Mode Splitting and Lasing in Detuned Lead Salt Microcavity and Microdisk Resonances

T. Schwarzl, W. Heiss, G. Springholz

Institut für Halbleiterphysik, Johannes Kepler Universität Linz, Altenbergerstraße 69, 4040 Linz, Austria

S. Gianordoli, G. Strasser

Institut für Festkörperelektronik, Technische Universität Wien, Floragasse 7, 1040 Wien, Austria

M. Aigle, H. Pascher

Experimentalphysik I, Universität Bayreuth, Universitätsstraße 30, 95447 Bayreuth, Germany

PbEuTe/EuTe microcavities and microdisks supporting strongly detuned resonances were fabricated by molecular beam epitaxy and reactive ion milling. For detuned cavity modes, we find a pronounced angle dependent relative polarization splitting of up to 1 % and vertical laser emission at 4.8 µm, for sample temperatures between 35 and 85 K. Furthermore, lateral confinement effects in circular microdisks with diameters below 20 µm are demonstrated.

1. Introduction

Microcavities have attracted immense interest in recent years due to their unique physical properties as well as their high potential for device applications. The very short cavities with lengths comparable to an optical wavelength require high reflectivity mirrors, which are realized by Bragg interference mirrors. Such Bragg mirrors exhibit a stop band with high reflectivity around a certain target wavelength. The width of this stop band is determined by the refractive index contrast between the mirror materials.

We have recently demonstrated PbEuTe/EuTe microcavities with Bragg mirrors having a very high refractive index contrast [1], which is more than four times higher than that of III-V [2] and II-VI [3] mirrors. In these cavities, the mirror stop band width is large enough to sustain Fabry-Perot resonances, which are highly detuned with respect to the stop band center wavelength. The range for this detuning is about six times larger than for III-V Bragg cavities.

In this work, we investigate the angle dependent polarization splitting between the TE and TM modes of detuned resonances (DRs) as well as mid-infrared vertical lasing [4], [5] from a DR. Furthermore, a splitting and a blueshift of resonances in laterally structured planar cavities into microdisks are shown.

2. Experimental

The microcavity samples were grown by molecular-beam-epitaxy (MBE) on (111) oriented BaF_2 substrates. They consist of two high reflectivity $Pb_{0.95}Eu_{0.05}Te$/EuTe Bragg mirrors with only three layer pairs and with (2λ) and (4λ) $Pb_{0.95}Eu_{0.05}Te$ cavities in between. The samples intended for laser emission have inserted several 20 nm thick PbTe quantum wells in the cavity layer as active material. Circular microdisks with various diameters were formed by lateral structuring of the planar cavities by reactive ion milling. The optical characterization of the microcavities was performed with polarization dependent FTIR transmission measurements. For investigation of the microdisks, an IR microscope mounted on the FTIR spectrometer was used allowing spatially resolved reflectivity measurements with a resolution of 8 μm. The laser samples were optically pumped with a pulsed Nd:YAG laser [5].

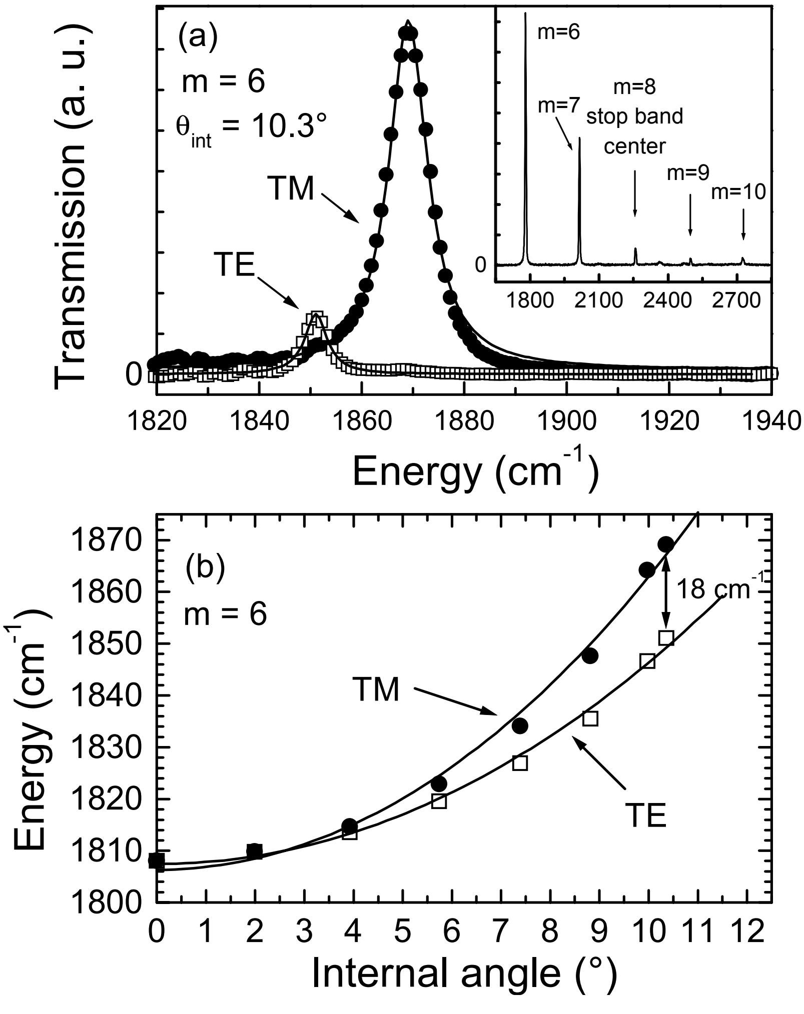

Fig. 1: (a) FTIR transmission of the m = 6 resonance of a 4λ microcavity for TE and TM polarization at an internal angle of 10.3°. Inset: FTIR transmission spectrum of the stop band region of the microcavity. (b) Angle dependent dispersion of the m = 6 mode for TE and TM polarization.

3. Polarization Splitting and Lasing in Microcavities

Our IV-VI microcavity with a length of 4λ supports five cavity resonances, as shown in the inset of Fig. 1(a) by the transmission spectrum of the cavity in the stop band region. The energy of the most detuned resonances with order m = 6 and m = 10 is about 450 cm^{-1} off from the mirror center. Figure 1(a) shows the polarization splitting of the m = 6 mode at 1860 cm^{-1}. At an internal angle of only 10.3° (64° external) it amounts 18 cm^{-1} yielding a relative splitting of 1 %. In comparison, in GaAs/AlAs cavities the tunability of the resonances is limited by the small stop band widths resulting in a polarization splitting of only 0.1 % at an external angle of 60° [6]. For the TE mode we observe, in addition, a considerable larger finesse than for the TM mode, which appears much higher and broader in the transmission spectrum. The difference of the finesse is due to a lower reflectivity for the TM polarization as predicted by the Fresnel formulas. The angular dispersion of the polarization modes of the m=6 resonance is shown in Fig 1(b). Both dispersions are fitted with the same equation [6] by using different values for the effective refractive index (3.55 and 4.25 for TM and TE mode, respectively).

The DRs have a lower quality factor than the central resonances, due to a about 3.5 % lower Bragg mirror reflectivity at the edges of the mirror stop band. Nevertheless, optically pumped lasing has been observed also at DRs, which is in particular important for IV-VI semiconductor lasers exhibiting a strong temperature dependence of the energy band gap. This enables vertical single mode laser operation over a large temperature range via mode hopping between central mode and DRs. This is observed indeed in the (2λ) laser cavity exhibiting three resonances. The sample shows narrow forward directed stimulated emission. At low temperatures around 4 K, emission is observed at the central m = 4 cavity mode at 5.87 µm, whereas at 35 K the emission switches to the m = 5 DR at 4.82 µm. Above 85 K the lasing quenches, because the band gap energy exceeds the energy of the DR [5].

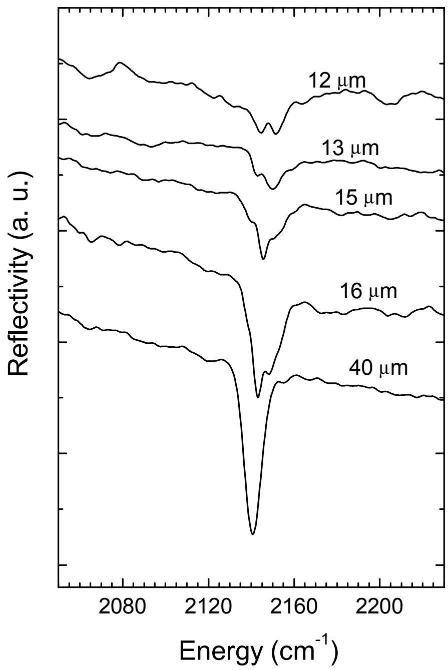

Fig. 2: Reflectivity spectra of circular microdisks with various diameters showing the m = 5 resonance dip.

4. Mode Splitting in Microdisks

The lower quality of the DRs can be improved by laterally structuring of the planar microcavities to obtain three dimensionally confined photonic states [7]. In Fig. 2, the reflectivity of one DR (m = 5) of circular microdisks with different diameters is shown. The disks were structured from a 2λ planar microcavity. For disks with diameters below 20 µm, the resonance dip shows a pronounced splitting into narrower modes.

The distance between the disk modes gets larger with decreasing diameter, as is expected from lateral confinement. Furthermore, the resonances shift to higher energies with decreasing diameter, also indicating lateral confinement. The narrow microdisk modes are attributed to radial-like modes as well as whispering-gallery-like modes [8].

5. Conclusion

In conclusion, we have demonstrated microcavities with strongly detuned resonances with respect to the mirror stop band center. These resonances exhibited a pronounced angle dependent polarization splitting and enable vertical laser emission despite low cavity finesse. Furthermore, circular microdisks showing lateral confinement effects were fabricated by laterally structuring planar microcavities.

Acknowledgements

We thank W. Krepper and O. Fuchs for technical assistance. This work is supported by the FWF P 13330 – TPH, Vienna.

References

[1] T. Schwarzl, W. Heiß, and G. Springholz, *Appl. Phys. Lett.* **75**, (1999) 1246.

[2] R. P. Stanley, R. Houdre, U. Oesterle, M. Gailhanou, and M. Ilegems, *Appl. Phys. Lett*. **65**, (1994) 1883.

[3] E. Hadji, J. Bleuse, N. Magnea, J. L. Pautrat, *Appl. Phys. Lett.* **68**, (1996) 2480.

[4] T. Schwarzl, W. Heiß, G. Springholz, M. Aigle, and H. Pascher, *Electron. Lett.* **36**, (2000) 322.

[5] G. Springholz, T. Schwarzl, M. Aigle, H. Pascher, and W. Heiss, *Appl. Phys. Lett.* **76**, (2000) 1807.

[6] D. Baxter, M. S. Skolnick, A. Armitage, V. N. Astratov, D. M. Whittaker, T. A. Fisher, J. S. Roberts, D. J. Mowbray, M. A. Kaliteevski, *Phys. Rev*. **B 56**, (1997) R10032.

[7] J. P. Reithmaier, M. Röhner, H. Zull, F. Schäfer, A. Forchel, P. A. Knipp, and T. L. Reinecke, *Phys. Rev. Lett.* **78**, (1997) 378.

[8] D. Labilloy, H. Benisty, C. Weisbuch, T. F. Krauss, C. J. M. Smith, R. Houdre, and U. Oesterle, *Appl. Phys. Lett*. **73**, (1998) 1314.