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S. Tsintzos[1,2], P. G. Savvidis[1,2], G. Konstantinidis[2], Z. Hatzopoulos[2,3], and N. T. Pelekanos[1,2]

[1] Materials Science and Technology Department, University of Crete, P.O. Box 2208, 71003 Heraklion, Greece
[2] Microelectronics Research Group, FORTH/IESL, P.O. Box 1527, 71110 Heraklion, Greece
[3] Physics Department, University of Crete, P.O. Box 2208, 71003 Heraklion, Greece

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[*] Corresponding author: e-mail simostsi@physics.uoc.gr

We present preliminary experimental results on a doped-DBR microcavity diode sample, designed for electrically-pumped operation at the elevated temperatures around 200 K. Low temperature reflectivity measurements as a function of incidence angle have shown clear evidence of polaritons in the strong coupling regime in this sample. Moreover, reflectivity spectra recorded at various temperatures between 185 and 217 K have demonstrated that the strong coupling regime persists at these elevated temperatures. Our results are very promising for the realization of polaritonic devices under electrical injection.

1 Introduction The strong coupling of resonant photons with confined excitons inside a submicron high-Q microcavity produces new quasiparticles, called exciton-polaritons, with strongly modified dispersion relations and drastically new optical properties. In the recent years, the unique properties of polaritons in the strongly coupled regime have attracted much attention. Recent work on microcavities has shed light on the bosonic properties of polaritons in the *strong coupling regime,* such as stimulated scattering [1, 2], parametric amplification [3-5], polariton lasing [6, 7], condensation [8-10] and superfluidity [11, 12] *under optical pumping***.** Until now, polariton lasing and nonlinearities have only been demonstrated in *optical experiments*, which have shown the potential of polariton lasers for reduced lasing thresholds by *two orders of magnitude* compared to conventional semiconductor lasers [13]. A number of key issues such as resistivity of the p-type DBR mirrors at low temperatures, cavity losses related to doping of the mirrors, and polariton stability under electrical injection have thwarted so far the realization of any electrically pumped polariton emitting semiconductor device. We note here that electrical injection in an organic microcavity LED in the strong coupling regime has been reported recently [14], where the much larger exciton binding energies and enhanced Rabi splittings allow operation at room temperature. However, the electroluminescence spectra are superposed with emission from the hole-injection TPD layer and localized excitonic states that do not strongly couple to cavity photons. In this work, as a first step towards electrically-pumped polariton emitters, we report optical characterization results from a doped-DBR microcavity diode, showing strong coupling up to 220 K.

2 Experimental The microcavity of our interest consists of a p-i-n diode grown by molecular beam epitaxy on n^+ GaAs (001) substrate. It comprises a $5\lambda/2$ cavity sandwiched between two doped GaAs/AlAs Bragg reflectors. To obtain high-Q cavity, the p-type DBR consists of 17 periods and the n-type of 21 periods. Three pairs of 10 nm $In_{0.1}Ga_{0.9}As$/GaAs quantum wells (QWs) are placed at the antinodes of the electromagnetic field, as shown in Fig. 1.

Two types of reflectivity experiments were used in order to characterize the above microcavity and decipher whether it can operate in the strong-coupling regime: angle-dependent reflectivity measurements performed at 20 K, and reflectivity spectra recorded as a function of temperature in the range of 185-217 K, at an incidence angle of $\theta = 10°$.

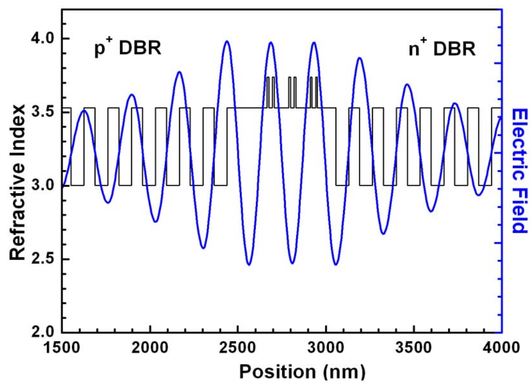

Figure 1 (Coloured online) Electric field and refractive index distribution inside the microcavity structure. The QWs are positioned at the maxima of electromagnetic field to increase light matter interaction.

3 Results and discussion The microcavity sample was designed and grown to exhibit strong coupling regime at elevated temperatures. However the initial characterization experiments have been performed at low temperatures to assess the strong coupling regime in such doped structures. This puts the cavity and exciton modes out of resonance, which can be brought back into resonance by resorting to reflectivity measurements at higher angles. In Fig. 2a, reflectivity spectra at 20 K are shown. The spectra were recorded at different incident angles in the range between 43° and 67°. At this temperature the condition of zero detuning is achieved at an angle of 54°.

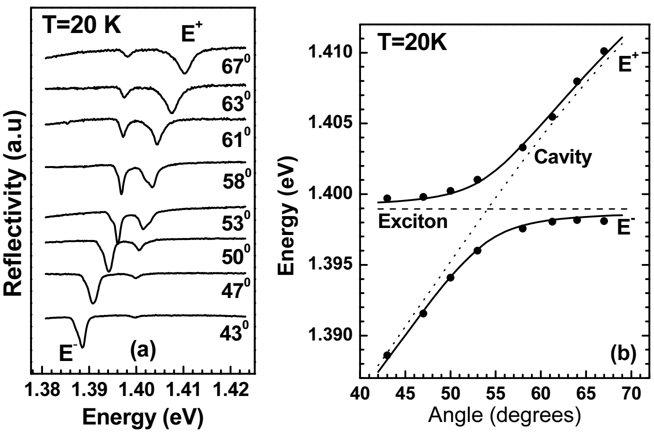

Figure 2 (a) Angle-resolved reflectivity spectra at 20 K. The spectra are shifted from each other for clarity. (b) Extracted reflectivity peak positions as a function of incidence angle. The solid lines running through the data points are theoretical fits.

The energy dispersion curves for the upper and low polariton branches are shown in Fig. 2b. The circular points are extracted peaks from the reflectivity spectra of Fig. 2a. The solid lines are theoretical fits which are generated using a coupled harmonic oscillator model [14],

$$E^{\pm} = \frac{E_x + E_{ph}}{2} \pm \frac{1}{2}\sqrt{(\hbar\Omega)^2 + \left(E_x - E_{ph}\right)^2},$$

with $E^{\pm}$ being the energy of the upper and lower polaritons, E_x and E_{ph} the bare exciton and cavity modes respectively, and $\hbar\Omega$ the Rabi splitting. Normal mode Rabi splitting of 4.6 meV at 54° is obtained. For this value of $\hbar\Omega$, excellent fitting of the experimental data is obtained as presented in Fig. 2b.

Another important issue concerns the cavity losses related to the doping of the DBRs [15]. To estimate the influence of doping on the photon confinement, we have fabricated a similar undoped microcavity structure, and compared the FWHM linewidths of the cavity modes in the two samples. Fig. 3 shows reflectivity spectra from the doped and undoped samples at an incidence angle of 5° at 20 K. The linewidth of the cavity mode in the doped sample measures 1.1 meV, while it is 0.7 meV for the undoped one. The respective Q factors are estimated at 1300 and 2000, approximately. Despite this reduction in the cavity Q factor, caused by doping of the DBR mirrors, the strong coupling regime remains intact, as shown in this work.

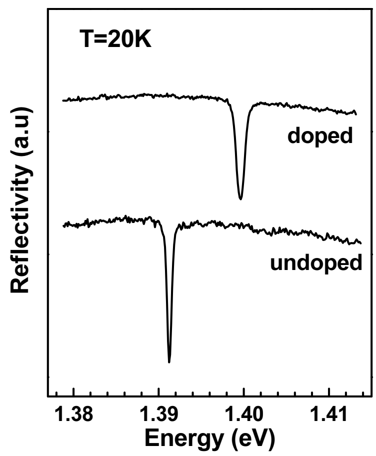

Figure 3 Cavity mode comparison between the doped and undoped microcavity samples described in the text.

The next step of the sample characterization was towards the observation of strong coupling at elevated temperatures. For this purpose, a set of reflectivity spectra were recorded at temperatures between 185 and 217 K, at an incidence angle of 10°, as shown in Fig. 4.

By changing the temperature of the sample, we are able to tune the exciton resonance through the cavity mode, which changes at a much slower rate. The anti-crossing behaviour, characteristic of the strong coupling regime between the cavity and the exciton modes, is clearly visible in the spectra of Fig. 4. The polariton energy dispersion curves, extracted from Fig. 4, are plotted in Fig. 5. The solid lines are theoretical fits, generated by the coupled harmonic oscillator model mentioned above, using a Rabi splitting of 4.1 meV at 196 K. It should be mentioned that in the model we have assumed temperature independent exciton oscillator strength, an assumption which appears to work rather well in our case. The significance of these results stems from the fact that it is the first demonstration of polariton existence at such high temperatures using a doped microcavity sample which can be readily processed into an LED structure for electrical injection of polaritons.

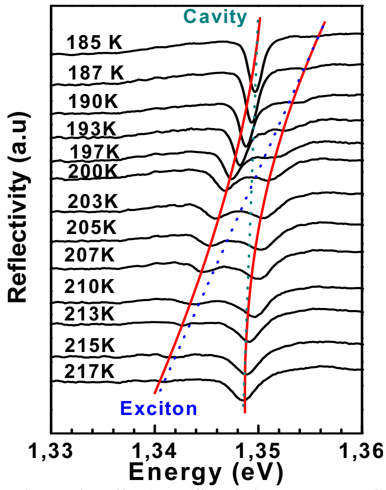

Figure 4 (Coloured online) Reflectivity spectra of the doped microcavity sample as a function of temperature at an incident angle of 10°. The spectra are presented with an offset for clarity and the red solid lines are guides to the eye.

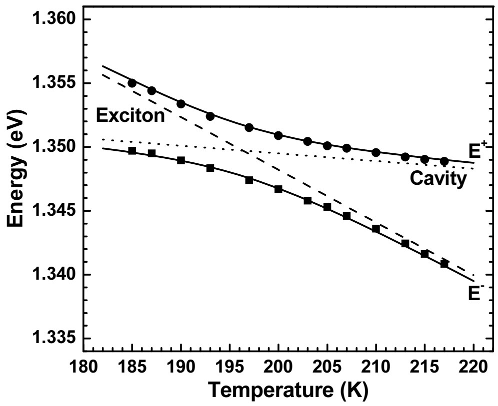

Figure 5 Polariton energy dispersion curves. Circles and squares are extracted reflectivity peak positions from Fig. 4. Solid lines are fits for the upper and lower polaritons and the dashed and dotted lines show the bare exciton and cavity modes, respectively.

4 Conclusion In this paper, we reported preliminary optical results which prove strong coupling in a GaAs-based microcavity with doped DBRs up to 217 K. As far as we know, this is the first demonstration of polaritons existence in such a microcavity. Comparing the FWHM of the cavity mode between the doped and a similar undoped microcavity structure, we confirm that the influence of the doped mirrors to the strong coupling is not significant. Finally, we note that, following submission of this manuscript, we have demonstrated polariton LED emission at 235 K [16] using the structures of the present work.

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