

# Structural Study of Buried Nitride Layers Synthesized by SIMNI Process

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**Abstract** - Silicon nitride (SiN) buried layers were synthesized by SIMNI process using 140 keV ( $^{14}\text{N}^+$ ) ion implantation at high fluence levels ranging from  $1.0 \times 10^{17}$  to  $5.0 \times 10^{17}$   $\text{cm}^{-2}$  into  $\langle 111 \rangle$  single crystal silicon substrates at high temperature (410  $^{\circ}\text{C}$ ). The samples were annealed at 1200  $^{\circ}\text{C}$  for 60 minutes in argon ambient. The FTIR spectra of samples reveal absorption band associated with the stretching vibration of Si-N bonds indicating the formation of silicon nitride. The transmission studies show that the annealing of the samples shifts all the IR peaks towards higher frequencies and the bands become sharper. The shift of the IR transmission band towards higher frequencies after annealing is due to release of bond strain which was introduced into  $\text{Si}_3\text{N}_4$  film during implantation.

**Index Terms** - Buried, FTIR, Silicon Nitrate, Implantation.

## I. INTRODUCTION

The research interest is growing currently in the area of high fluence ( $\geq 10^{16}$  ions- $\text{cm}^{-2}$ ) reactive ion-implantation in silicon at medium energy to produce buried layer of materials with compositions and structures unattainable by conventional technique. The synthesis of buried insulating layers to produce silicon-on-insulator (SOI) structures by SIMNI (separation by implanted nitrogen) process using high fluence nitrogen ion implantation into silicon has scope of potential applications in semiconductor device technology. In this paper, we present the synthesis of buried silicon nitride insulating layers by implantation of nitrogen ( $^{14}\text{N}^+$ ) ions at 140 keV to high fluence levels ranging from  $1.0 \times 10^{17}$  to  $5.0 \times 10^{17}$  ions- $\text{cm}^{-2}$  into silicon substrates at room temperature and at high temperature (410  $^{\circ}\text{C}$ ). The structural characterization of ion-beam synthesized SIMNI structures has been carried out using Fourier transform infrared (FTIR) spectroscopy.

## II. EXPERIMENTAL DETAILS

Single crystal silicon wafers (p-type, 10-15  $\Omega\text{-cm}$  resistivity and  $\langle 111 \rangle$  orientation) were used as substrate material. The silicon wafers were thoroughly cleaned adopting standard RCA-I and RCA-II cleaning procedures using electronic grade chemicals and distilled deionized (DI) water. These wafers were then cut into  $1\text{cm} \times 1\text{cm}$  size samples for loading onto the sample holder of the implanter. To synthesize the buried silicon nitride insulating layers, samples were implanted at 140 keV with nitrogen ( $^{14}\text{N}^+$ ) ion beam to fluence levels ranging from  $1.0 \times 10^{17}$  to  $5.0 \times 10^{17}$  ions- $\text{cm}^{-2}$  at room temperature and at high temperature (410  $^{\circ}\text{C}$ ). The samples at low fluence rate were implanted using 150 KV ion accelerator facility at Materials Science Division, IGCAR, Kalpakkam. The ion-beam current density varied from 1 to 3  $\mu\text{A}\text{-cm}^{-2}$ . The scanned beam was collimated through a collimator of diameter 12.5 mm. A vacuum of the order of  $1.0 \times 10^{-6}$  mbar was maintained in the target chamber during implantation. A vacuum of  $10^{-7}$  mbar was maintained in the target chamber during implantation. The identification of structure of ion-beam synthesized buried silicon nitride insulating layers was carried out using FTIR spectroscopy studies. The FTIR spectra were recorded in the spectral region 6000-400  $\text{cm}^{-1}$  in transmission mode at normal incidence on JASCO-610 FTIR spectrometer at the Department of Physics, University of Mumbai. The spectra were calibrated with respect to an etched reference silicon sample for background correction.

## III RESULTS AND DISCUSSION

Fig. 1 shows FTIR spectra of the silicon samples implanted at high temperature (410  $^{\circ}\text{C}$ ) with 140 keV

$^{14}\text{N}^+$  at fluence levels of  $1.0 \times 10^{17}$ ,  $2.5 \times 10^{17}$  and  $5.0 \times 10^{17} \text{ cm}^{-2}$ .

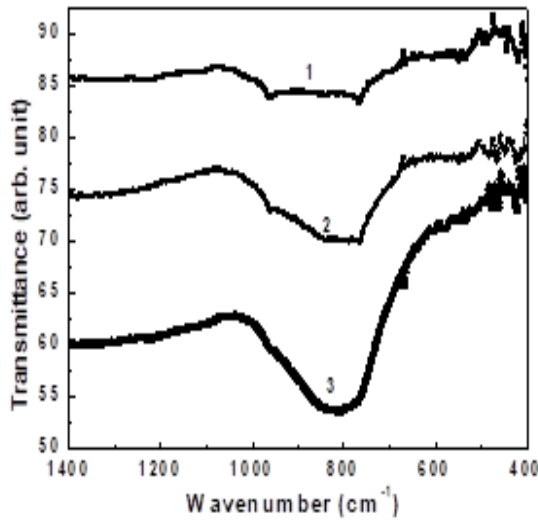


Fig.1: FTIR spectra of silicon samples implanted at 140 keV at high temperature (410 °C) to fluence level; (1)  $1.0 \times 10^{17}$ , (2)  $2.5 \times 10^{17}$  and (3)  $5.0 \times 10^{17} \text{ N}^+ \text{ cm}^{-2}$ .

The samples show an absorption band in the wavenumber range  $1040\text{-}580 \text{ cm}^{-1}$ . The area of the band increases with increasing the ion fluence. The sample implanted to fluence of  $1.0 \times 10^{17} \text{ ions}\text{-cm}^{-2}$  show broad absorption band in the range  $960\text{-}582 \text{ cm}^{-1}$  centered at  $781 \text{ cm}^{-1}$ . As fluence increases, it is observed that the range of the IR absorption band and peak position both shift towards higher wavenumber (Table 1). The silicon nitride films are reported to show IR main absorption band in the range  $1000\text{-}700 \text{ cm}^{-1}$  [1]. The observed absorption band in the present work is associated with the stretching vibration of the Si–N bonds and indicates the formation of silicon nitride. As the fluence increases, the transformation of implanted layer into stoichiometric  $\text{Si}_3\text{N}_4$  occurs.

Table 1. Absorption band range, peak position and number of bonds determined from FTIR spectra.

| Fluence ( $\text{cm}^{-2}$ ) | As Implanted                       | Annealed at 1200 °C                |     |     |     |
|------------------------------|------------------------------------|------------------------------------|-----|-----|-----|
|                              | Peak Position ( $\text{cm}^{-1}$ ) | Peak Position ( $\text{cm}^{-1}$ ) |     |     |     |
| $1.0 \times 10^{17}$         | 781.0                              | 798.3                              | 850 | 889 | 935 |
| $2.5 \times 10^{17}$         | 796.4                              | 798.3                              | 845 | 884 | 930 |
| $5.0 \times 10^{17}$         | 813.8                              | 798.3                              | 845 | 884 | 930 |

The concentration of absorbing bonds from the FTIR spectra was calculated using the following relation;

$$C = C_n (\text{cm}^{-2}) \int \alpha(\omega) / \omega d\omega (\text{cm}^{-1}) \quad (1)$$

where C is the concentration of the absorbing bonds,  $\alpha(\omega)$  is the absorption coefficient of the layer,  $\omega$  is the wavenumber and  $C_n$  is the proportionality constant [2]. After converting the transmission spectra of Fig.1 into absorbance spectra,  $\alpha(\omega) / \omega$  versus  $\omega$  plots were generated. From these plots, the total integrated absorption coefficients were determined and the concentration of the absorbing bonds was calculated using Eq. (1) as shown in Table I. In these calculations, the thickness  $d = 1802 \text{ \AA}$  ( $2\Delta R_p$  for 140 keV nitrogen in silicon) for buried silicon nitride layer and  $C_n = 6.9 \times 10^{18} \text{ ions}\text{-cm}^{-2}$  [3] were used. It is observed that the number of bonds increases with ion-fluence.

Table 2. FTIR peak position for as-implanted and annealed samples

| Fluence ( $\text{ions}\text{-cm}^{-2}$ ) | Position of band ( $\text{cm}^{-1}$ ) | Peak Position ( $\text{cm}^{-1}$ ) | No. of bonds ( $\text{cm}^{-3}$ ) |
|------------------------------------------|---------------------------------------|------------------------------------|-----------------------------------|
| $1.0 \times 10^{17}$                     | 960-582                               | 781.0                              | $5.44 \times 10^{21}$             |
| $2.5 \times 10^{17}$                     | 1008-600                              | 796.4                              | $1.10 \times 10^{22}$             |
| $5.0 \times 10^{17}$                     | 1040-607                              | 813.8                              | $1.95 \times 10^{22}$             |

Fig. 2 shows the FTIR spectra of the silicon samples implanted with 140 keV nitrogen at high temperature to fluence levels of  $1.0 \times 10^{17}$ ,  $2.5 \times 10^{17}$  and  $5.0 \times 10^{17} \text{ cm}^{-2}$  and annealed at 1200 °C are shown in Fig. 2. The FTIR spectra of the annealed samples of fluence  $1.0 \times 10^{17} \text{ cm}^{-2}$  (Table 2) shows a fairly sharp absorption peak near  $798 \text{ cm}^{-1}$ , together with the small peaks overlapping the main broad Si-N band present at 850, 889 and  $935 \text{ cm}^{-1}$  [2,3,4,5]. This absorption band is associated with the stretching vibration of the Si–N bonds and indicates the formation of  $\alpha\text{-Si}_3\text{N}_4$ . Absorption peaks due to the Si-O bond at  $1083 \text{ cm}^{-1}$  indicating that silicon is thermally oxidized during annealing. As the fluence increase the transmission spectra of the annealed samples showed the band become sharp and intense. The shift of the IR transmission band towards higher frequencies after annealing is due to release of bond strain which was introduced into  $\text{Si}_3\text{N}_4$  film during implantation.

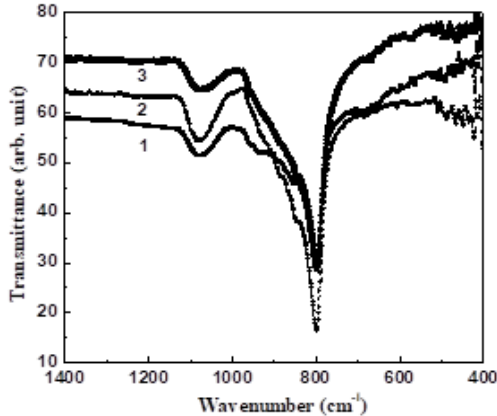


Fig.2: FTIR spectra of annealed silicon samples implanted at 140 keV at high temperature (410 °C) to fluence level; (1)  $1.0 \times 10^{17}$ , (2)  $2.5 \times 10^{17}$  and (3)  $5.0 \times 10^{17} \text{ N}^+ \text{ cm}^{-2}$ .

### CONCLUSION

The buried silicon nitride layers were synthesized using SIMNI process by implantation at 140 keV with nitrogen ( $^{14}\text{N}^+$ ) ions at high fluence levels into silicon substrates held at room temperature and at high temperature (410 °C). The FTIR studies show absorption band associated with the stretching vibration of the Si–N bonds indicating the formation of buried silicon nitride layer. The shift towards higher frequencies with increasing ion fluence shows gradual chemical transformation of implanted layer towards stoichiometric composition of  $\text{Si}_3\text{N}_4$ . Higher fluence rate implanted sample shows more amorphization than the lower fluence rate implanted sample.

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