Investigation of Carbon Doped Amorphous Silicon, an Alternative Material for All-Optical Signal Processing for On-Chip SOI PICs

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We investigate the properties of carbon-doped hydrogenated amorphous silicon (a-Si_xC_{1-x}:H) thin-films produced by radio frequency plasma enhanced chemical vapour deposition (rf-PECVD) under low temperature condition, and compare them with those of non-carbon-doped amorphous silicon. Spectroscopic ellipsometry (SE) analysis has been used to characterise the deposited thin-films. During deposition argon gas has been used for passivation with different dilution ratio. The deposition temperature, dilution ratio and rf-power are important parameters that influence both the hydrogen content and the optical band gap. Optical multimode waveguides have been fabricated with this material on an SOI wafer and have been characterised.

Introduction

Silicon based photonic devices have great potential for applications in optical communications. They are small in dimensions, need low power consumption and are compatible with present CMOS technology. Many optical signal-processing applications like optical signal regeneration, wavelength conversion [1, 2], multiplexing and optical logic use non-linear effects. In the communication wavelength range, silicon on insulator (SOI) photonic integrated circuits (PICs) are ideal for those operations having low loss, high power confinement and high power density. Amorphous silicon (a-Si) on SOI has many advantages over crystalline silicon (c-Si) such as high Kerr-effect and low non-linear absorption. Non-linear effects [1, 3] based on the Kerr effect such as Self-Phase Modulation (SPM) and Cross-Phase Modulation (XPM) are useful for all optical signal regeneration, multiplexing, wavelength conversion [4, 5].
In spite of many advantages though, hydrogenated amorphous silicon (a-Si:H) exhibits a degradation when exposed to high intensity of light for a long time. This effect is called the Staebler-Wronski effect. By slightly increasing the band gap value by doping carbon in a-Si:H, it could be possible to reduce this effect to a large extent.

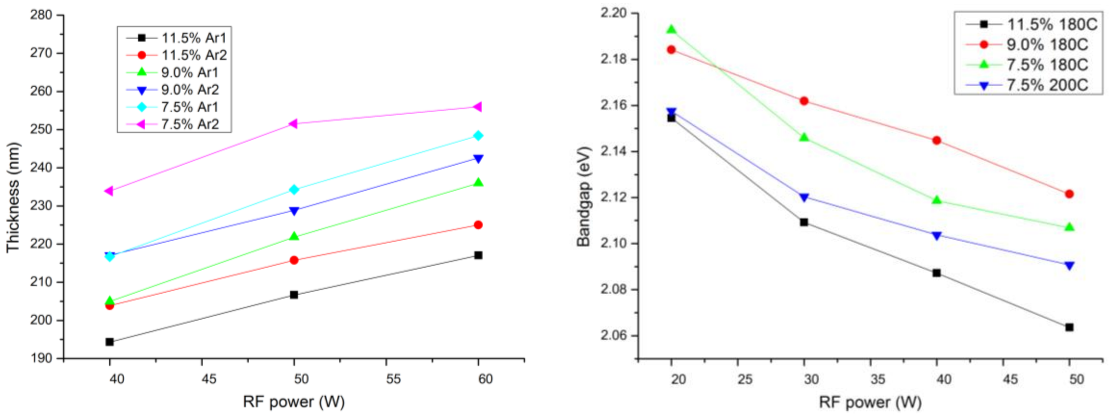
Experimental

We prepared various carbon doped a-Si:H and non-doped a-Si:H thin-layers on glass and silicon wafer by a high frequency rf plasma-enhanced chemical vapour deposition (PECVD) using different rf powers and different substrate temperatures. The substrate temperature was kept between 180^0C and 200^0C. The rf power was varied from 20 to 150W. Silane (SiH_4) and methane (CH_4) flow-ratio control the percentage of carbon-doping during deposition. Argon gas was used for passivation. Both the carbon doped a-Si:H and a-Si:H thin-films were characterized by ultraviolet-visible-infrared (UV-VIS-IR) spectroscopic ellipsometry (SE). The SE data are analyzed to obtain structural and optical properties of the carbon doped a-Si:H and a-Si:H thin-films. In order to calculate the desired values (e.g. films thickness, optical constants) from the measured data, a suitable optical model has been applied.

First, 220 nm of a-Si:H was deposited using PECVD process on top of 2000 nm buried oxide. Waveguides of varying width (2µm to 8µm) were fabricated using optical lithography and dry etching [6]. The waveguides were cleaved at both facets with different lengths and interfaced to optical lensed fibers for input and output coupling of light.
Carbon doped a-Si:H and a-Si:H thin-films were exposed to high power radiation (15mW cw laser at 1550nm) for 30 and 50 hours to estimate the degradation.

Results

The deposition rate increases with increasing r.f. power (Fig.1 (a)). From SE data analysis of optical constants, it is evaluated that the band gap value decreases with increasing r.f. power (Fig.1 (b)). It is observed that the Ar gas flow has strong influence on the deposition rate. It is found that the deposition rate varies from 38nm/min to 50nm/min for a substrate temperature at 180^{0}C. Also the band gap value decreases with increasing dilution ratio for Ar gas (Fig.2).



(a) (b)

Fig.1: (a) Variation of deposition thickness and (b) band gap value with the r.f. power for different SiH_4-CH_4 mixtures and different temperatures.

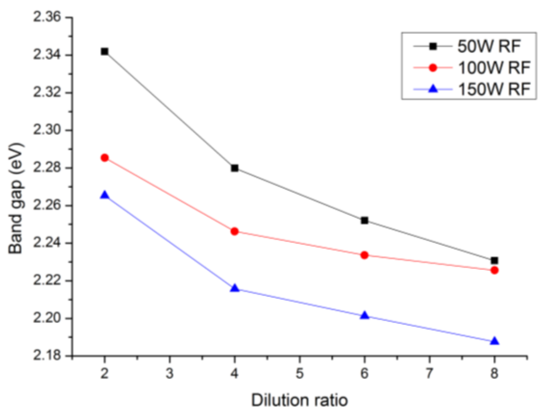


Fig.2: Variation of band gap value with dilution ratio of Ar gas with different rf power.

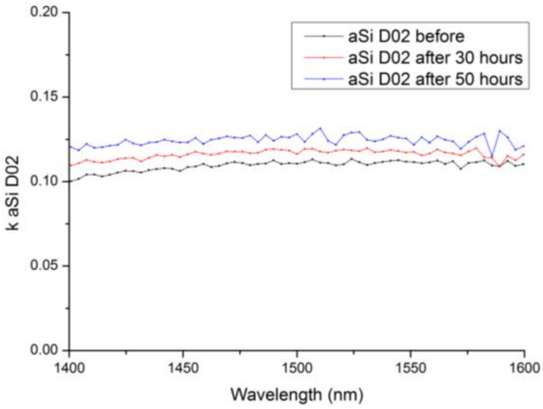


Fig.3: Increase in k-value of a-Si:H due to degradation with exposure of high intensity light for 30 and 50 hours.

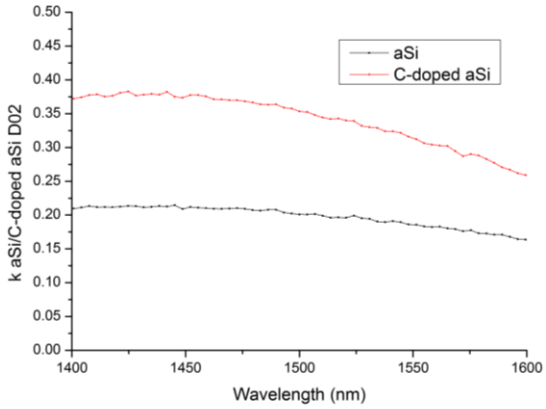
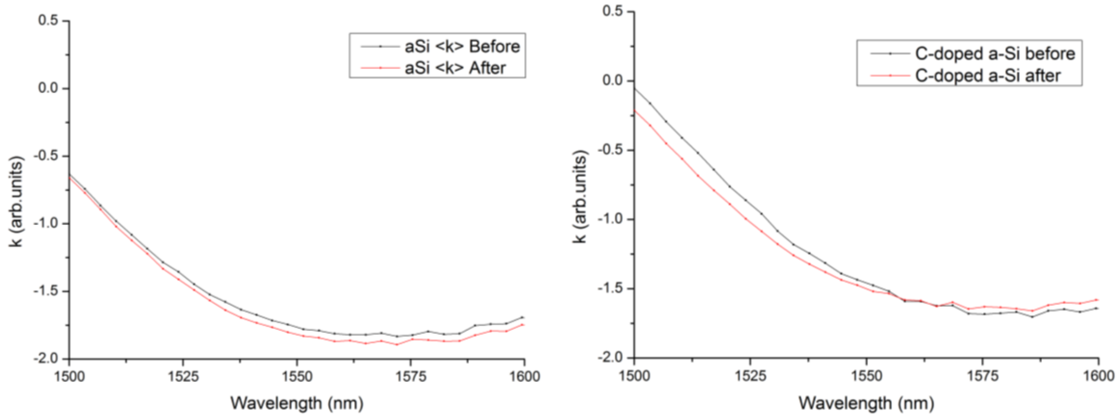
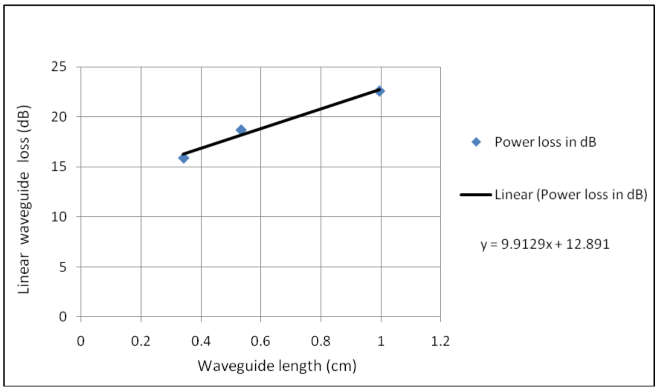


Fig.4: Relative comparison for k-values between aSi:H and carbon-doped aSi:H.



(a) (b)

Fig.5: (a) Change in k-value of a-Si:H and (b) carbon doped a-Si:H thin-films deposited on SOI with exposure of high intensity light for 30 hours.



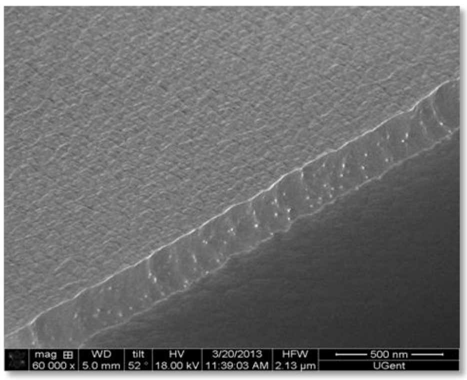


Fig.6: Linear loss of carbon-doped a-Si:H waveguide with dimensions 6µm X 0.220µm

Fig.7: SEM image of 6um wide carbon-doped a-Si:H waveguide.

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Fig.3 shows the degradation of a-Si:H due to exposure with high intensity of light for 30 and 50 hours. Syntune tuneable cw laser has been used for exposure at 12dBm output power and with central wavelength tuned at 1550nm. It is found from the figure that we have around 10% and 20% increased in k-value for the exposed duration of 30 and 50 hours respectively. Fig.4 shows a relative comparison for k-values between aSi:H and

carbon-doped aSi:H. Fig.5.(a) and Fig.5.(b) represents the change in k-values for a-Si:H and carbon-doped a-Si:H thin-films deposited on SOI with exposure of high intensity of light for 30 hours. It is found that the carbon-doped a-Si:H thin-film has less degradation for the central wavelength around 1550nm.
Fig.6 represents the measured linear loss of carbon-doped a-Si:H waveguides with cross-sectional dimensions as 6μm X 0.220μm. The linear loss for the multimode waveguides have been calculated as 9.9dB/cm. Fig.7 shows the sidewall roughness of such multimode waveguides.

Conclusions

Thin film thickness, structural and optical properties of carbon doped a-Si:H and a-Si:H thin films deposited using PECVD system have been measured by UV–VIS-IR SE. It has been found that carbon doped a-Si:H material has low degradation compared to a-Si:H in the wavelength regime around 1550nm. Carbon-doped a-Si:H waveguides have been successfully fabricated and measured for linear loss. The sidewall roughness of those waveguides needs to be minimized by optimizing the etching process to have low linear loss waveguides.

Acknowledgement

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