Flexible Optical Waveguide Film with 45degree micro-mirror couplers for hybrid E/O integration or parallel optical interconnection

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Abstracts

Short-range optical interconnection is more emphasizing in high performance systems. Multimode waveguide array is considered as a major interconnection medium due to the relatively easy packaging with devices. The multimode fiber array conjunction with VCSEL and Pin photodiode array is widely used in board to board and/or system to system interconnection. We demonstrate a flexible optical waveguide film which was composed of VCSEL, photodiode array, multimode waveguide array and 45 degree micro mirror couplers. The flexible waveguide film has many potentials such as it can be integrated with typical rigid electronic board and free from geometrical constraint. The waveguide film with 45° mirror was fabricated on a flexible transparent substrate using soft molding technique and then thin film VCSEL and photo-detector array are integrated. Master structure of the waveguide, which has multimode waveguide array and 45° mirror structure was fabricated using conventional lithography and microtome technique.

Introduction

The speed and complexity of integrated circuits are increasing rapidly as integrated circuit technology advances from very large scale integrated (VLSI) circuits to ultra large scale integrated (ULSI) circuits. As the number of devices per chip, the number of chips per board, the modulation speed, and the degree of integration continue to increase, electrical interconnects are facing their fundamental bottle-necks, such as speed, packaging, fan-out, and power dissipation. In the quest for high density packaging of electronic circuits, the construction of multi chip modules (MCM), which decrease the surface area by removing package walls between chips, improved signal integrity by shortening interconnection distances and removing impedance problems and capacitances [1,2].

The employment of copper and materials with lower dielectric constant materials can release the bottleneck in a chip level for next several years. The ITRS expects on chip local clock speed will constantly increase to 10GHz by year 2011. On the other hand, chip to board clock speed is expecting slow increasing rate after year 2002 [3]. Electrical interconnects operating at high frequency region have many problems to be solved such as crosstalk, impedance matching, power dissipation, skew, and packing density. Several optical interconnect techniques such as free space, guided wave, board level, and fiber array interconnections were introduced for system level applications to relieve from these problems. These alternative approaches do not solve all problems. We have proposed a fully embedded optical interconnects. In this architecture, all optical components are embedded within electrical printed circuit layers. Flexible planar waveguide circuits and 45°mirror couplers are key components in the E/O hybrid integration regardless fully embedded or embedded waveguide integration. Especially, waveguide 45°mirror coupler is the most important in VCSEL based interconnection.

The hybrid integration of optical layer with electrical layers is the most important part in the realization of optical interconnects. PCB technology is already well matured; therefore, great deviation from current fabrication technique may result in the failure of commercialization. Hence, we have to minimize the change of fabrication process. The optical interconnects in board level can not replace all copper lines. There are slow interconnecting lines such as data, control, power, and ground lines. Especially, slow data lines do not need to be replaced by optical means because the fabrication cost and process of copper lines are very cheap and reliable.

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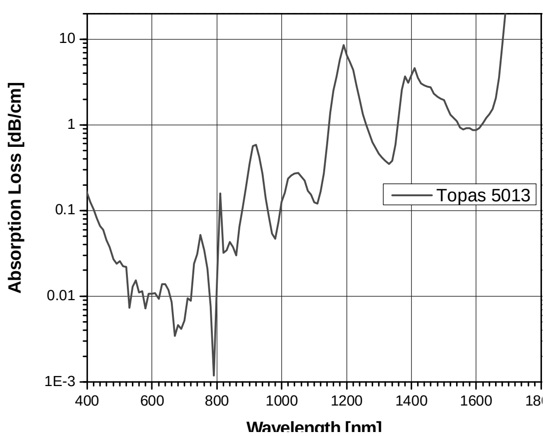
A flexible optical waveguide film is necessary in realization of board level optical interconnection and parallel link in volume production level. In this reports, flexible optical layer fabrication technique and its characteristics are discussed.

2. Flexible optical waveguide film

Typically, solid substrates such as glass, silicon wafer or PCB layer is used to fabricate flexible form optical waveguide. Planar waveguide were formed on the solid substrate using various techniques, and then peeled off from the substrate. It is not a practical approach in production. We used polymeric optically transparent film as a substrate. Required properties of a flexible optical film are compatibility with industrial standard PCB process, low cost material and process, low optical loss and reliability. The compatibility with PCB process means that the waveguide film should be treated like a traditional electrical layer and survive under harsh PCB lamination environments. Molding process or imprinting is the most suitable method for low cost approach and manufacturability. The materials of the waveguide film should have well matched thermal expansion coefficients to prevent delamination. The integration of the VCSEL and the photo-detector onto the waveguide film should be easy and robust.

127m thick Cycloolefin copolymer [Topas™, from Ticona] film was used as a substrate and bottom cladding, and Su-8 photoresist as a core material. Figure 1 shows absorption loss as a function of wavelength.



The absorption loss of the Topas is 0.01 dB/cm and 0.03dB/cm at 630nm and 850nm, respectively. The minimum absorption loss at 790nm does not represent an exact value because there is a change of grating during wavelength scan.

Soft molding technique was used to form waveguide and 45° mirror coupler. Therefore, master waveguide patterns were fabricated by typical lithography. Thick photoresist [Su-8, 50µm thick] was spin coated on silicon wafer and then developed. After development, waveguide ends were cut at 45° using microtome setup. During the cutting, the wafer was heated to cut smoothly. The 45° cut mirror couplers are shown in figure 2.

Figure 1. Absorption loss of Topas™ Film [Ticona]

After master fabrication, mold was fabricated using PDMS (Sylgard 184, Dow Corning). Prepolymer and curing agent were mixed at 1:10 ratio. Air bubbles trapped in PDMS were removed in a vacuum chamber. After removing air bubbles, the PDMS was poured on the master and cured at 90°C in vacuum chamber for 10 hours. Surface relief structures were transferred from master to the mold.

The fully embedded board level optical interconnection requires a thin flexible optical layer. Current electroplating technology can plate easily a through-hole or a via having an aspect ratio of 1 in production line and can plate a hole having an aspect ratio of 3 in laboratory. The size of a typical electrical pad on the device is about 100µm. These are main reasons for the thickness limit of substrate film.

The fabrication step is straightforward. First, core material (SU-8) was poured on the heated PDMS, which is kept at 50°C (Figure 3a). The heated PDMS mold suppresses bubble generation during molding process. And then, excess SU-8 was scraped out using squeegee (Figure 3b). The squeegee was made of PDMS, also. The Topas film was applied on the top of the PDMS mold filled with SU-8. In the next step, the mold and the Topas film were inserted into the press machine and then was applied with the pressure of 6000Pa for 30 minutes while plunge plate was held at 90°C (Figure 3c). The cooling down procedure was followed. In this procedure, the mold pressure decreased gradually due to the thermal contraction. The core material (SU-8) was transferred to the substrate film (Figure 4d). In the next step, the substrate film without the top cladding was exposed to UV to cross-link the SU-8. Once the film was exposed, it becomes chemically and thermally stable. Aluminum was deposited on the mirror facets in a vacuum chamber to make the mirror. Finally, top cladding material was coated on the film. Fabricated optical interconnection layer is shown in figure 4. It has micro-mirror couplers and 12 channel waveguides of 50mm in length.

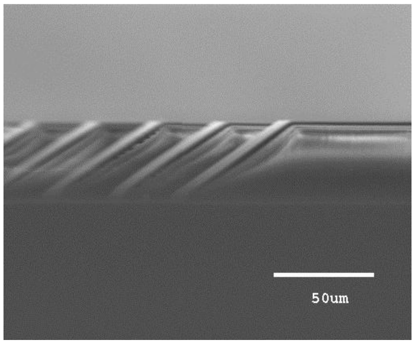


Figure 2. SEM photograph of master (45° mirrors and waveguides)

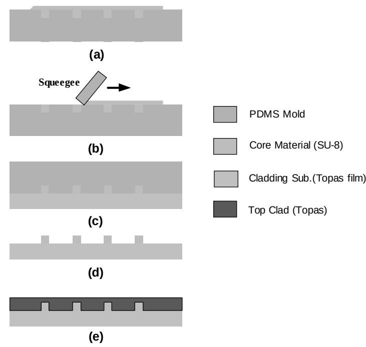


Figure 3. Optical interconnection layer fabrication process flow

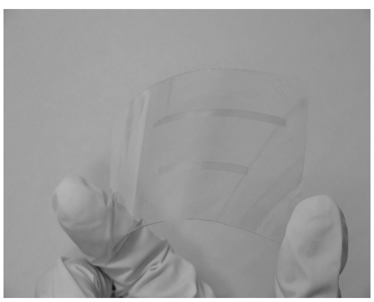


Figure 4. Fabricated flexible optical interconnection layer.

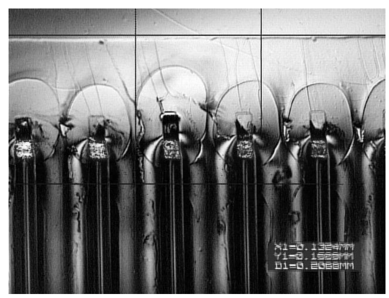


Figure 5. Coupled out beams from 45° waveguide mirrors. (He-Ne laser was lunched from the other side of the wave guide)

Waveguide propagation loss was measured by cut back method. The core dimension was 50X50µm. Measured propagation loss was 0.6dB/cm at 850nm wavelength.

3. Devices integration on flexible waveguide film

High integration cost must be avoided. This requirement can be satisfied by separating fabrication processes. Obviously, the fabrication of waveguide layer and the integration of optoelectronic devices must be cheap. Optical interconnection layer and electrical layers are fabricated independently. At the final integration step, two different types of layers are laminated together using matured lamination process.

Interface between optoelectronic device and control device is important because of the requirement for high density (HD) packing. Laser drilled micro-via technology is utilized to satisfy HD packing. The thermal management of VCSEL is important also because of reliability concerns. Embedded VCSEL can not be replaced to repair in a fully embedded integration; therefore, we have to be aware of good VCSEL before the integration and provide optimal operating condition.

The integration of optoelectronic devices with the flexible waveguide film is the most important process among the whole integration steps including the final laminating process with PCB. The flexible waveguide film has the thickness of 127µm. The VCSEL and photo-detector arrays have pad of the diameter of about 95µm. In general, copper electroplating allows plating of a via with aspect ratio of 1; however, it is possible to plate a via with an aspect of 3 in a laboratory environment. The maximum diameter of the laser drilled via is limited by the pad size of devices, the aspect ratio, and the registration error during lamination process. Figure 6 illustrates device integration process.

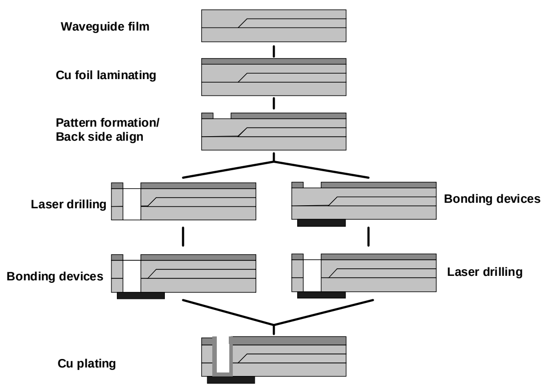


Figure 6. Devices integration process flow chart

First, One mil (25.4µm) thick copper foil is laminated on the top of the flexible wave guide layer by applying heat and pressure. And then, this copper foil is patterned to form the top electrical pads for VCSEL and photo-detector. The main reason for the formation of the laminated copper foil is the limitation of electroplating. The thickness of additional electrical layers easily exceeds 1mm, and the diameter of device pad is 95µm. This translates to an aspect ratio of 100; therefore, this hole can not be electroplated.

The aspect ration of via can be reduced by introducing the copper foil just above the waveguide layer; hence, we can electroplate micro via. Furthermore, the patterns on the copper foils can be bigger. This means that larger registration error can be allowed during laminating process with electrical layers.

Next step is either laser drilling or device bonding on the waveguide layer. The bonding of device to waveguide film can be accomplished by melt bonding without using UV curable adhesive. When alignment is completed, device is heated just above the melting temperature of waveguide film for a short period. And, device is bonded to the waveguide film without deforming the micro-vias. So far, the integration of devices on the flexible waveguide film is accomplished. The final step is electroplating. Integrated waveguide film was submerged in copper electroplating solution to plate the side walls of micro-vias and device pad. Now, the optical interconnection layer is ready to be laminated with the electrical layers. Flexible waveguide film with integrated VCSEL and PIN photodetector arrays is shown in figure 7.

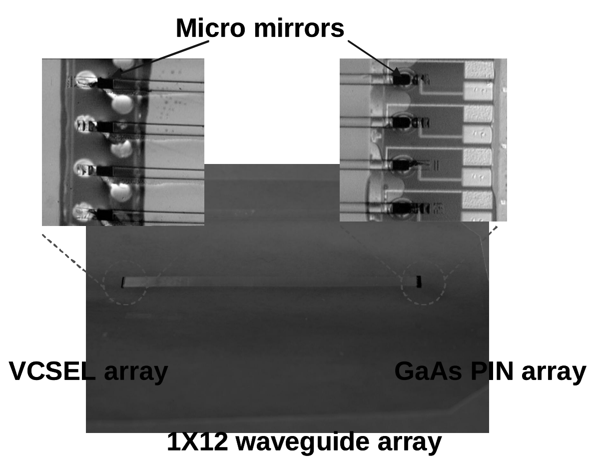


Figure 7. Flexible waveguide film with integrated VCSEL and PD array (Before micro via formation)

4. Conclusion

The optical interconnection layer was fabricated by compressive soft molding process. Molding is a suitable process for mass production. 45˚ waveguide micro-mirror couplers were fabricated by cutting waveguide ends at 45˚ using a microtome blade. Mold was made of PDMS rubber. The micro-mirrors and waveguide were fabricated at the same time. The core material of the waveguide was SU-8. Measured propagation loss of the waveguide was 0.6dB/cm at 850nm. VCSEL and photo-detector array were integrated on the flexible waveguide film.

Reference

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