Mid-Infrared Quantum Dot LEDs and Microdisk Laser Grown by MBE

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In spite of extensive research, mid-infrared (MIR) emission from self-assembled Stranski-Krastanow quantum dots (QDs) has remained difficult due to the unfavorable band alignments of the most narrow band gap semiconductor material systems. For the realization of quantum dots with strong infrared emission, we have therefore developed an alternative strain-free synthesis method in which dot formation is induced by phase separation rather than by heteroepitaxial strain. The resulting QDs exhibit almost spherical shapes with abrupt interfaces, are essentially defect- and strain-free and show intense mid-infrared photoluminescence (PL) even at room temperature [1].

In this work, we show for the first time mid-infrared light emitting diodes (LEDs) operating in cw up to room temperature and we demonstrate cw optically pumped lasing up to 200 K in microdisk structures based on these unique PbTe QDs.

The samples were grown by molecular beam epitaxy on high quality CdTe buffer layers predeposited on GaAs (001) substrates and the PbTe dots are formed by nanoprecipitation from thin 2D layers embedded in CdTe. The emission wavelength of the dots can be tuned either by changing the PbTe layer thickness [1] or by varying the growth temperature of the PbTe layer. The dot emission wavelength for an initially 1 nm thick PbTe layer grown at different temperatures ranges from 2.1 µm to 2.7 µm. This corresponds to a change of the diameter of the nearly spherical dots from 8 nm to 14 nm. An even more pronounced change of the emission wavelength can be achieved by changing the PbTe layer thickness. A variation of the layer thickness from 0.3 nm to 80 nm results in the tuning of the dot emission from 1.4 µm to 4 µm with dot diameters ranging from 5 nm to 30 nm.

For LED emission, p-i-n structures were fabricated, where the active PbTe dot layer is embedded in the center of a 0.5 µm thick CdTe intrinsic region. Cw electroluminesensce (EL) spectra were measured at various temperatures up to 300 K for dots with average diameters of 10 and 12 nm, respectively. The LED emission was compared to PL spectra from the same sample region using a 1064 nm laser with photon energy well below the CdTe band gap. At all temperatures from 30 K to 300 K the EL exactly matches the PL for both samples proving that the EL indeed arises from the embedded PbTe QDs. At 300 K the total output power was found to be 0.7 µW at 8 mA diode current [2].

To obtain lasing from the PbTe QDs, microdisks with a diameter of 40 µm were fabricated by photolithography and wet chemical etching. The single active PbTe dot layer is positioned in the center of the 2 µm thick CdTe waveguide. The QD microdisks were optically excited in cw below the CdTe band gap at a wavelength of 1030 nm, resulting in laser emission up to temperatures as high as 200 K with a maximum output power at

50 K of 0.15 mW considering homogenous emission. Thus, our unique PbTe QDs proof their suitability for novel mid-infrared optoelectronic devices.

References

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