Amorphous silicon: Material for Photonic-Photonic and Electronic-Photonic Integration.

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Amorphous silicon is an excellent alternative material for high-index contrast material technology, beside crystalline silicon. Deposited as layers it can be used to build multiple layers of photonic circuit on top on each other. In addition this layer staking can be used for integrating electronic circuits with photonic circuits through back-end integration.

In this paper, we present low propagation loss amorphous silicon deposited using plasma enhanced chemical vapour deposition. Using this material, we demonstrate fabrication of dual layer photonic circuit connecting with a grating optical via with which a modest via efficiency of 11% and optical crossing loss of 0.013dB/crossing between the layers. In addition, high efficiency grating fibre couplers is demonstrated using bottom mirrors using amorphous silicon. A coupling efficiency of 69.5% was demonstrated using such structure.

Introduction

High-refractive index platform, in particular, Silicon-On-Insulator (SOI) is exploited to a great extent for making compact photonic circuits. In addition, the availability of matured manufacturing technology from silicon microelectronic is an added advantage in using silicon. However, despites its superior material quality the integration options are limited to single layer level circuits. Even though the circuits can be made compact, thanks to high-refractive index contrast, they can not be scaled down beyond the wavelength of light in the material. Hence vertical staking of photonics circuits can help to increase the device density and also can open frontier for wide range of applications using multiple circuit layers.

In order to realize multiple layers of photonic circuits various methods has been proposed and demonstrated [1-2]. Among them deposition of waveguide layer is the most promising integration scheme. The most popular deposition technique used for silicon deposition is chemical vapour deposition, either at low pressure or plasma enhanced. Among these two, plasma enhanced chemical vapour deposited (PECVD) is the most suitable for integrated photonic circuit application. Few advantages of using PECVD is the ability to deposited amorphous silicon at low temperature (<400C), material property can be tuned by tuning the deposition parameters such as, pressure, power etc, and most important, low-loss amorphous silicon can be deposited.

Amorphous silicon: waveguide material

The most important quality of a waveguide material is the propagation loss. Low propagation loss is essential for efficient operation of an optical devices and the optical chip as a whole. As mentioned earlier, PECVD is used to deposit low-loss amorphous silicon. Low-loss is achieved by tuning the deposition parameters and the material propertied of the deposited material.

In PECVD chamber, silicon containing precursor gas in our case silane (SiH4) is decomposed in the presence of plasma and the decomposed gas species are adsorbed on the wafer surface to form a solid film. We have demonstrated that propagation loss as low as 1.37 and 3.45 dB/cm can be achieved for low and high contrast waveguide configurations [3]. Figure 1 depicts the linear regression of transmitted power through photonic wires of various lengths.

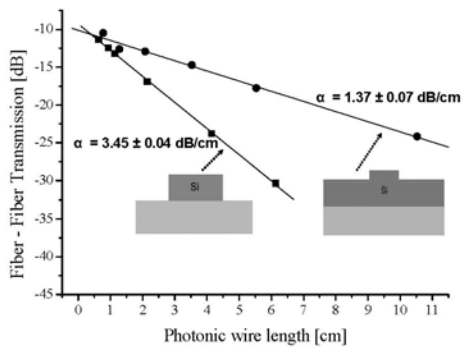

Figure 1. Propagation loss of a shallow and deep etched waveguide. The thickness of the waveguide is 220 nm in both case and the width the ~450 nm.

Multilayer photonic devices and circuit

In order to build multiple layers of photonic circuits there are two primary requirements: optical isolation and coupling. Although these two requirements are complementary it is essential to meet them to take advantage of the multilayer circuits. Coupling between two layers has been demonstrated through evanescent coupling mechanism [4], where the proximity between the two waveguides is important. However, to avoid crosstalk the photonic circuits they should be optically isolated. An elegant solution is to used grating to couple light between layers which can be optically isolated (>1 µm) [5].

Figure 2 depicts one of the fabricated grating optical via. The two optical layers were coupled using a shallow etch grating coupler with 630 nm pitch and 50% fill factor. Despite an optical isolation of 1000 nm (Figure 2 right) the two optical layers were optically coupled though grating coupler (see next section for measurements).

In addition to the dual layer optical circuit we have also fabricated DBR mirror to enhance the coupling efficiency of a grating fibre coupler [6]. Figure 3 depicts the cross-section micrograph of a grating coupler with a DBR mirror. The bottom mirror was first defined over the wafer followed by grating fabrication. By using a bottom mirror the light diffracted downwards is reflected upwards which increases the coupling efficiency. This structure demonstrates the flexibility of deposited amorphous silicon.

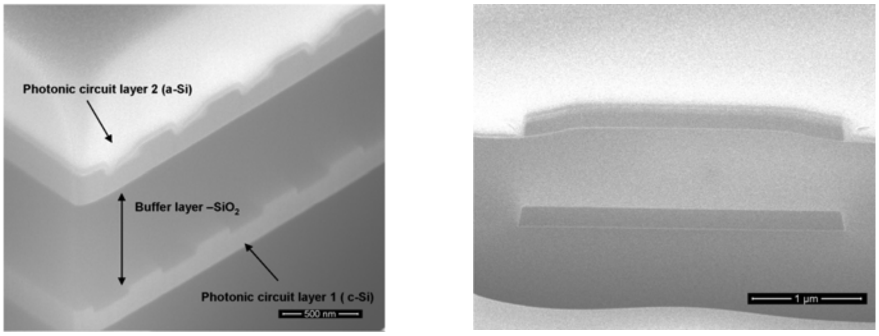

Figure 2. (Left) Crosssection of a grating optical via. (Right) Optically isolated waveguide layers.

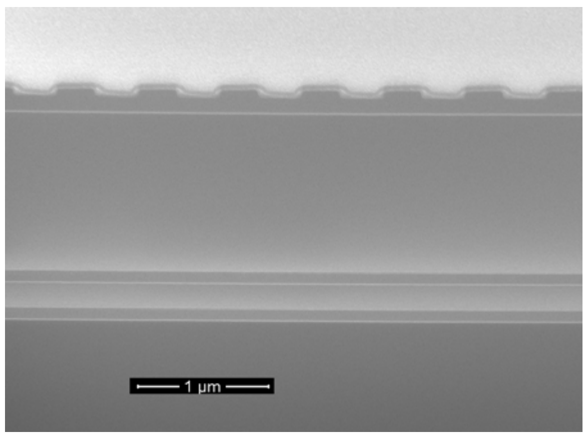

Figure 3. Grating fibre coupler with bottom DBR mirror

Measurement results

The fabricated devices were characterized using a broad-band light source (SLED) and a spectrum analyzer in the telecom wavelength range 1500-1600 nm. The light is coupled in and out using a grating fibre coupler [6].

Figure 4 shows the spectral response of an optical via. We have measured a coupling efficiency of 11% per via (Figure 2). As mentioned earlier the gratings were isolated by 1000 nm oxide layer, which is used for optical isolation. Figure 5 shows the crossing loss between the two layers. The crossing loss is measured by placing dummy photonic wires in one layer which intercepts a live wire in the other layer. By varying the number of intercepts the loss per crossing can be calculated. We have measured a crosstalk loss of 0.013 dB/crossing, which is a negligible value. Through these characterization we demonstrate that it is possible to couple optically isolated layers and achieve low crosstalk loss.

Figure 6 depicts the coupling efficiency of a grating coupler with bottom mirror. We have measured an efficiency of 69.5 % at 1500 nm. There is a disagreement of 6% between the simulated and measured efficiency which is attributed to the variation of silicon dioxide buffer thickness between the mirror and the gratings.

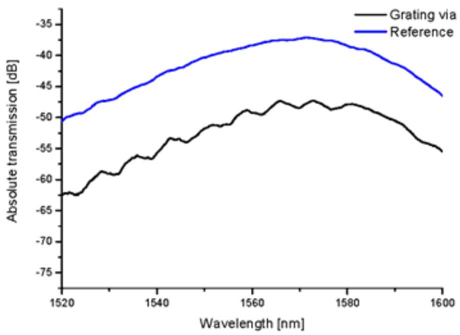

Figure 4. Spectral response of an optical via.

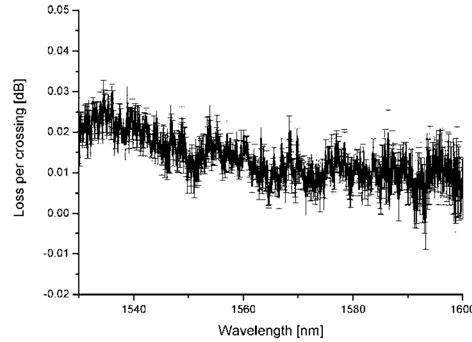

Figure 5. Crossing loss in a dual layer photonic circuit.

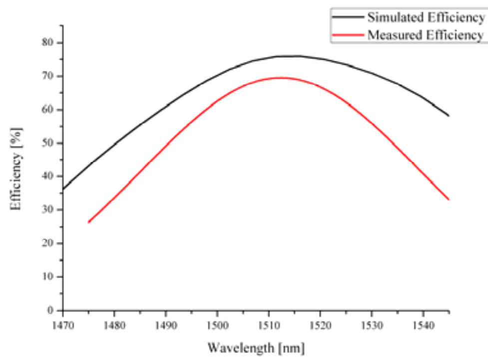

Figure 6.Measured and simulated coupling efficiency of a grating fibre coupler with bottom mirror.

Conclusion

In conclusion, we have demonstrated low-loss amorphous silicon deposited using PECVD technique. Grating optical via has been demonstrated with a modest efficiency of 11% and the crosstalk loss of 0.013 dB/crossing has been achieved. In addition, grating fibre couplers with bottom DBR mirrors were fabricated and measured an efficiency of 69.5 %.

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