Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 1047-1049

Micron-Size Optical Waveguide for Optoelectronic Intergrated Circuits

T. Nagata, T. Tanaka, K. Miyake, H. Kurotaki, S. Yokoyama and M. Koyanagi

Research Center for Integrated Systems, Hiroshima University
1-4-2 Kagamiyama, Higashi-Hiroshima 724, Japan

The fundamental technologies for the optical interconnection in the VLSI chip have been developed by using conventional Si LSI technologies. The micron-size optical waveguide consisting of Si_3N_4 core and SiO_2 cladding layers has been fabricated by low pressure CVD and atmospheric pressure CVD, respectively. The small size lenses and the light direction converter which changes the light propagation direction from vertical to horizontal for the interlayer connection have also been fabricated.

1. Introduction

Optoelectronic integrated cirsuits (OEIC's) are expected as next generation LSI's with massively pararell processing power. Figure 1 shows an example of OEIC with optical interconnections in vertical (interlayer) and horizontal (intralayer) directions[1]. The purpose of this study is to develop fundamental technologies for fabricating the OEIC's.Figure 2 shows an example of more detailed structure of the OEIC in which Light Emitting Diode (LED) is installed by hybrid technique and the detector is n^+/p junction.To realize this structure, the micron-size optical waveguide for the intralayer connection and the small size lenses for the interlayer connection have been fabricated by using Si LSI technologies. The micron-size converters which change the light propagation direction from vertical to horizontal and horizontal to vertical have also been formed and operated with high efficiency.

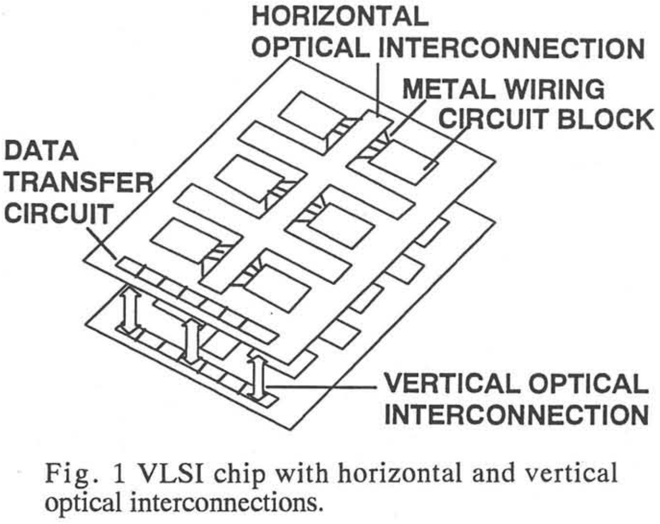

Fig. 1 VLSI chip with horizontal and vertical optical interconnections.

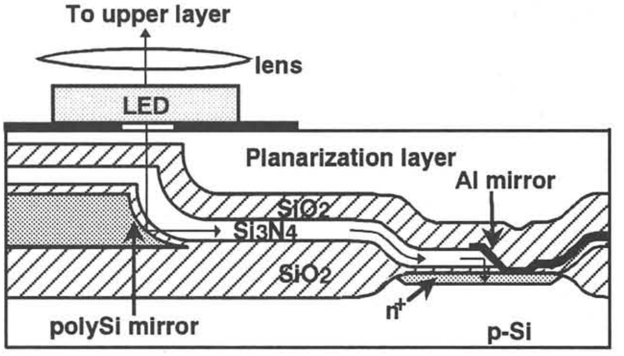

Fig. 2 An example of detailed structure of OEIC.

2. Intralayer (Horizontal) Optical Waveguide

Figure 3 shows a fabrication process of the waveguide consisting of Si_3N_4 core (n=2.0) and SiO_2 cladding (n=1.45) layers. The SEM photograph of the cross section of the fabricated waveguide is also shown in the figure. All the processes used are conventional Si LSI fabrication technologies.The process temperatures of the thermal oxidation,LPCVD and APCVD are 1000°C,750°C and 450°C, respectively. Figure 4 shows a propagation loss of the waveguide (width of the core: $W_{core}=10\mu m$) with different core thicknesses measured at a wavelength of 940 nm. The simply simulated loss using a slab-waveguide approximation[2], in which the loss is expressed by R^N(R: reflectivity at the core/clad interface , assumed to be 0.99995 here, N: the number of the reflection events in 1 cm) is well fitted to the experimental results. The loss measured at a shorter wavelength (560 nm) was larger than that measured at 940 nm. These results suggest that the loss is determined dominantly by the roughness of the core surface. In order to reduce the loss, the isotropic etching of the core surface was carried out by the chemical dry etching (CDE) in the remote plasma of CF_4+N_2 gas mixture generated by the microwave (2.45GHz) excitation. The etch depth dependence of the loss is shown in Fig. 5. The loss is first decreased as the etching proceeds, while it increases for the deeper etching depth. The reduction of the loss by the initial shallow etching seems to be due to the improvement of the smoothness of the core surface, while the increase in the deeper etching region is due to the thinning of the film. In spite of the smaller size (thin and narrow) compared with the usual optical fibers for long distance communication, the obtained minimum loss of ~1.5 dB/cm is still available in the short intrachip connection (at most a few cm in length).

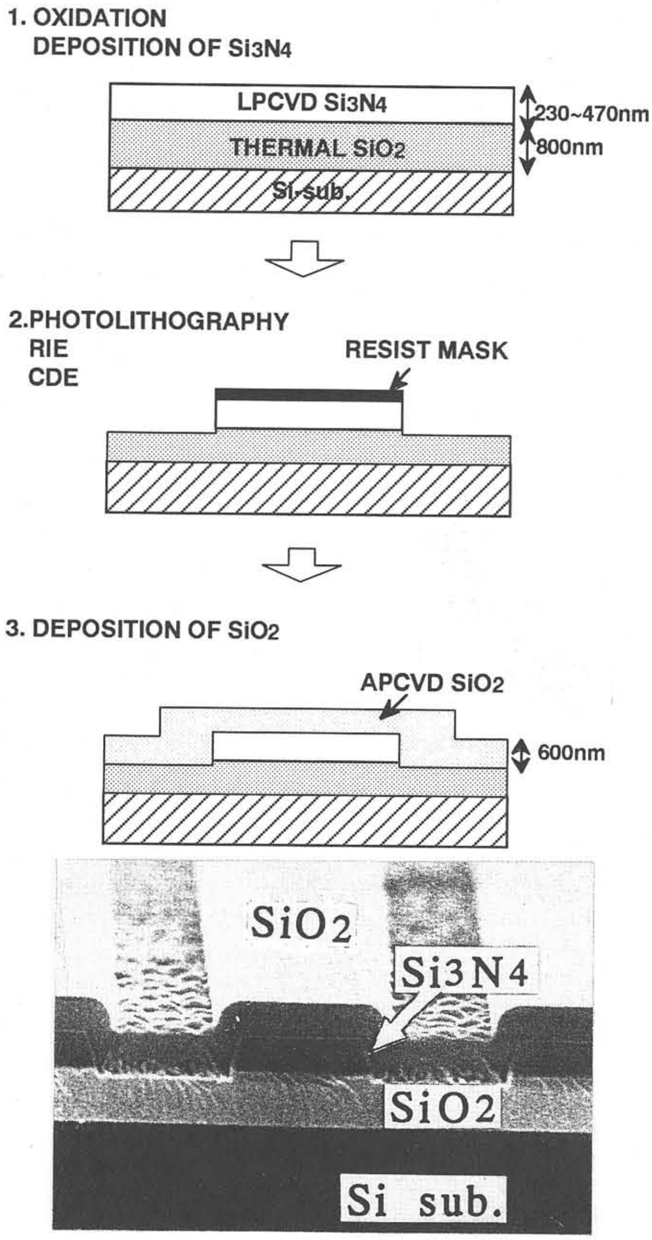

Fig. 3 Fabrication process for micron-size optical waveguide. For CDE, the sample is isotropically etched. Width of the core was changed from 1.5 to 10μm. CDE: Chemical Dry Etching, RIE: Reactive Ion Etching, LPCVD: Low Pressure CVD, APCVD: Atmospheric Pressure CVD.

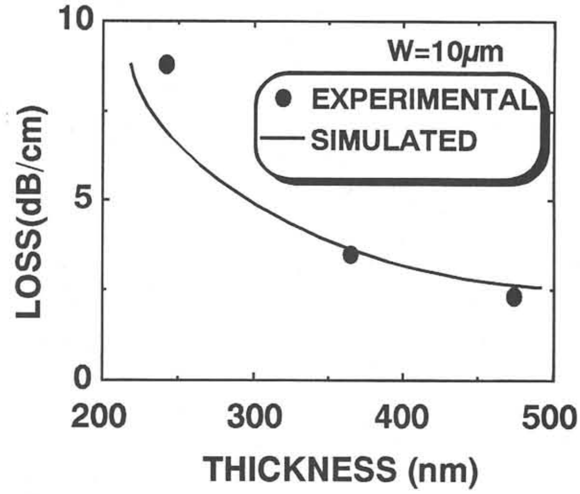

Fig. 4 Propagation loss as a function of core thickness. The measured wavelength was 940 nm.

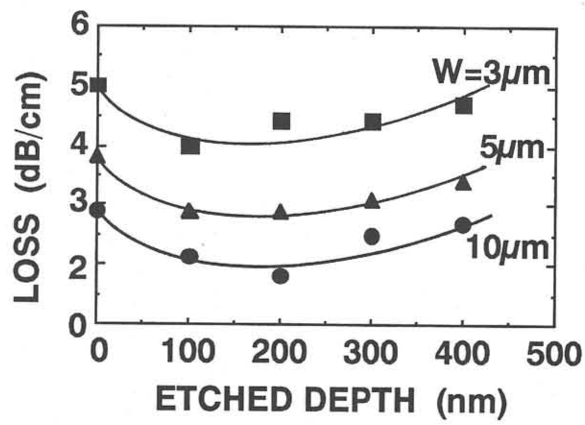

Fig. 5 Etched depth dependence of propagation loss. The initial core thickness was 470 nm.

3. Interlayer (Vertical) Optical Interconnection

For the three dimensional optical interconnection, the collimation of the light is very effective especially when the LED with isotropic nature for the light emission is used. We made microlenses from the resist and poly-Si films. Figure 6 shows a fabrication process. First the resist is patterned by the photolithography to produce a rectangular shape, then it is heated to ~200 °C to obtain a lens shape surface. The poly-Si lens is made by the etching with a low selectivity etching condition using a lens-shaped resist as a mask. The SEM photograph of the fabricated poly-Si lens is also shown in the figure. The light collimation function of this lens was experimentally confirmed. The effect of these lenses are simulated by using the obtained lens shape. One example is shown in Fig. 7, in which the transmission efficiency can be dramatically increased to 70% by using the properly designed configuration.In this case the sizes of the photodetector and the LED are fixed 15x15μm^2,5x5μm^2 ,respectivery and the diameter of the lens is changed.The positions of these parts are also maintained.

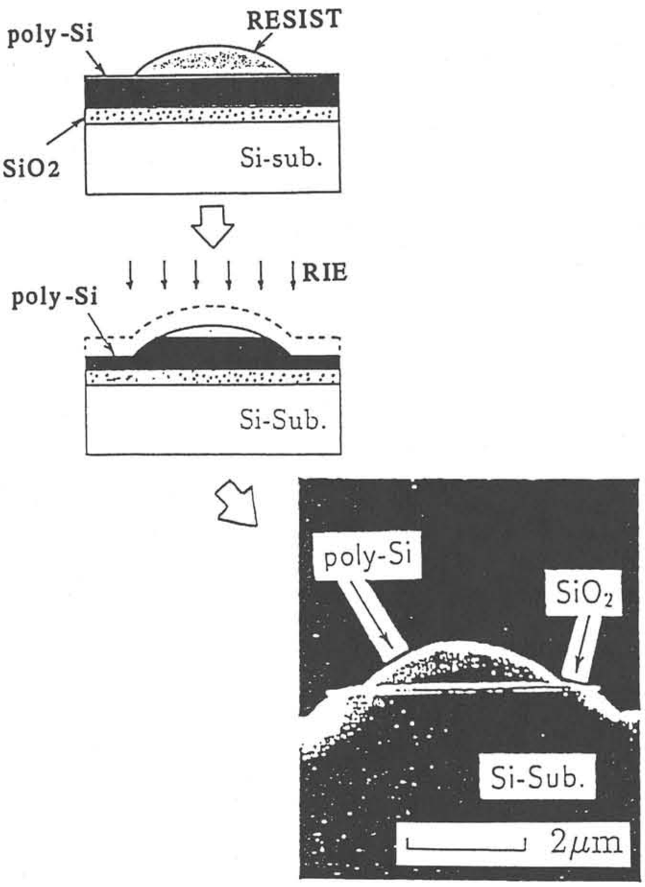

Fig. 6 Fabrication process for micron-size poly-Si lens.

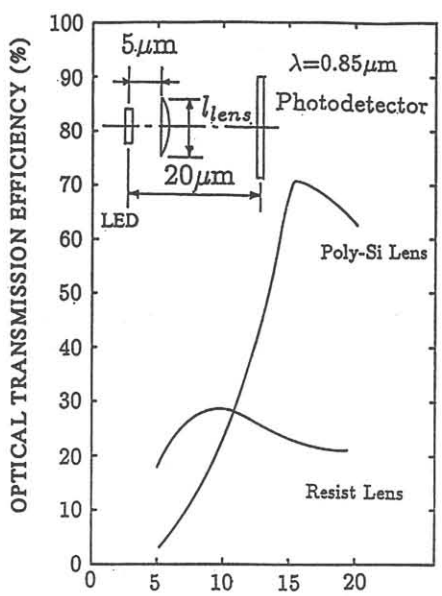

Fig. 7 Optical transmission efficiency as a function of lens diameter.

4. Conversion of the Light Propagation Direction

The conversion of the light propagation direction from vertical to horizontal within a small region is an important technolgy for the OEIC. The fabrication procedure for the converter is shown in Fig. 8. The curved Si surface is first prepared by the wet chemical etching (1μm in HF:HNO_3=5:95) with a Si_3N_4 mask. Then the waveguide is formed by the usual technique. In Fig.9 the output light intensity is shown for the straight wavegude and the converter with the same length. A relatively high conversion efficiency (~80%) is obtained presumably due to the contribution of the light reflection (or scattering) at the curved Si surface region. This conversion efficiency includes the difference in the incident efficiency for the both waveguides (straight and curved ones).

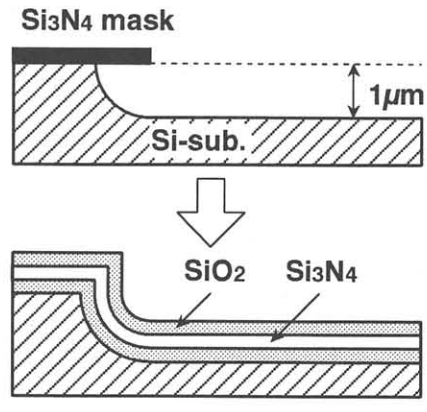

Fig. 8 Fabrication process for the light-direction converter.

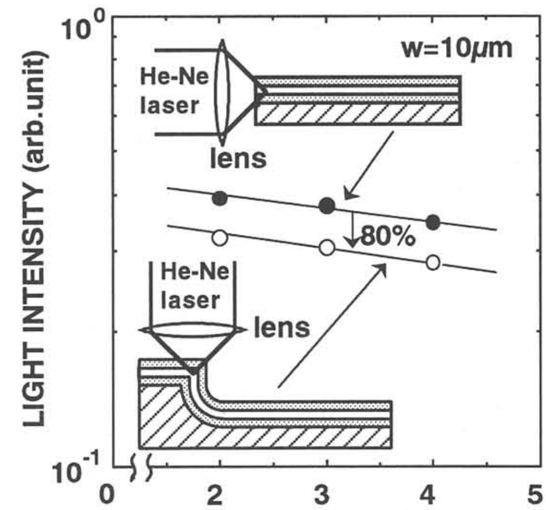

Fig. 9 Output light intensity versus waveguide length for the light converter and straight wavegude. The thickness of Si_3N_4 was 400 nm.

5. Conclusion

The fundamental technologies for fabricating micron-size optical waveguides including vertical, horizontal and also the mutual conversion were, for the first time, developped by using Si LSI technologies.

[1] M. Koyanagi, Proc. Int. Conf. on VLSI 91, p.377.
[2] Y. Suematsu and K. Iga, *Introduction to Optical Fiber Communication* [in Japanese], Ohm Corp. (1986).