Single Chip Integration of LED, Waveguide and Micromirrors

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Fundamental technologies for optical interconnection on a Si LSI chip have been developed by using conventional silicon process technologies. Micron-size poly-Si and Al mirrors which change the light propagation direction have been fabricated. Moreover, optical waveguides with SiOxNy core and SiO2 cladding layer have been fabricated. It is also shown that the light propagation loss in curved waveguide is good agreement with calculated result.

1. Introduction

The signal propagation delay in the global metal interconnections increases with decreasing feature size in the submicron region [1]. In order to overcome this problem, optoelectronic integrated circuits (OEIC's) on a Si chip have recently attracted great interest due to their high functional performance and high speed. The purpose of this study is to integrate LEDs, optical waveguide and micro-mirrors onto a single chip. We have already developed a micro bonding technology of LEDs onto the chip [2], crystal-Si mirrors and waveguides with Si3N4 core [3].

In this paper, we report on newly developed poly-Si and Al mirrors and waveguides deposited by low-temperature (300°C) remote-plasma CVD. A simple test chip integrated with LEDs, Si mirrors, curved waveguides and detectors (LED itself is used for the detector) is demonstrated. The propagation loss of the curved waveguides has also been simulated and compared with experimental results.

2. Poly-Si and Al Mirrors

A typical example of the detailed structure of OEIC on a Si chip is schematically shown in Fig. 1 [3]. SEM photographs of the fabricated poly-Si and Al mirrors are shown in Fig. 2. Since Al melts at the temperatures used for LPCVD of the Si3N4 core, poly-Si is the preferred mirror-material. The fabrication process of the poly-Si mirror is almost the same as that employed for the crystal Si mirror [3], the undercut formed during the chemical dry etching is intentionally used. The light bending efficiency of the poly-Si mirror is deduced to be 62% from the result of Fig. 3. A comparable efficiency (64%) has been obtained when the light propagation direction is reversed (horizontal to vertical). The Al mirror is fabricated by sputtering deposition of Al (0.2μm thick) on top of tapered waveguide. The tapered shape of the Si3N4 core is formed by reactive ion etching with a tapered photoresist mask which is made by heating (~200°C) rectangular shape photoresist. The reflected light by

![Fig. 1 Detailed structure of OEIC on Si.](image1)

![Fig. 2 Cross-sectional SEM photograph of](image2)

(a) poly-Si mirror and (b) Al mirror.

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this Al mirror was observed by CCD camera. The quantitative data for the Al mirror has not been obtained.

3. Optical Waveguide with SiOxNy Core Deposited by Remote-Plasma CVD

If one uses Ge doped SiO2 as core material for optical fibers and waveguides, high process temperatures are needed. Low-temperature damage-free deposition of an alternative core material is required to form the waveguide onto Si LSI chips. We have employed SiOxNy films grown by remote-plasma CVD as a core material. Since the discharge region is separated from the substrate in remote-plasma CVD, the plasma-induced damage is very small. The SiOxNy films have been deposited by a gas mixture of SiH4, NH3 and N2O, where only the N2O and NH3 gases are excited in the plasma. The refractive index of the film can be precisely controlled by changing the partial pressure of N2O as shown in Fig. 4. The propagation loss of the slab waveguide with SiOxNy core (470nm thick) and SiO2 cladding layer (800nm thick) has been evaluated for different refractive indices of the core. The loss is in the range from 0.93 to 1.54 dB/cm which is acceptable for chip-scale optical interconnections.

4. Propagation Characteristics of Curved Waveguides

The simulation of the propagation loss for the curved waveguide is necessary to optimize the shape of the waveguide. We have developed a simulator for calculating the propagation loss of the optical waveguide by means of the beam propagation method [4]. The propagating light intensity profiles in a curved waveguide is shown in Fig. 6. The optical loss after 90

The curvature radius is 100μm, core and cladding layer indices are 1.6 and 1.45, respectively. The thickness of the core is 0.4 μm and the cladding layer thickness is assumed to be infinite. The width of the core is 10μm.
degree bending is plotted as a function of the curvature radius in Fig. 7. Experimental results are consistent with the simulated data within the measurement accuracy.

![Bending loss plot](image)

Fig. 7 Bending loss at the corner vs curvature radius.

5. Single Chip Integration

![Single Chip Integration](image)

6. Conclusion

Process technologies for fabricating micron-size poly-Si and Al mirrors and optical waveguide at low temperatures have been developed and evaluated. The feasibility of integration of these optical components has been demonstrated.

7. References


Figure 8 represents the integration of LED, Si-mirrors and curved waveguides on a Si chip. LEDs with In/Au microbumps were bonded on the chip using a newly developed wafer aligner [2]. The light from the bonded LED has been observed by CCD camera. The light output versus current characteristics has not been changed after bonding.

![OEIC integration](image)

(b) Cross sectional view of fabricated OEIC on Si chip.

Fig. 8 (a) Optical micrograph of an integrated test chip.