Low Temperature Hot-Wire Polysilicon Waveguides

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***Abstract*—We fabricated and measured low loss polysilicon waveguides deposited using Hot-Wire Chemical Vapor Deposition (HWCVD) at 240 °C. The optical propagation loss was measured to be 11.9 dB/cm at λ = 1550 nm.**

I. Introduction

Silicon photonics technology can offer an alternative to wired interconnections on LSI circuits by using ultra-compact silicon waveguides. The high bandwidth and small footprint of silicon waveguides have the potential to improve the performance of LSI circuits [1]. Silicon on insulator (SOI) has been the dominant development platform for silicon photonics technology due to its low optical propagation loss. However, it is constrained by the need for integration of multi-layered silicon photonics to the more established CMOS technology. Recently, there has been an increasing interest in polysilicon waveguides due to their low cost and added design flexibility [2]. However, most of the reported polysilicon films were deposited or post-treated at high temperatures ($\geq$ 900 °C) which may not be compatible with the CMOS fabrication process. Therefore, we propose polysilicon waveguides with low loss and low thermal budget achieved using hot-wire chemical vapour deposition (HWCVD).

An important characteristic of polysilicon waveguides is their low-cost compared to SOI. However, the high optical propagation losses ($\sim$ 1700 dB/cm) that were reported in early studies abated the interest of using polysilicon in photonics applications [3]. Engineering the waveguide structure and deposition processes has resulted in reducing the optical propagation loss to ~ 6.45 dB/cm for TE mode [4]. However, annealing polysilicon at temperatures $\geq$ 900 °C has been widely used to improve the crystallinity of the as-deposited films. Takei et al. reported low-loss silicon waveguides using hydrogenated microcrystalline silicon (μc-Si:H) deposited at 250 °C [5]. Although a loss as low as 6.5 dB/cm was reported for TE mode, hydrogenated microcrystalline silicon (μ c-Si:H) should still have higher optical loss than polysilicon due to its smaller grain size and amorphous nature. To avoid high deposition temperature, we propose Hot-Wire Chemical Vapor Deposition (HWCVD) instead of the more conventional Plasma-Enhanced Chemical Vapor Deposition (PECVD) and Low-Pressure Chemical Vapor Deposition LPCVD processes. Polysilicon HWCVD can be deposited at temperatures as low as 300 °C and can result in reduced ion-induced damage, high deposition rate, improved uniformity, and low-cost polysilicon films [7].

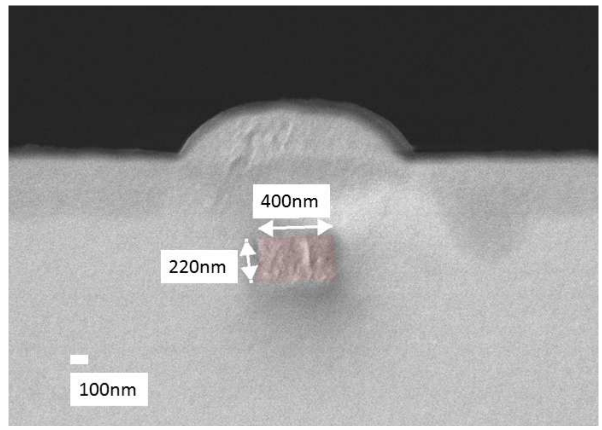

Fig. 1. An SEM cross-section of the polysilicon waveguide covered with PECVD SiO_2.

II. Experiment and Results

Thin polysilicon films (230 nm thick) were deposited using a Hot-Wire Chemical Vapor Deposition (HWCVD) system (Echerkon Nitor 301) at a temperature of 240 °C on top of a 2000 nm thick PECVD silicon dioxide (SiO_2) on a silicon wafer. Sub-micron waveguides were then patterned using e-beam lithography and conventional RIE etch. The waveguides were then covered with 700 nm PECVD SiO_2 that was deposited at a temperature of 350 °C. The surface roughness of the deposited polysilicon film was characterized using atomic force microscopy (AFM). The RMS value of the surface roughness was 8 nm. Figure 1 shows an SEM image of a polysilicon waveguide (400 nm) covered with PECVD SiO_2. The roughness of the cross-section and the top surface is a consequence of poly-crystalline grain. Raman scattering measurement with a 532 nm excitation wavelength was used to estimate the crystalline volume of the HWCVD polysilicon. The crystalline volume fraction, X_c, of the film was calculated using [6]

$$X_c = \frac{I_{c-Si}}{I_{c-Si} + I_{a-Si}} \quad (1)$$

where I_{c-Si} and I_{c-Si} are the sum of deconvoluted intensities for the c-Si peak centred at 520 cm^{-1} and the a-Si peak centred at 480 cm^{-1}, respectively. The crystalline volume was found to be $> 91\%$. Moreover, the transmission properties of the fabricated HWCVD polysilicon waveguides were

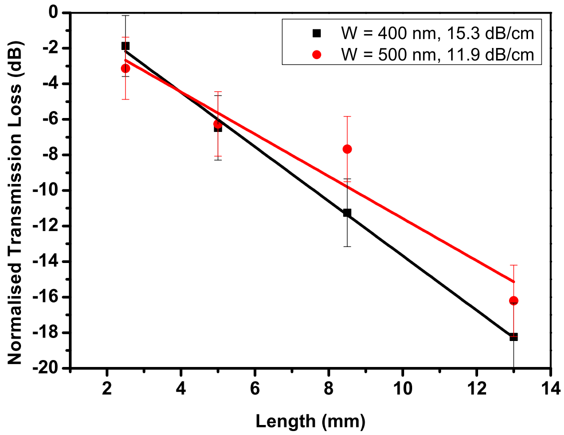

Fig. 2. (b) Transmission characteristics of the TE mode of the polysilicon waveguides of widths 400 nm and 500 nm.

characterised at a wavelength of 1550 nm. The polysilicon waveguides had lengths of 1, 2.5, 5, 10 and 13 mm and widths of 400 and 500 nm. The propagation loss of the TE mode of the 400 nm was 15.3 ± 0.3 dB/cm, while that of the 500 nm wide waveguide was 11.9 ± 0.3 dB/cm. Figure 2 shows the transmission loss of the 400 nm and the 500 nm waveguides where the loss in dB was normalised to a length of 1 mm. The relatively high surface roughness is expected to contribute most to the total propagation loss. Smoothing the surface using chemical mechanical polishing (CMP) should result in decreasing the loss to single figures.

III. Conclusion

In summary, we report on low loss (11.9 ± 0.3 dB/cm) polysilicon waveguides deposited using HWCVD at 240 °C. Further study is being conducted to quantitatively estimate the contribution of the material-induced and scattering losses. Surface smoothing by means of CMP is being investigated to improve the optical propagation loss.

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