Organic electroluminescent diodes as a light source for polymeric integrated devices

Y. Ohmori [a*], H. Kajii [a], T. Tsukagawa [a], K. Yoshino [b], M. Ozaki [b], A. Fujii [b], M. Hikita [c], S. Tomaru [c], S. Imamura [c], H. Takenaka [d], J. Kobayashi [d], and F. Yamamoto [d]

[a] *Collaborative Research Center for Advanced Science and Technology, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan*
[b] *Department of Electrical Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan*
[c] NTT Advanced Technology Corp., Tokai, Ibaraki, 319-1193, Japan
[d] NTT Advanced Technology Corp., Musashino, Tokyo 180-8585, Japan

ABSTRACT

Organic electroluminescent diodes (OLED) were fabricated on a polymeric optical waveguide for use as an optical interconnector in data communication systems. The OLED were fabricated on an ITO sputtered polymer waveguide with a 45° mirror by vacuum deposition. The OLEDs, with an emission peak center at 520 nm consist of diamine derivative as a hole transporting layer and tris(8-hydroxyquinoline) aluminum (Alq_3) as an emissive layer. We estimated the propagation losses of the waveguide to be 1.35 dB/cm at 520 nm. However, it decreases as increasing the wavelength of the light source and is estimated as 0.37 dB/cm at the wavelength of 614 nm. The optical pulse of more than 5Mb/s has been obtained from the OLED with Alq_3 and diamine derivative. We discuss the properties of the OLED for the light source for polymeric integrated devices.

Keywords: organic light emitting diode, organic electroluminescent diode, polymeric waveguide, optical integration, optical integrated circuits

1. INTRODUCTION

Organic electroluminescent diodes (OLED) utilizing fluorescent dye[1] or conducting polymer[2] have attracted great interest because they are capable of an emission over a wide visible spectral range[3], are highly efficient and require only a low driving voltage. It is essential to develop material systems with high reliability, high emission efficiency and good chromaticity for practical OLEDs. Recently, OLEDs have been realized to have a long lifetime and excellent durability for flat panel display applications. An additional advantage is that they are for simple to fabricate on various kinds of substrate, including polymer and glass substrates. That is, their mechanical flexibility is one of key advantage of OLEDs. In addition, the nanosecond transient electroluminescence of OLED has also been reported[4]. In particular, it is important to focus on the transient properties of OLEDs.

On the other hand, polymer waveguide devices have attracted attentions with regard to their use as flexible optical circuits and switches. The combination of polymer waveguide and organic optical devices[5] will provide huge advantages as regards fabricating optical integrated circuit such as that shown schematically in Fig. 1. This organic optical device can be expected to be used as an optical inter-connector at more than 100Mb/s in data communication systems. Since polymer waveguides have a low transmission loss in the near-infrared and red light region, use of a red-emitting device [7-8], as a light source will provide an efficient tool for optical integration.

In this paper, we demonstrate the properties of EL device that consists of a tris(8-hydroxyquinoline) aluminum (Alq_3) as an emissive layer onto a polymeric waveguide for the fabrication of polymer integrated devices as the initial step. We also discuss transmission characteristics in polymeric waveguide at two different wavelengths from organic light emitting device.

* Correspondence: Y. Ohmori. Tel: +81-6-6879-4212, Fax: +81-6-6879-4212, E-mail:ohmori@crcast.osaka-u.ac.jp

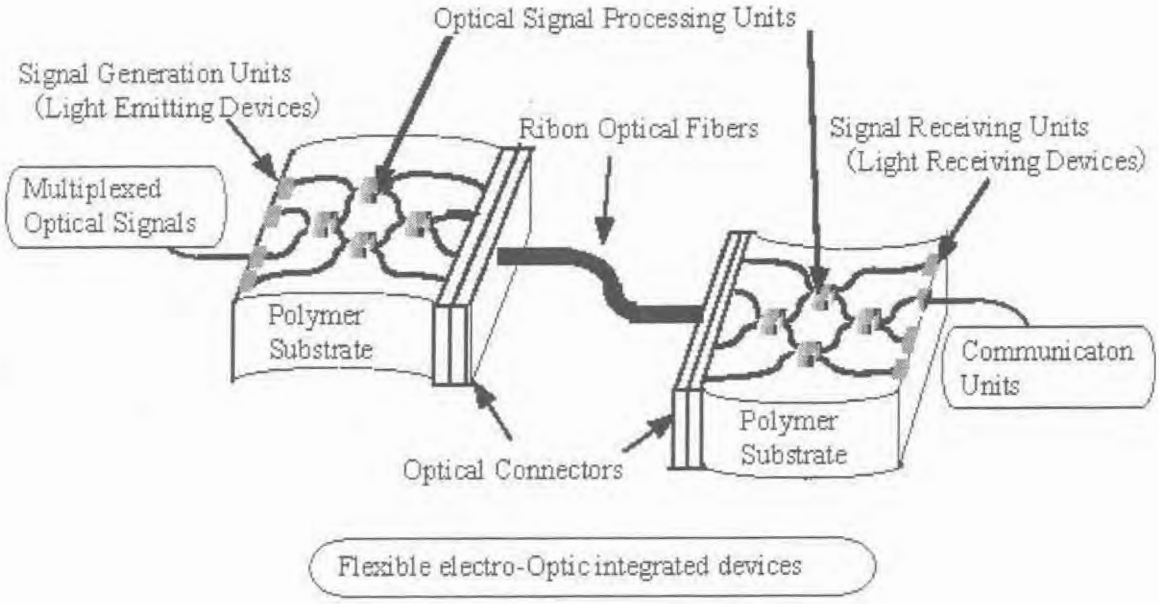


Fig. 1. Schematic of proposed integrated device with polymeric waveguide.

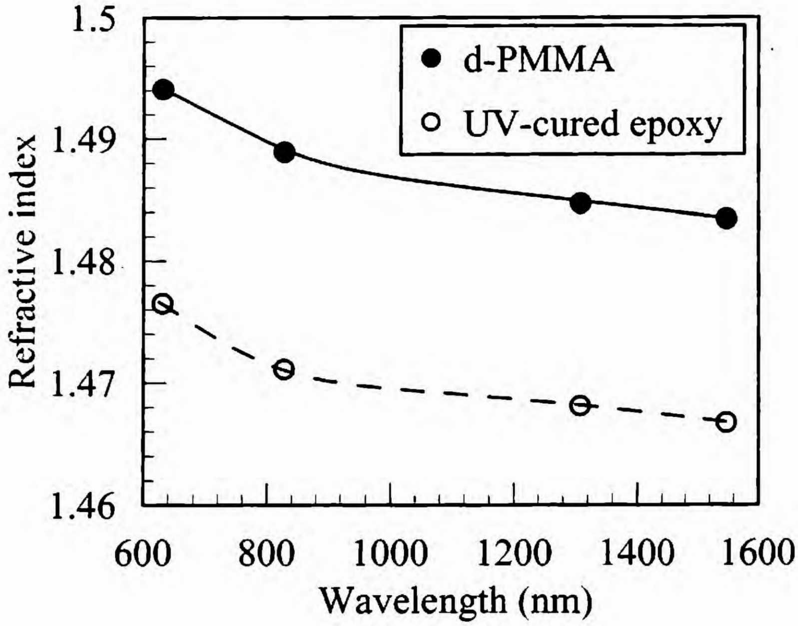
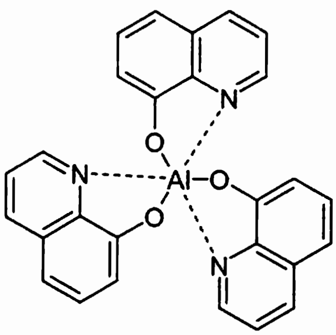


Fig. 2. The refractive indices of the core (d-PMMA) and cladding (U- cured epoxy resin).

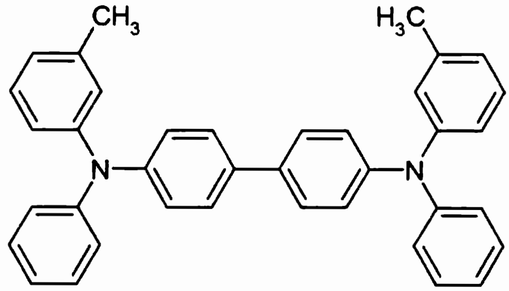
2. EXPERIMENT

We used deuterated-polymethylmethacrylate (d-PMMA) and UV-cured epoxy resin for the core and the cladding of the polymeric waveguide [6], respectively. We fabricated the waveguide on a copper deposited Si wafer by spin-coating, reactive ion etching and conventional photolithography. The waveguide has a square shaped core (40 μm x 40 μm). Next, we cut the waveguide using a 90° V-shaped diamond blade to form a 45°-mirror formation. We removed the waveguide film from the substrate by wet etching. The refractive indices of the core and cladding polymers were measured at 633 nm, 830 nm, 1.31 μm and 1.55 μm as shown in Fig. 2. The relative refractive index differences between the core and cladding polymers are approximately the same as 1.2 % in the wide wavelength range. An indium-tin-oxide (ITO) was sputtered on the polymeric waveguide to form the anode.

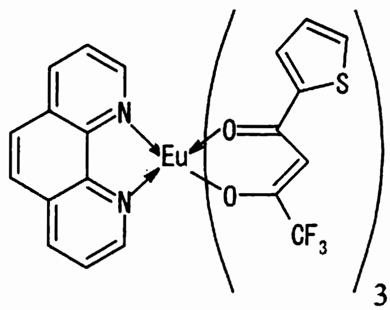
Molecular structures of the materials used for OLEDs are shown in Fig. 3. Two kinds of OLEDs were fabricated as the light sources for the polymer waveguide devices. The first OLED was directly fabricated on a polymeric waveguide, which consists of diamine derivative as a hole transporting layer and an emissive layer of Alq_3, whose emission peak center is around 520 nm. Figure 4 schematically shows the fabricated device configuration without optical connector. The second OLED consisted of (1,10-phenanthroline)-tris-(4,4,4-trifluoro-1-(2-thieny)l-butane-1,3-dionate)Europium(III)[8] ($Eu(TTA)_3$ phen) as a red light emissive layer. The layer structure was fabricated by organic molecular beam deposition on ITO-coated substrates to form the EL devices at a background pressure of about 10^{-5} Pa. The organic materials were located into separate Knuden cells, heated to their sublimation temperature, and subsequently deposited onto the substrate. The layer thickness of the deposited material was monitored *in situ* using an oscillating quartz thickness monitor. Finally, Mg:Ag cathode was vapor-deposited at a background pressure of 10^{-5} Pa onto the organic films. Forward bias condition is defined as the case in which the ITO electrode is positively biased against the Mg:Ag electrode, and negative bias, vice versa. All of the measurements were carried out at room temperature. The optical pulse was observed by using an avalanche photo detector (APD) and the whole measurement system was terminated at 50 ohms.



(a) Alq_3



(b) TPD



(c) $Eu(TTA)_3Phen$

Fig. 3. Molecular structure of low molecular dye materials used for fabricating organic light emitting diode.

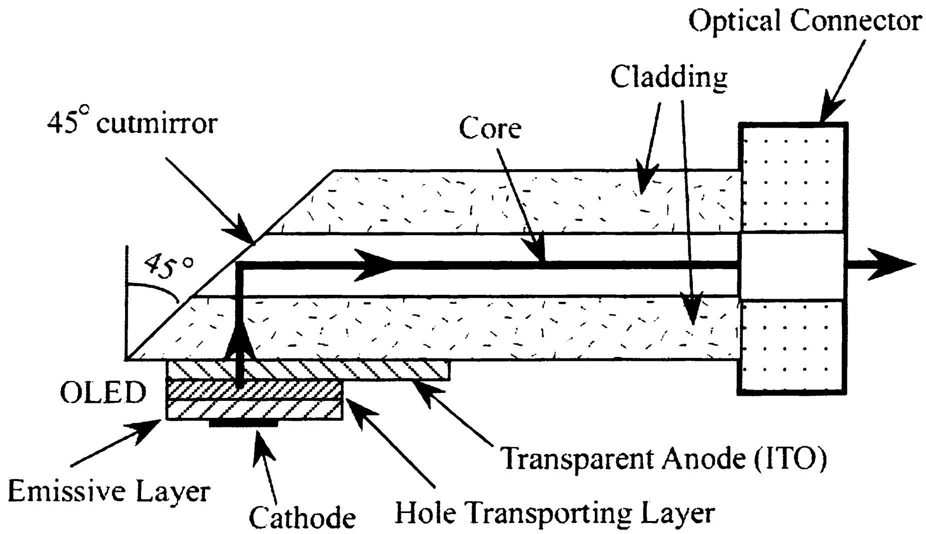


Fig. 4. Schematic of integrated organic light emitting diode with polymeric waveguide device.

3. RESULTS AND DISCUSSION

3.1 Optical properties of polymeric waveguide

We measured the waveguide dependent insertion loss of both a waveguide with a 45° mirror and a straight waveguide by using an optical spectrum analyzer. We used a 50-μm-GI multimode fiber and a plastic cladding fiber (PCF) with a 200 μm diameter core as input and output fibers, respectively. Figure 5 indicates measured results for the waveguides, which are 3-cm length. The insertion loss increased slightly below the 700 nm wavelength region, and rapidly increased below 600 nm. The insertion loss of the 45° mirror was approximately constant at 0.7 dB above a wavelength of 600 nm. However, it increased slightly below 600 nm.

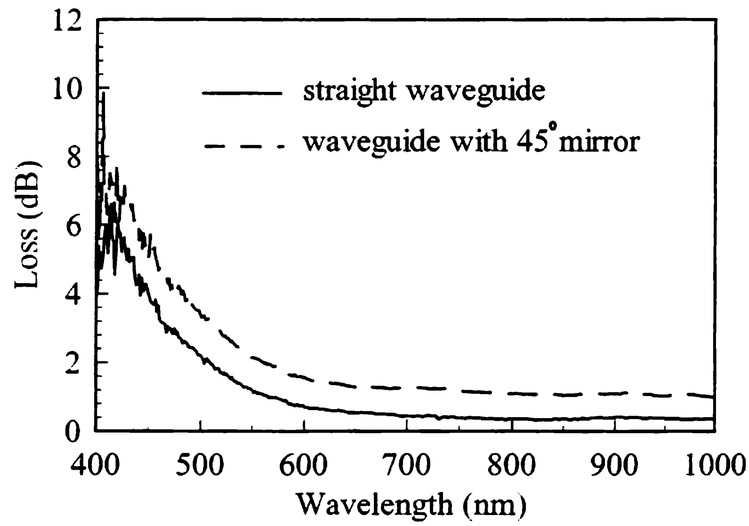


Fig.5. Insertion loss of the waveguide with 45° mirror and the straight waveguide.

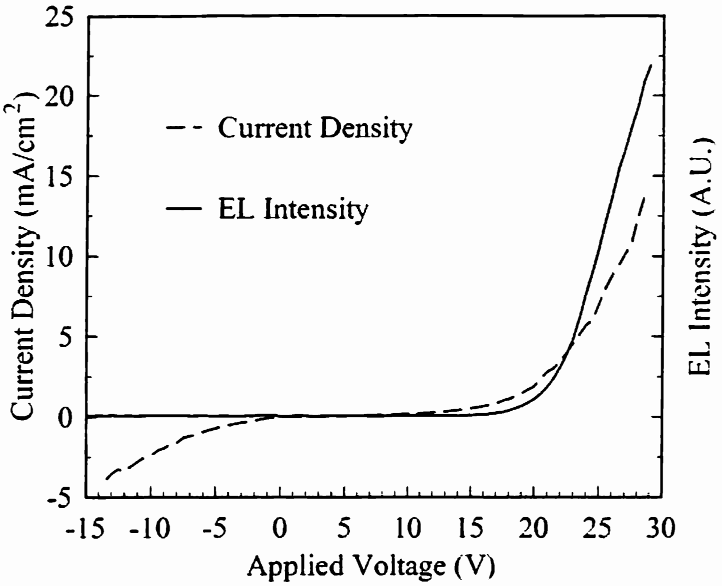


Fig. 6. Current – voltage (I-V), emission intensity- voltage (I-L) characteristics of organic light emitting diode of TPD / Alq_3 directly fabricated on a polymeric waveguide.

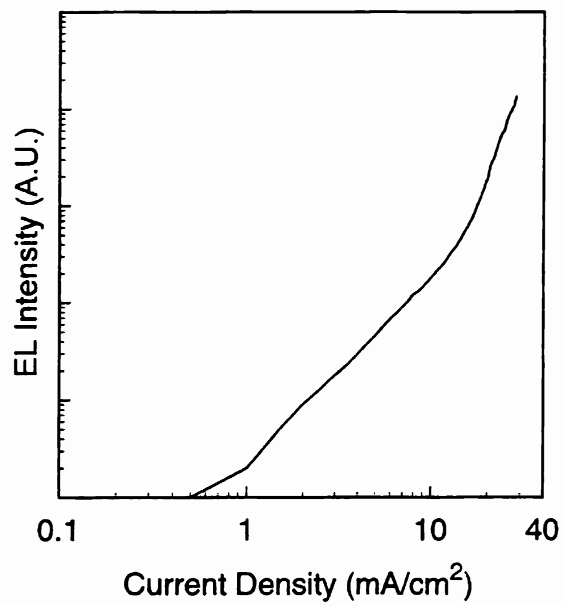


Fig. 7. Emission intensity - injection current characteristics of organic light emitting diode of TPD / Alq_3 directly fabricated on a polymeric waveguide.

3.2 Optical properties of organic EL diodes directly fabricated on a polymer waveguide

There are two types of integration of OLED with waveguide devices using the output light perpendicular or along the substrate. In this experiment, we integrated the OLEDs with polymeric waveguide using the output light perpendicular to the substrate, since it is easy to integrate just fabricating the OLED on the substrate, as shown in Fig. 4. One of the edges of the polymer waveguide was cut in 45 degrees, which was served as a mirror, in order to introduce the output light from OLED to the waveguide. ITO was sputtered onto the polymeric waveguide, which served as an anode. Then 40-nm-thick TPD and 50-nm-thick Alq_3 films were vacuum deposited onto the anode, whose device structure is schematically shown in Fig. 4. We fabricated the EL device using Alq_3 and TPD, since it is easy to fabricate and characterize the device characteristics for the light source for the polymeric waveguide.

The current - voltage (I-V) and EL intensity - voltage (L-V) characteristics of OLED with Alq_3/TPD directly fabricated on the polymeric waveguide are presented in Fig. 6. The turn-on voltage is rather high compared with the ordinary device fabricated onto the ITO glass substrate, whose turn-on voltage is about 5-8 volts, because the resistivity of the ITO fabricated on the polymer waveguide is more higher than that on the glass substrate. However, the current - EL intensity (I-L) characteristics of the device is linear to the injection current as shown in Fig.7. The emission spectra of the device fabricated on the polymer waveguide are similar to that on ITO coated glass substrate, which have the emission peak centered at 520 nm.

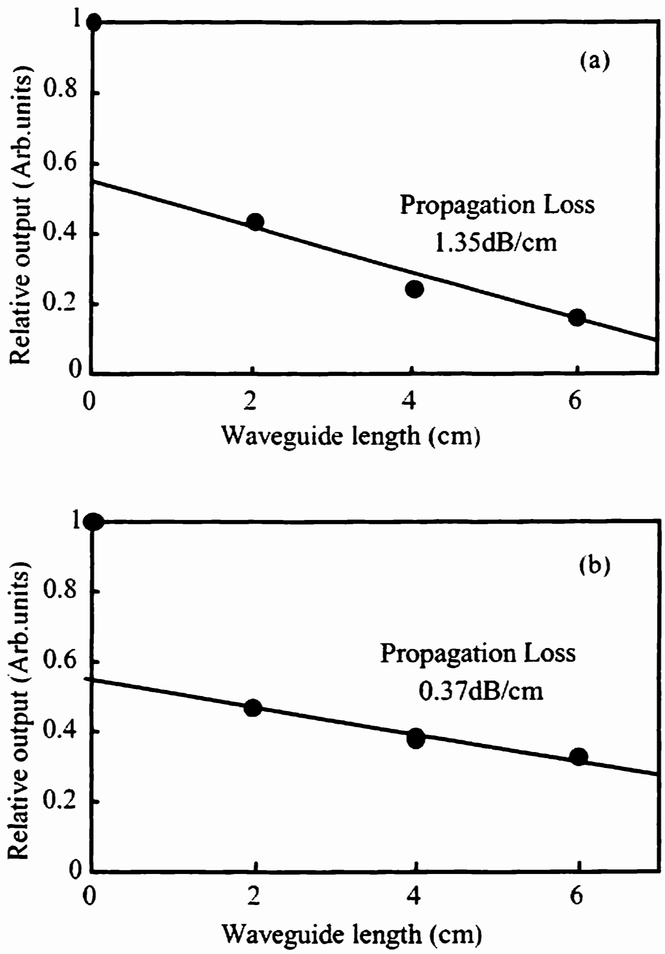


Fig. 8. Relative transmitted light intensity from OELD at (a) 520 nm and (b) 614nm.

3.3 Transmission characteristics of polymeric waveguide with organic EL diode

Since the transmission loss of the waveguide decreases with increasing the emission wavelength, the output light intensity after the transmission of polymer waveguide decreases with decreasing the wavelength. We measured the propagation loss using the two different wavelength of organic EL device. The transmission loss is estimated for the polymer waveguide using the light from an OLED, with an emission peak center at 520 nm consists of diamine derivative as a hole transporting layer and Alq_3 as an emissive layer and is estimated as 1.35 dB/cm at 520nm. On the other hand, it is estimated as 0.37

dB/cm at the wavelength of 614 nm from the measurement utilizing Eu complex as a red light emissive layer. As shown in Fig. 8, the results show that the OLED with long wavelength is suitable for the light source for the polymer waveguide.

3.4 Optical pulse fabrication by directly modulated organic EL diode

We generated an optical pulse by injecting a pulsed current into an organic electroluminescent device with Alq_3 and TPD. The 0.5 mm square device consisted of 50 nm-thick TPD and 30 nm-thick Alq_3 vacuum-deposited on an ITO substrate. Figure 9 shows the applied voltage and optical output characteristics of the OELD driven at 5 Mb/s. We created a clear light pulse by direct modulation of the organic EL.

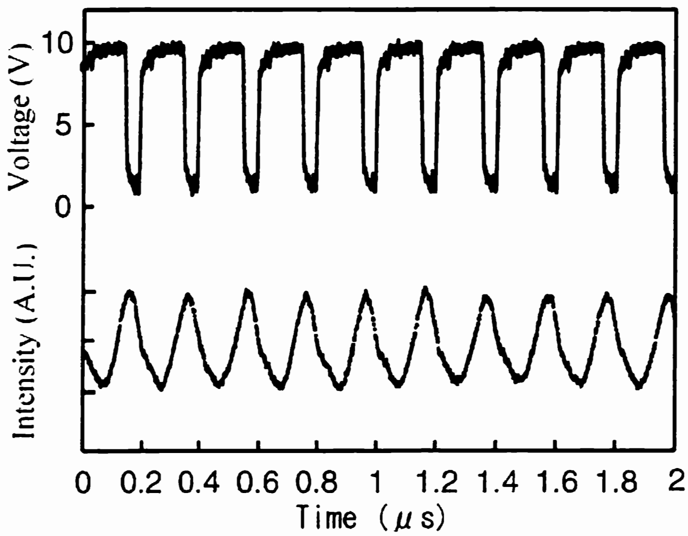


Fig. 9. The applied voltage and the optical output pulse characteristic of OLED.

4. SUMMARIES

Organic EL device is directly fabricated onto a polymer waveguide. The emission and transmission characteristics of organic EL diodes, which consist of Alq_3 and TPD, integrated with the polymer waveguide device were discussed. The transmission loss is estimated for the polymer waveguide using the light from an OLED, with an emission peak center at 520 nm consists of diamine derivative as a hole transporting layer and Alq_3 as an emissive layer and is estimated as 1.35 dB/cm at 520nm. On the other hand, it decreases as increasing the wavelength of the light source and is estimated as 0.37 dB/cm at the wavelength of 614 nm. Optical pulses of more than 5Mb/s were created by directly modulating an OELD

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