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Cluster Carbon implants – cluster size and implant temperature effect

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Abstract

In this paper we present results for amorphous layer thickness and interface roughness for various cluster carbon ions as well as monomer carbon implants for various doses implanted at different implant temperatures. The effect of cluster size, implant dose, implant dose rate and wafer implant temperatures are discussed based on Spectroscopic Ellipsometry, TEM and RBS/channeling techniques.

1. Introduction

Cluster ion implantation is an attractive alternative approach to satisfy stringent conditions required for technology nodes below 32nm. Cluster Carbon is an alternative for creating ~~an~~ amorphous layers as well as controlling dopant diffusion [1]. Use of co-implants (such as C, F etc) to control dopant diffusion has been studied earlier [2, 3]. Heavier species, such as Ge, Xe or Sb, have been used to create amorphous layers to avoid channeling and as well as to increase dopant activation [4, 5]. However, such "pre-amorphization implants" (PAI) implants produce end of range (EOR) damage that is difficult to anneal, creating leaky junctions [6]. Recently low temperature (-50°C) implants have been used to produce thicker amorphous layers [7]. Although there has been considerable progress in understanding the mechanisms and modeling of damage and amorphous layer formation at various implant temperatures and dose rates for single-atom ions [8] and room temperature impact of molecular ions [9, 10], there has been, as yet, very little systematic study of the effect of implant temperature on damage created by molecular ions.

In this study we highlight self-amorphization and discuss the amorphous layer thicknesses produced by the various cluster ion species, C_{16} & C_7 and C. Measurements are made using Spectroscopic Ellipsometry (SE) and Rutherford Backscattering (RBS/channeling) techniques of the effect of cluster size, implant dose, implant dose rate and wafer implant temperatures. This study will enhance the understanding of how low temperature implant and clusters can be utilized to enhance damage accumulation during implant. The impact of implant temperature and cluster ion type on residual damage after annealing and progress towards the goal of reduction of junction leakage current will be addressed in a follow-on study.

2. Experiment

All of the wafers used in this study were 300mm, p-type, (100) silicon substrates. Cluster Carbon species $C_{16}H_{10}$ (referred as C_{16}), C_7H_7 (referred as C_7) and monomer C are used in this study.

The wafers were implanted at 3keV monomer equivalent energy at various doses and different wafer implant temperatures using a CLARIS tool at Nissin's USA demo center at the SemEquip facility. The implant doses used were 5e13, 1e14, 3e14 and 1e15 atoms/cm^2. The coolant temperatures, assumed as the wafer implant temperature, were, room temperature (RT), 0°C and minus 30°C (-30°C). All the samples were analyzed using SE and RBS/channeling to measure the amorphous layer thickness and interface roughness. RBS/channeling measurements were carried out using a grazing (84.5°) detection geometry to enhance the depth resolution.

3. Results and Discussions

Fig. 1 shows SE measurements for amorphous Si layer thickness (α-Si) for 3keV equivalent energy for C, C_7 and C_{16} for various doses and wafer implant temperatures.

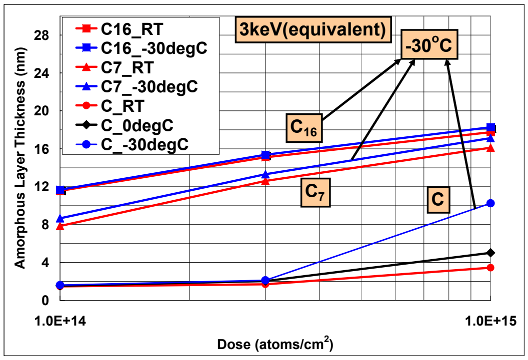

Fig. 1 shows amorphous layer thickness determined using SE for C, C_7 and C_{16} ions implanted at 3keV per carbon atom for various doses at three different implant temperatures.

From the Fig. 1, it can be easily seen that heavier cluster species (C_{16}) creates thicker amorphous layers when compared to lighter ones (C_7 and C_1). Low temperature is more effective for C_1 than for C_7 and C_{16}. The general trend of larger amorphous layer thickness with increase in dose is seen here too. The amorphous layer thickness from C_7 and C_{16} at 3e14 dose (> 11nm) at RT is larger than the value at 1e15 dose (~ 10nm) for C_1 at -30^{o}C. Similarly, the amorphous layer thickness for C_{16} at 3e14 dose (~16nm) is similar to the value at 1e15 dose (~ 16nm) for C_7 at -30^{o}C. Heavier clusters at RT at a lower dose can be more efficient for creating thick a-Si layers than C_1 for higher doses at -30^{o}C.

Fig. 2 shows the difference in amorphous layer thickness between C_{16} and C_7 for various doses at different wafer implant temperatures. The difference is highest for RT implants when compared to low temperature implants for all the implant doses. The reference amorphous layer thickness here is 16nm for C_7 for 1e15 dose at RT. The cluster effect is more if this difference is larger. This heavier cluster effect reduces from 3.6nm at 1e14 dose (~ 25%) to 1.6nm for 1e15 dose (~10%). This indicates that heavier clusters are more effective for low implant doses. When the dose is high, even the cold implant effect (at -30^{o}C) is reduced from 18% at 1e14 dose to about 6% at 1e15 dose.

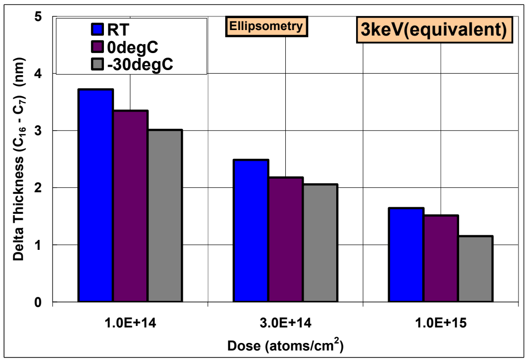

Fig. 2 shows the difference in amorphous layer thickness between C_{16} and C_7 species, determined using SE, implanted at -30^{o}C for 3keV per carbon atom at doses ranging from 1e14 to 1e15 atoms/cm^2.

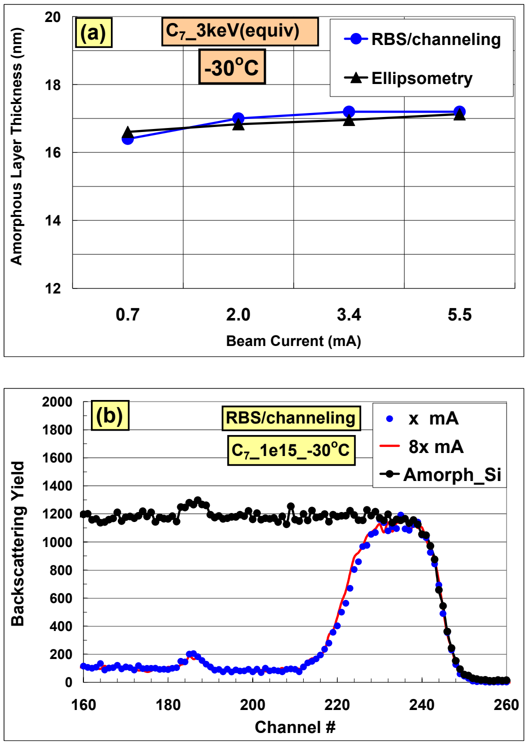

Fig. 3 (a) shows the amorphous layer thickness dependence on dose rate for C_7 @ 3keV per atom at 1e15 atoms/cm^2 using RBS/channeling and SE techniques. (b) shows RBS/channeling spectra for the lowest and highest dose rate cases along with a thick amorphous layer reference .

Fig. 3(a) shows both the ellipsometric and RBS/channeling results on the dose rate effect of C_7 species on the amorphous layer thickness for 3keV at 1e15 dose at -30^{o}C. It is clear from the figure that both ellipsometry and the RBS/channeling results agree very well on the amorphous layer thickness. From the figure the difference is just 0.5nm between the lowest and highest dose rate (8 times). This corresponds to a thickness variation of just 3% . This lies well within the ellipsometric resolution. Practically we can argue that there is no significant dose rate effect even for a lighter cluster. Heavier cluster or heavier mass will have no significant effect too. Shibata et al. have shown that with 2keV equivalent $B_{18}H_{22}$ implant showed roughly 7% increase in amorphous layer thickness for 100 fold increase in beam current and at room temperature implants [11]. Fig. 3(b) shows RBS/channeling spectra for the lowest and highest dose rate cases along with the reference spectrum for a thicker amorphous layer sample. The low dose spectrum lie one on top on the high dose case indicating basically identical amorphous layer thickness.

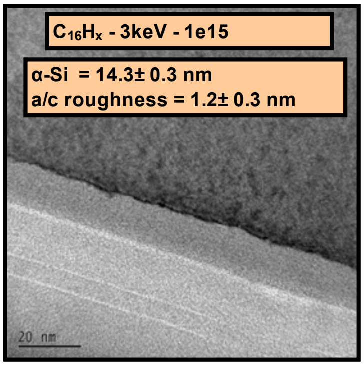

Fig. 4 shows XTEM image of the amorphous layer for C_{16} @ 3keV per atom at 1e15 atoms/cm^2 at room temperature.

Fig. 4 shows XTEM image of a C_{16} implant at 3keV, 1e15 at RT. The α-Si is 14.3nm and the a/c interface roughness is 1.2nm. But according to RBS data (Fig. 5), the interface thickness at RT is about 6nm, a clearly different measure of the a-Si boundary. The interesting point here is that, according to RBS, the roughness decreases by 1nm from RT to -30°C, which indicates a more abrupt interface for cold implant conditions.

Fig. 6 shows RBS/channeling spectra C_7 and C_{16} implanted at various implant temperatures at an implant energy of 3keV equivalent at various doses. Fig. 6(a) shows RBS spectra at 3e14 dose where both C_7 and C_{16} show incomplete amorphization.

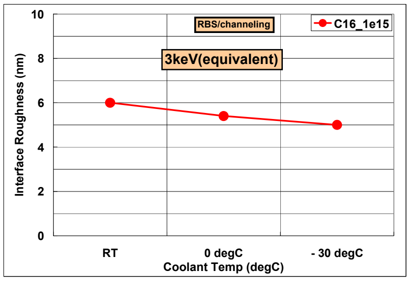

Fig. 5 shows interface roughness determined from RBS/channeling spectra for C_{16} @ 3keV per atom at 1e15 atoms/cm^2 at various implant temperatures.

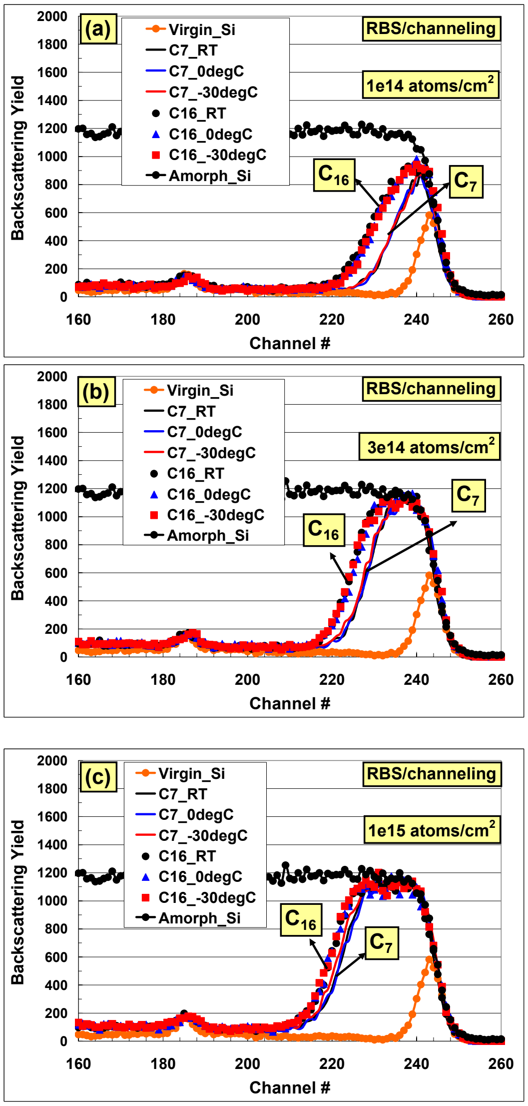

Fig. 6 (a), (b) and (c) show RBS/channeling spectra for C_7 and C_{16} implanted at various implant temperatures at an implant energy of 3keV equivalent. Fig. 6(a) shows spectra at 1e14 atoms/cm^2 (b) shows spectra at 3e14 atoms/cm^2 (c) shows spectra at 1e15 atoms/cm^2.

If there is continuous and complete amorphization, the top of the damage peak will merge with the reference thicker amorphous layer sample. A virgin Si spectrum is shown for clarity in understanding. The threshold of amorphization is more than 1e14 dose for both cluster carbon ion types. Looking at the temperature effect, it is clear that there is no significant effect on the C-cluster damage profiles, indicating that no temperature effect is active at low doses. But there is a significant difference between C_{16} and C_7 (bigger gap) indicating a strong cluster effect at low doses. For the higher dose at 3e14, the cluster size effect decreases slightly but again no temperature effect is observed. But the top of the profiles match with the reference thick amorphous sample indicating that 3e14 dose is equal to or above the amorphization threshold.

At 1e15 dose, there is just a slight difference between C_{16} and C_7, indicating a further reduction in the cluster size effect. But there appears a slight temperature effect at higher dose for C_7. The effect of implant temperature is much more significant for cluster sizes less than C_7.

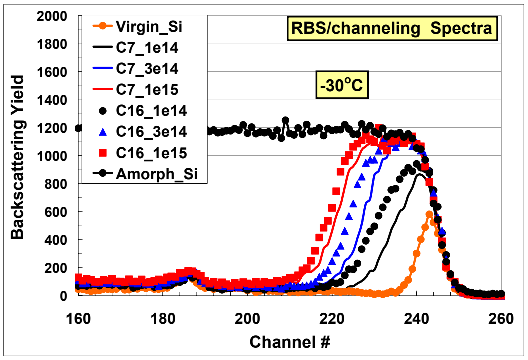

Fig. 7 shows RBS/channeling spectra for C_7 and C_{16} implanted at -30°C with an implant energy of 3keV equivalent at various doses.

Fig. 7 shows RBS/channeling spectra for C_7 and C_{16} implanted at -30°C at various doses. The difference between the profiles for C_7 and C_{16} is larger at lower dose and this difference decreases with increasing dose. This indicates that cluster size effects are more pronounced at lower doses.

4. Conclusions

Here we presented the amorphous layer thickness for C_{16}, C_7 and C species at 3keV equivalent implant energy for various doses at different wafer implant temperatures. SE and RBS/channeling measurements were in good agreement with each other. The amorphous layer thickness increases for heavier clusters and higher dose. The effect of implant temperature is significantly less for cluster ions, C_7 and C_{16}, than for monomer C_1 ions. Overall, cluster ions result in thicker a-Si layers than monomer C_1 at all doses and implant temperatures for 3keV equivalent energies. Additional studies are underway to evaluate the effects of implant temperature and ion type on residual damage after annealing and p-n junction leakage currents.

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