Propagation-Loss Reduction in InGaAsP Photonic-wire Waveguides by InP and Al_2O_3 Passivation Layers

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***Abstract*—Scattering loss in InGaAsP photonic-wire waveguides fabricated on III-V-OI on Si wafer was effectively reduced by InP and Al_2O_3 passivation layers. Thus the propagation loss was improved from 1.7 dB/mm to 0.4 dB/mm.**

Keywords-InGaAsP photonic wire waveguide; scattering loss; III-V CMOS photonics

I. Introduction

III-V CMOS photonics [1] has been an attractive platform which can integrate high-performance III-V semiconductor based CMOS transistors [2, 3] and InP-based photonic-wire waveguide devices [4] on III-V on insulator (III-V-OI) on Si wafer. The strong optical confinement of the III-V-OI wafer enables drastic reduction of the sizes of III-V photonic devices as like silicon photonics. Using this platform, a sharp bend waveguide with 5-μm bend radius and an ultra-small arrayed waveguide grating multiplexer have been demonstrated [5]. In addition, the loss reduction of the InGaAsP photonic-wire waveguides has been demonstrated by atomic layer deposited (ALD) Al_2O_3 activated direct wafer bonding [6]. However, the propagation loss of the InGaAsP photonic-wire waveguide was still 1.7 dB/mm, higher than that of Si photonic-wire waveguides. Thus, the propagation-loss reduction in the InGaAsP photonic wire waveguide is mandatory for achieving large scale photonic integrated circuits.

In this paper, we have investigated scattering loss in the InGaAsP photonic-wire waveguides. The loss mainly comes from scattering at the (1) top, bottom and (2) sidewall of the waveguide as shown in Fig. 1. To suppress scattering at the waveguide surfaces, we have introduced the InP and Al_2O_3 passivation layers that effectively reduced the propagation loss from 1.7 dB/mm to 0.4 dB/mm.

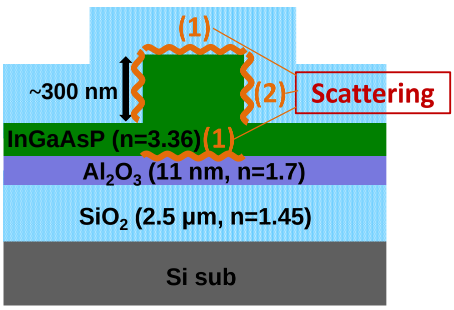

Fig. 1 Scattering of InGaAsP photonic-wire waveguide.

II. Fabrication

To investigate scattering loss in the InGaAsP photonic-wire waveguide, we have prepared three types of waveguide: (a), (b), and (c) as shown in Fig. 2. Figure 2(a) shows the conventional waveguide structure, in which the InGaAsP (λ_g=1.25μm)/Al_2O_3 layer is directly bonded on the SiO_2 buried oxide (BOX) layer with SiO_2 passivation. The Al_2O_3 layer enables the large surface energy of the bonded interface without any plasma treatments [6]; however, the InGaAsP/Al_2O_3 interface is still rough, increasing the scattering loss. To improve the scattering loss at the bottom interface of the waveguide, we have put 25-nm-thick InP layers on the top and bottom of the InGaAsP layer as shown in Fig. 2(b). We expect that the surface roughness of the InP/Al_2O_3 interface is much improved as compared with the InGaAsP/Al_2O_3 interface. The InP layer is also expected to reduce scattering at the InP/Al_2O_3 interface because the index contrast between InP (n=3.17) and Al_2O_3 (n=1.7) is smaller than that of between InGaAsP (n=3.36) and Al_2O_3. We have also examined an 11-nm-thick Al_2O_3 passivation layer deposited on the waveguide by atomic layer deposition (ALD) before SiO_2 passivation as show in Fig. 2(c). The scattering at the sidewall of the waveguide is expected to be reduced by Al_2O_3 passivation because the index of Al_2O_3 is higher than that of SiO_2 [7].

The fabrication procedure is as follows. Firstly, 5.5-nm-thick Al_2O_3 layer is deposited on a 2-inch III-V wafer and a SiO_2/Si wafer by ALD.

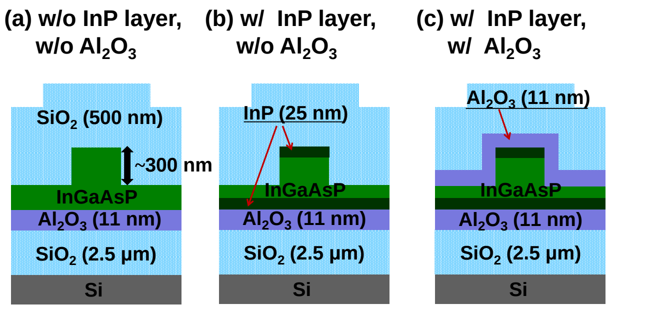

Fig. 2 Schematics of three types of fabricated waveguides.

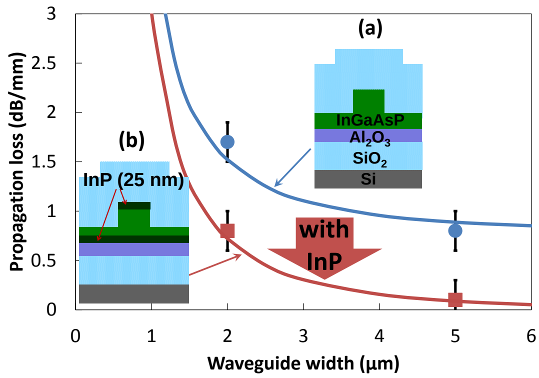

Fig. 3 Propagation losses of the waveguides (a) without InP passivation and the waveguide (b) with InP passivation.

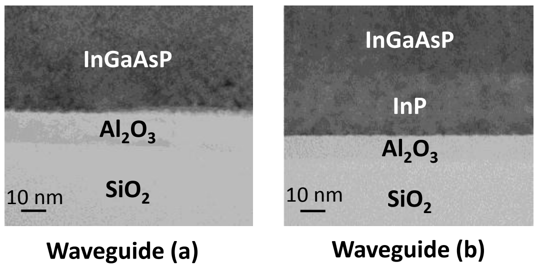

Fig. 4 TEM images of the bonded interfaces of the waveguide (a) and (b).

After bonding, the wafer was annealed at 350 °C for 1 hour. Then, the InP substrate was selectively etched by HCl. After patterning by photolithography, the waveguide mesa was formed by reactive ion etching (RIE). Finally the SiO_2 or Al_2O_3/SiO_2 passivation layer was deposited.

III. MEASUREMENT

To investigate the scattering loss, the propagation loss was measured by the cut-back method. Figure 3 shows the propagation losses of the waveguides (a) and (b) as a function of the waveguide width. The solid lines show the simulated propagation losses based on the scattering model by Payne and Lacey [8], which explain well the experimental results. By introducing the InP layers at the bottom and top of the waveguides, the propagation loss in the 2-µm-wide waveguides was reduced from 1.7 dB/mm to 0.8 dB/mm and the loss in the 5-µm-wide waveguides was also reduced from 0.8 dB/mm to 0.1 dB/mm. Figure 4 shows the transmission electron microscopy (TEM) images of the bonded interfaces of the waveguide (a) and (b). It is clearly observed that the interface between InP and Al_2O_3 is more flat than that between InGaAsP and Al_2O_3. Thus, the propagation-loss reduction of approximately 0.7 – 0.9 dB/mm was obtained by the smooth InP/Al_2O_3 interface in conjunction with the less index contrast between InP and Al_2O_3.

The scattering at the sidewall of the waveguide was also examined by comparing the propagation losses between the waveguides (b) and (c) as shown in Fig. 5. The propagation loss of the 2-µm-wide waveguide was reduced from 0.8 dB/mm to 0.4 dB/mm by Al_2O_3 passivation due to the less index contrast between InGaAsP and Al_2O_3 as compared with

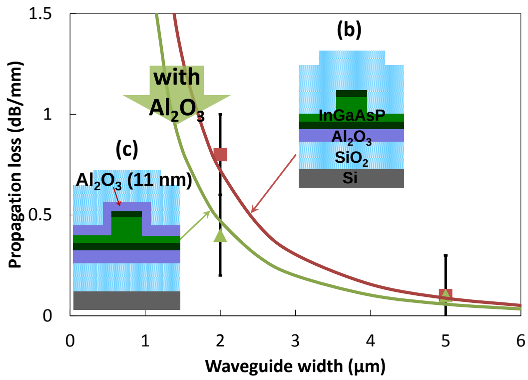

Fig. 5 Propagation losses of the waveguides (b) without Al_2O_3 passivation and the waveguide (c) with Al_2O_3 passivation

that between InGaAsP and SiO_2. The propagation loss of the waveguide (c) increases from 0.1 dB/mm to 0.4 dB/mm when the waveguide width decreases from 5 µm to 2 µm, indicating that the sidewall roughness is still not negligible even with Al_2O_3 passivation. Therefore, the propagation loss is expected to be reduced to less than 0.4 dB/mm by the optimizing dry etching of InGaAsP and lithography.

IV. CONCLUSIONS

We have investigated the scattering loss in the InGaAsP photonic-wire waveguide. The propagation loss was reduced from 1.7 dB/mm to 0.4 dB/mm by the InP and Al_2O_3 passivation layers owing to the reduction in scattering at the bottom, top and sidewall of the waveguide. Since the propagation loss of the 5-µm-wide waveguides, in which the sidewall scattering is not significant, is approximately 0.1 dB/mm, the propagation loss of the InGaAsP photonic-wire waveguide is expected to be lowered as that of the Si photonic-wire waveguide by improving sidewall roughness.

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