High-efficiency Optical Coupling to Planar Photodiode using Metal Reflector loaded Waveguide Grating Coupler

G. Li, Y. Hashimoto, S. Ebuchi, T. Maruyama, and K. Iiyama
Natural Science and Technology, Kanazawa University,
Kakuma, Kanazawa, Ishikawa, 920-1192 Japan,
Tel: +81-76-234-4886, Fax: +81-76-234-4870, E-mail: maruyama@ec.t.kanazawa-u.ac.jp

Abstract- We propose a high-efficient vertical optical coupler using an amorphous Si waveguide grating coupler with top reflector. The coupling efficiency of 80% is calculated at the grating period of 380 nm and the duty ratio of 0.75 with top metal reflector.

1. Introduction

Recently, the operating speed of large-scale integrated (LSI) circuits is approaching a limit because global electrical inter-connection is becoming bottleneck. An optical inter-connection instead of the electrical interconnection on LSI is proposed to solve this problem [1]. Especially, a crystalline silicon (c-Si) optical waveguide have been studied intensively for optical interconnection at the 1.55 μm-wavelength range. The active device at this wavelength needs to introduce compound semiconductor such as GaInAs and AlInAs on c-Si substrate. These materials were difficult to grow epitaxially on Si substrate because of the lattice mismatch. A wafer bonding technique as one of the approaches to integrate on Si-LSI was reported [2].

On the other hand, c-Si can be used as the active device such as a photo-detector at 0.8 μm-wavelength range. We fabricated the c-Si avalanche photodiode by 0.18 μm-CMOS standard process [3]. The device realized a bandwidth of more than 1 GHz at 830 nm. However, c-Si is unsuitable as a waveguide at the 0.8 μm-wavelength range because of absorption at this wavelength. We propose the use of amorphous silicon (a-Si) as a waveguide material for the 0.8 μm-wavelength range because a band-gap energy of a-Si is about 1.4 eV-1.8 eV. We fabricated a-Si waveguides by photolithography and wet chemical etching, and obtained the propagation loss of 15 dB/cm at 830 nm[4]. It is promising for the realization of an all-Si optoelectronic integrated circuit (OEIC) using c-Si APDs and a-Si optical waveguides.

The optical coupling between APDs on Si-substrate and a-Si waveguides is a serious problem for realization of all-Si OEIC. To overcome this problem, grating couplers is the most qualified candidate [5]. In this paper, we describe a design of a high-efficient vertical optical coupler using the grating coupler between the APD on Si substrate and a-Si waveguide.

2. Calculation Results and Discussion

A simulation model of grating coupler is shown in Fig.1. The cross-sectional size of the a-Si single mode waveguide is 100 nm thickness and 300 nm width. The grating structure is fabricated into the a-Si waveguide on 2 μm-thick SiO_2 layer. The waveguide is covered with a BCB (1 μm-thickness) of dielectric material for top cladding layer. A reflecting mirror (Au) is located on top for higher efficient coupling.

The optical propagation in grating structure is analyzed by the two-dimensional finite element method. The incident wavelength and the refractive index of core is 850 nm and 3.39, respectively. The grating period (Λ= 340~380nm), the duty ratio (w/Λ= 0.25, 0.5, 0.75), and the etching depth (d= 5~100nm) dependence of the coupling efficiency, diffraction angular were analyzed.

Fig.2 shows the grating period dependence of coupling efficiency and diffraction angle. The coupling efficiency significantly reduced at the grating period of 360 nm. Because a strong Bragg reflection occurs at the Bragg period. On the other hand, the

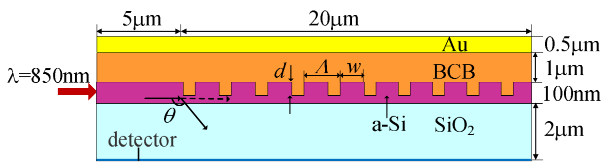

Fig.1: Analytical model of a-Si grating coupler

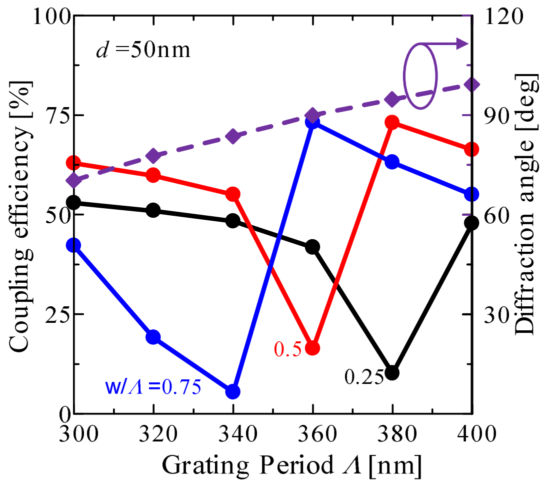

Fig.2: Grating period and duty ratio dependence of coupling efficiency and diffraction angle.

diffraction angle is independent of grating period.

The relationship between grating duty ratio and coupling efficiency is also shown in Fig.2. The grating period at dipping coupling efficiency becomes short at large duty ratio. The reason is that the equivalent refractive index of the waveguide becomes a high value at large duty ratio.

The etching depth dependence of the coupling efficiency is shown in Fig.3. A deeper etching depth, a stronger Bragg reflection and a longer Bragg period.

To improve the coupling efficiency, a metal reflector is loaded on top cladding layer. Fig.4 shows the etching depth dependence of coupling efficiency

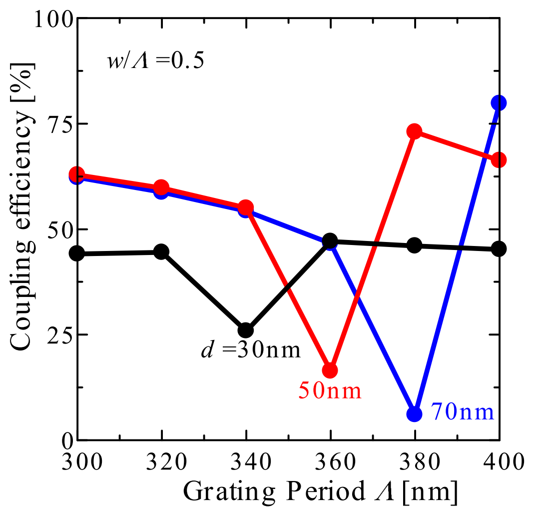

Fig.3: Etching depth dependence of coupling efficiency

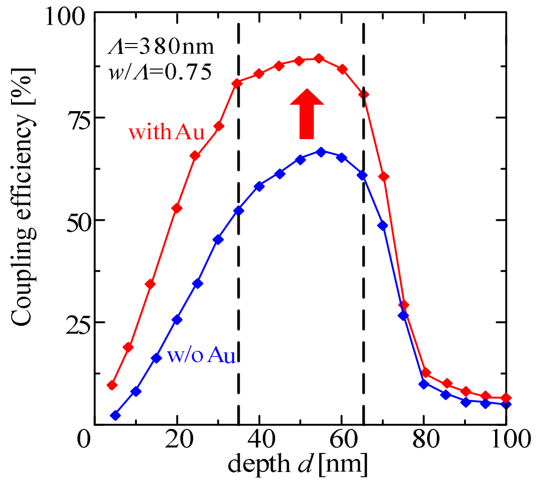

Fig.4: Etching depth dependence of coupling efficiency with and without top metal reflector.

with and without top metal reflector at grating period of 380nm and duty ratio of 0.75. It can be clearly observed that the coupling efficiency with the metal reflector achieved 1.4 times higher than that without the reflector.

3. Conclusions

We proposed and simulated the high-efficient vertical optical coupler using the grating coupler between the APD on Si substrate and a-Si waveguide with top metal reflector. The coupling efficiency of 80% was calculated at the metal loaded grating coupler. This coupling efficiency is 1.4 times higher than that without a reflector. This grating coupler can be expected to realize the high-efficiency optical coupler on all-Si OEIC.

References

[1] D. A. B. Miller, *Proc. IEEE* **97** (2009) 1166..

[2] D. Liang and J. E. Bowers, *Electron. Lett.* **45** (2009) 578.

[3] K. Iiyama, H. Takamatsu and T. Maruyama, *IEEE Photon. Technol. Lett.* **22** (2010) 932.

[4] T. Asukai, M. Inamoto, T. Maruyama, K. Iiyama, K. Ohdaira and H. Matsumura, *IEEE Group IV Photonics 2010,* **P2.16** (2010).

[5] R. Takei, K. Uchino and T. Mizumoto, Conference on Laser and Optics 2010, **CthP1** (2010)