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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 SiO_xN_y core and SiO_2 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 Si_3N_4 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 Si_3N_4 core, poly-Si is the prefered 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 chemial 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 spettering deposition of Al (0.2μm thick) on top of tapered waveguide. The tapered shape of the Si_3N_4 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

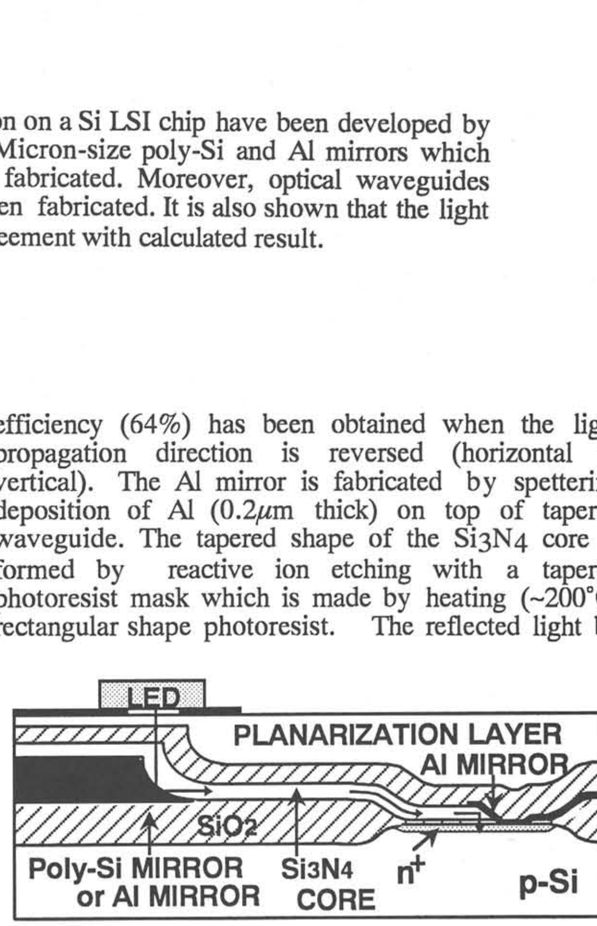


Fig. 1 Detailed structure of OEIC on Si.

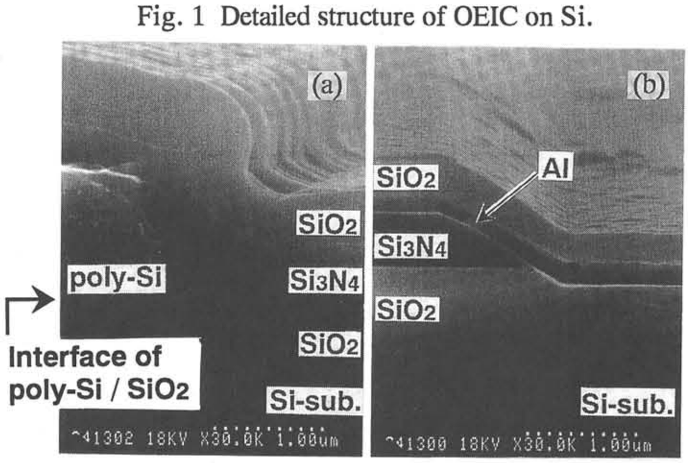


Fig. 2 Cross-sectional SEM photograph of (a) poly-Si mirror and (b) Al mirror.

**Present Address : Faculty of Engineering, Tohoku University this Al mirror was observed by CCD camera. The quantitative data for the Al mirror has not been obtained.

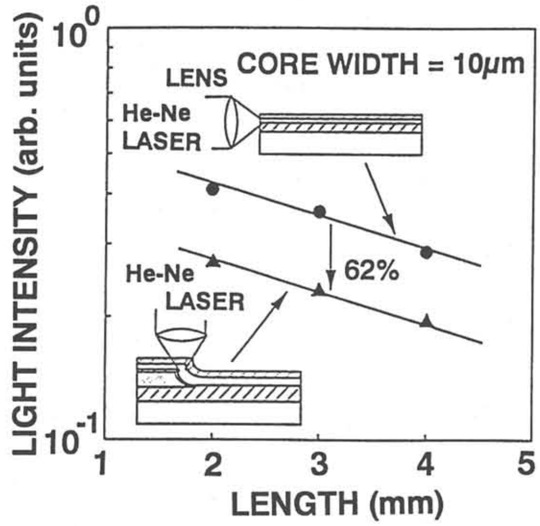


Fig. 3 Output light intensity versus waveguide length for poly-Si mirror and straight waveguide.

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

If one uses Ge doped SiO_2 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 SiO_xN_y 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 SiO_xN_y films have been deposited by a gas mixture of SiH_4, NH_3 and N_2O, where only the N_2O and NH_3 gases are excited in the plasma. The refractive index of the film can be precisely controlled by changing the partial pressure of N_2O as shown in Fig. 4. The propagation loss of the slab waveguide with SiO_xN_y core (470nm thick) and SiO_2 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.

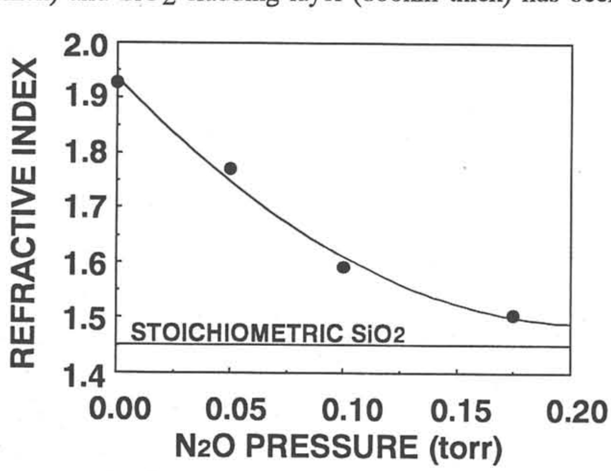


Fig. 4 Refractive index of SiO_xN_y vs N_2O pressure.

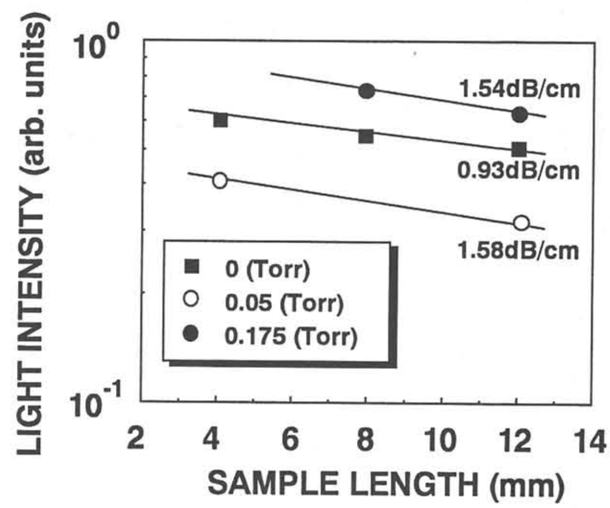


Fig. 5 Light propagation loss for slab waveguides with SiO_xN_y core.

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

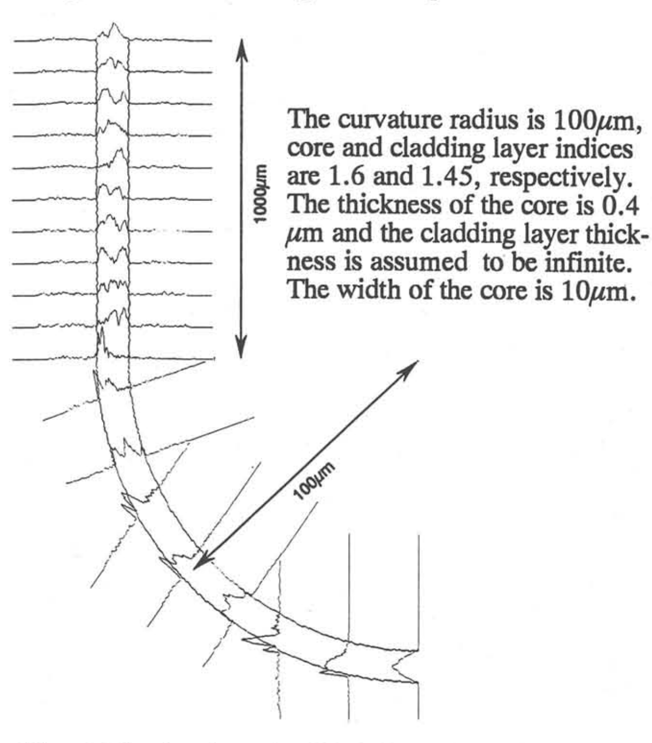


Fig. 6 Simulated result of light intensity profile along a curved waveguide.

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.

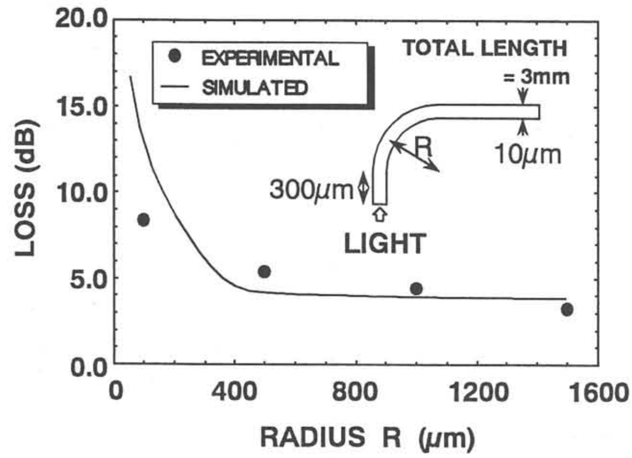


Fig. 7 Bending loss at the corner vs curvature radius.

5. Single Chip Integration

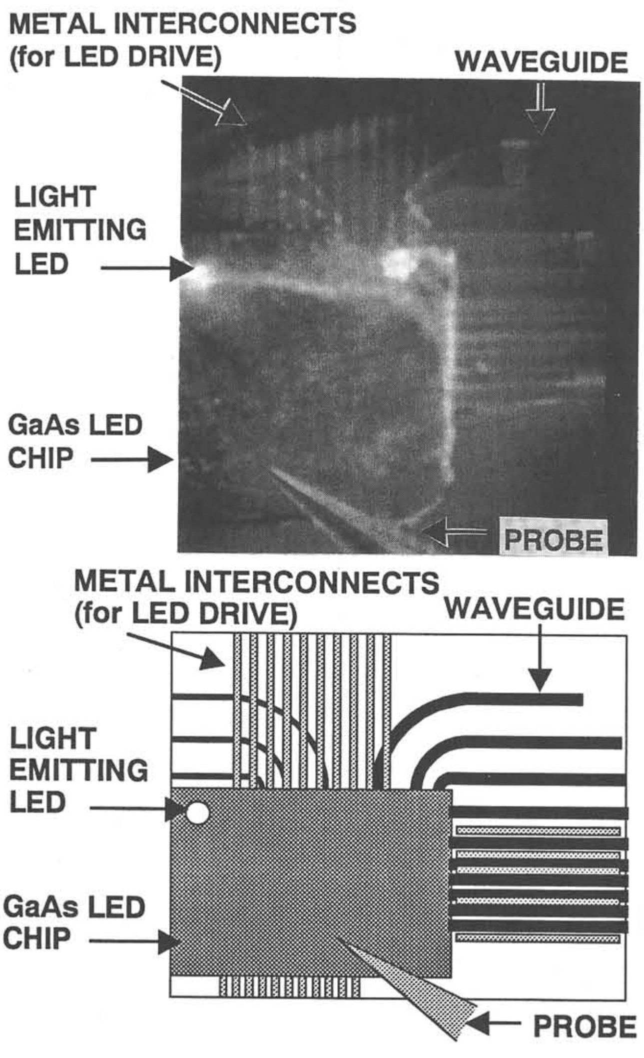
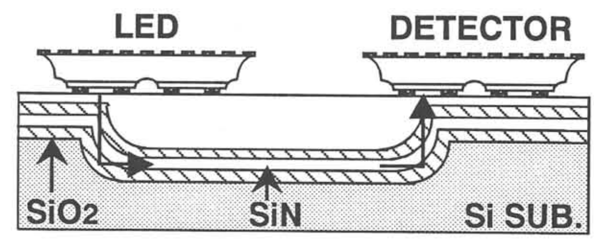


Fig. 8 (a) Optical micrograph of an integrated test chip.

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.



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

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 feasability of integration of these optical components has been demonstrated.

7. References

[1] W. Goodman, F. I. Leonberger, S. Y. Kung and R. A. Athale: Proc. IEEE (1 J. 984) 850.

[2] K. Miyake, T. Tanaka, T. Etoh, M. Tsuno, S.Yokoyama and M. Koyanagi: Jpn. J. Appl. Phys. 33 (1994) 848.

[3] T. Nagata, T. Tanaka, K. Miyake, H. Kurotaki, S. Yokoyama and M. Koyanagi: Jpn. J. Appl. Phys. 33 (1994) 822.

[4] K. Okamoto : Theory of Optical Waveguides (Koronasha, Tokyo, 1992) [in Japanese].