ELECTROLUMINESCENT MECHANISM OF ORGANIC THIN FILM DEVICES

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ABSTRACT

We elucidated that the thickness of an emitter and a carrier transport layers drastically influenced electroluminescent efficiency. The key to obtain high luminance is to confine charge carriers and molecular excitons inside of an emitter layer. Another important key is to adjust the distance between an emitting layer (excited molecules) and a metal mirror.

1.INTRODUCTION

Organic electroluminescent (EL) devices composed of a double hetero (DH) structure, hole transport layer (HTL)/ emitter layer (EML)/ electron transport layer (ETL), seem to be fascinating, because we can expect confinement of charge carriers, confinement of optical field, and some quantum mechanical effects(1,2). Our study of the organic EL devices started from the construction of the DH structure(3,4). Due to the lack of adequate ETL materials, however, our preliminary test of introduction of the ETL did not contribute the enhancement of EL efficiency. Our recent study, in particular, was focused on the wide search of ETL materials and the insertion effect of the ETL into EL devices. Then, we obtained bright EL devices with a novel EL cell structure composed of ITO/ EML/ ETL/ MgAg (single hetero type:SH) in which the EML has a hole transport tendency(5). More recently, we furthe more could advance the SH structure to an ideal DH structure(6).

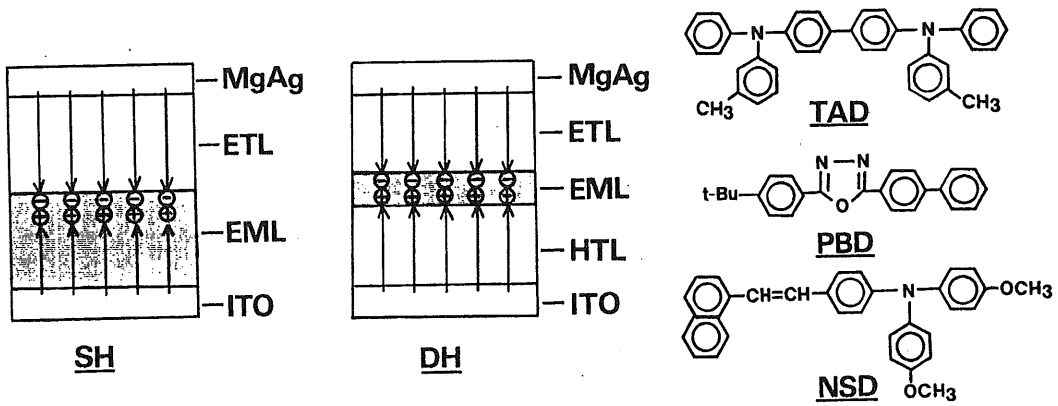

Fig.1 The structures of the EL devices and the molecular structures of materials used for the devices.

In this study, we demonstrate that the thicknesses of both an EML and an ETL drastically affect EL efficiency in SH and DH structures. First, we show the EML thickness dependence of luminance in SH and DH structures. The effective confinement of both charge carriers and molecular excitons within a very narrow emitter layer, 50Å, was achieved in a DH structure. We show that high luminance was derived from the confinement of both charge carriers and molecular excitons inside of an EML. Second, we show the ETL thickness dependence of luminance in a SH structure. The thickness of an ETL also drastically affects EL efficiency. This phenomenon will be discussed in terms of the interaction between excited molecules and a metal mirror, the retardation effect(7,8).

2.EXPERIMENTAL

EL devices were fabricated by conventional vacuum vapor deposition(5). The organic materials used in our experiment are shown in Fig.1(9). We used an aromatic diamine (TAD) as a hole transport material and an oxadiazole derivative (PBD) as an electron transport material. For an emitter material, triphenylanime derivative (NSD) was used.

3.CONFINEMENT OF CHARGE CARRIERS AND MOLECULAR EXCITONS

Figure 2 shows the thickness dependences of luminance at the fixed current density of 100mA/cm^2 for DH and SH structures. The thickness of the HTL and the ETL was fixed at 500Å. When the EML thickness was 500Å, the luminance of 1000cd/m^2 was observed in both of the SH and the DH structures. The SH structure worked to give high EL efficiency, and no effect of the insertion of a HTL (DH structure) was found. However, when the thickness of an EML was reduced to less than 300Å, new feature appeared. The SH structure showed the drastic decrease of luminance with the decrease of the emitter thickness. In contrast, constant high luminance was retained in the wide range of the emitter thickness in the DH structure. The luminance continued to lie in high level, even when the emitter thickness was only 50Å. This result

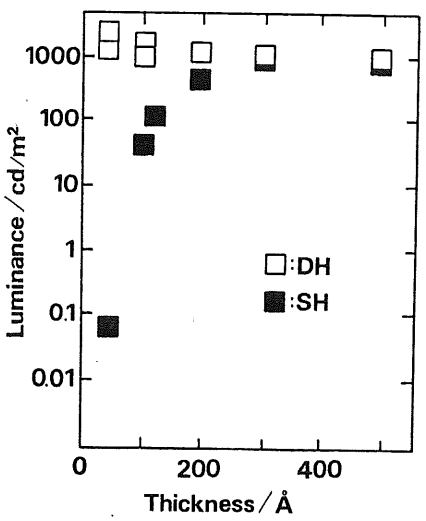

Fig.2 Luminance at the current of 100mA/cm^2 as a function of emitter thickness in DH (□) and SH (■) structures.

means that the confinement of both charge carriers and molecular excitons within the EML was achieved even in the 50Å-thick EML in the case of the DH structure. On the other hand, we can point out two major reasons for lower EL efficiency in the SH structure with the EML thickness less than 300Å. First, the part of electrons injected from the ETL pass through the EML without the encounter with holes. Second, the significant portion of the excitons produced within the EML reach an ITO electrode during a migration process and are quenched. These consideration was supported by the estimation of an emission region. According to our separate experiment, in the case of the SH structure with the 500Å-thick EML, the emission region was found to locate near the EML/ETL interface and the emission width was about 250Å. This value, which allows us to estimate the maximum exciton migration length and/or the width of the carrier recombination region, is very close to the emitter thickness at which the luminance began to drop abruptly in the SH structure.

The EL spectrum of the DH structure also indicates such confinement. Figure 3 shows the EL spectrum of the DH structure with 50Å emitter thickness at the current density of 10mA/cm^2. Also, the photoluminescent (PL) spectra of NSD, TAD and PBD layers are included. The EL spectrum corresponded exactly to the PL spectrum of the EML and no emission from the carrier transport layers was observed. This means that the site of carrier recombination located only within the EML; electrons injected from the ETL into the EML layer are blocked at the HTL/EML interface, and holes injected from the HTL layer into the EML layer are blocked at the EML/ETL interface. Also, the EL spectrum gives the evidence of the confinement of molecular excitons within the EML. The excitons created within the EML have no ability to migrate into carrier transport layers, because the carrier transport layers have large exciton energies than that of the EML.

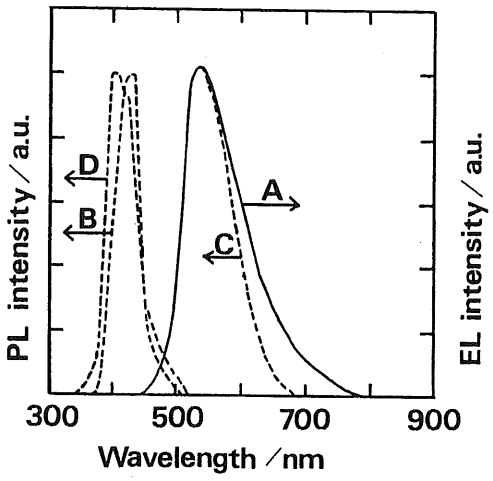

Fig.3 EL spectrum of the DH structure (A) and PL spectra of TAD (B), NSD (C) and PBD (D).

4.INTERACTION BETWEEN EMITTING MOLECULES AND A METAL MIRROR

Figure 4 shows the ETL thickness dependence of luminance at the current density of 100mA/cm^2 in the SH structure. The thickness of the EML was fixed at 500Å. Evidently the luminance strongly depends on the ETL thickness. This phenomenon can never be understood in terms of a conception of non-radiative energy transfer from excited molecules to a metal mirror. The phenomenon should be explained by considering the radiation field of excited molecules(7,8). The radiation field originated from a excited molecule which locates closely near the EML/ETL interface is reflected at a metal mirror (MgAg) and interacts with the same excited molecule. This effect largely influences the intensity of luminescence. In the case of the SH structure cell with nearly 500Å ETL thickness, the radiation probabilities of the excited molecules are enhanced by its own reflected radiation field, and the enhancement of luminance occurrs. We believe that this phenomenon is very significant for both fundamental physics in thin-film EL and further developement of organic EL devices.

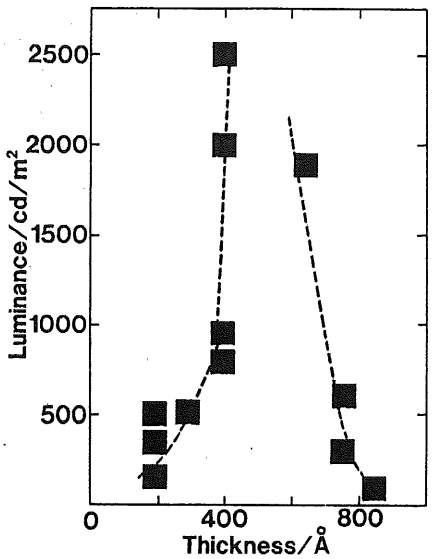

Fig.4 Luminance at the current density of 100mA/cm^2 as a function of ETL thickness in the SH structure.

5.REFERENCES

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