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Order and temperature dependence of surface blistering in H and He co-implanted Ge

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ABSTRACT

The effect of implantation order and post-annealing temperature on surface blistering of H and He co-implanted germanium was investigated in the samples implanted with H and He in different orders (H first then He or He first then H). It was found that blisters were easily formed in H-alone sample after annealing at 350 °C. However, with the increasing annealing temperature, the blistering phenomena were inclined to occur in the co-implanted samples, especially in He-first sample. The different behaviors of blister formation were closely correlated with the thermal stability of He implantation-induced damage. For low temperature annealing, most of the implanted He atoms were localized at the original site as implanted and the diffusion of He was efficiently suppressed, thus the blistering mainly originated from the platelets which were pressurized by implanted H. In consequence, blisters were more easily formed in H-alone sample in which the implantation dose of H was relatively higher than the co-implanted samples. However, for higher temperature annealing, the enhanced blistering behavior of co-implanted samples was attributed to an increasing contribution of He to the internal pressure of H-platelets. Compared to the He-first sample, the formation of large defect clusters with high vacancy/hydrogen ratio in the H-first sample may retard the blistering phenomenon.

1. Introduction

Germanium on insulator (GOI) is of considerable interest for various applications in both micro- and opto-electronics fields. The feasibility of such substrates using the Smart-Cut™ technology has been demonstrated [1]. Many researches have reported that co-implantation of H and He ions in silicon allows blistering at considerably lower total dose than H ions alone [2–4]. In general, this effect has been attributed to a synergy between the passivation of the internal surface of the crack by H and the efficient crack pressurization by He. However, the real physical mechanism behind the co-implantation is still under controversy, since the microstructure evolution of co-implantation induced defects strongly depends on the experimental parameters, such as the implantation order, the fluence range, and the relative depth distribution of H and He [5]. So far, there are few works studying the layer transfer behavior in germanium co-implanted by H and He [6]. In this work, we present a more systematic study on the effect of order and post-annealing temperature on surface blistering of H and He co-implanted germanium and the mechanism underlying the H–He synergy effect in the layer transfer process of germanium has been elucidated.

2. Experimental details

N-type (100) germanium wafers were cut into 1 cm^2 pieces. Some samples were implanted with H at the energy of 30 keV with a dose of 3×10^{16} cm^{-2} and He at the energy of 50 keV with a dose of 1×10^{16} cm^{-2} at room temperature(RT) in different orders—H first then He or He first then H, the control samples were implanted with H alone at the energy of 30 keV with a dose of 4×10^{16} cm^{-2} (In the following, they were named as H-first, He-first, and H-alone, respectively). According to stopping range of ions in matter (SRIM) simulation, the ion energies chosen for H and He ensure that the implanted H has the similar ion range as the implanted He. The dose of the control sample was equivalent to the total dose co-implanted. The wafer holder was kept near room temperature and tilted 7° off the direction of the beam to minimize the ion channeling effects. All the implanted samples were annealed at various temperatures from 200 to 500 °C in the flowing ambient of N_2 gas for 30 min.

Surface morphology of the implanted Ge after annealing at different temperatures was carried out by a Veeco multimode Ns-3A atom force microscope (AFM) in contact mode. The strain evolution during annealing process was characterized by a Philips X'Pert MRD X-ray diffraction (XRD) with Cu Kα radiation (λ = 1.5406 Å). The microstructures of implantation induced damage were observed by transmission electron microscopy (TEM) using a FEI Tecnai G2 F20 S-TWIN microscope with an accelerating voltage of 200 keV.

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3. Results and discussion

3.1. Surface morphology

The evolution of surface blistering at various temperatures is characterized by AFM, as shown in Fig. 1. For all the samples, no optically visible blisters can be found after annealing at 300 °C (Fig. 1a–c), however, individual doom-like blisters with an average size ranging from 0.5 to 2 μm have been observed after annealing at 350 °C (Fig. 1d–f). Compared to the co-implanted samples (Fig. 1e–f), the density of blisters is higher and the size of blisters is larger in H-alone sample (Fig. 1d). Furthermore, the blisters formed on He-first sample (Fig. 1f) are less but larger than that of H-first one (Fig. 1e).

When increasing the temperature up to 400 °C or 500 °C, due to the excessive pressure of H and He trapped within the platelets that leads to the exfoliation of the surface layer of germanium, a few popped-off blisters have already shown. It is worth noting that, the surface blisters as well as localized exfoliations from those co-implanted samples, especially for He-first sample, are larger than H-alone sample. We speculate that the difference may be attributed to the synergy effect among implanted ions and ion-induced defects on the evolution of implantation-induced strain and microstructure as discussed in the following. Quantitative measurement of craters for all the three samples has shown that the exfoliation occurs at a similar depth of about 330 nm, which coincides with the distribution of the implantation damage as observed by TEM.

3.2. XRD results

Fig. 2 displays the XRD curves from H-alone, H-first and He-first sample prior to the annealing process. The diffraction pattern consists of a series of fringes with increasing width at lower angles, indicating a tensile strain gradient in the direction normal to the surface of Gaussian-like shape [7]. The maximum strains given by the position of the last fringe away from the Bragg peak of all as-implanted samples

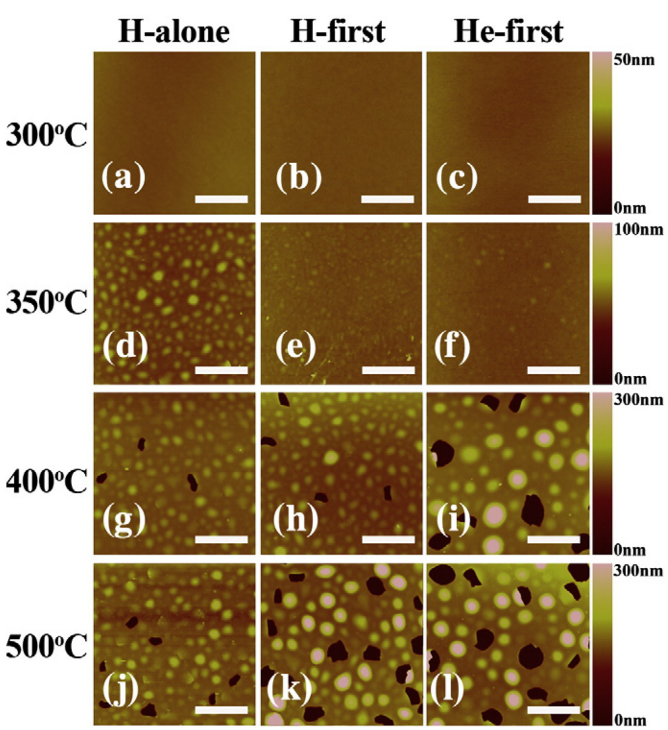

Fig. 1. AFM images of the surface morphology of samples annealed from 300 to 500 °C for 30 min: (a), (d), (g) and (j) for H-alone; (b), (e), (h) and (k) for H-first; (c), (f), (i) and (l) for He-first. All scale bars are 10 μm.

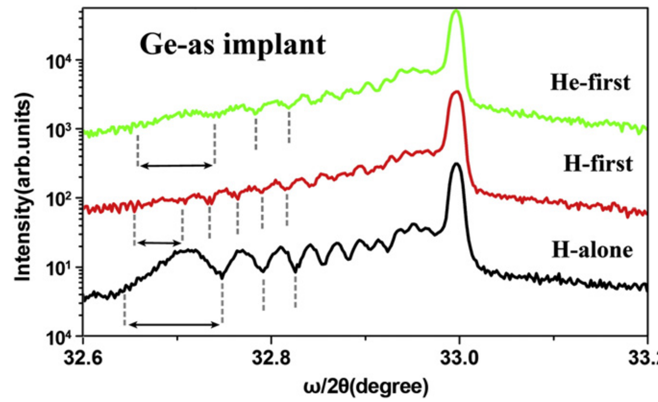

Fig. 2. X-ray measurements of three as-implanted samples.

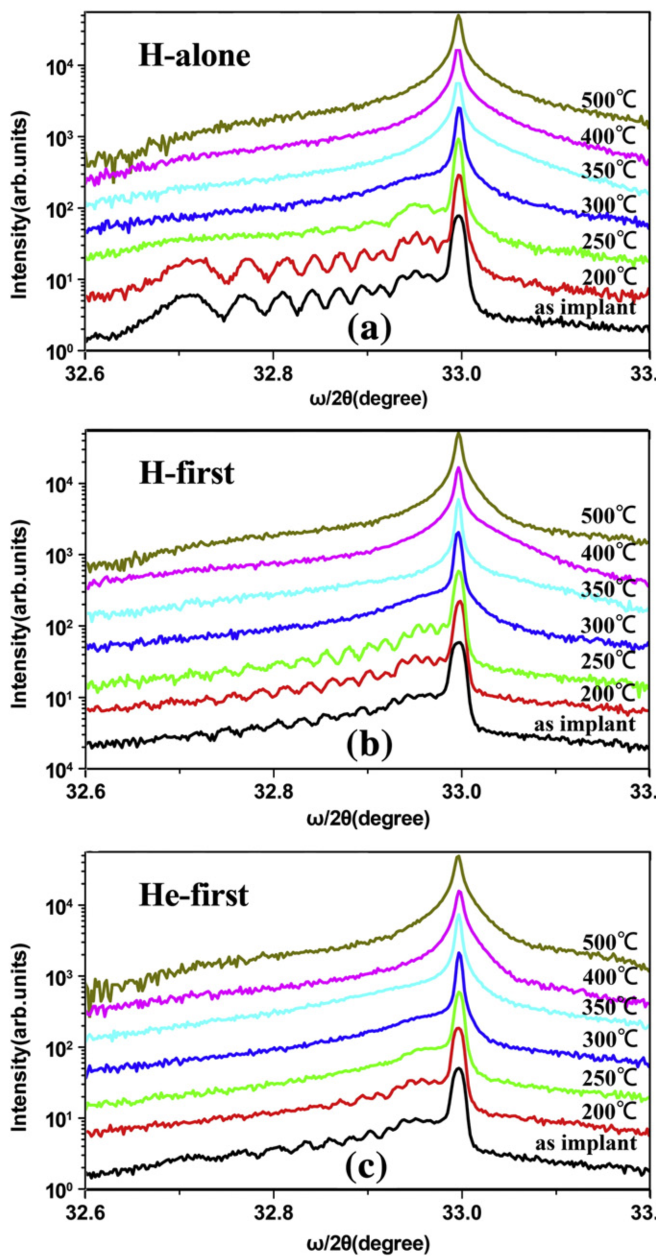

Fig. 3. X-ray measurements of samples after annealing from 200 to 500 °C for 30 min: (a) H-alone, (b) H-first and (c) He-first.