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Signal Propagation Characteristics in Polymide Optical Waveguide with Micro-Mirrors for Optical Multichip Module

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1. Introduction

The performance of LSI chips has dramatically improved by scaling down the device size. A microprocessor with a clock frequency of 1GHz has been already announced. It is expected hereafter that the internal clock frequency of LSI chips will continue to increase further. However, such improvement will become to be cancelled out by the increase of the inter-chip wiring delay in the system level. Therefore, it is very important to develop a high-performance bus with a high data rate to improve the system performance.

The optical interconnection is a strong candidate for such high-performance bus. The optical interconnection has an advantage in speed over the electrical interconnection even at the wiring length of a few centimeter. Therefore, we have been developing a new optical interconnection for multichip module (MCM) system.

2. Multichip Module With Polyimide Optical Waveguides

Figure 1 shows a cross-sectional view of MCM system with optical waveguide which we have proposed. We choose fluorinated polyimide as a waveguide material due to its easiness in processing and fairly low optical transmission losses. In our MCM, polyimide optical waveguides with micro-mirrors are formed on the MCM substrate called the optical plate[1][2]. The optical coupling between the waveguide and the laser diode (LD) or photodetector is achieved by using the micro-mirrors which are formed under the waveguides. The LD's are integrated onto the LSI chips by using the micro-bonding technology. The LSI chips with the LD and photodetector are mounted onto the optical plate by using the flip-chip bonding technology after carefully aligning the chip to the optical plate.

We are going to use such MCM to develop a parallel processor system with a high performance and a compact machine size specific for the scientific computation[3][4]. Figure 2 shows the system configuration of parallel processor system which we have proposed. Several processors are connected by the polyimide waveguides on an optical plate which act as ring-bus, and the optical plates are connected each other by free-space optical interconnections.

In this paper, we fabricate the test module with the polyimide optical waveguides and evaluate the propagation characteristics of the polyimide waveguides in this test module.

3. Polyimide Optical Waveguide and Test Module Fabrication

To fabricate the polyimide optical waveguides, the polyimide films are spin-coated on the oxidized silicon wafers varying the thickness from 4 to 10 μm. Then, they are patterned using the O_2 reactive ion etching method. These polyimide optical waveguides are formed on the oxidized silicon wafer with silicon-steps on its surface. The maximum number of silicon-steps was 25. The silicon steps are formed by chemical etching. Figure 3 shows the photomicrograph of the MCM substrate after forming the polyimide waveguides. Aluminum micro-mirrors with a thickness of 200nm are formed on the steps. The propagation direction of the signal light is changed from horizontal to vertical or vertical to horizontal by these aluminum micro-mirrors. The experimental results obtained in such polyimide optical waveguide with micro-mirrors are shown in Fig.4 where the horizontal input signal light is bent to the vertical direction. He/Ne laser (λ =633nm) is used as an input light source.

It is obvious from the figure that more than 20 output signals can be obtained from one input signal although the output signal intensity slightly decreases after passing through the micro-mirrors.
Micro-mirrors also act as input couplers. When the signal light is introduced vertically into waveguide at a micro-mirror, the light is reflected by a micro-mirror and thus its propagation direction is changed from vertical to horizontal. After the direction is changed, the light is guided along the waveguide. Figure 5 shows photomicrograph of the output signal light which is guided through the polyimide optical waveguide after the propagation direction is changed from vertical to horizontal at a micro-mirror.

Thus, the optical waveguide with multi-fan-out can be easily achieved by using polyimide and aluminum micro-mirrors.

Copper bumps are formed on the optical plate with these optical waveguides in order to mount LSI chips on it by flip-chip bonding. The copper bumps were fabricated by electroplating and then silver filled epoxy adhesive layer was formed on the top surface of the copper bumps using printing technique. LSI chips were bonded electrically and mechanically onto the optical plate by the silver filled epoxy adhesive layer formed on copper bumps. Figure 6 shows an SEM-micrograph after LSI chip is bonded on the optical plate through copper bumps. It is observed in the figure that the LSI chip is successfully bonded on the optical plate.

Figure 7 shows the dependence of transmission losses y [dB] on the distance between micro-mirrors x [cm]. Since the intensity of the vertical output signal obtained at a position of micro-mirror is proportional to the intensity of the guided wave at the same position of micro-mirror, $y - x$ plot is essentially the same as the plot of the transmission loss versus the distance in the scattering detection method for transmission loss evaluation[5]. In Fig.7, the relation between x and y can be expressed as

$y = 9.60x + 0.16$ approximately. From the y section of the plot, we can obtain the loss by a mirror. The value of 0.16 indicates that the signal is decreased by 0.16 dB when it passes through a micro-mirror. Since this loss may limit the number of fan-outs, careful design of micro-mirrors will be necessary to achieve a sufficient number of outputs.

4. Conclusion

Key technologies for the multichip module with polyimide optical waveguides have been developed. In this multichip module, small micro-mirrors are buried under the polyimide optical waveguide formed on the module substrate. The propagation properties of polyimide optical waveguide with micro-mirrors are evaluated. It is evaluated that the propagation loss at a micro-mirror is 0.16 dB. A new parallel processor system with a high performance and a compact machine size using such multichip module with the polyimide optical waveguide has been proposed.

5. Acknowledgment

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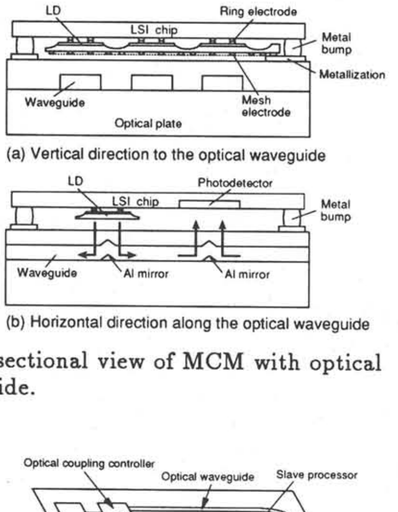

Fig.1 Cross-sectional view of MCM with optical waveguide.

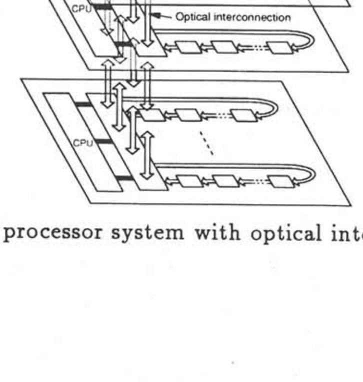

Fig.2 Parallel processor system with optical interconnection.

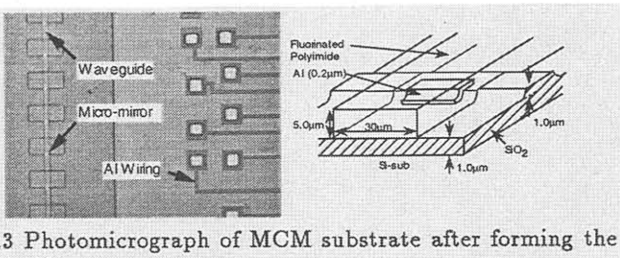

Fig.3 Photomicrograph of MCM substrate after forming the polyimide waveguide.

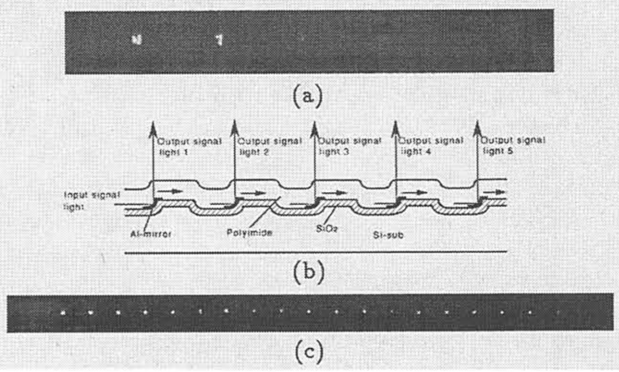

Fig.4 Photomicrograph of output signal lights vertically reflected by micro-mirrors (a) (not optimized) and (c) (optimized) and cross-sectional view of polyimide optical waveguide with micro-mirrors (b).

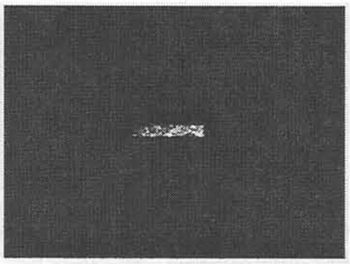

Fig.5 Photomicrograph of output signal light from polyimide optical waveguide with the signal introduced vertically at a micro-mirror.

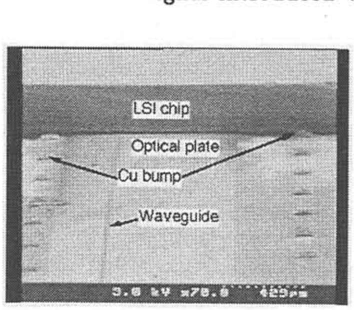

Fig.6 SEM-micrograph of MCM test module with polyimide optical waveguide.

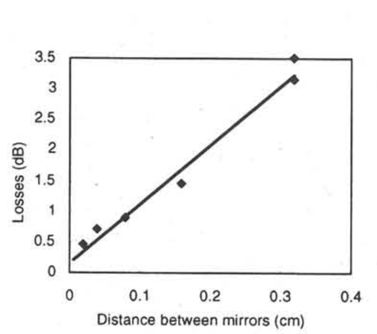

Fig.7 The dependence of transmission losses on the distance between mirrors.