Structural and Loss Characterization of SiON Layers for Optical Waveguide Applications

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Silicon oxynitride films for optical waveguide applications were grown at 350°C in a PECVD reactor. ATR-FTIR spectroscopy was used to identify the bond structure and absorption characteristics in the mid-infrared region. Annealing of the films was performed together with close monitoring of the N-H bond at 3400 cm⁻¹ and correlated with optical loss measurements. The possibility of a new method for the reduction of the N-H bonds without annealing is discussed.

PECVD Deposition. Silicon oxynitride films were grown on a parallel plate PECVD reactor at 13.56 MHz and 350 °C. The index of refraction of the films could be changed between 1.46 and 2.0 by controlling the flow rates of 2%SiH₄/N₂, N₂O and NH₃ precursor gases, Fig.1.

Figure 1: Variation of the index of refraction with the change of flow rate of N₂O and NH₃ at constant 2%SiH₄/N₂ flow rate of 180 sccm.

FTIR Characterization. The compositional properties of oxynitrides are expected to vary between those of silicon oxide and nitride. Therefore, monitoring of their bond structure should result in a

better control of the properties of SiON films. In the absorption spectrum of the SiO_x films, (Fig.2) the characteristic vibrations are observed: Si-O rocking and stretching vibrations at 490 cm⁻¹ and 1070 cm⁻¹ respectively, Si-H stretching and bending vibrations at 2230 and 800 cm⁻¹ and O-H stretching at 3500 cm⁻¹ and N-H stretching at 3350 cm⁻¹ [1]. As seen from Fig. 2, with increasing N₂O flow rate the N-H bond absorption is reduced, while that of O-H absorption has increased.

Figure 2: FTIR spectrum of PECVD silicon oxide films.

In the absorption spectrum of silicon nitrides there is no significant change with the flow rate change of NH₃. The

characteristic absorption bands are identified as Si-N stretching and bending vibrations at 850 & 1170 cm^{-1} , Si-H stretching at 2200 cm^{-1} and N-H stretching at 3350 cm^{-1} , [2].

Owing to the above considerations SiON films were grown with N_2O and NH_3 flow rates of 225 & 15 sccm respectively with the refractive index of 1.51.

Annealing Study. The first overtone of the N-H stretching vibration is known to be the main cause of the optical loss at 1.55 μm wavelength region. Therefore our first concern is to reduce this absorption by elimination of the N-H bond incorporated

Figure 3. Behavior of the N-H absorption band with annealing in N_2 ambient at different temperatures.

into the film [3]. Silicon oxynitride films were annealed at different temperatures and the N-H absorption band was monitored (Fig.3). The N-H peak was observed to be eliminated at 1000 $^{\circ}\text{C}$ within the detection limit. For more sensitive analysis a Si ATR prism was used. The evanescent wave penetrating into the SiON film samples only about 0.2 μm of the SiON film close to the interface. We observe that there is still residual N-H absorption present even at 1000 $^{\circ}\text{C}$ annealing, in contrast with simple absorption experiments. It disappears completely at 1150 $^{\circ}\text{C}$ after 4 hrs annealing (Fig.4).

Figure 4. ATR study of the annealing behavior of the N-H bond.

Deconvolution of the N-H band shows several different species of N-H bonds some of which disappear upon annealing suggesting that it may be possible to control them through appropriate process parameters during growth.

Optical loss of the deposited and annealed SiON films was measured and found to be correlated with the obtained ATR results.

Conclusion. The compositional properties of SiON films were investigated. The N-H absorption, responsible for the optical loss, was monitored by ATR-FTIR and showed residual absorption even after 1000 $^{\circ}\text{C}$ annealing. Deconvolution of the N-H band showed several N-H species. The optical loss at 1.55 μm was reduced by annealing above 1100 $^{\circ}\text{C}$.

References:

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