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High Intensity Blue Light EL Device Using Heterostructure of *p*-Sexiphenyl and TPD

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Enhanced electroluminescence (EL) from vapor deposited *p*-sexiphenyl (6p) layer has been observed utilizing heterostructure of *p*-sexiphenyl emissive layer and *N,N'*-diphenyl-*N,N'*-(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD) hole transporting layer. The device emits blue light centered at 420 nm, and the EL intensity reaches as high as 3,400 cd/m^2 at an applied voltage of 10 V. The heterostructure device emits 2 orders of magnitude higher intensity than the conventional single layer device.

Keyword: organic electroluminescent device, organic EL device, *p*-sexiphenyl, heterostructure device, blue light emitting device

INTRODUCTION

Recently, organic electroluminescent (EL) diodes have been studied for various types of emission characteristics, for example, variable color emission white color emission and sharp spectrum emission. There are some requirements for blue light emission not only for display application but also for light source for printing equipment and so on. There has been developed some materials for blue light emission [1, 2], however, origophenylene [3, 4] is one of the promising candidates for blue light emissive source in organic light emitting diodes. Early work of Y. Ohmori et al. [1] published a paper of blue-light emitting diodes using poly(alkylfluorene) and Prof. G. Leising's group published a paper [2] of blue light emitting EL device utilizing poly-*p*-phenylene (PPP). The device fabrication process for these materials is spin-coating method and is not suitable for fabrication of heterostructure device. By using origomer as an emissive material, we can fabricate EL device by means of vacuum deposition, and we can easily fabricate heterostructure device [5] with an emissive layer and a carrier transporting layer, i. e., hole transporting or electron transporting layer, to enhance emission from the emissive layer.

In this study, we investigated a heterostructure device with *p*-sexiphenyl with hole transporting layer of *N,N'*-diphenyl-*N,N'*-(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD). TPD is one of the popular materials for hole-transporting layer and is suitable for fabricating heterostructure device with the *p*-sexiphenyl emissive layer.

EXPERIMENTAL

Figure 1 shows the molecular structures of the organic materials, (a) *p*-sexiphenyl and (b) *N,N'*-diphenyl-*N,N'*-(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD), and (c) a schematic description of the organic EL device with the heterostructure of *p*-sexiphenyl and TPD. The device consists of an indium-tin-oxide (ITO)-coated glass substrate, N,N'-diphenyl-N,N'-(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD) hole transporting layer, *p*-sexiphenyl emissive layer, terminated with a silver containing

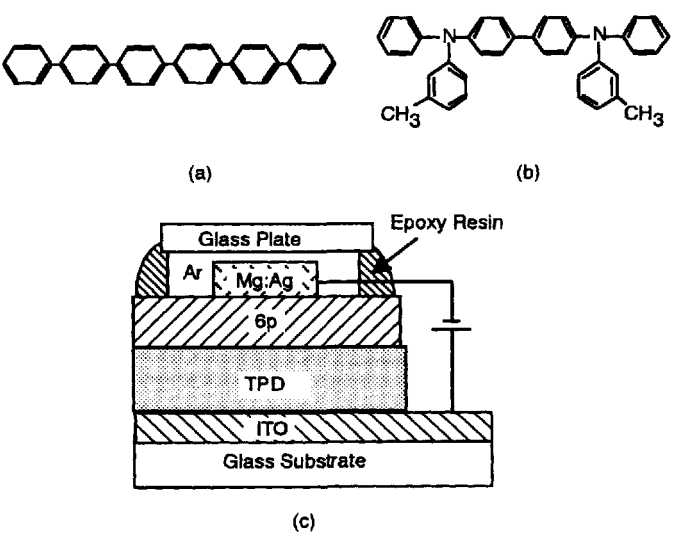

FIGURE 1 Molecular structure and a schematic of device structure used in this experiment.

magnesium (Mg:Ag) cathode. Several devices with different layer thickness were prepared for the EL measurements.

EMISSION CHARACTERISTICS OF *p*-SEXIPHENYL DEVICE

Figure 2 shows the dependence of the injection current and EL intensity on applied voltage for the device with 50-nm-thick *p*-sexiphenyl and 60-nm-thick TPD. The current density increased superlinearly with increasing applied voltage under the forward bias condition, however, it remained

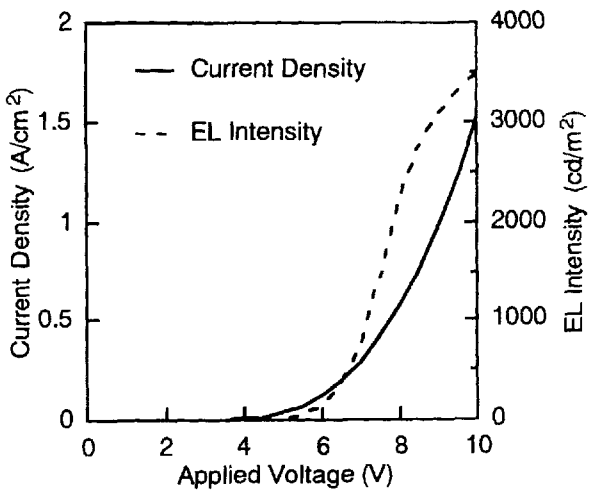

FIGURE 2 Voltage - injection current, and voltage - emission intensity characteristics of a heterostructure device.

small under the negative bias condition. The devices had a turn-on voltage below 6 V. The emission intensity drastically increases above 6 V as increasing an applied voltage, and it turns to increase gradually at an applied voltage above 8 V, and finally it saturates. The emission intensity reaches 3,000 cd/m^2 at 8 V, and it reaches 3,400 cd/m^2 at 10 V. The maximum efficiency is obtained at 0.6 A/cm^2 and it reaches as high as 0.4 cd/A.

From the results of single layer device with 50-nm-thick *p*-sexiphenyl, the emission intensity reaches as 30 cd/m^2 at an applied voltage of 20 V. Comparing the emission intensity of these heterostructure and single layer devices, the former device emits 2 orders of magnitude higher intensity than the latter device. That means the heterostructure is effective to enhance the emission from the *p*-sexiphenyl emissive layer.

Figure 3 shows the emission spectra of the diode with 50-nm-thick *p*-sexiphenyl and 60-nm-thick TPD, which are driven at an applied voltage of 15 V. Three emission peaks are observed from the heterostructure device at 400 nm, 420 nm and 450 nm, respectively. The emission peak of 420 nm is the highest peak among them, and we could observe clear blue emission from the device.

DISCUSSION FOR ENHANCEMENT OF EMISSION INTENSITY

The results of the enhanced emission from the heterostructure are explained using the energy band diagram as shown in Fig. 4. Photoelectron spectroscopy and optical absorption measurements were used to examine the energy levels of these materials.

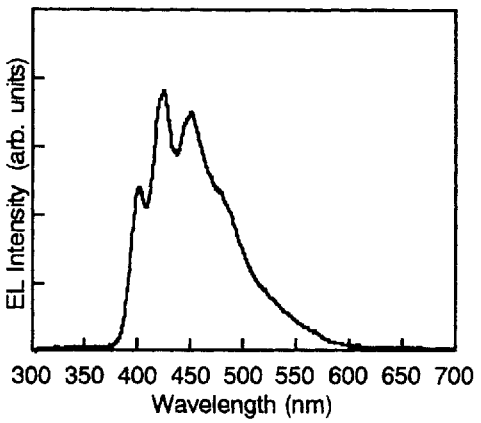

FIGURE 3 Emission spectra of a heterostructure device.

Electrons injected from the Mg:Ag cathode move to the lowest unoccupied molecular orbital (LUMO) states of the *p*-sexiphenyl emissive layer. The injected holes from the ITO anode are transferred to the HOMO states of the TPD hole-transporting layer. Energy barriers exist at the interface of *p*-sexiphenyl and TPD, i.e., 0.6 eV for electrons and 0.3 eV for holes.

Excitons are formed at the interface of TPD and *p*-sexiphenyl, and the energy relaxation of excitons in *p*-sexiphenyl layer results in the blue emission. The results show that the confinement of excitons at the interface of *p*-sexiphenyl and TPD enhances emission from *p*-sexiphenyl emissive layer at 2 orders of magnitude stronger emission than the single layer device of *p*-sexiphenyl emissive layer.

The optimum layer thickness of *p*-sexiphenyl and TPD layers and the layer structure have to be investigated to improve the emission intensity.

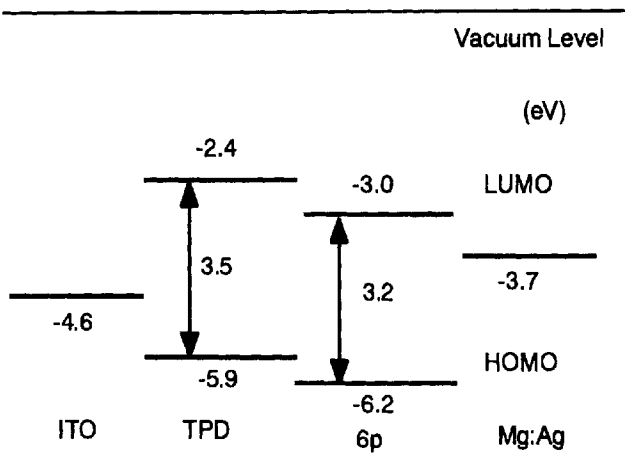

FIGURE 4 Schematic of energy band diagram of a heterostructure device.

Further studies are under way to optimize the layer thickness of the layers and the materials for hole transporting layer to obtain highest emission efficiency from the *p*-sexiphenyl emissive layer.

SUMMARIES

In summary, heterostructure device with *p*-sexiphenyl and TPD is efficient to obtain enhanced blue emission from *p*-sexiphenyl. The emission intensity reaches 3,400 cd/m^2 and is 2 orders magnitude higher than that of *p*-sexiphenyl single layer device. Carrier confinement at the interface of the heterostructure is effective to enhance the emission from the emissive layer. The energy band diagram of *p*-sexiphenyl and TPD shows the

carrier confinement of excitons at the interface of *p*-sexiphenyl and TPD.

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