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PHOTOLUMINESCENCE ENHANCEMENT IN ORGANIC MICROCAVITY STRUCTURES

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Abstract: We have studied the photoluminescence properties of the metal chelates aluminum-tris(8-hydroxychinoline) (Alq_3) and tris(4,4,4-trifluoro-1-(2-thienyl)-1,3-butanediono)-1,10-phenanthroline europium(III) ($Eu(TTFA)_3Phen$) sandwiched between a planar Fabry-Perot microcavity structure. A strong influence of the position of the emission thin film on the luminescence spectra has been observed. The emission intensity normal to the substrate surface is drastically enhanced by an order of a magnitude if the active layer is placed at the antinode of the standing wave in the cavity. In comparison to non-resonant Alq_3 structures, the FWHM of the spectrum is reduced from 100 nm to about 20 nm. We also show that the $Eu(TTFA)_3Phen$ luminescence is spacially directed due to the inherent linewidth of only 5 nm.

INTRODUCTION

Based on the pioneering work on organic thin film electroluminescent devices by Tang and VanSlyke (Ref. 1), many research activities have been directed towards investigation of organic microcavity structures. Both vacuum deposited molecular thin film devices and spin-coated polymeric structures can be realized (Ref. 2 – 4). Resonant devices with cavity lengths in the order of the emission wavelength offer a possibility to modify the spontaneous emission characteristics (Ref. 5 – 7). A decrease in fluorescence lifetime can be observed accompanied by a spacially enhanced luminescence spectrum because of the reduced density of the optical modes (Ref. 8).

The multilayer structure design is critical to fully benefit from the advantages of microcavity devices. Due to the influence of the standing wave of the optical field in the cavity, the position of the active layer plays an important role for the emission characteristics. Therefore, the photoexcited luminescence spectra have to be studied first.

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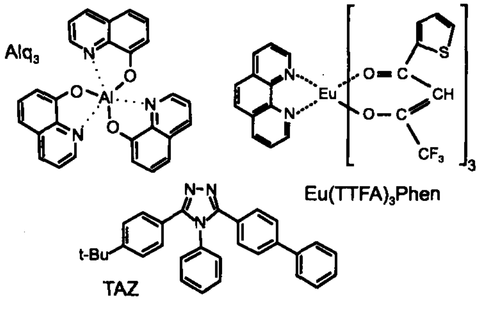


Fig. 1: Molecular structures of the organic compounds Alq_3, $Eu(TTFA)_3Phen$, and TAZ.

ORGANIC MATERIALS AND SPECTRAL PROPERTIES

Two low molecular weight organic compounds have been used to investigate the emission of microcavity structures in comparison to their non-cavity equivalents. The chemical structures, the thin film absorbance, and the luminescence properties of aluminum-tris(8-hydroxychinoline) (Alq_3) with a broad (100 nm) and tris(4,4,4-trifluoro-1-(2-thienyl)-1,3-butanediono)-1,10-phenanthroline europium(III) ($Eu(TTFA)_3Phen$) with a narrow (5 nm) fluorescence spectrum are shown in Fig. 1 and 2, respectively.

For the photoluminescence experiments, the UV-line (363 nm) of an Ar^+-laser is used as excitation source. Thin films of TAZ (3-(4-biphenylyl)-4-phenyl-5-4-tert)-butylphenyl)-1,2,4-triazole) with no absorbance or fluorescence at the excitation (363 nm) and emission (450 – 700 nm) wavelength regions serve as optically neutral spacer layers to place the active thin film at the antinode or node position of the optical field amplitude within the etalon.

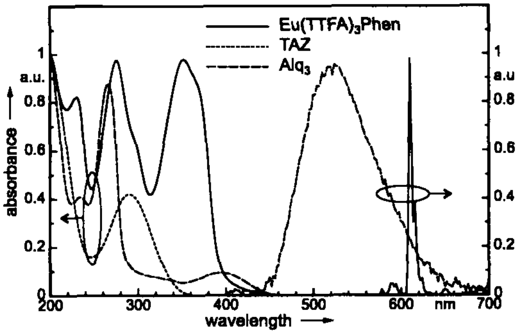
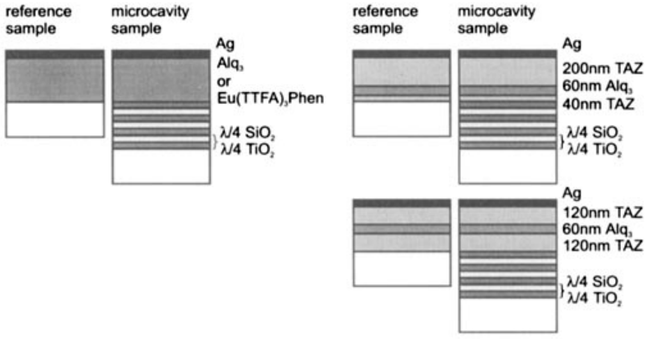


Fig. 2: Thin film absorbance and luminescence spectra.



(a) Single layer device

(b) Multilayer structure

Fig. 3: (a) Single layer device and (b) multilayer structure.

DEVICE PREPARATION AND MICROCAVITY MODELLING

Reference and microcavity samples with the same effective cavity lengths have simultaneously been prepared by organic molecular beam deposition at a base pressure of about 10^{-9} hPa.

The single layer device structure with Alq$_3$ or Eu(TTFA)$_3$Phen is depicted in Fig. 3 (a). The resonator is formed by a dielectric Bragg mirror (3.5 $\lambda/4$ TiO$_2$/SiO$_2$ pairs) and a Ag layer, which serves as metallic reflector. The reflectivity of the dielectric layers grown by e-beam evaporation and of the Ag film are about 0.85 and 0.90, respectively. Therefore, the quality factor of a cavity with an etalon length of one wavelength is approximately 50 (Ref. 9).

Fig. 3 (b) shows the different reference and microcavity structures with an organic layer sequence of TAZ/Alq$_3$/TAZ that have been realized to investigate the influence of the emission layer position. To obtain adequate thicknesses and to optimally position the active thin film, the standing

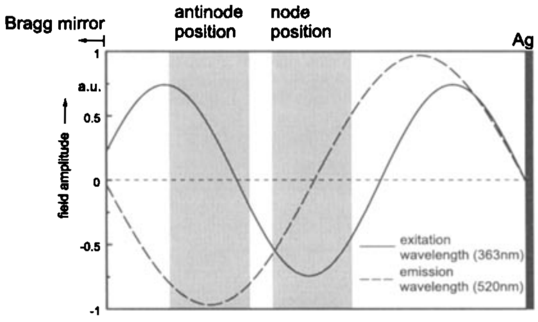


Fig. 4: Cavity standing wave for device modelling

wave of the optical field in the cavity has been calculated for the emission wavelength maximum of Alq_3 (520 nm) and the excitation wavelength (363 nm). Fig. 4 shows that the active layers overlap with the optical field (520 nm) at the antinode (TAZ(200 nm)/Alq_3(60 nm)/TAZ(40 nm)) or at the node (TAZ(120 nm)/Alq_3(50 nm)/TAZ(120 nm)) position.

For optical path length estimations, the refractive indices of the organic thin films are in a range from 1.65 to 1.75 as determined from reflection and transmission measurements.

RESONANT ALQ_3 STRUCTURES

Fig. 5 (a) and (b) show the angle dependent luminescence characteristics of the single layer devices with 150 nm and 110 nm Alq_3, respectively. The spectra have been recorded in comparison to the reference spectrum measured normal to the sample surface. Different microcavity effects can be observed.

First, the halfwidths of all the spectra are reduced from 100 nm to about 24 nm. Besides, the 0° luminescence is enhanced by a factor of about 3 (Fig. 5 (b)). Due to the relatively broad Alq_3 spectrum, the emission peaks are furthermore shifted to shorter wavelengths with increasing detection angle, depending on the resonance wavelength. Two emission modes are detected if the active layer consists of 410 nm Alq_3 (Fig. 5 (c)). Here, the halfwidths are further reduced to 18 nm and the fluorescence enhancement factors reach values of about 4. It should be noted that the reflectivity of the Bragg mirror also decreases with increasing detection angle.

The previously described multilayer devices allow to investigate the influence of the emission layer position. Fig. 6 shows the luminescence spectra of the reference and the microcavity devices measured normal to the surface. Placing the active layer at the antinode (Fig. 6 (a)), strong enhancement due to an efficient coupling between the emission dipoles and the optical mode can be achieved. On the other hand strong suppression is obtained if the node position is chosen (Fig. 6 (b)).

Although the resonance wavelength do not overlap with the emission peak of the Alq_3, a maximum intensity enhancement ratio of about 18 is obtained. Further improvement is therefore expected if the cavity wavelength corresponds more exactly to the peak of the emission spectrum.

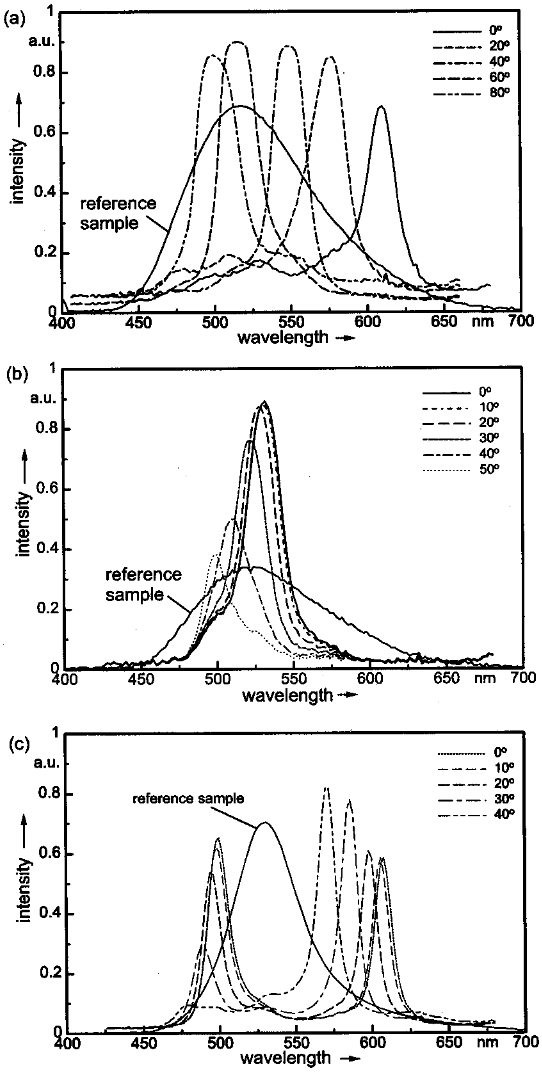


Fig. 5: Angle dependent luminescence spectra and reference spectrum of the single layer structures with (a) 150 nm, (b) 110 nm, and (c) 410 nm Alq$_3$.

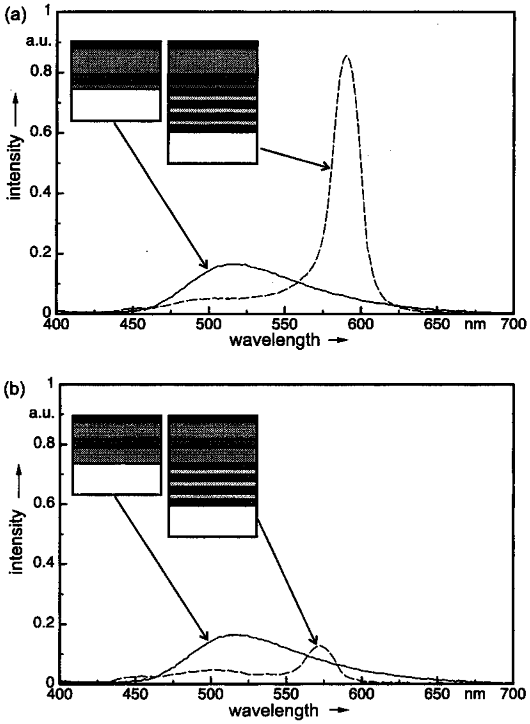


Fig. 6: Luminescence spectra of reference and microcavity Alq_3 devices with the same effective resonator thicknesses: emission layer placed at (a) the antinode and (b) the node of the cavity standing wave.

EU(TTFA)$_3$PHEN MICROCAVITY DEVICES

Similar experiments have been carried out with Eu(TTFA)$_3$Phen as active material. Device structures and angle dependent spectra measured from the microcavity and reference samples are shown in Fig. 7. In the first device, the etalon length is 190 nm resulting in an intensity peak located at angles of about +10° and −10° with a spacial halfwidth of 40°. For the second structure with an organic layer thickness of 203 nm, the values are ±40° and 12°, respectively. The emission is increased by a factor of about 8 times. The reference samples have a nearly Lambertian emission characteristic with a halfwidth of 60°. In case of the sample with 203 nm Eu(TTFA)$_3$Phen, the emission can therefore be spacially confined by a factor of about 5 due to the inherent fluorescence line width of only 5 nm. The symmetry of all spectra results from the planar device geometry.

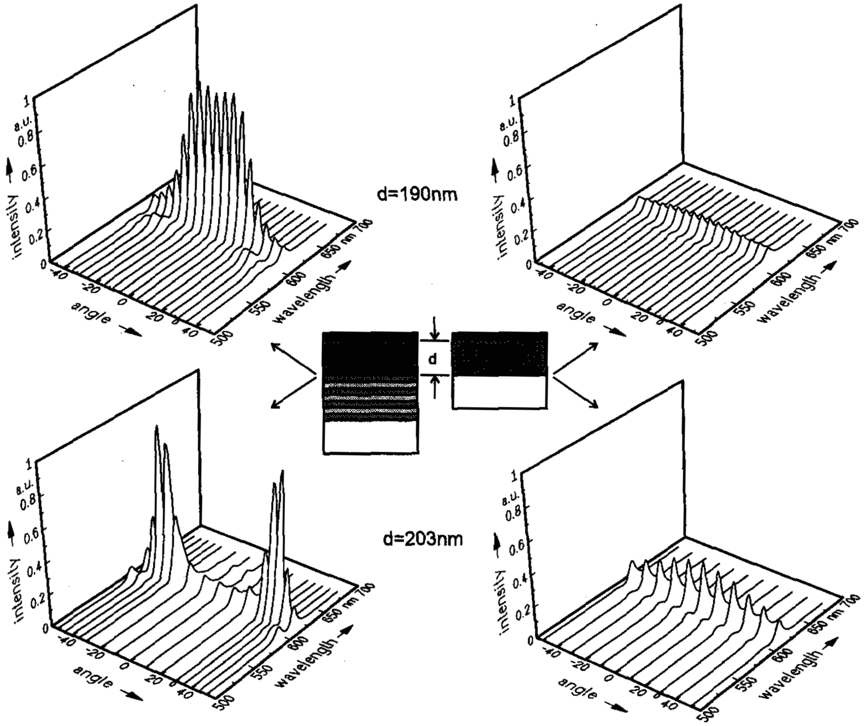


Fig. 7: Eu(TTFA)$_3$Phen based structures and the angle dependent luminescence spectra.

CONCLUSION

We have investigated the luminescence properties of Alq$_3$ and Eu(TTFA)$_3$Phen sandwiched between a planar Fabry-Perot structure. Different microcavity effects have been demonstrated. Moreover, a strong influence of the position of the emission thin film on the luminescence spectra has been observed. The emission intensity normal to the substrate surface is drastically enhanced if the active layer is placed at the antinode of the standing wave in the cavity. In comparison to non-resonant Alq$_3$ structures, the FWHM of the spectra are reduced from 100 nm to about 20 nm. If an active material with a narrow fluorescence spectrum (Eu(TTFA)$_3$Phen) is chosen, the luminescence can be spacially directed.

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