JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AFM analysis of SOI structures synthesized by dual ion implantation of oxygen and nitrogen in silicon

A. P. Patel*
*Department of Physics, VPMK's, Arvind (Appasaheb) Bhanushali College, Kinhavali, Shahapur, Thane, Maharashtra, India.
E-mail: ajaypatel13@gmail.com

Abstract

The silicon-on-insulator (SOI) structures were synthesized by separation by implanted nitrogen-oxygen (SIMNOX) process. Silicon oxynitride ($Si_xO_xN_x$) buried insulating layers of different structures were synthesized by $^{14}N^+$ and $^{16}O^+$ ion implantation sequentially in the ratio 1:1 to different fluence levels at 150 keV into single crystal silicon wafers. The roughness analysis of the SOI structures synthesized by implantation of nitrogen and oxygen in silicon at 150 keV are characterized by the AFM techniques. The hills surrounded by the crater type features are observed for higher fluence samples. The rms roughness increases for fluence 1.0×10^{18} cm^{-2} and becomes maximum for the fluence 2.0×10^{18} cm^{-2}. The hills observed on the surface are due to swelling which occur as a result of outdiffusion and segregation of the displaced Si atoms on the surface during implantation. At higher fluences, the decrease in the density followed by increase in the height of hill type structures may be due to sputtering and accumulation of the displaced atoms through surface diffusion

Keywords: Silicon oxynitride, AFM

1. Introduction

The silicon oxynitride films are being examined as potential materials in re-placing silicon oxide (SiO_2) in metal-oxide semiconductor (MOS) devices [1]. The main advantages of SiO_2 are high electrical resistivity, low interface state density and high dielectric strength. However, it has limitation of being susceptible to alkali ion diffusion and radiation damage effects. On the other hand, the silicon nitride (Si_3N_4) films have very low permeability to alkali ions and other impurities, high radiation resistance and high dielectric constant but it refers from the undesirable features of high interface states. Moreover, the Si_3N_4 films exhibit high tensile stress that led to cracking of the films on some substrates, notably after post deposition heat treatments. In view of the above, silicon oxynitride ($Si_xO_yN_z$) layer seems to be a potential candidate for the incorporation of the positive features of both silicon dioxide (SiO_2) and silicon nitride (Si_3N_4). It may be possible to preserve the excellent electronic characteristics of the SiO_2 and the alkali ion diffusion barrier properties of the Si_3N_4 in silicon oxynitride by choosing the proper composition. Silicon oxynitride has the advantage that it does not crystallize even after high temperature annealing. The dielectric constant is found to increase from 3.9 for SiO_2 (SiO_2N_0) to 7.5 for Si_3N_4 ($Si_3O_0N_4$) almost linear with the nitrogen content in the oxynitride [2]. The diffusion suppressing properties of oxynitrides are also of interest [3]. The silicon oxynitride ($Si_xO_yN_z$) thin films are of great importance for the development of integrated devices and sensors in the microelectronics and opto-electronic industries due to the wide range of variation of their stoichiometric properties. These films are transparent in the visible range and their refractive index (RI) can be varied from 1.46 (silicon oxide) to 2 (silicon nitride) by changing their stoichiometry. These interesting properties of ($Si_xO_yN_z$) films are required for the optical applications. The large variation of the refractive index of silicon oxynitride ($Si_xO_yN_z$) films, is useful for the design of a large variety of waveguide structures.

In these paper silicon oxynitride ($Si_xO_yN_z$) buried insulating layers of different structures were synthesized by $^{14}N^+$ and $^{16}O^+$ ion implantation sequentially in the ratio 1:1 to different fluence levels at 150 keV into single crystal silicon wafers. AFM micrograph for dimension of 10 µm × 10 µm of silicon surface unimplanted and implanted with 150 keV O^+ and N^+ ions at total fluence level of 1.0×10^{17}, 2.5×10^{17}, 5.0×10^{17}, 1.0×10^{18} and 2.0×10^{18} cm^{-2}

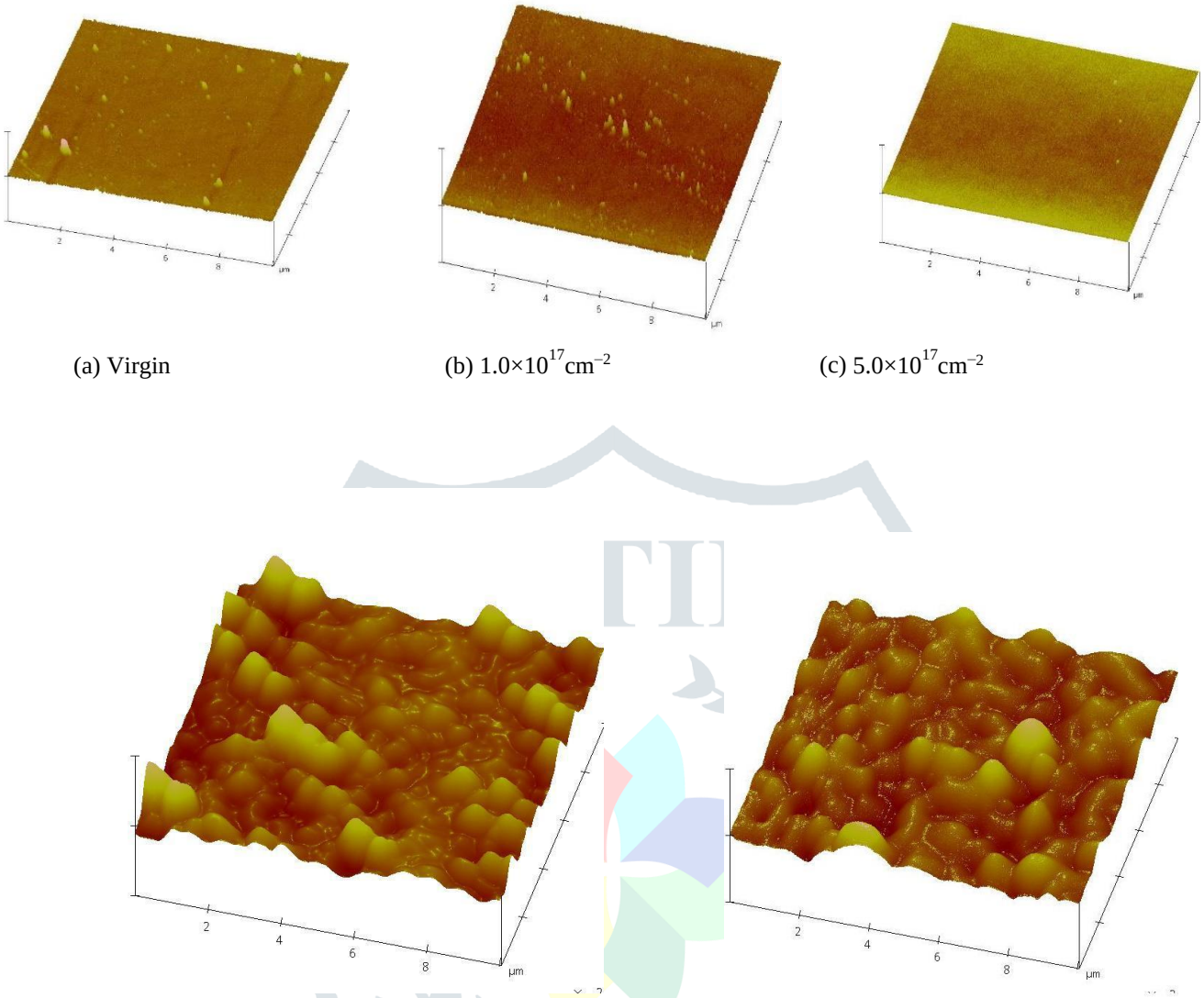
2. Experimental Details

Single crystal silicon wafers (p-type, 10 - 50 Ω-cm resistivity and <100> 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 sizes of 1cm × 1cm samples for loading onto the sample holder of the implanter. To synthesize the silicon oxynitride insulating layers, samples were implanted with $^{16}O^{2+}$ and $^{14}N^{2+}$ in the ratio 1:1 into silicon at room temperature to total fluence level of 1.0×10^{17} cm^{-2} to 2.0×10^{18} cm^{-2} at 150 keV energy. The samples with oxygen to nitrogen ratio of 1:1 was prepared using the 150 keV energy using low energy ion beam facility (LEIBF) at IUAC, New Delhi. Atomic force microscopy measurements were carried out Nanoscope IIIa scanning probe microscope in a tapping atomic force microscope (AFM) mode. The atomic force microscopy were carried out with silicon nitride tip under ambient conditions in the contact mode. The surface morphology of implanted silicon samples for different ion fluences were examined. AFM micrograph for dimension of 10 µm × 10 µm of silicon surface unimplanted and implanted with 150 keV O^+ and N^+ ions at total fluence level of 1.0×10^{17}, 2.5×10^{17}, 5.0×10^{17}, 1.0×10^{18} and 2.0×10^{18} cm^{-2}.

3. Results and Discussions

AFM micrographs of the reference and samples implanted with different fluence levels are presented in Fig. 1. The unimplanted sample shows some small hill type scattered structure with root mean square (rms) roughness of 1.20 nm. The rms roughness is found to vary with ion fluence. After implantation to the fluence of $1.0\times10^{17}cm^{-2}$, the density of the hill type structure increases. However, the density of hills decreases for fluence $5.0\times10^{17}cm^{-2}$. The surface of this sample is smoother than the surface of the sample implanted with fluence $1.0\times10^{17}cm^{-2}$. The hills surrounded by the crater type features are observed for higher fluence samples. The rms roughness increases for fluence 1.0×10^{18} cm^{-2} and becomes maximum for the fluence 2.0×10^{18} cm^{-2}. It is observed that the rms roughness for the dual implanted silicon surface initially shows small variation but for very high fluence it increases ($\geq 1.0\times10^{18}$ cm^{-2}) rapidly.

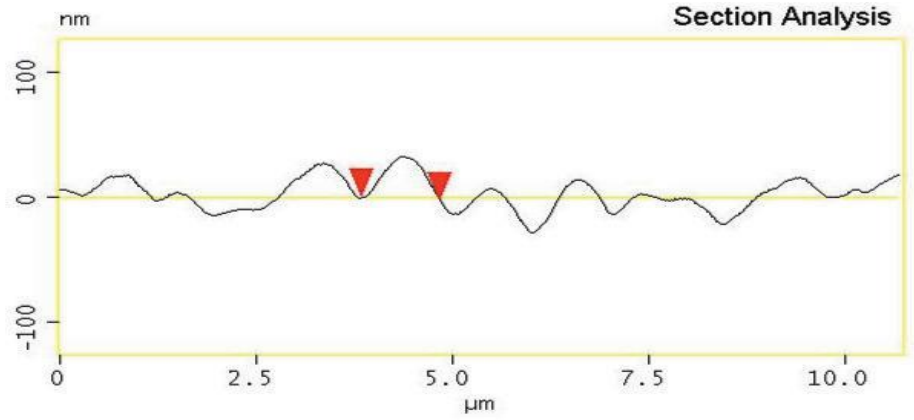
Initially at lower implantation fluences, the surface smoothening occurs due to surface sputtering. At higher fluences, the surface is heavily damaged which gives rise to higher surface sputtering which results in increase in the surface roughness. From the section analysis of the Si surface (Fig. 2), the density of hills for 1.0×10^{18} cm^{-2} irradiated sample is found to be more than that observed for 2.0×10^{18} cm−2 however the height of the hill is observed to increase with fluence. The height of the combined or grouped damaged zones calculated from Fig. 2a is of the order of 8-50 nm and that for highest fluence (Fig. 2b) is 10-88 nm. It appears that a group of non-diffusing damaged zones are combined to form a big damaged zone [4]. The hills observed on the surface are due to swelling which occur as a result of outdiffusion and segregation of the displaced Si atoms on the surface [4] during implantation. At higher fluences, the decrease in the density followed by increase in the height of hill type structures may be due to sputtering and accumulation of the displaced atoms through surface diffusion [5].



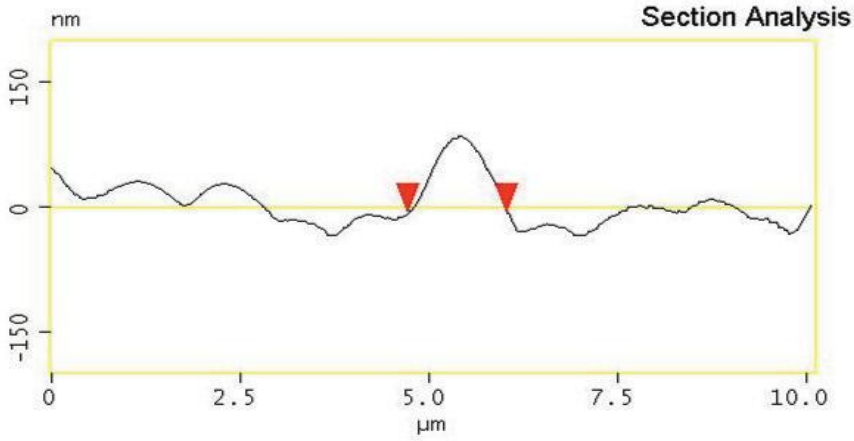
(a) Virgin (b) $1.0\times10^{17}cm^{-2}$ (c) $5.0\times10^{17}cm^{-2}$

(d) $1.0\times10^{18}\ cm^{-2}$ (e) $2.0\times10^{18}\ cm^{-2}$

Figure 1: 2-Dimensional AFM (10 µm x 10 µm) micrograph of silicon surface irradiated with 150 keV O^+ and N^+ ions with fluence levels, (a) Virgin, (b) 1.0×10^{17}, (c) 5.0×10^{17}, (d) 1.0×10^{18} and (e) $2.0\times10^{18}\ cm^{-2}$



(a)



(b)

Figure 2: Section analysis of the Si surface irradiated with 150 keV $O^+$and N^+ ions at total fluence of (a) 1.0×10^{18} cm^{-2} and (b) 2.0×10^{18} cm^{-2}.

4. Conclusion:

Silicon oxynitride ($Si_xO_xN_x$) buried insulating layers of different structures were synthesized by $^{14}N^+$ and $^{16}O^+$ ion implantation sequentially in the ratio 1:1 to different fluence levels at 150 keV into single crystal silicon wafers. The AFM studies show that the high fluence ion implantation leads to the surface swelling due to out diffusion of silicon atoms from the bulk. The formation of conical hill-like structure in the surface region is observed in the silicon wafer as a result of ion bombardment. The decrease in the surface roughness is caused by surface sputtering. The increase in the density of the hills on the silicon surface at higher fluences is found to be the result of swelling as the fluence increases.

5. References

1. N. Konofaos, E. K. Evangelou, Semicond. Sci. Technol. 18 (2003) 56.
2. M. L. Green, E. P. Gusev, R. Degraeve and E. L. Garfunkel, J. Appl. Phys. 90 (2001), 2057.
3. T. Murataa, T. Yamaguchia, M. Sawadaa, S. Shimizua, K. Asaia, K. Kobayashib, H. Miyatakea and M. Yonedaa Thin Solid Films 515 (2007) 4966.
4. J. P. Singh, R. Singh, D. Kanjilal, N. C. Mishra and V. Ganesan J. Appl. Phys., 87 (2000) 2742.
5. P. K. Giri, V. Raineri, G. Franzo and E. Rimini, Phys. Rev. B 65, (2001) 012110.