earth polychalcogenides RTe_n ($n=2$ and 3)

Internal MaNEP Workshop 2008, Neuchatel, Switzerland, 14.01.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave ground state

Colloquium at Walther Meissner Institut Munich-Garching, Munich, Germany, 19.06.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave ground state

Seminar Series of the Nebraska Center for Materials and Nanoscience, University of Nebraska, Lincoln, U.S.A., 23.06.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave ground state

Solid State Physics Seminar at University of California San Diego, San Diego, U.S.A., 26.06.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave in the rare earth poly-chalcogenides $R\text{Te}_n$

International Conference on Low Energy Electrodynamics in Solids 2008, Vancouver-Whistler, Canada, 30.06.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave ground state

Solid State Physics Seminar at Stanford University, Stanford, U.S.A., 07.07.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave in the rare earth polychalcogenides $R\text{Te}_n$

International Workshop on Electronic Crystals, ECRYS 2008, Cargese, France, 24.08.2008

★ Degiorgi, L.

Infrared and Raman study of the charge-density-wave ground state

Conference on Concepts in Electron Correlation, Hvar, Croatia, 24.09.2008

De Pietro, L.

NFESEM-Near field emission scanning electron microscopy

EMPA PhD Student's Symposium 2008, St. Gallen, Switzerland, 13.11.2008

De Pietro, L.

NFESEM-Near field emission scanning electron microscopy

Seminar, ETH Zurich, Zurich, Switzerland, 26.11.2008

Dröscher, S.

Graphene Nanostructures

QSIT Start Meeting, Arosa, Switzerland, 23.-26.1.2008

Dröscher, S.

Structuring of graphene by AFM-lithography

Third MRC Graduate Symposium Zurich, Switzerland, 14.5.2008

Dröscher, S.

Structuring of graphene by AFM-lithography

Graphene Week Italy, Trieste, 25.-29.8.2008

Dröscher, S.

Nanostructuring of graphene by AFM-lithography

Capri Spring School on Transport in Nanostructures Italy, Capri, 30.3.-6.4.2008

★ Ensslin, K.

Quantum physics with quantum dots

Physics Colloquium, University of Konstanz, Germany, January 15, 2008

★ Ensslin, K.

Electron counting in quantum dots

Nanoscience Seminar, Grenoble, France, 27.5.2008

★ Ensslin, K.

Graphene quantum dots

Seminar, Laboratory of Photonics and Nanostructures, CNRS, Marcoussis, France, 10.6.2008

★ Ensslin, K.

Electrons in quantum dots - one by one

Physics colloquium, University of Ulm, Germany, 7.7.2008

★ Ensslin, K.

Electrons in quantum dots - one by one

Seminar, IBM Research Lab, Rüschlikon, Switzerland, 27.8.2008

★ Ensslin, K.

Electrons in quantum dots - one by one

Symposium on the occasion of the 10th anniversary of the Institute for Nanotechnology at the Research Center Karlsruhe, Karlsruhe, Germany, 13.10.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

NanoScience colloquium, TU Delft, The Netherlands, 12.11.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

Physics Colloquium, Ecole Normale Supérieure, Paris, France, 20.11.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

Physics colloquium, University of Aachen, Germany, 1.12.2008

★ Ensslin, K.

Electron counting with quantum dots

Workshop on "Frontiers in Nanoscale Science and Engineering, Basel, Switzerland, 6.-8.1.2008

★ Ensslin, K.

Graphene single electron transistors

Spring meeting of the German Physical Society, Berlin, Germany, 25.-29.2.2008

★ Ensslin, K.

Tunable single electron transistor in graphene

IWEPNM 2008, Kirchberg (Tirol), Austria, 1.-6.3.2008

★ Ensslin, K.

Time-resolved single electron interference

Moriond conference on Quantum Transport and Nanophysics, La Thuile, Italy, 8.-15.3.2008

★ Ensslin, K.

Coulomb blockade, Graphene, Graphene quantum dots, Quantum manipulation

4th Capri Spring School on Transport in Nanostructures, Capri, Italy, 31.3.-4.4.2008

★ Ensslin, K.

Electron counting in quantum dots

International workshop on Quantum Phenomena and Information: From atomic to mesoscopic systems, ICTP Trieste, Italy, 5.-16.5.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

International workshop on New Frontiers of Quantum Chaos in Mesoscopic Systems, Dresden, Germany, 19.-22.5.2008

★ Ensslin, K.

Electron transport through quantum dots

International summer school on Nanotechnology and Nanoscience, Brno, Czech Republic, 16.-21.6.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

Workshop on Fundamentals of Electronic Nanosystems, St. Petersburg, Russia, 28.6.-4.7.2008

★ Ensslin, K.

Non-linear transport in quantum dots

Workshop on nonlinear electron transport in nano-junctions, Copenhagen, Denmark, 7.-11.7.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

Conference on Nanoscale Spectroscopy and Nanotechnology, Athens, Ohio, USA, 15.-19.7.2008

★ Ensslin, K.

Electrons in quantum dots - one by one

Plenary talk, 29th International Conference on the Physics of Semiconductors, Rio de Janeiro, Brazil, 27.7.-1.8.2008

★ Ensslin, K.

Electron transport in quantum dots

2nd INSTANS Summer Conference on Exact Results in Low-Dimensional Quantum Systems, Florence, Italy, 8.-12.9.2008

★ Ensslin, K.

From quantum dots to quantum circuits

Plenary talk, Meeting of the Austrian Physical Society, Leoben, Austria, 23.-26.9.2008

★ Ensslin, K.

Graphene quantum dots

Heraeus seminar on single charge effects in semiconductor nanostructures, Bad Honnef, Germany, 29.9.-1.10.2008

★ Ensslin, K.

Time-resolved electron transport through quantum dots

Conference on Quantum Dynamics in Dots and Junctions: Coherent Solid State Systems, Lago di Garda, Italy, 5.-10.10.2008

★ Erbudak, M.

Advances in photoemission spectroscopy

Symposium on Surface Science, Bilkent University, Ankara, Turkey, 21.3.2008

★ Erbudak, M.

Novel oxide substrates for nanometer-size growth of thin films
NanoTR IV, Istanbul, Turkey, 11.6.2008.

★ Erbudak, M.

Adsorbate structures on the decagonal surface of AlCoNi: experiments and simulations
10th Int. Conf. Quasicrystals, Zurich, Switzerland, 9.7.2008

★ Erbudak, M.

Oxide structures on quasicrystals
Seminar in Physics, Bogazici University, Istanbul, Turkey, 8.12.2008

Felder, F.

Durchstimbare resonanzverstärkte Detektoren für das mittlere Infrarot
DMBE WS08, Deutscher MBE-Workshop, Zürich, Switzerland, 1.-2.9.2008

Felder, F.

Mid-Infrared Tunable Resonant Cavity Enhanced Detectors
MIOMD-IX, 9th International Conference on Mid-Infrared Optoelectronics: Materials and Devices, Freiburg, Germany, 8.-11.9.2008

Felder, F.

Durchstimbare resonanzverstärkte Detektoren für das mittlere Infrarot
38. IR-Kolloquium, Freiburg, Germany, 11.-12.3.2008

Fink, J.

Quantum Mechanics with Superconducting Circuits: The Science
QSIT - Quantum Science and Technology Start Meeting, Arosa, Switzerland, 23.01.2008

Fink, J.

Vacuum Rabi Mode Splitting at High Drive Powers and Elevated Temperatures
APS March Meeting, New Orleans, USA, 11.03.2008

Fink, J.

Multi-Qubit and Multi-Photon Cavity QED
Quantum Dynamics in Dots and Junctions: Coherent Solid State Systems, Astoria Park Hotel, Riva del Garda, Italy, 06.10.2008

Fink, J.

Climbing the Jaynes-Cummings Ladder in a Cavity QED System
Solid State Quantum Information, Centro De Giorgi of the Scuola Normale Superiore, Pisa, Italy, 04.12.2008

Fognini, A.

Wachstum und Charakterisierung von PbTe Quantendots in CdTe Matrix auf Si(111)
DMBE WS08, Deutscher MBE-Workshop, Zürich, Switzerland, 1.-2.9.2008

Gasser, U.

QPC driven photon assisted tunneling through a double quantum dot
QSIT Meeting Arosa 2008, 23.-25.1.2008

Gasser, U.

Single CHarge Effects in SEMiconductor Nanostructures

WE-Heraeus-Seminar, Physikzentrum Bad Honnef (Germany), 29.9.-1.10.2008

Göpl, M.

Quantum Mechanics with Superconducting Circuits: The Technology

QSIT - Quantum Science and Technology Start Meeting, Arosa, Switzerland, 24.01.2008

Göpl, M.

Fabrication and Characterization of Superconducting Coplanar Waveguide Resonators for Circuit QED Applications

APS March Meeting, New Orleans, USA, 10.03.2008

Gustavsson, S.

Time-resolved detection of single-electron interference

Workshop on Nanoelectronics and Nanophotonics Quantum Information Processing Basel, Switzerland, 7.1.2008

Gustavsson, S.

Time-resolved detection of single-electron interference

Interaction and Interference in Nanoscopic Transport, Dresden, Germany, 20.2.2008

Gustavsson, S.

Quantum dot spectroscopy using radiation emitted from a quantum point contact

29th International Conference on the Physics of Semiconductors (ICPS), Rio de Janeiro, Brazil, 31.07.2008

Güttinger, J.

Charge Readout of a Graphene Quantum Dot

Capri Spring School on Transport in Nanostructures 2008, Capri, Italy, 1.4.2008

Güttinger, J.

Graphene single electron transistor with integrated charge detection

QSIT Meeting Ausserferrera, Ausserferrera, Switzerland, 13.06.2008

Güttinger, J.

Graphene Quantum Dot with integrated charge detection

Graphene Week 2008, Trieste, Italy, 25.08.2008

Güttinger, J.

Coulomb blockade in nanostructured graphene

Frontiers in Nanoscale Science and Technology Workshop, Basel, Switzerland, 6.-8.01.2008

Güttinger, J.

Tunable Coulomb Blockade in Nanostructured Graphene

IWEPNM 2008, Kirchberg, Austria, 1.-8.03.2008

Hellmüller, S.

Graphene single electron transistor with integrated charge detection

Nanophysics, ETH Zurich, Switzerland, 14.5.2008

Hüfner, M.

Scanning gate microscopy on a superconducting SET

Frontiers in Nanoscale Science and Technology Workshop, Switzerland, Basel, 6.-8.1.2008

Hüfner, M.

Scanning gate microscopy on low dimensional structures

QSIT-Meeting, Arosa, Switzerland, 23.-26.1.2008

Hüfner, M.

Scanning gate microscopy

Industry day, Zuerich, Switzerland, 8.5.2008

Hüfner, M.

Scanning gate microscopy on a superconducting SET

Graduate Symposium, Zuerich, Switzerland, 14.5.2008

Hüfner, M.

Scanning gate microscopy on a superconducting SET

Transalp'Nano 2008, Lyon, France, 27.-29.10.2008

★ Ihn, T.

Low-temperature electronic transport in graphene nanostructures

Graphene Canada 2008, Banff, Canada, September 2008

★ Ihn, T.

Single electron tunneling in quantum dots

Summer School of the Braunschweig International Graduate School of Metrology, Goslar, Germany, September 2008

★ Ihn, T.

Electronic transport in Quantum Dots: from GaAs to Graphene

Annual meeting of the Condensed Matter Division of the European Physical Society, Rome, Italy, August 2008

★ Ihn, T.

Time-resolved single electron detection in quantum dot structures

Spin and Qubit 2008, Carlsberg Academy, Copenhagen, Denmark, July 2008

★ Ihn, T.

Electronic Transport in Quantum Dots Made of Different Materials: from GaAs to Graphene

Workshop on Recent Advances of Low Dimensional Structures and Devices, Nottingham University, UK, April 2008

★ Ihn, T.

Counting single electrons: from shot noise to self-interference of electrons

Interaction and Interference in Nanoscopic Transport, Dresden, Germany, February 2008

★ Ihn, T.

Transport in quantum dots with time- and spatial resolution

Int. Conf. on Interaction among Nanostructures, Orlando, USA, February 2008

★ Ihn, T.

Counting electrons one by one

Physikaisch-Technische Bundesanstalt, Abteilungsseminar, Braunschweig, Germany, November 2008

★ Ihn, T.

Electronic Transport in Graphene Constrictions and Quantum Dots

RWTH Aachen, Festkörpercolloquium, December 2008

★ Ihn, T.

Time-resolved single electron detection in quantum dot circuits Hamburg, Institut für Angewandte Physik, July 2008

★ Ihn, T.

Time-resolved single electron detection in quantum dot structures

Ludwig-Maximilians-Universität München, Sektion Physik, June 2008

Kalb, W.

Defect healing at room temperature in pentacene thin films and improved transistor performance

APS March Meeting, New Orleans, USA, 10.03.2008

Kalb, W.

Highly stable organic field-effect transistors with a fluoropolymer gate dielectric

3. MRC Graduate Symposium, 2008, Zürich, Schweiz, 14.05.2008

Kalb, W.

Room temperature defect healing in pentacene based thin-film transistors

E-MRS Spring Meeting, Strasbourg, Frankreich, 27.05.2008

Kalb, W.

Defect healing at room temperature in pentacene thin films and improved transistor performance

MSE 08, Nürnberg, Deutschland, 02.09.2008

Karpinski, J.

Li hole doping, Li/C and Li/Al hole/electron co-doping in MgB_2 single crystals

Swiss Physical Society and Manep Topical Meeting, Geneva, Switzerland, 27.03.2008

★ Karpinski, J.

Hole and electron doping in MgB_2 single crystals: Influence of substitutions and vacancies on superconducting properties

Workshop on the European Project: COMEPHS, University of Rome "La Sapienza" Roma, Italy, 09.04.2008

★ Karpinski, J.

Influence of substitutions and vacancies in MgB_2 single crystals on superconducting properties and structure
Seminar in the Physics Department University of Leipzig, Germany, 27.05.2008

★ Karpinski, J.

Hole and electron doping in MgB_2 single crystals: Influence of substitutions and vacancies on superconducting properties

International conference: From Solid State to BioPhysics IV, Cavtat, Kroatia, 06.06.2008

★ Karpinski, J.

High pressure growth, structure refinement and superconducting properties of $\text{SmAsFeO}_{1-x}\text{F}_x$ single crystals and polycrystalline samples

Exploratory Workshop on: Interplay between Superconductivity and Magnetism at nanometer scale Paestum (Salerno), Italy, 20.06.2008

Karpinski, J.

$\text{Ga}_{1-x}\text{Al}_x\text{N}$ crystals growth at high nitrogen pressure

International Conference on Electronic Materials (IUMRS-ICEM), Sydney, Australia, 28.07.2008

★ Karpinski, J.

High pressure growth, structure refinement and superconducting properties of $\text{SmFeAsO}_{1-x}\text{F}_y$ single crystals and polycrystalline samples

International Conference on Electronic Materials (IUMRS-ICEM), Sydney, Australia, 29.07.2008

★ Karpinski, J.

$\text{SmFeAsO}_{1-x}\text{F}_y$ single crystals, high pressure growth, structure and superconducting properties

Int. Conference on Superconductivity and Magnetism (ICSM-2008), Side-Antalya, Turkey, 25.08.2008

★ Karpinski, J.

High pressure growth and properties of superconducting single crystals $\text{SmFeAsO}_{1-x}\text{F}_y$ and $\text{NdFeAsO}_{1-x}\text{F}_y$

Seminar in the Institute of Physics PAN, Warszawa, Poland, 03.09.2008

★ Karpinski, J.

Single crystals of $\text{RFeAsO}_{1-x}\text{F}_y$ (R=Sm, Nd, Gd, La): high pressure growth, structure and superconducting properties

Int. Workshop on Iron (Nickel)-based Superconductors, Beijing, China, 17.10.2008

★ Karpinski, J.

High pressure growth, structure and superconducting properties of single crystals of $\text{RFeAsO}_{1-x}\text{F}_y$ (R = Sm, Nd, Gd, La)

Int. Workshop "Physics and Chemistry of FeAs-based Superconductors", Dresden, Germany, 28.10.2008

★ Karpinski, J.

Single crystals of $\text{RFeAsO}_{1-x}\text{F}_y$ (R = Sm, Nd, Pr, Gd, La): high pressure growth, structure and superconducting properties

Seminar in Physik-Institut der Universität Zürich, Switzerland, 19.11.2008

Katrych, S.

Crystal structure of a high pressure triclinic polymorphic modification of the KOs_2O_6 pyrochlore

Swiss Physical Society Meeting, Geneva, Switzerland, 27.03.2008

★ Kirk, T.

Near field emission scanning electron microscopy

Sabanci University, Istanbul, Turkey, 20.11.2008

★ Kirk, T.

Near field emission scanning electron microscopy

Bogazici University, Istanbul, Turkey, 19.11.2008

Kirk, T.

Field emission scanning electron microscope with polarization analysis

Industry Day, ETH Zurich, Zurich, Switzerland, 08.05.2008

Kirk, T.

Near field emission scanning electron microscopy

IFES08, Rouen, France, 29.06.-04.07.2008

Kirk, T.

Near field emission scanning electron microscopy (NFESEM)

IVNC08, Wroclaw, Poland, 13.07-17.7.2008

Kirk, T.

Near field emission scanning electron microscopy

EMC08, Aachen, Germany, 01.-05.09.2008

Kirk, T.

Birth of a new scanning electron microscope: from inception to commercialization,

EPSS08, St. Gallen, Switzerland, 13.11.2008

★ Kirk, T.

Field emission scanning electron microscope,

Seminar, Venture Leaders, Zurich, Switzerland, 14.03.2008

Komijani, Y.

Observation of excited states in a p-type GaAs quantum dot

QSIT Meeting, Ausserferera, Switzerland, June 2008

Komijani, Y.

Observation of excited states in a p-type GaAs quantum dot

2nd Fone Workshop, Palermo, Italy, December 2008

Küng, B.

Correlation Measurements in Charge Sensing Experiments

QSIT Junior meeting Ausserferrera, Switzerland, 11.6.2008

Küng, B.

Time-Resolved Charge Detection with Cross-Correlation Techniques

WE-Heraeus-Seminar on Single Charge Effects in Semiconductor Nanostructures, Bad Honnef, Germany, 29.9.2008

Lavagnini, M.

Infrared and Raman study of the charge-density-wave rare-earth polychalco-genides RETe_n

SPS Meeting, University Geneva, Geneva, Switzerland, 26.03.2008

★ Leek, P.

Observation of Berry's Phase in a Superconducting Qubit Embedded in a Cavity

72. Annual Meeting of the DPG and DPG Spring Meeting of the Condensed Matter Division, Berlin, Germany, 25.02.2008

Leek, P.

Observation of Berry's Phase in a Solid State Qubit

APS March Meeting, New Orleans, USA, 10.03.2008

★ Leek, P.

Observation of Berry's Phase in a Solid State Qubit

Seminar, Institute of Physics, Chinese Academy of Sciences, Beijing, China, 11.08.2008

★ Leek, P.

Generation of entanglement using sidebands in Circuit QED

Seminar Semiconductor Physics, Cavendish Laboratory, University of Cambridge, Cambridge, England, 27.10.2008

Leek, P.

Generating Entanglement with Sideband Transitions in Circuit QED

A First Workshop on Analog Quantum Information Processing with Electrical Circuits, Boulder, Colorado, USA, 29.10.2008

★ Molitor, F.

Transport gap in graphene constrictions

Seminarvortrag am Max-Planck-Institut für Festkörperforschung, Abteilung v. Klitzing, Stuttgart, Germany, 8.12.2008

Molitor, F.

Local gating of a graphene Hall bar by graphene side gates

Frontiers in Nanoscale Science and Technology Workshop, Basel, Switzerland, 6.-8.1.2008

Molitor, F.

Tunable Coulomb Blockade in Nanostructured Graphene

15th International Winterschool, Bad Hofgastein, Austria, 18-22.2.2008

Molitor, F.

Aharonov-Bohm Oscillations in a Graphene Ring

ICTP Conference Graphene Week 2008, Trieste, Italy, 25.-29.8.2008

Molitor, F.

Single electron effects in nanostructured graphene

QSIT meeting, Arosa, 23.-25.1.2008

Molitor, F.

Coulomb blockade in graphene quantum dots

NCCR evaluation, Basel, 14.4.2008

Molitor, F.

Transport gap in graphene constrictions

QSIT Seminar, Zürich, 4.12.2008

★ Monnier, R.

Elements of bandstructure theory in a nutshell

Université de Genève, DPMC, Ecole doctorale, 7.3.2008

★ Monnier, R.

Low temperature transport in correlated systems and its evolution under pressure

ARW workshop on properties and applications of thermoelectric materials, Hvar, Croatia, 23.9.2008

Müller, T.

Counting Statistics with a Radio-Frequency Quantum Point Contact Charge Read-Out

Quantum Dynamics in Dots and Junctions: Coherent Solid State Systems, Riva del Garda, Italy, 5.-10.10.2008

Pfund, A.

Spin mixing and relaxation in InAs nanowire double quantum dots

Konferenz/Winterschool Mauterndorf, February 2008

Pfund, A.

Spin Dependent Pumping and Spin Relaxation in InAs Double Quantum Dots

Konferenz LT25, Amsterdam, August 2008

Pfunder, F.

Infrared and Raman study of the charge-density-wave rare-earth polychalcogenides RETe_n

SPS Meeting, University Geneva, Geneva, Switzerland, 26.03.2008

Puebla-Hellman, G.

Quantum Transport through Nanostructures

QSIT - Quantum Science and Technology Start Meeting, Arosa, Switzerland, 23.01.2008

Quack, N.

Mid-Infrared Tunable Resonant Cavity Enhanced Detectors Employing Vertically Moving Comb Drive Actuated MEMS Micromirrors

Optical MEMS and Nanophotonics 2008, Freiburg, Germany, 11.-14.8.2008

Quack, N.

A Comb Drive Actuated Vertically Moving Micromirror for Mid-Infrared Resonant Cavity Enhanced Detectors

MNE 2008, 34rd International Conference on Micro- and Nano-Engineering, Athens, Greece, 15.-18.9.2008

Rahim, M.

Mid-Infrared Vertical External Cavity Surface Emitting Lasers for Spectroscopy

38. IR-Kolloquium, Freiburg, Germany, 11.-12.3.2008

Rahim, M.

5 μm Vertical External Cavity Surface Emitting Lasers grown on BaF_2 and Si substrates

DMBE WS08, Deutscher MBE-Workshop, Zürich, Switzerland, 1.-2.9.2008

Rahim, M.

5 μm Vertical External Cavity Surface Emitting Lasers grown on BaF_2 and Si substrates

MIOMD-IX, 9th International Conference on Mid-Infrared Optoelectronics: Materials and Devices, Freiburg, Germany, Sep. 8-11, 2008

Ramsperger, U.

Local Magnetic Fields

Micro and Nano Science Platform - Industry Day, ETH Zurich, Zurich, Switzerland, 08.05.2008

Romeo, A.

Study of CSS and PVD-CdTe by different recrystallisation processes

E-MRS Spring Meeting 2008, Strasbourg, France, 26.-30.5.2008

Ruh, E.

Investigation of the Local Crystal Lattice Parameters in SiGe Nanostructures by Convergent-Beam Electron Diffraction Analysis

Aachen, Germany, 1.-5.9.2008

Saratz, N.

Magnetic bubble domains in Fe/Cu(001)

JEMS, Dublin, Irland, 18.09.2008

Saratz, N.

Magnetic bubble domains in Fe/Cu(001)

MMM, Austin, USA, 13.11.2008

★ Schnez, S.

Excited States in Graphene Quantum Dots

ICTP Conference Graphene Week, 25.-29.8.2008

Schnez, S.

Excited States in Graphene Quantum Dots

3rd MRC graduate symposium ETH, 14.5.2008

Schnez, S.

Confinement in Graphene Quantum Dots

QSIT Lunch Seminar 5.6.2008

Schnez, S.

Excited States in Graphene Quantum Dots

ICTP Conference Graphene Week, Triest, Italien, 25.-29.8.2008

★ Shorubalko, I.

Electronic properties of gate defined and etched quantum dots in InAs nanowires

72. Annual meeting of the German Physical Society, Berlin, Germany, 25.-29.2.2008

★ Shorubalko, I.

Self-aligned charge read-out for nanowire quantum dots

International conference on functional materials and nanotechnologies (FM&NT), Riga, Latvia, 1.-4.4.2008

★ Shorubalko, I.

Tunable Few Electron Double Dots in InAs Nanowires

International Conference on Solid State Devices and Materials (SSDM), Tsukuba, Japan, 23.-26.9.2008

Shorubalko, I.

Decay and evolution of spin states in InAs nanowire double dots

29-th International conference on Physics of Semiconductors (ICPS), Rio de Janeiro, Brazil, 27.7.-1.8.2008

Shorubalko, I.

Self-aligned charge-detector for nanowire quantum dots

29-th International conference on Physics of Semiconductors (ICPS), Rio de Janeiro, Brazil, 27.7.-1.8.2008

Shorubalko, I.

Self-aligned charge read-out for InAs nanowire quantum dots

Frontiers in Nanoscale Science and Technology Workshop, Basel, Switzerland, 6.-8.1.2008

★ Stampfer, C.

Tunable Coulomb blockade in nanostructured graphene

Interactions among Nanostructures (VC-IAN), Orlando, Florida, USA, February 2008

★ Stampfer, C.

Tunable Coulomb blockade in nanostructured graphene

High Magnetic Fields in Semiconductor Physics and Nanotechnology (HMF18), Sao Pedro, Brazil, 3.-8.8.2008

★ Stampfer, C.

Graphene Quantum Dots

Quantum Transport and Fluctuations at the Nanoscale, Dusica Obradovic, Montenegro, 1.-5.9.2008

★ Stampfer, C.

Graphene Quantum Dots

Conference on Concepts in Electron Correlation, Hvar, Croatia, 26.9.2008

★ Stampfer, C.

Quantum Confinement in Graphene Quantum Dots

SLAFES XIX, Latin American Symposium on Solid State Physics, Puerto Iguazu, Argentina, 7.10.2008

★ Stampfer, C.

Carbon nanomaterials for future information technology

Lehrstuhl J. Kotthaus, LMU, München, Germany, 12.02.2008

★ Stampfer, C.

Graphene and Carbon Nanotube Quantum Dots

Freie University Berlin, Berlin, Germany, 04.04.2008

★ Stampfer, C.

Graphene and Carbon Nanotube Quantum Dots

Seminar Talk at the IBM Research Lab Zurich, Rueschlikon, Switzerland, 08.04.2008

★ Stampfer, C.

Graphene and Nanotube Quantum Dots

Seminar Talk at the Universite Pierre et Marie Curie, Paris, France, 15.05.2008

★ Stampfer, C.

Graphene and Carbon Nanotube Quantum Dots

von-Klitzing Seminar at the Max Planck Institute (MPI) Stuttgart, Germany 19.05.2008

- ★ Stampfer, C.
Graphene Single Electron Transistors
Electrical Engineering Departement at Cambridge University, Cambridge, UK 19.06.2008
- ★ Stampfer, C.
Graphene Single Electron Transistors
RWTH Aachen, Germany 24.06.2008
- ★ Stampfer, C.
Carbon Nanotube Transducers
Seminar Talk at Stanford University in the group of H. Dai, Stanford (CA), USA 18.08.2008
- ★ Stampfer, C.
Graphene Quantum Dots
Seminar talk at Stanford University in the group of D. Goldhaber-Gordon, Stanford (CA), USA 19.08.2008
- ★ Stampfer, C.
Graphene and Nanotube Quantum Dots
Seminar talk at the Physics Departement at Oxford University, Oxford, UK 20.11.2008
- ★ Stampfer, C.
Nano Electromechanical Systems (NEMS) based on Carbon Materials
Colloquium at the Materials Departement at Oxford University, Oxford, UK 20.11.2008
- ★ Stampfer, C.
Carbon Nanomaterials: from Nano Electromechanical Systems to Quantum Dots
CAPE Seminar at the Electrical Engineering Departement at Cambridge University, Cambridge, UK 21.11.2008
- ★ Stampfer, C.
Graphene Quantum Dots
Invited seminar talk at the University Würzburg am Hubland in the group of B. Trauzettel, Würzburg, Germany 02.12.2008
- Stampfer, C.
Quantum Confinement in Graphene Quantum Dots
29th International Conference on the Physics of Semiconductors (ICPS), Rio de Janeiro, Brazil, 1.8.2008
- Stampfer, C.
Graphene, Nanostructures
QSIT Start Meeting, Arosa, Switzerland, 23.-25.1.2008
- Stampfer, C.
Graphene Nanostructures
The Global Challenges - How can Nanotechnology help?, San Servolo, Venice, Italy, 21.-24.4.2008
- Studer, M.
Optical measurement of spin-orbit interaction in quantum wells
Workshop on Nanoelectronics and Nanophotonics Quantum Information Processing, Basel, 6.-8.1.08

Studer, M.

Towards spin-orbit mediated spin-control

QSIT Meeting, Arosa, 23.-25.1.08

Studer, M.

Measurement of spin-orbit magnetic fields in two-dimensional electron gases

NCCR Nanoscale Science, Review Meeting, Basel, 14.4.08

Studer, M.

Spin-orbit interaction and spin relaxation in a two-dimensional electron gas

Spin Phenomena in Reduced Dimensions, Workshop, Regensburg, 24.-26.9.08

Studer, P.

Vacuum Rabi Splitting at Elevated Temperatures

New Frontiers in Quantum Information Science, 423. Wilhelm und Else Heraeus Seminar, Bad Honnef, Germany, 03.11.2008

★ Vaterlaus, A.

Magnetism far from equilibrium probed with spin polarized photoemission,

PSI-XFEL Science Workshop, Bern, Switzerland, 05.06.2008,

★ Vaterlaus, A.

Magnetism on ultra short time scales

Seminar, Stanford Linear Accelerator Center, Stanford, USA, 20.06.2008

Verma, R.

Cu(In,Ga)Se₂ Solar Cells with In₂S₃ Buffer Layers grown by Vacuum Evaporation and Chemical Spray Methods

23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, 1.-5.9.2008

Verma, R.

Cd-free Buffer Layers for Cu(In,Ga)Se₂ Thin-Film Solar Cells

A look inside solar cells, EMPA Workshop, Monte Verita, Ascona, Switzerland, 16.-18.11.2008

Vindigni, A.

From geometry and characteristic time scales to different relaxation regimes in single-chain magnets

APS March Meeting 2008, New Orleans, USA, 10-14.3.2008

Vindigni, A.

Mean field aspects of magnetic domain pattern evolution in ultrathin Fe/Cu(001) films

APS March Meeting 2008, New Orleans, USA, 10-14.3.2008

Vindigni, A.

Domain shrinking and localized fluctuations in ultrathin Fe/Cu(001) films

Summer School on Long-Range Interacting Systems, Les Houches, France, 27.08.2008

Vindigni, A.

Selection rules for single-chain-magnet behaviour in non-collinear Ising systems

11th Intl. Conf. on Molecule-based Magnets, Firenze, Italy, 21.-24.09.2008

★ Wachter, P.

Strong phonon softening in a condensed excitonic state

16th Int. Conf. on Solid Compounds of Transition Elements SCTE, Dresden, Germany, 31.07. 2008

★ Wachter, P.

Strong phonon softening in a condensed excitonic state

Freie Universität Berlin, Kolloquium, Berlin, Germany, 01.08.2008

★ Wallraff, A.

Hybrid Quantum Systems: Ions, Molecules and Electronic Circuits

QSIT - Quantum Science and Technology Start Meeting, Arosa, Switzerland, 23. 01.2008

★ Wallraff, A.

Circuit quantum electrodynamics: observing strong coupling between a superconducting qubit and a photon

LPN-CNRS, Site Alcatel de Marcoussis, Marcoussis, France, 22.01.2008

★ Wallraff, A.

Photons, Qubits and Computers - A Quantum Mechanics Lab on a Chip

Linnaeus Colloquia on Engineered Quantum Systems, Department of Microtechnology and Nanoscience - MC2, Chalmers University of Technology, Göteborg, Sweden, 31.01.2008

★ Wallraff, A.

Photons, Qubits and Computers - A Quantum Mechanics Lab on a Chip

Alpine Joint Group Seminar on Molecular Physics, Diavolezza, Switzerland, 03.02.2008

★ Wallraff, A.

Circuit Quantum Electrodynamics

72. Annual Meeting of the DPG and DPG Spring Meeting of the Condensed Matter Division, Berlin, Germany, 25.02.2008

★ Wallraff, A.

Quantum Electrodynamics in Superconducting Circuits

LOW TEMPERATURES 2008: Symposium on quantum phenomena and devices at low temperatures, Low Temperature Laboratory, Helsinki University of Technology, Espoo, Finland, 28.03.2008

★ Wallraff, A.

Circuit Quantum Electrodynamics: Quantum Optics Experiments with Electronic Circuits

Optics Colloquium by the optics network at the ETH Zurich (optETH), Nano-Optics, LPC, ETH Zurich, Zurich, Switzerland, 05.05.2008

Wallraff, A.

Two-Photon and Two-Qubit Circuit QED (contributed talk)

EuroSQIP Workshop 2008, Goteborg, Sweden, 29.05.2008

★ Wallraff, A.

Photons, Qubits and Computers - A Quantum Mechanics Lab on a Chip

Van der Waals-Zeeman Colloquium, Van der Waals-Zeeman Instituut, Amsterdam, The Netherlands, 10.06.2008

★ Wallraff, A.

Quantum Information Processing and Quantum Optics with Superconducting Circuits

Finnish National Graduate School in Materials Physics: Introduction to Quantum Systems and Devices, Laboratory of Physics, TKK, Helsinki, Finland, 15.06.2008

★ Wallraff, A.

Quantum Information Processing in the Circuit QED Architecture

2nd International Workshop on Solid State Quantum Computing (IWSSQC), Nat. Taiwan University, Taiwan, 23.06.2008

★ Wallraff, A.

Circuit Quantum Electrodynamics for Quantum Information Processing

The Fourth Asia Pacific Conference in Quantum Information Science, Cairns, Australia, 02.07.2008

★ Wallraff, A.

Circuit Quantum Electrodynamics for Quantum Information Processing

Quantum Information and Control In Queensland - QICIQ, Cairns, Australia, 30.06.2008

★ Wallraff, A.

Cavity Quantum Electrodynamics in Electronic Circuits: Quantum Optics Experiments with Single and Multiple Photons

Seminar, Centre for Quantum Technologies, National University of Singapore (NUS), Singapore, 15.07.2008

★ Wallraff, A.

Quantum Geometric Phases in Superconducting Qubits

Seminar, Physics Department, Macquarie University NSW 2109, Australia, 10.07.2008

★ Wallraff, A.

Photonen, Qubits und Computer: Die Welt der Quantenmechanik auf einem Mikrochip

Festkolloquium, RWTH Aachen, Aachen, Germany, 20.06.2008

★ Wallraff, A.

Cavity Quantum Electrodynamics with Multiple Photons and Multiple Atoms

seminar, Atominstitut der österreichischen Universitäten, Wien, Austria, 21.07.2008

★ Wallraff, A.

Cavity Quantum Electrodynamics with Superconducting Circuits

Summer School of SFB/TR 21, Control of quantum correlations in tailored matter: Common perspectives of mesoscopic systems and quantum gases, Blaubeuren, Germany, 23.07.2008

★ Wallraff, A.

Circuit QED for Quantum Information Processing

Summer School of SFB/TR 21, Control of quantum correlations in tailored matter: Common perspectives of mesoscopic systems and quantum gases, Blaubeuren, Germany, 24.07.2008

Wallraff, A.

Coherence and Decoherence in Circuit Quantum Electrodynamics

Workshop on Quantum Information Science and Quantum Decoherence, Lorentz Center, International Center for workshops in the Sciences, Leiden, The Netherlands, 11.08.2008

★ Wallraff, A.

Circuit QED with Multiple Photons and Multiple Atoms

Seminar, Institut fuer Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften and Universitaet Innsbruck, Innsbruck, Austria, 20.08.2008

★ Wallraff, A.

Photons, Qubits and Computers - A Quantum Mechanics Lab on a Chip

7th PSI Summer School on Condensed Matter Research: Probing the Nanometer Scale with Neutrons, Photons and Muons, Lyceum Alpinum, Zuoz, Engadin Valley, Switzerland, 22.08.2008

★ Wallraff, A.

Controlling Photons, Qubits and their Interactions in Circuit Quantum Electrodynamics

Workshop on Quantum/Classical Control in Quantum Information: theory and experiments, Otranto, Italy, 13.09.2008

★ Wallraff, A.

Two-Qubit Control and Tomography in Circuit Quantum Electrodynamics (QED)

ESF Networking Programme "Arrays of Quantum Dots and Josephson Junctions (AQDJJ)" conference Quantum Dynamics in Dots and Junctions: Coherent Solid State Systems, Astoria Park Hotel, Riva del Garda, Italy, 05.10.2008

★ Wallraff, A.

Quantum Optics Experiments with Multiple Photons and Multiple Qubits in Superconducting Electronic Circuits

Physik Kolloquium, Eberhard Karls Universitaet Tuebingen, Tuebingen, Germany, 22.10.2008

★ Wallraff, A.

Superconducting Qubits and Cavity QED

Seminar, Cavendish Laboratory, University of Cambridge, Cambridge, England, 10.11.2008

★ Wallraff, A.

Quantum Optics Experiments with Zero, One and Two Photons in Superconducting Electronic Circuits

Colloquium Department of Physics, University of Konstanz, Konstanz, Germany, 25.11.2008

★ Wallraff, A.

Generating and Characterizing Entangled Qubit States in Circuit Quantum Electrodynamics (QED)

Solid State Quantum Information, Centro De Giorgi of the Scuola Normale Superiore (Pisa), 03.12.2008

Zhigadlo, N.

The effect of high temperature vacuum annealing on properties of MgB_2 single crystals

Swiss Physical Society Meeting, Geneve, Switzerland, 27.03.2008

Zhigadlo, N.

Role of the apical sites in cuprate superconductors

Swiss Physical Society Meeting, Geneve, Switzerland, 26.03.2008

Zhigadlo, N.

Single crystals of superconducting $\text{SmFeAsO}_{1-x}\text{F}_y$ grown at high pressure

25th International Conference on Low Temperature Physics (LT25), Amsterdam, Netherland, 06.08.2008

Zhigadlo, N.

High pressure single crystal growth and characterization of MgCNi_3

Int. Conference on Superconductivity and Magnetism (ICSM-2008), Side-Antalya, Turkey, 25.08. 2008

Zhigadlo, N.

Exploratory synthesis and characterization of transition metal pnictides and pnictide oxides

Int. Workshop "Physics and Chemistry of FeAs-based Superconductors", Dresden, Germany, 27.10. 2008

* Zogg, H.

Lead-chalcogenide sensors and lasers for the mid-infrared range

10th Takayanagi Kenjiro Memorial Symposium and 5th International Symposium on Nanovision Science: Nanospace

Manipulation of Photons and Electrons for Nanovision Systems, Hamamatsu, Shizuoka University, Japan, 17.-18.11.2008

* Zogg, H.

Epitaxial lead-chalcogenides on Si for mid-IR detectors and emitters including cavities

SPIE Infrared Spaceborn Remote Sensing and Instrumentation XVI, San Diego, 10.-14.8.2008

* Zogg, H.

Flexible Thin Film CdTe and CIGS Solar Cells

The 2008 Int. Symp. on Optoelectronic Materials and Devices, Chicago, IL, USA, 2008