Research Paper -Physics

Surface blistering/exfoliation phenomenon in high temperature H-implanted Ge

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A B S T R A C T

H-implantation-induced surface blistering/exfoliation in Ge have been presented in this work. The reason for the blistering/exfoliation in the as-implanted state is the increase in H-induced damage in as-implanted state and beam heating effect. Ge samples were implanted at 300 •C by 100 keV H+ ions for a fluence of 1 × 1017 ions/cm2. The surface exfoliation occurred in the as-implanted state without going through the post-implantation annealing. Stylus profilometry revealed that in the case of samples implanted at 300 •C, the lateral size (b) and maximum vertical deflection (?) of the blisters were measured to be about 4-30 µm and 50-210 nm, respectively. AFM showed the thickness of the transferred layer to be about 890 nm for the implantation at 300 •C. The internal pressure and stress in the buckled layer have been investigated using Föppl-von Karman theory (FvK) of thin plates.

Keywords: Fluence, Buckling, Exfoliation, AFM.PACS: 68.35.bg, 68.55.Ln, 61.72.Cc

Introduction

Hydrogen (H) ion implantation-induced surface blistering/exfoliation phenomena in semi-conductors play an important role in layer transfer applications. This can be done using H ion implantation and (DWB) direct wafer bonding, so called as ion-cut process.[1] H-implantation-induced surface buckling phenomena was successfully applied to germanium (Ge) for the fabrication of germanium-on-insulator (GeOI) substrates. Importantly in Ge, the hole mobility is very high about 1800 cm2 V-1 sec-1. Hence, it would be a good material for high speed microprocessors [2, 3]. The investigation of H ion-implantation induced surface blistering and exfoliation phenomena can be studied without going through the wafer bonding process [4].

However, in Ge H-ion implantation induced surface blistering/exfoliation is not fully understood. Therefore, the detailed analysis is needed to develop the ion-cut process into a viable industrial technique. Since, an implanted ions creates various type of imperfections inside the material in the form of point defects (Ge vacancies or interstitial), H defect complexes close to their projected range [5, 6]. Therefore, H-induced defects upon annealing agglomerates to extended defects (nano/micro-cracks). These extended defects acts as an efficient trapping centre or nucleation sites for the formation of molecular H_2 hydrogen [7]. H-ions tend to segregate into these cavities which grow and coalesce at elevated temperature. Consequently, the gas pressure inside the cavities finally deforms the implanted surface. When this H-induced internal pressure reaches to the fracture limit of the implanted material, it ultimately lifts the implanted surface in the form of surface blisters[8].

Further, earlier study of H-implantation in Si, had shown some indications about the increase of H-induced damage rather than its normal decrease with the increase in implantation/post-implantation annealing temperature [8]. However, in H-implanted Ge, no report is still available which can explain why as-implanted blistering/exfoliation occur at higher implantation temperature. Hence, in this work, blistering process has been investigated by taking into account the various mechanisms which are responsible for blistering/exfoliation process in H-implanted Ge.

Experimental

n-type (100) Ge samples of size 1 × 1 cm2 were implanted with 100 keV H+ ions at 300 °C for a fluence of 1 × 1017 ions/cm2. During implantation, ion current density was kept at 15 µA/cm2. During H-implantation, the sample surface normal was inclined at ~7° off relative to the incident ion beam in order to minimize ion channeling effects. The samples were investigated in the as-implanted state using optical microscope, atomic force microscopy (AFM) and stylus profilometry.

Results And Discussion

In order to check the optically detectable surface buckling phenomena in H-implanted Ge at 300°C, we have used optical microscope in

Nomarski mode. It was observed that surface buckling (mainly craters) occurred in the as-implanted state. The lateral size of these surface craters varied from about 10-100 µm in diameter (fig.1). In addition, it was also seen that the surface of crater bottom showed different exfoliated regions. These exfoliated regions correspond to the different crater bottom, which is confirmed by our AFM analysis at the edge of crater in contact mode. In H-implanted Ge samples at 300 °C, the implanted hydrogen may get sufficient diffusion activation energy, which is due to (overheating) sufficient temperature. This may results in the agglomeration of the implanted hydrogen into molecular form[6].

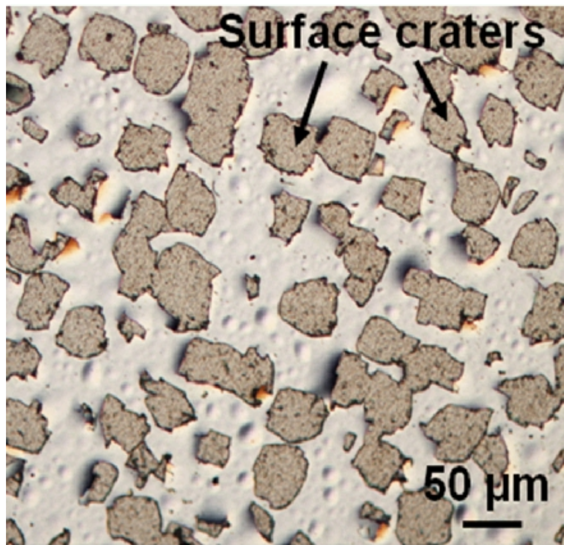

Figure.1.Nomarski optical image of the Ge sample at 300 °C in the as-implanted state. Fig shows exfoliation along with blisters.

Hence, the molecular hydrogen could lead to the formation of overpressurized extended defects in the presence of higher implantation temperature of 300 °C. These overpressurized hydrogen induced microcracks may eventually result in buckling of the top implanted Ge surface in the as-implanted state.

The morphology of the samples has been characterized using AFM in contact mode. The root mean square (RMS) surface roughness of the crater bottom region was found to be 25 nm. This roughness of the exfoliated region as compared to pristine sample < 1 nm showed that the exfoliated region has more roughness than pristine sample. Moreover, the thickness of exfoliation (crater depth) region measured by AFM at the edge of the crater.

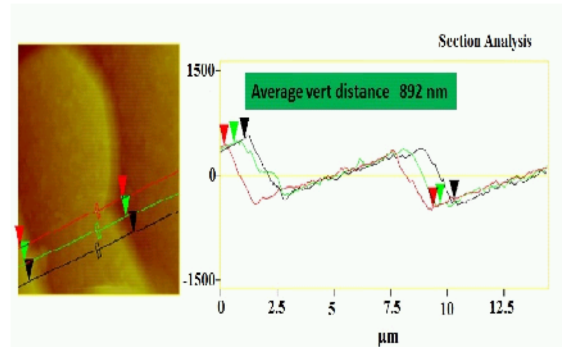

Figure. 2. AFM sectional analysis was done between the top of the H-implanted surface and the crater bottom. The sets of arrows indicate the position used for the crater depth measurement for the implantation at 300 °C in as-implanted state. The thickness of the exfoliated region came out be 890 nm, which corresponds to the thickness of the transferred layer. Thus, in the case of H-implanted Ge samples at 300 °C, the exfoliation depth lies away from the H-concentration peak as predicted by the SRIM simulation code (see Fig. 3).

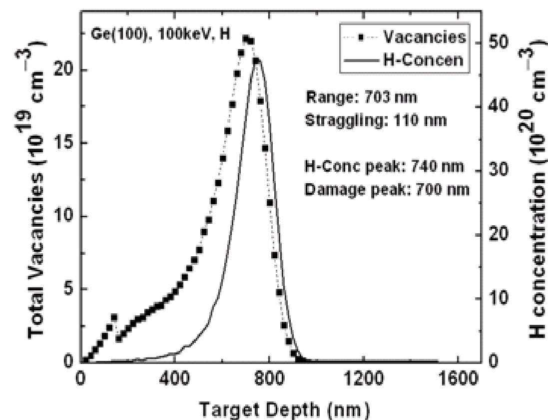

Figure. 3. Depth profile of the implanted ions and number of vacancies produced for the energy of 100 keV hydrogen in Ge.

The physical dimensions of the buckled layer were measured using stylus profilometry. It showed that lateral size (2b) of the blisters varied from 4-30 µm for the implantation at 300 °C. However, their maximum vertical deflection (?)

from the implanted surface was measured to be about 50-210 nm. These measurements were used in order to study the internal pressure mismatch (?p) between the blister inside pressure and external pressure acting over its surface, and stress (?o) in the buckled layer using FvK theory of thin plates [9, 10]. It showed that internal pressure and stress in the range of 0.85-19 and 8.3-15.2 MPa, respectively, for the implantation at 300 °C, This suggested that internal pressure and stress in the buckled layer was sufficiently enough to cause the surface buckling phenomena in as-implanted state. The variation of ?p with ? and internal stress (?o) of the blister (buckled layer) shown in the

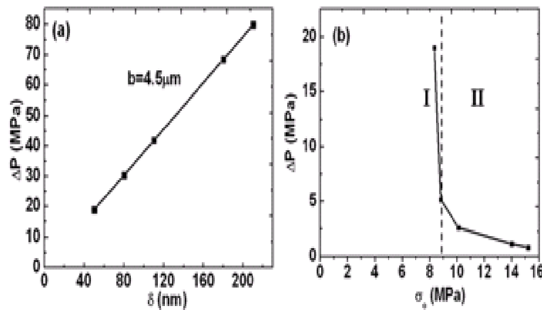

Figure. 4.

(a) Variation of the internal pressure (?p) with maximum vertical deflection (?) for a fixed value of b and h,

(b) Shows the behaviour of ?p versus ?o for various value of b and h with H-implanta tion at 300 °C.

fig. 4(a). It shows that ?p increases with the increase in ? of the surface blisters. Internal pressure decreases with the increase in stress of the buckled layer [9]. This can be understood in terms of compressive stress and positive pressure, which give surface blistering. In Fig. 4, showed two regimes: (I) low stress regime, where slightly increase in ?o 0.8-0.9 MPa value gives significant drop in ?p from 19-5.2 MPa (Fig. 4b). High stress regime, in which stress in the buckled layer, is compressive in nature. Hence, this corresponds to the transition from tensile to compressive stress state in the buckled layer. In this state, buckled layer reaches its fracture limits, in order to change the blisters morphology [10]. Thus we conclude that blistering and exfoliation is attributed to compressive stress in the implanted layer.

Conclusions

Surface blistering/exfoliation occurred in as-implanted state. The thickness of the exfoliated region found to 890 nm away from H concentration peak. H-induced internal pressure and stress in the buckled layer varied with blister size, vertical deflection and exfoliation depth.

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