4.3 Thin Film Physics

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Mid-IR devices with epitaxial IV-VI narrow-gap semiconductor layers

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By employing epitaxial narrow gap lead chalcogenide (IV-VI) layers, it was possible to realize mid-IR VECSEL (vertical external cavity surface emitting laser) and RCED (resonant cavity enhanced detector) for the first time. The materials are grown by solid source molecular beam epitaxy (MBE) onto Si(111)-substrates by employing a CaF_2 buffer layer. Despite the huge lattice and thermal expansion mismatch between the materials, device quality layers result. This is because lead-chalcogenides are fault tolerant. Typical compositions of the active mid-IR layers include Pb1-xSnxX, Pb1-xEuxX and Pb1-xSrxX (X=Te, Se). They allow to realize devices in the $< 3\mu$m up to $> 10\mu$m wavelength range by choosing appropriate compositions x. In addition, extremely high reflectivity Bragg mirrors are needed to realise such devices. Such epitaxial Bragg mirrors with very high reflectivity over a broad spectral range are again easily obtained with IV-VI materials. The mirrors consist of quarter wavelength layers with alternating high and low refractive indices. Due to the high index contrast, a few pairs only suffice.

Vertical External Cavity Surface Emitting Laser (VECSEL) on Si

A recent lay out consists mainly of a 800 nm thick PbTe active layer grown on a Si-substrate. It is followed by a 3 $\frac{1}{2}$ pair Bragg mirror and soldered on a Cu heat sink. The opposite curved mirror is again of Bragg type and serves as output coupler. Pumping is done optically with a commercial 1.55 μm wavelength laser diode. The device operates up to room temperature. At 100 K heat sink temperature, output power is above 1 W in pulsed mode, and 20 mW in continous wave (cw). Compared to the well known edge-emitting quantum cascade lasers (QCL) which consist of several hundred interfaces, the lay-out of our VECSELs is extremely simple. In addition, VECSEL exhibit a very good beam quality (emission in a 1°circular cone). This is in contrast to QCLs where the wide angle astigmatic beam requires elaborate optical beam conditioning for most applications.

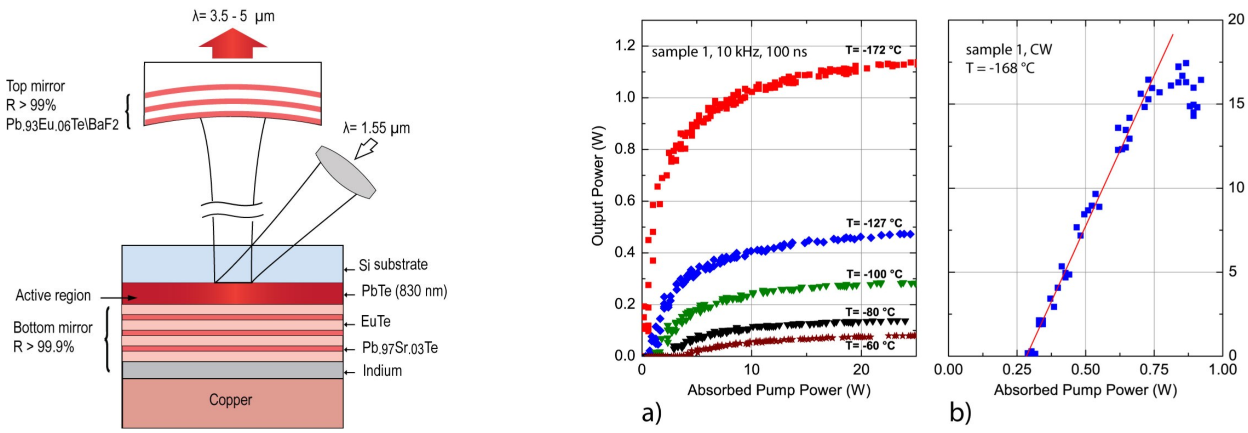

Figure 4.6: Schematic representation of a PbTe-based IV-VI VECSEL realized on a Si-substrate. The curved Bragg mirror is used as output coupler (left). Light-in/light-out characteristics at different temperatures (right) in pulsed mode (a) and cw (b).

We currently work on further improvements:

- diamond heat-spreaders will allow room temperature cw operation
- using short cavities (L $\lesssim 100\mu$m), monomode operation results. The wavelength is continuously tunable by slightly changing L with piezo-drivers across a range of up to 10%
- using quantum well structures in the active layers, threshold powers will decrease considerably

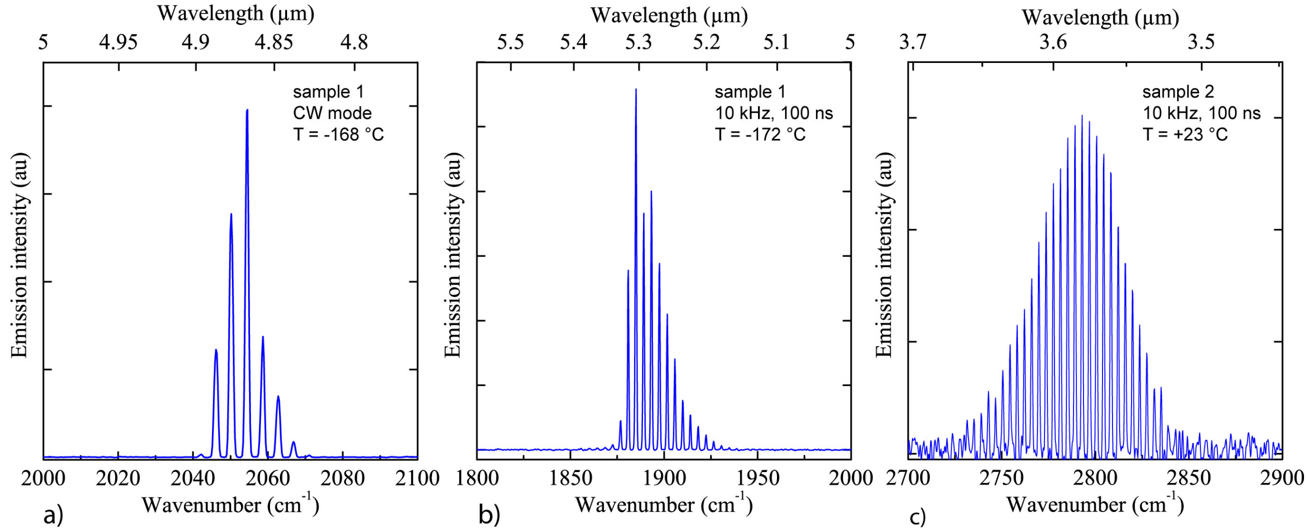

Figure 4.7: Normalized PbTe based VECSEL-on-Si lasing spectra at different heat sink temperatures

Resonant cavity enhanced detector (RCED)

Collaboration with the Center of Mechanics, ETH Zurich (J. Dual, S. Blunier, N. Quack), www.zfm.ethz.ch

A resonant cavity enhanced detector (RCED) is an embedded absorber layer within a Fabry-Perot cavity. The RCED 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 RCEDs with movable MEMS micromirrors. They operate in the 3 to 7 μm range using different compositions of the absorber layer. A typical total tunable range is 0.5 μ for a specific device.

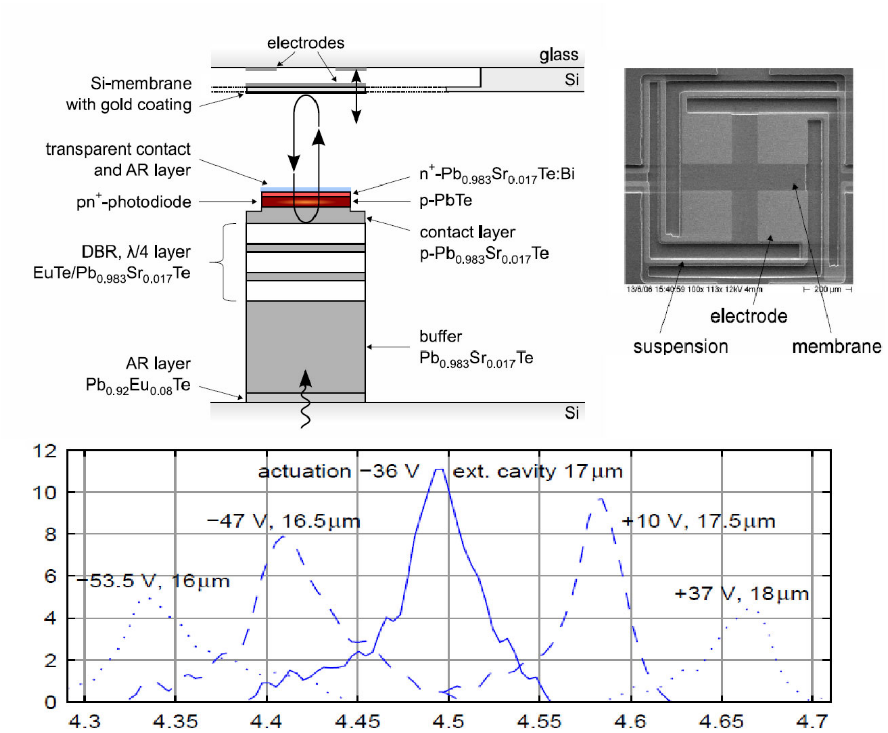

Figure 4.8: Schematics of a RCED (top left), micromirror (top right), and measured spectra for different MEMS actuation voltages (left)