**Strong coupled organic microcavities**

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**Abstract.** Strong coupled organic-inorganic microcavities device has been realized and studied. One of the two cavities contains an organic thin film of tetrakis(4-methoxyphenyl)porphyrin, whereas the other microcavity is a dielectric structure coupled to the organic one by means of a LiF/ZnS Bragg mirror. Reflectivity spectra show the presence of two well defined cavity dips. We observe an energy splitting of the two cavity-modes. Despite only one cavity contains the active layer, the photoluminescence spectra display two peaks at the same energy of the reflectivity dips. These observations indicate the strong coupling of the two cavities. The comparison of the diagonalized effective Hamiltonian with the observed resonances further confirms the strong coupling.

1. **Introduction**

Single¹⁻⁶ and Multiple⁷⁻¹¹ optical microcavities (MCs) have demonstrated to be very successful systems for observing some interesting phenomena of light-matter interaction and for designing optical devices.¹²⁻¹⁷

Coupled MCs display a coupling between the photon fields of the two cavities, that can be controlled by the transmission of the central mirror. The mode interaction in such coupled systems leads to mode splitting, that depends on the coupling strength between the two cavities.¹⁸ The reflection spectrum of such structures displays two dips in the photonic band gap at the resonance energies of the coupled MCs.¹⁰

Here, we report on a monolithic organic based optical device constituted by two coupled MCs. The photoluminescence spectra (PL) display two peaks at the same energy of the reflectivity dips despite only one cavity contains the active layer, thus confirming the effective coupling of the two cavities. The active structure can be considered as the photonic analogue of cavity polaritons resulting from QW excitons strongly coupled to cavity photons. PL from polaritons is obtained by pumping incoherently one subsystem (QW excitons) and detecting light from the other subsystem. Analogously, in the present device, we detect light from the passive top cavity while pumping the bottom cavity and exciting the incoherent PL from the active organic layer.

2. **Coupled Microcavities**

The structure, grown by thermal evaporation in Ultra High Vacuum, consists of two MCs coupled via a central distributed Bragg reflector (DBR) and enclosed between a bottom and a top Bragg mirrors (Fig.1). Both cavities have a λ/2 optical length, but only the “bottom” cavity contains at its centre an
 ultra thin film (<10 nm) of tetrakis(4-methoxyphenyl)porphyrin (TMPP).\textsuperscript{[20,21]} The second (top) cavity is completely dielectric.

![Diagram of device structure](image)

**Figure 1.** Device structure consisting in two microcavities coupled by a middle DBR. The sample is closed between a bottom and a top DBR.

![Reflectivity spectra](image)

**Figure 2.** Reflectivity spectra. The inset is the bottom DBR reflectivity; the dashed dotted curve is the bottom cavity reflectivity, while the continuous line is the top cavity reflectivity.

The normal-incidence optical reflectivity at room temperature was taken stepwise while growing the structure. The inset of Fig.2 shows the bottom DBR reflectivity. The dashed dotted curve represents the reflectivity of the bottom cavity containing the organic layer and a single resonance dip at about 1.962 eV is evident. The continuous curve is the reflectivity of the whole device. The two coupled cavity modes can be easily identified as the dip at 1.898 eV and 1.980 eV. The coupling is confirmed by the blue shift of the bottom MC resonance. The shift of the two modes is not symmetric with respect to the energy of the single cavity mode, this effect may be attributed to the refractive index of the organic layer in the bottom structure whose effect leads to a slight detuning. The PL of the sample was measured, at room temperature, by pumping the bottom cavity at $\lambda=473$ nm (Fig.4) and measuring the light emitted from the top side of the device.

At normal incidence the device emits two peaks arising from the two optical modes of the two coupled cavities despite only one cavity contains the active layer. The peaks are at the same energy of the reflectivity dips 1.898 eV and 1.980 eV. The angle resolved measurements (Fig.5) shows an energy blue shift of PL peaks in accordance with the usual parabolic–like dispersion relation.\textsuperscript{[20,21]} On increasing the detection angle, a noticeable splitting of the TE-TM modes only for the higher energy peak appears. This effect is attributable to the organic layer anisotropy.\textsuperscript{[20,22]} The lower energy peak reveals only a negligible TE-TM splitting which nevertheless can be detected with polarization and angle resolved measurements. The observed behavior supports the hypothesis that the lower energy peak mainly arises from the empty dielectric cavity, while the peak at higher energy mainly comes from the cavity containing the organic layer.
2.1. Theoretical analysis and comparison with experiment

The coupled cavity energies can be obtained theoretically from diagonalization of the matrix [8]:

\[
\begin{pmatrix}
E_1 & V_{OPT} \\
V_{OPT} & E_2
\end{pmatrix}
\]

(1)

where \(E_1=1.962\) eV is the energy of the uncoupled mode of the bottom cavity, \(E_2\) is the unknown energy that the top cavity would exhibit in absence of coupling, and \(V_{OPT}\) is the optical coupling between the cavities. This latter parameter depends on the transmission of the central mirror. To derive the values of \(E_2\) and \(V_{OPT}\) from the experimental data, we can set the eigenvalues of the above matrix equal to the experimental resonance energies. In this way, we have a system of two equations which can be solved for \(E_2\) and \(V_{OPT}\) as unknowns, obtaining \(E_2=1.916\) eV and \(V_{OPT}=34\) meV. We notice that the \(V_{OPT}\) obtained is much larger than the half width at half maximum which is of about 9 meV, hence the system is in the very strong coupling regime. In this regime each of the two reflectivity dips comes from both the cavity modes. Nevertheless, in this specific case, the strength \(V_{OPT}\) is comparable with the detuning \(E_2 - E_1 =46\) meV and the eigenvectors of matrix (1) display unequal contributions from the two cavities: the lower energy peak has a dominant contribution from the top-cavity while the higher energy peak comes mainly from the bottom-cavity.

A quantum statistical approach for interacting quantum system in the strong coupling regime [23] reproduces with very good agreement the experimental PL spectra. The left panel shows the best fit of

**Figure 3.** PL Setup. The pump beam’s incident angle for PL measurements is 0° with respect to the sample surface.

**Figure 4.** Angle-resolved PL spectra detected at room temperature from the top side of the device.

**Figure 5.** The best fit of the PL experimental collected from the side of the empty (Top) cavity.

**Figure 6.** The best fit of the PL experimental collected from the side of the fully (Bottom) cavity.
the PL experimental collected from the side of the empty cavity. The right panel displays the experimental data obtained collecting the light from the opposite side. The corresponding theoretical calculation has been obtained without free parameters and by using the fitting parameters of the previous analysis.

3. Conclusion

In conclusion, we have realized and investigated a light emitting double coupled MC structure working at room temperature. Its emission arises from an organic ultra thin layer at the center of the bottom cavity. The reflectivity and the photoluminescence spectra clearly show that the two cavities are coupled with a strength of 0.034 eV. These devices are very promising for the study of the rich physics and applications promised by active media in multi-cavity systems.

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