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Spontaneous emission properties of organic film in plane optical microcavity

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Abstract

The spontaneous emission properties of a single layer organic film in plane optical microcavities were studied. Optical microcavity was formed by a Tris(8-quinolinolato) aluminium (Alq) film sandwiched between a distributed Bragg reflector (DBR) and a Ag metallic reflector. Two kinds of microcavities were devised by using a different DBR structure. Compared with a Alq film, significantly spectral narrowing and intensity enhancement was observed in the two microcavities, which is attributed to the microcavity effect. The spectra characteristics of the two microcavities showed that the structure of DBR has much influence on the emission properties of a microcavity. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Optical microcavity; Spontaneous emission; Organic film; Distributed Bragg reflector

1. Introduction

Organic materials have become very attractive as effective emitting layers for flat-panel displays [1–3]. However, because of the vibronic sidebands and the strong inhomogeneous broadening of the transitions, the emission spectra of most organic materials are too broad to acquire the pure colors. In the past few years, optical microcavity has been introduced into the organic light emitting devices to control the emission properties of the organic materials [4–10]. A variety of microcavity effects on spontaneous emission such as linewidth narrowing of the spectra and intensity enhancement have been observed [5–8]. These microcavity effects lead to a significant interest in the use of microcavities for the development of novel display devices [9–11].

An optical microcavity is a structure with one or more spatial dimensions on the order of an optical wavelength. The simplest microcavity structure is a plane Fabry–Pérot cavity bounded by two reflectors. In this kind of microcavity, a distributed Bragg reflector (DBR) is mostly used as a reflector. A DBR usually consists of a stack of quarter wavelength thick slabs of dielectrics with alternating high and low refractive index. The advantage of DBRs is that they may have very high reflectivity and very low loss. However, in a Bragg mirror, there is no single well-defined reflection plane, the reflections are wavelength independent, so it can be inferred that the structure of a DBR plays an important role in controlling the emission properties of a microcavity. In this paper, the spontaneous emission properties of organic films in plane optical microcavities with two kinds of structures of DBRs were studied.

2. Experimental

The molecular structure of organic material and the generic microcavity structure used in the experiment are shown in Fig. 1.

The microcavity is sandwiched between a DBR and a metal Ag reflective mirror. The Tris(8-quinolinolato) aluminium (Alq) was used as the light-emitting layer. Two DBR stack structures were used. In one structure, DBR A consists of one quarter-wavelength stack, which is made according to the prescription: $G[HL]^5H$. There the G label represents the glass substrate, the notation $[HL]^5$ implies a quarter-

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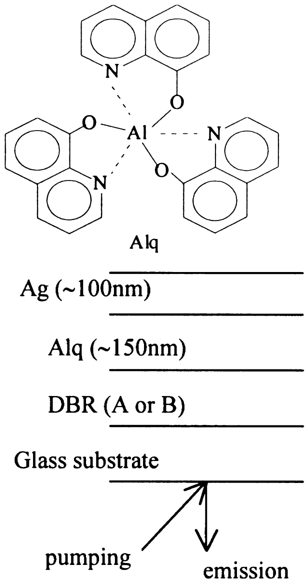

Fig. 1. Microcavity structure and the molecular structure of the organic material.

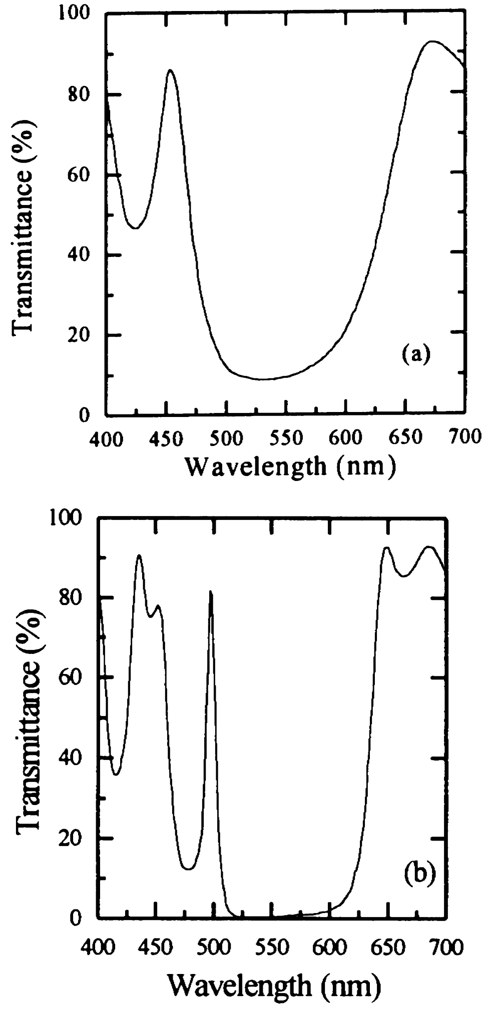

Fig. 2. Transmittance spectrum of (a) DBR A and (b) DBR B.

wave of high-index material, H, followed by a quarter-wave of low-index material, L, 5 times. The high-index material is ZrO_2 with a refractive indices n_H of 2.0. The low-index material used here is SiO_2 with a refractive indices n_L of 1.46. The Bragg wavelength of DBR A was 530 nm (λ_1). In the other structure, DBR B is a chirped one, the structure of which is $G[HL]^5[H'L']^5H'$. It places a quarter-wave stack for the wavelength of 550 nm (λ_2) on top of another for the wavelength λ_1. In order to get the maximum reflectivity, each DBR has an odd number of layers, starting and finishing with the high-index layer of ZrO_2.

The DBRs were electron-beam evaporated on the K9 glass substrates. An Alq layer was deposited on the two DBRs layers and another K9 glass substrate simultaneously by vacuum deposition in a vacuum of 1×10^{-3} Pa. Then, the sample of single Alq layer on glass substrate was taken out to form a non-cavity film structure. The thickness of the Alq film was controlled to be about 150 nm to form a $\lambda/2$ resonant microcavity. Finally, metal Ag layer of 100 nm thick was deposited on the Alq layer, which serves as another reflector of the cavity. The transmittance spectra were measured on a Shimadzu dual-wavelength/double-beam

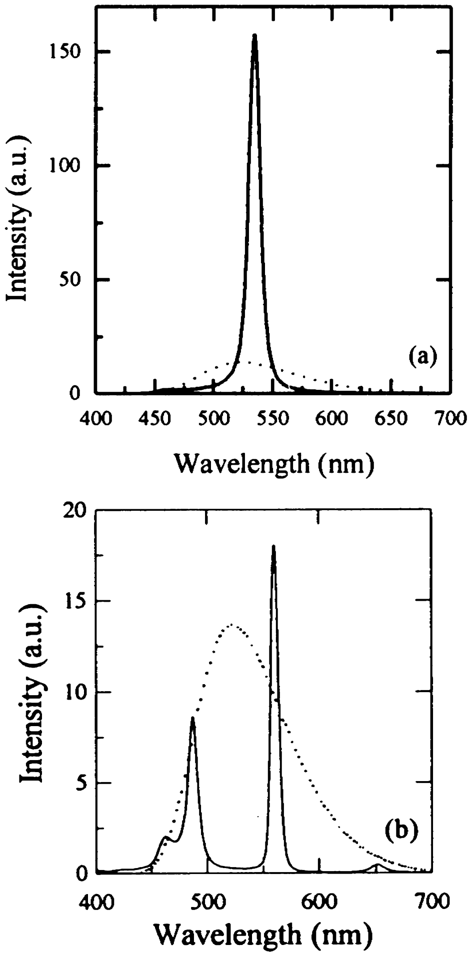

Fig. 3. (a) The PL spectra of microcavity A (line) and single Alq film (dot), (b) the PL spectra of microcavity B (line) and single Alq film (dot).

Table 1
Experimental data of intensity enhancement and comparison of spectra characteristics of the samples

Sample	PL peak (nm)	FWHM (nm)	Peak enhancement factor	Net enhancement factor
Alq film	521	93	1	1
Cavity A	535	10	12	1.8
Cavity B	560	8	1.8	
	487	11	1.1	0.26
	462	14	1.2	
	652	15	0.57	

recording spectrophotometer UV-3000. The photoluminescence (PL) emission spectra were recorded on a Hitachi spectrophotometer F4500. The PL excitation and detection were through the glass substrate with detection normal to the sample surface.

3. Results and discussion

Fig. 2 shows the transmittance spectra of DBR A and B. The reflectivity at the stopband of the DBR A and B were estimated from the transmittance spectra to be about 90 and 99%, respectively. It shows that the high reflectance of DBR A centered at 530 nm is obtained over a limited range of wavelengths due to a lower ratio of n_H and n_L. The stopband range of DBR B centered at 550 nm was extended because of the overlapping of the two stacks.

Fig. 3a shows the PL spectrum of the cavity A. The PL spectrum of the Alq film at the same excitation condition was also plotted for comparison. An effect of spectral narrowing and an enhancement of the emission intensity of the microcavity A are clearly observed. It showed that the PL spectrum of Alq film is a wider band, centered at 521 nm with a FWHM of 93 nm. The PL peak of the cavity A is located at 535 nm with a FWHM of 10 nm, which reduced eight times. Compared with the spectrum of Alq film, the emission was enhanced at the resonating wavelength and suppressed in the other regions. The emission intensity of microcavity A at the resonance peak was 11 times stronger than that from the Alq film at the same wavelength.

The PL emission spectrum of microcavity B and that of Alq film are shown in Fig. 3b. It showed that there are four peaks in the PL spectrum of microcavity B. The two strong peaks are located at 560 and 487 nm. The other two weaker peaks are located at 462 and 652 nm. The peak at 560 nm, which had an enhancement factor of 1.8, is located in the high reflectivity range of DBR B and attributed to the cavity mode. The enhancement of the peak intensity in the microcavity B is also observed at 487 and 462 nm. Though there is a higher transmission in this wavelength region, the effects observed should not be thought to be due to filter effects. These two peaks were assumed to be the optical modes of the microcavity B. The peak at 652 nm probably results from the regular luminescence of Alq passing through the transmittance peak of DBR B.

Table 1 presented the values of the spectra characteristics and the intensity enhancement of the samples. Considering the loss of excitation intensity caused by the limited transmittance of DBR, the actual intensity enhancement factor should be a little higher. It shows that the enhancement of peak emission intensity of microcavity B is not as much as that of microcavity A. In Table 1, net enhancement represents the enhancement of total spectrally integrated intensity. Microcavity B shows no net enhancement. However, microcavity A exhibits a significant net enhancement of 1.8. It means that there was an increase in the absolute amount of light emitted compared to the non-cavity Alq film. The difference of the PL emission behaviors of the two microcavities clearly shows that the structure of DBR has much influence on the emission properties of a microcavity.

4. Conclusion

Two single-layer organic optical microcavities with two kinds of DBR structures were fabricated. Compared with the Alq film, the emission from the two microcavities showed a clear cavity effect. The comparison of the spectra characteristics of the microcavities showed that the structure of DBR has much influence on the emission properties of a microcavity.

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