DIRECTED BEAM EMITTING DIODE BASED ON ORGANIC ELECTROLUMINESCENCE

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ABSTRACT

Narrow beamed light emission was successfully obtained in a new type of organic electroluminescent (EL) diode whose organic layer was sandwiched between two metal layers acting as charge injecting electrodes and mirrors. EL from the organic film edge showed much sharper spectrum with a peak depending on the thickness of the organic layer and about 100 times larger emission density compared with that from the film surface of a conventional EL diode.

INTRODUCTION

Since Tang and VanSlyke's work on a charge injection type organic electroluminescent (EL) diode emitting bright green light [1,2], many studies have been extensively made aiming at an application to EL display [3,4]. We have tried to explore new applications of organic EL other than flat panel display and succeeded in fabricating a new type of light transducer combining organic EL diode with photoresponsive amorphous silicon carbide film, which performed the light up-conversion from red to green [5-7]. On the other hand, charge injection type organic EL diodes work based on the very similar principle to inorganic LED (light emitting diode), which can be regarded as the prototype of diode laser. In addition, there are a lot of highly efficient organic laser dyes and they have been already applied to the organic EL devices [2,8]. These facts imply the possibility of organic diode laser. Of course, there are many obstacles to achieve the laser action, for example, the degradation of the organic films due to the high injection current density, etc. However, organic diode laser is expected to have many advantages. First, emission wavelength can be tuned in the wide range from UV to IR because of the variety of the organic fluorescent materials. Second, the value of threshold current of laser diode making use of laser dyes is expected to be small due to their high fluorescence efficiency. From these considerations, it seems an attractive challenge to realize the inverted population in organic EL diode by the sufficient charge injection and light confinement.

In the present study, we have attempted to achieve the confinement of EL light, as a first step, by fabricating a new type of EL device in that the organic layer is sandwiched between two metal layers acting as the charge injecting electrodes and mirrors. In such a device, EL from the organic film is emitted from the organic film edge. It should be noted that most of the studies reported so far on organic EL have directed to the flat panel display devices in which EL is emitted through a glass substrate coated a transparent ITO (indium tin oxide) electrode. We have succeeded in demonstrating the narrow-beamed blue green EL output from the film edge of the organic EL diode. About 100 times concentrated EL output was obtained when compared with the conventional surface output type EL device. The device described here is very primitive, however, this is the first step to realize the organic diode laser.

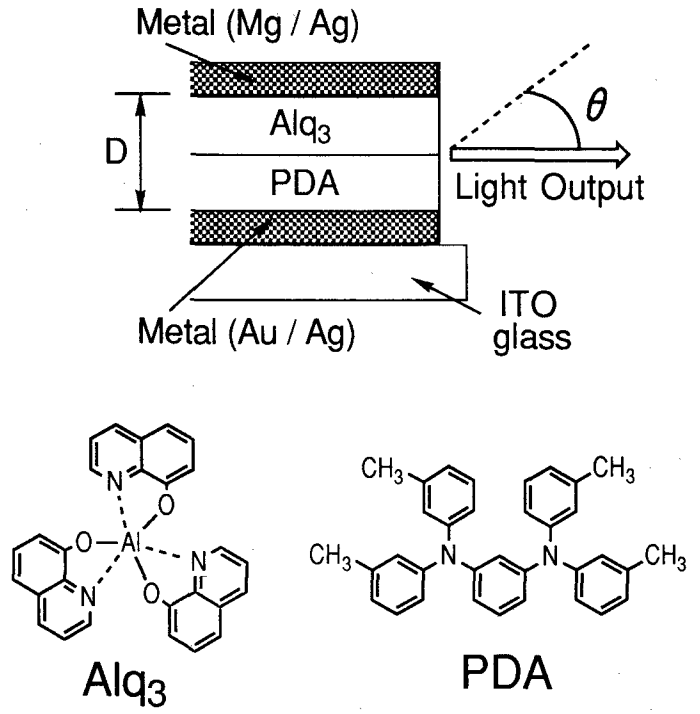

Figure 1. Device structure of the film edge output type of organic EL diode.

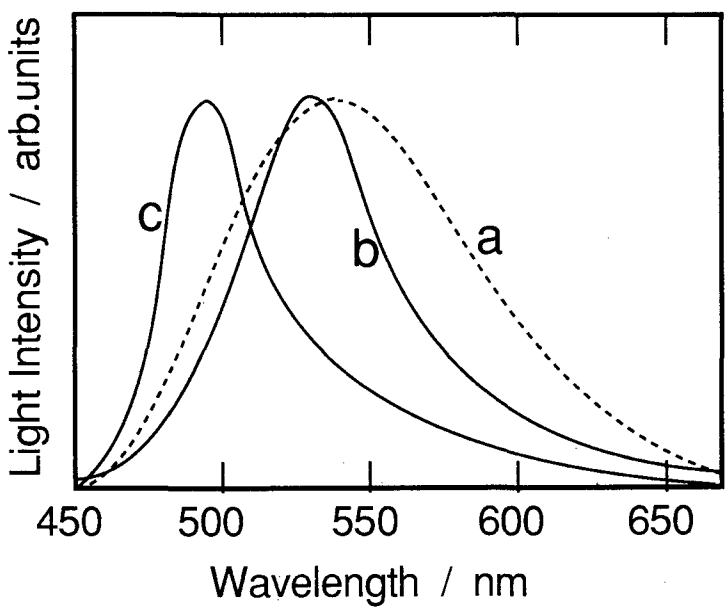

Figure 2. Output-light spectra for the surface output type device (a) and for the film edge output type devices whose thicknesses of organic EL layer (D) are 160 nm (b) and 350 nm (c).

EXPERIMENTAL

The device structure is depicted in Fig. 1. Tris(8-hydroxyquinoline) aluminum complex (Alq_3) [1] and N,N,N',N',-tetrakis(*m*-methylphenyl)-1,3-diaminobenzene (PDA) were used as the organic emitter and hole transport compound [9], respectively. Bottom metal layer was laminated with Ag (20 nm) and Au (3 nm) on ITO glass substrate and upper metal layer with Mg (50 nm) and Ag (50 nm) on the organic film. Au and Mg metals act as hole and electron injecting electrodes, respectively and Ag metal was introduced as a reflector. All films were deposited by vacuum evaporation at room temperature. The total thickness of organic films (D) was varied from 160 nm to 400 nm, while the thickness of two organic layers was kept equal. Measurements were carried out under 0.1 Pa at -140°C. Output light intensity was monitored by a silicon photodiode (Hamamatsu Photonics, S1337-66BQ) set closely to the film edge of the device. Light emitting area was determined by the dimension of film edge covered by the upper electrode, i.e., 500 μm (wide) x D. The length of the upper electrode was 2 mm long. No special treatments were made to cut the film edge sharp.

RESULTS AND DISCUSSION

When a negative voltage was applied to the electron injecting electrode, an intense and narrow-beamed green output light was observed from the film edge. Its directivity can be confirmed visually. Namely, the strong output was recognized only when one observed the output light from the direction indicated by the arrow in Fig. 1. Moreover, the tone of EL output was observed to change depending on the thickness of the organic layer sandwiched with two metal layers.

Figure 2 shows EL spectra from film edge of the present device (solid curves) and from film surface of the conventional EL diode (broken curve). Interestingly, the film edge output showed much sharper spectrum than surface output. Moreover, the peak position depended on the thickness of the organic layer (D). At D = 350 nm, a bluish green output (curve c, Fig. 2) was observed, which was largely shifted to shorter wavelength from that of the film surface emission. Dependence of the peak position on D was found to be not straightforward as shown in Fig. 3. It gradually shifted from 530 to 500 nm when D was varied from 160 to 250 nm, whereas it returned to 530 nm at D=300 nm and then shifted to shorter wavelength again with increasing D. These behaviors of the output spectrum may be interpreted as the result of a propagation of a waveguiding mode allowed between two parallel metal mirrors separated by D.

Figure 4 shows the angle dependence of the output-light intensity from the film edge. Light expanding angle (θ) with respect to the film surface is schematically defined in Fig. 1. The angle dependence was measured by monitoring the output light intensity passed through the narrow slit while rotating the sample. It is clearly shown that the output-light was directive within the narrow angle of about 10 degrees.

Figure 5 shows the dependence of the output light intensity on the injecting current density. EL intensity per unit area from the film edge of the present device was about 100 times larger than that from the film surface of a conventional EL diode. This is explained by the EL light was well confined between two metal films before emitted from the film edge. However, the current quantum efficiency of the film edge output type device was 0.002%, which is far small as compared with that of a surface output type device (0.2%). This is mainly due to the leakage of photons through the thin lower Ag film (20 nm) having about 20% transmittance and from the three remainder film edges since the observed output-light was emitted from a single film edge of EL diode.

Although EL output is concentrated 100 times before emission, it is a very primitive result for the purpose to achieve the laser action. The present device, however, can be applied

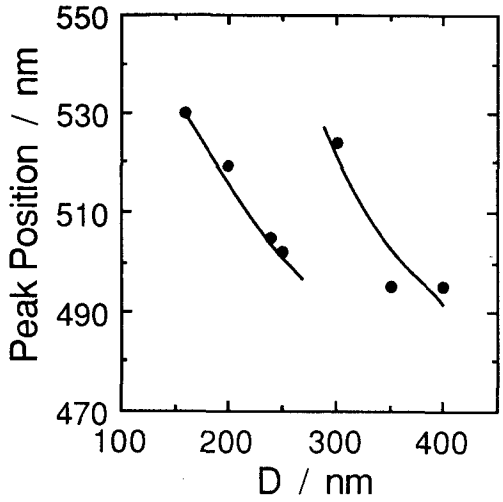

Figure 3. Dependence of the peak position on the thickness of organic layer (D).

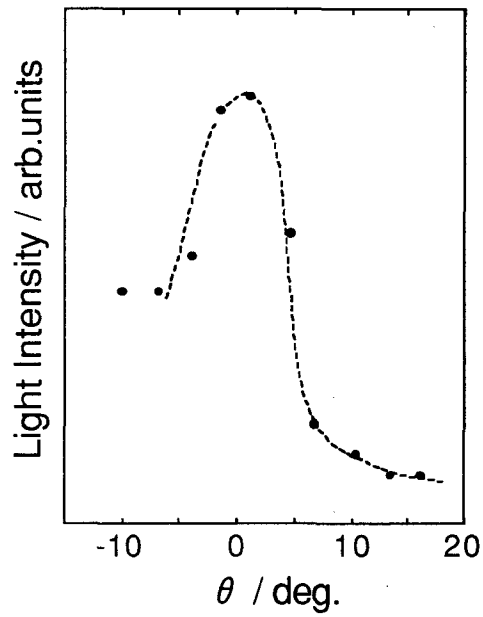

Figure 4. Beam profile for the film edge output. θ is the expand angle indicated in Fig. 1. D=160 nm.

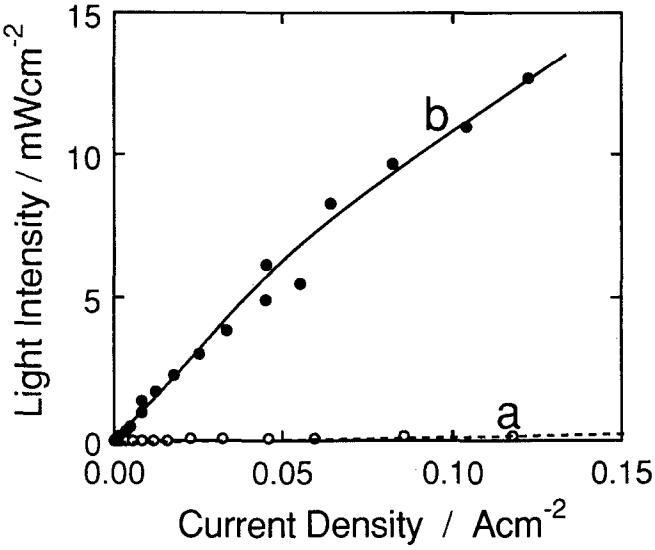

Figure 5. Dependence of output light intensity on injecting current for surface output type device (a) and for film edge output type device (b). Thickness of the organic layer was 100 nm (a) and 140 nm (b), respectively.

to the organic LED array emitting directed beams instead of the laser diode array, which is important component both for the two dimensional optical computing [10] and for the optical neural network [11]. The following is the possible strategy to obtain the inverted population in organic EL diode. Sufficient light confinement and sufficient charge injection are of prime importance. The light confinement in the lateral direction to the film by surrounding the EL diode with the lower refractive index material is effective. Latter issue is related to the degradation of the organic films. Actually, the present device suffered from the degradation when large amount of current was injected. This problem can be reduced by making the very small diode because the heat generated under the device operation is removed efficiently. At present stage, we observed the large current density of 1.5 Acm^{-2} in our device having a very narrow electrode of several tens μm. It should be noted that diode lasers generally have the cavity of very small dimension, which is very effective to concentrate the injection current and confine the light into the very small region. Therefore, we concluded that the fabrication of such a cavity is very important. Additional approach is to make the so-called double hetero structure to confine the injected carriers energetically. Due to the abundance of organic materials having a variety of absorptions, such energy structure can be constructed its appropriate combination. Finally, it should be pointed out that the utilization of high efficient laser dye as an emitter layer instead of Alq_3 is necessary.

CONCLUSION

In conclusion, we successfully demonstrated the directed light emission by using a new type of organic EL diode whose organic layer was sandwiched between two metal layers acting as charge injecting electrodes as well as mirrors. EL from organic film edge showed much sharper spectrum and about 100 times larger emission density compared with that from the film surface of conventional EL diode. EL output can be tuned from blue to green by varying the organic layer thickness. An attempt is now in progress to construct the optical cavity for the aim to realize the organic diode laser.

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