All Quantum-Dot Based Femtosecond VECSEL

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We present the first quantum dot (QD) VECSEL (vertical external cavity surface emitting laser) modelocked with a QD-SESAM (semiconductor saturable absorber mirror) producing 780-fs pulses at 960 nm.

VECSELs combine the advantages of semiconductor and diode-pumped solid-state lasers. Semiconductor bandgap engineering enables operation in wavelength regions that are not covered by established solid-state laser gain materials. The output power can be scaled up by increasing the mode area on the gain region and the pump power, if the heat flow through the layer structure is nearly one dimensional. Ultrafast VECSELs achieve high average output powers of up to 2.1 W [1] and pulse repetition rates of up to 50 GHz [2] using semiconductor saturable absorber mirrors (SESAMs) for modelocking. The shortest pulse duration generated by a VECSEL is 60 fs, which is achieved at less than 35 mW average output power [3]. Until recently, passively modelocked VECSELs were based on a quantum well (QW) gain material. QD gain materials offer a larger inhomogeneously broadened spectral bandwidth which potentially supports shorter pulse durations. Furthermore, the temperature dependence of QD gain materials is reduced compared to QW. Modelocked QD-VECSELs have recently been reported at an emission wavelength of 1060 nm with pulse durations of 18 ps at 27.4 mW [4].

Here, we have demonstrated for the first time a femtosecond QD-based VECSEL. The VECSEL structure is based on two individual distributed bragg reflectors (DBRs) for the laser and pump wavelengths, respectively. For better thermal management we removed the substrate and mounted the VECSEL semiconductor structure onto of a copper heat sink. The active region of the VECSEL consists of 7 groups of 9 QD-layers. These groups have been distributed according to the standing wave pattern of the electric field of the laser, however, the group spacing is not equidistant in order to broaden the emission spectrum. Additionally, the absorption was engineered to be higher for the center of the emission band. A low dispersion section was added on top for reduced dispersion with values of less than $\pm 10\ fs^2$ over a range of 30 nm around the central emission wavelength. The used QD-SESAM has been grown at low temperature and has a standard resonant design.

We obtained fundamental modelocking in a standard V-shaped cavity with an average output power of 63 mW at a repetition rate of 3.2 GHz with 780-fs pulses (Fig. 1). In the same cavity configuration we could also achieve 108 mW with somewhat longer pulses of 820 fs. In both cases the emission wavelength was around 960 nm and the heat sink was cooled down to around -30°C. In cw operation, in a simple straight cavity, we obtained output powers of more than 5.2 W using an intra cavity diamond heat spreader, which has been the highest output power from a QD-VECSEL so far. This shows that further power scaling is expected also for modelocked operation.

The 780-fs pulses had a time bandwidth product of 0.41, corresponding to 1.3 times the transform limit for a $sech^2$-pulse. Therefore, it should be possible to obtain pulse durations as short 600 fs with this configuration. We believe that by using an antiresonant SESAM, as opposed to the resonant one used in the experiments demonstrated here, will result in even shorter pulses. Furthermore, using diamond instead of a copper heat sink should increase the output power significantly.

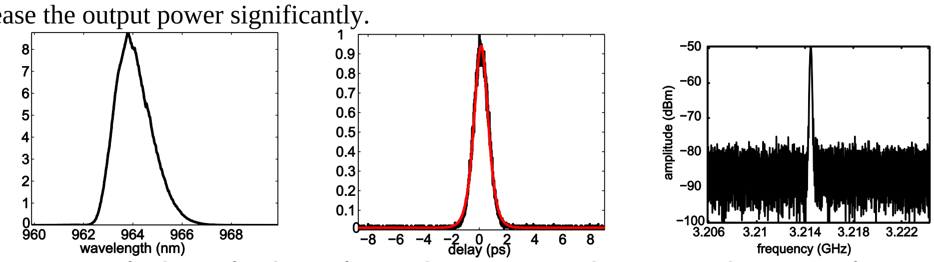

Fig.1 Measurement for the 780 fs pulses. Left: Optical spectrum centered at 964 nm with a FWHM of 1.64 nm. Middle: Second harmonic autocorrelation trace and its fit in red, showing a deconvoluted pulse duration of 780 fs. Right: RF-spectrum, showing the repetition rate of 3.2 GHz using a resolution bandwidth of 10 kHz and a spectral span of 10 MHz.

References:

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