Analysis of fabrication tolerance based on uneven thickness of Su8-photo-resist

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In this paper, we have analyzed the relationship between light propagation performance and uneven thickness of Su8-photo-resist based on EOPCB. Although spinning process is used to even the Su8-photo-resist, the obtained Su8-photo-resist is uneven, which directly affect cross-section shape of core layer. As long as we control $h \in [0, 3\mu m]$ and $a, b \in [0, 2\mu m]$, light propagation performance does not affected. But, it is easy to actually fabricate EOPCB.

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1. Introduction

With data transfer faster and faster between chips, electrical inter-connection becomes a bottleneck. So, polymer optical waveguide is used to electro-optical printed circuit board (EOPCB) to connect chips [1-2]. However, during the spinning process, thickness of su8-photo-resist can not be precisely controlled. After lithography, development and blade process, the cross-section of core layer become trapezoidal shape. So, this paper analyzes the impacts between fabrication errors of su8-photo-resist and optical output power. And, fabrication tolerance can also be obtained. By some experiments, as long as $h \in [0, 3\mu m]$ and $a, b \in [0, 2\mu m]$ are set, there is little effect for light propagation in the polymer waveguide, while this fabrication is easy to achieve.

2. Spinning process of polymer optical waveguide

Spinning process is an important step [3-4] to fabricate the polymer optical waveguide. Under ideal circumstances, spinning process is as follows: When temperature is 20~30 ^{o}C, high-spinning-speed attains 800~1100 (r/min) for 45~50 seconds. Then, low-spinning-speed is 600~750 (r/min) for 15 seconds. As shown in the Fig. 1, it makes su8-photo-resist coat on the glass-substrate, uniformly.

However, thickness of su8-photo-resist is relatively thin at the center of glass-substrate, as shown in the Fig. 2. After development, cross-section of su8-photo-resist becomes trapezoidal shape. Consequently, cross-section of core layer will be formed, as shown in the Fig. 4. It will affect light propagation performance. On the contrary, an ideal cross-section of core layer is shown in the Fig. 3. By some experiments, we obtain an approximate relationship between ***h*** and (***a***, ***b*)**, as shown in the Fig. 5.

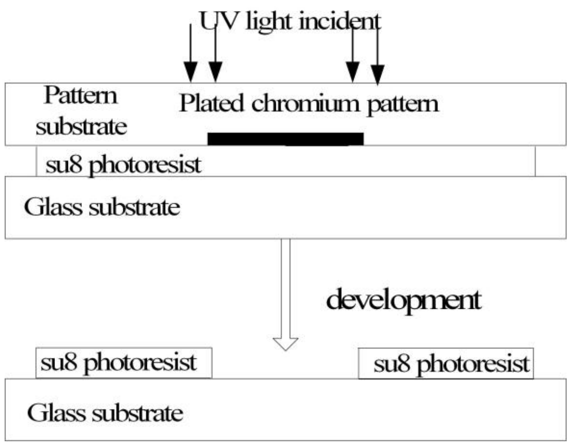

Fig. 1. Ideal su8 photoresist and development.

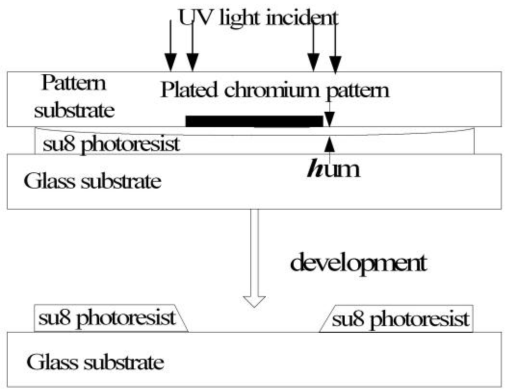

Fig. 2. Actual Su8 photoresist and development.

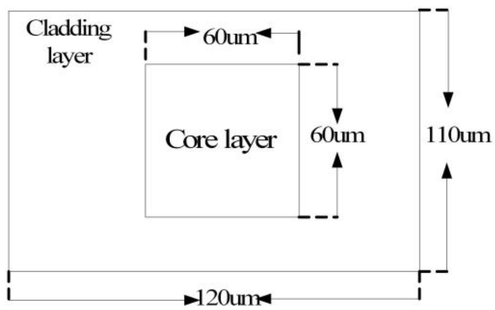

Fig. 3. Ideal cross-section of waveguide.

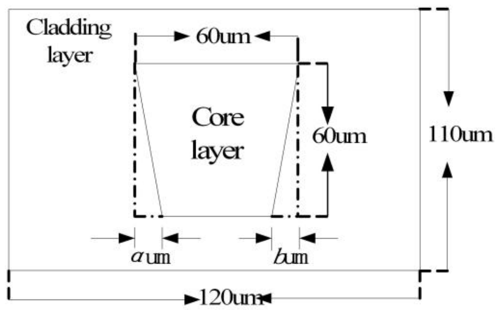

Fig. 4. Actual cross-section of waveguide.

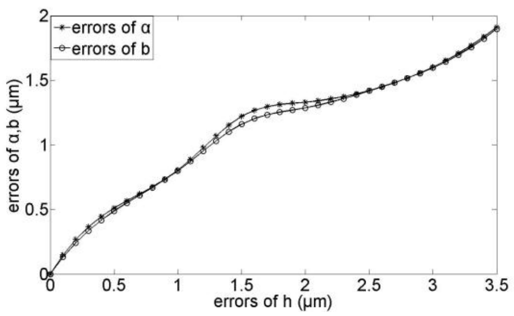

Fig. 5. Statistical relationship between the h and α,b.

3. Simulations and experimental results

Because the polymer waveguide is integrated into a printed circuit board, its thickness is 110 μ m. Thickness of core layer is 60 μm, width of core layer is 60 μ m, while width of cladding layer is 120 μm. Relative refractive index of core layer is 1.43, relative refractive index of cladding layer is 1.41, and wavelength is 850 nm.

Fig. 3 shows an ideal cross-section of waveguide, where (***h***,***a***,***b***=0,0,0) have no variation. Fig. 4 illustrates actual cross-section of waveguide, where (***a***,***b***) change with ***h***.

There are some modes in the multimode waveguide. Because several main modes dominate most of optical power in the multimode waveguide, we only analyze the changes of six main modes, when cross-section of core layer is not ideal. For simplicity, six effective refractive indices, which correspond to six modes respectively, are shown in the Table 1. $N_{effi}\ i = 1, 2, ...6$ indicate six effective refractive indices computed by finite element methods [5,6]. N_{eff1} is effective refractive index of fundamental mode.

Table 1. Effective refractive indices of $(a, b = 0, 0\mu m)$.

$(a, b = 0, 0\mu m)$	**Effective Refractive Indices**
N_{eff1}	1.429828
N_{eff2}	1.429829
N_{eff3}	1.429863
N_{eff4}	1.429914
N_{eff5}	1.429914
N_{eff6}	1.429966

We can define the relative errors of effective refractive indices (**REERI**s, $\Delta_{i,a,b}$) as follows:

$$\Delta_{i,a,b} = \frac{\left|N_{effi,a,b} - N_{effi,0,0}\right|}{N_{effi,0,0}} \times 100\% \quad i = 1, 2, 3, 4, 5, 6$$

Subscript *effi* shows the effective refractive indices and $i \in [1, 2, 3, 4, 5, 6]$. Subscript (***a***,***b***) indicates the change of trapezoidal sides in the cross-section of core layer. (***a***,***b***=**0,0**) is an ideally square shape.

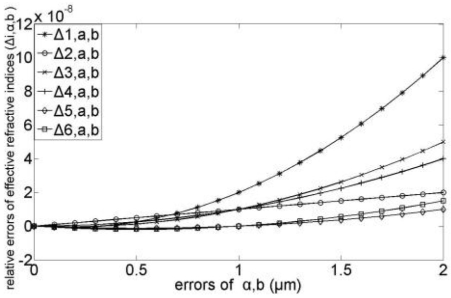

Fig. 6. Relationship between the REERIs and α,b.

Fig. 6 shows six **REERIs** increase correspondingly, when ***(α,b)*** increases. Although N_{eff1} is seriously affected, $\Delta_{1,2,2}$ is still below 10^{-8}. So, $a,b \in [0,2\mu m]$ is a error tolerance. As long as fabrication error is not more than 2μm, **REERIs** can be minimized, then, the effect of optical transmission will not be affected.

We can also define the power loss (dB) of optical waveguide as follows,

$$\theta_{a,b} = -10\log\frac{P_{out,a,b}}{P_{in,a,b}}$$

Here, $P_{in,a,b}$ is input optical power, $P_{out,a,b}$ is output optical power, θ indicates power loss. Subscript (***α***,***b***) indicates the change of trapezoidal sides in the cross-section of core layer. Furthermore, the relative power errors (**RPE**s, $\eta_{i,a,b}$) can be defined as follows,

$$\eta_{i,a,b} = \frac{\left|\theta_{a,b} - \theta_{0,0}\right|}{\theta_{0,0}} \times 100\% \qquad i = 1,2,3,4,5$$

We have five experiments as shown in the Fig. 7. The subscribe *i* indicates the corresponding experiment. **RPE**s can show the relationship between (***α***,***b***) and power loss as shown in the Fig. 8.

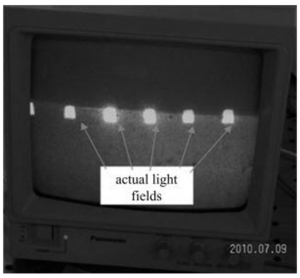

Fig. 7. The actual light fields of optical waveguides.

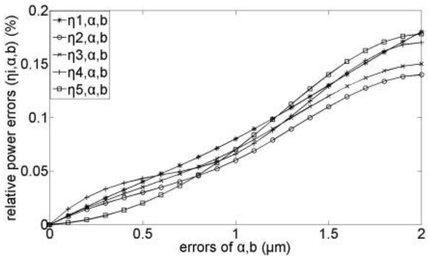

Fig. 8. The relationship between RPEs and α,b.

Fig. 8 shows five **RPEs** are growing, when ***(α,b)*** increases. Although $\eta_{1,2,2}$ gets maximum, it is still below 0.2%. So, as long as ***(α,b)*** change in the range of 2 μm, **RPEs** can be ignored. The light propagation performance can not be affected. That is, $h \in [0,3\mu m]$ and $a,b \in [0,2\mu m]$ are the fabrication tolerance.

4. Conclusions

During the fabrication of polymer optical waveguide in the EOPCB, spinning process is an important step. However, it is actually difficult to make the cross-section of core layer be square shape. As long as $h \in [0,3\mu m]$ and $a,b \in [0,2\mu m]$ are set, light propagation performance can not be affected and this fabrication is easy to achieve.

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