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Passively mode-locked diode-pumped surface-emitting semiconductor laser

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Abstract: For the first time we passively mode-locked a vertical-external-cavity surface-emitting laser using a semiconductor saturable absorber mirror. We achieved 5-ps pulses with 15.3 mW average power or 12-ps pulses with 40 mW.

OCIS Codes: (140.4050) Mode-locked lasers, (140.5960) Semiconductor lasers

We demonstrate the first passively mode-locked surface-emitting semiconductor laser, using a semiconductor saturable absorber mirror (SESAM [1, 2]). We obtained 5-ps pulses with 15.3 mW average power and 2.5 GHz repetition rate or 12-ps pulses at 1.8 GHz with 40 mW. We anticipate that even multi-watt average powers should be achievable with our concept; more than 0.5 W has been demonstrated with a similar device in continuous-wave operation [3]. This potential arises from the fact that optically pumped semiconductor vertical-external-cavity surface-emitting lasers (OPS-VECSELs), in contrast to edge-emitting semiconductor lasers, allow one to scale up the mode area in order to generate a high average power and high pulse energy, while the external cavity enforces a diffraction-limited output. Multi-GHz repetition rates without Q-switching instabilities are possible. In addition, the broad amplification bandwidth should be sufficient for pulse durations in the sub-picosecond regime.

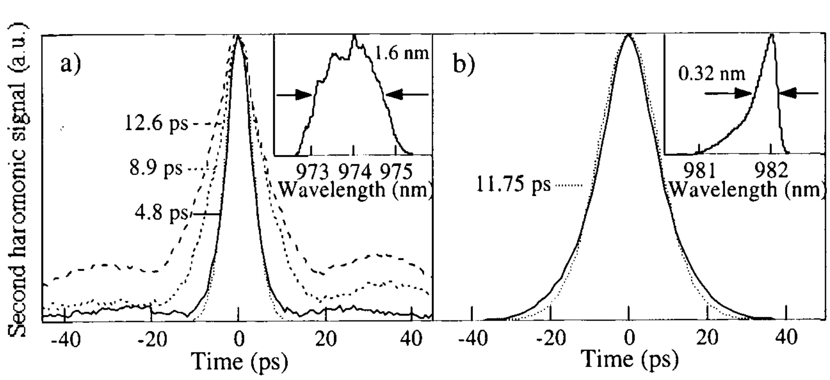

Fig. 1 Autocorrelation and optical spectrum, a) of the V-cavity (Fig. 2a) with the area ratio being 24, 34, and 60 (largest for the shortest pulse), and b) of the Z-cavity (Fig. 2b) with a fixed area ratio of 30.

Mode locking was achieved with a SESAM containing a low-temperature grown InGaAs quantum well absorber. The optically pumped gain structures consist of a Bragg mirror, an active region with multiple InGaAs quantum wells, and in one case an additional anti-reflection structure [4], all grown with molecular beam epitaxy (MBE) on a GaAs substrate. For efficient cooling, the substrate has to be soldered with indium to a copper heat sink. Because of the residual transmission of the Bragg mirror, an etalon is formed by the Bragg mirror and the soldered interface. In the first sample, the substrate was lapped and polished to • 200 μm thickness before soldering, and the resulting etalon limited the bandwidth of the mode-locked output to 0.25 nm. The pulse duration was 25 ps [5]. With a similar sample we reduced the substrate

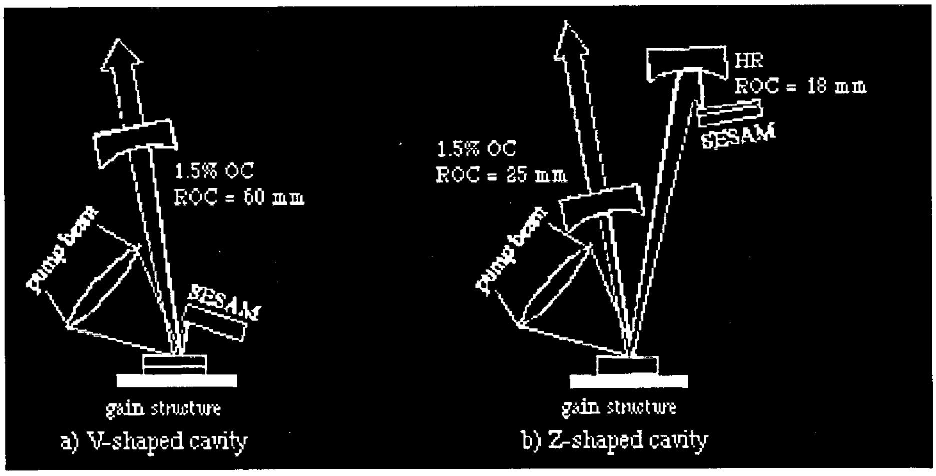

Fig. 2 The laser setups. a) The V-shaped cavity allows to change the ratio of the laser mode areas on the gain medium and the SESAM. b) The Z-shaped cavity is uncritical aligned and gives cleaner pulses. HR = high reflector, OC = output coupler, ROC = radius of curvature, SESAM = semiconductor saturable absorber mirror.

thickness to • 50 μm by etching and achieved a bandwidth of up to 1.6 nm. The minimum pulse duration achieved was 5 ps (Fig. 1a). The V-shaped laser cavity (Fig. 2a) allowed to adjust the ratio of the laser mode areas on the gain medium and the SESAM. This area ratio was found to have a strong influence on the pulse duration. Another cavity (Fig. 2b) was found to generate a more stable output because it did not require operation close to a stability limit. It allowed us to generate up to 40 mW with a cleaner spectrum, however with a longer pulse duration of 12 ps due to the fixed area ratio of 30. Also it did not generate the weak satellite pulses which are apparent from Fig. 1a. In all cases, the pulses were not transform-limited and may thus be compressible to shorter durations.

In conclusion, we demonstrated for the first time passive mode locking of optically pumped semiconductor vertical external cavity surface-emitting lasers (OPS-VECSELs), using semiconductor saturable absorber mirrors (SESAMs). We believe that our concept will lead to compact, reliable, cost-effective and efficient pulsed laser sources with high average power in a diffraction-limited beam, sub-picosecond pulse durations, and multi-GHz repetition rates.

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