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INVESTIGATION OF IMPLANTATION-INDUCED DAMAGE IN INDIUM PHOSPHIDE FOR LAYER TRANSFER APPLICATIONS

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100 *keV* H^+ *and* He^+ *ion implantation was performed in* 300 *μm thick* (100) InP *substrates at liquid nitrogen temperature with a constant fluence of* 1×10^{17} cm^{-2}. *The surface morphology of the as-implanted* InP *samples was studied by optical microscopy. The implantation-induced damage was investigated by cross-sectional TEM, which revealed the formation of damage band in both cases near to the projected range of implanted ions. The formation of hydrogen-induced nanocracks and helium filled nanobubbles was observed in as-implanted* InP *samples.*

Keywords: *ION IMPLANTATION, DAMAGE, TEM, NANOCRACKS, NANOBUBBLES.*

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1. INTRODUCTION

InP is a promising material of III-V family for its use in optoelectronics, microelectronic and high speed devices [1]. The combination of InP with ion-cut process provides a fruitful platform for the commercialization of low cost InP technology [2]. The ion-cut process is comprises of ion implantation and wafer bonding technique, which provides an easy approach to transfer multiple thin layers from implanted substrate (donor) onto inexpensive foreign substrate (handle), thereby realizing the use of single donor substrate for multiple times [3]. However the critical aspect involved in ion-cut process is the nature of damage induced by implanted ions (hydrogen, helium), along with its dependence on implantation temperature [4].

In some earlier works, there have been certain investigations carried out on the hydrogen and helium ion implantation-induced damage and blistering study in InP particularly near to the room temperature (RT), which reported the extreme sensitivity of hydrogen-induced damage towards implantation temperature [5, 6]. Since layer splitting is predominately control by the temperature and time dependent effective diffusion role of implanted ions within the damage region, therefore these factors makes ion implantation at RT some but reliazent towards uniform blistering and hence layer splitting of InP, especially with hydrogen ions [6]. However, the nature of damage produced by implanted ions at cryogenic conditions is totally different, which results in the controlled diffusion of implanted ions (H^+) within the damage region and hence may assist in the easier transfer of InP layers [7]. Therefore, in this work we have carried out investigation on the hydrogen and helium implantation-induced damage in InP at LN_2 in as-implanted state.

2. EXPERIMENTAL WORK

We have performed 100 keV H^+ and He^+ ion implantation separately at LN_2 with a constant fluence of 1×10^{17} cm^{-2} in semi-insulating (100) InP substrates of sample size 1×1 cm^2. The ion implantation was performed at low energy ion beam facility (LEIBF) [8] of the Inter University Accelerator Centre (IUAC), New Delhi. During implantation the sample surface normal was inclined ~7° off relative to the incidence ion beam in order to avoid channeling effects. The amount and nature of implantation-induced damage was analyzed by computer aided Monte Carlo program [9]. All samples were investigated in the as-implanted state using optical microscopy and cross-sectional TEM. The XTEM measurements were carried out using a Philips CM20T machine operated at accelerating voltage of 200 kV.

3. RESULTS AND DISCUSSION

The implantation of energetic hydrogen and helium ions in InP results in the dislodge of host lattice atoms, thereby creating different types of defects in the form of vacancies, interstitials, hydrogen and helium defects complexes within the damage region [10, 11]. As hydrogen ions are lighter than helium ions, so they (H^+) created a maximum damage within the InP at deeper depth location in comparison to helium ions. This was also indicated by stopping and range of ions in matter (SRIM) program (Fig. 1) [9].

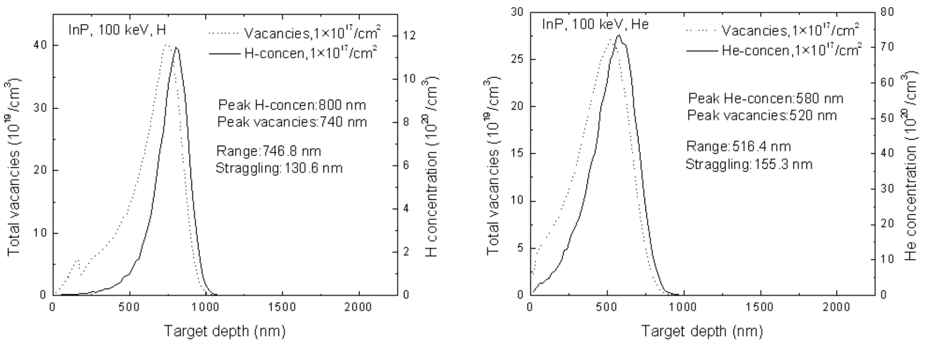

***Fig. 1** – Implantation profile of ion range and vacancies produced for* 100 *keV hydrogen and helium ions implanted* InP

In addition to this, heavy helium ions created more damage within the narrow damage region in comparison to hydrogen implanted InP samples. This has been clearly observed by the cross-sectional TEM measurements of as-implanted InP samples at LN_2 implantation temperature (Fig. 2). Also, the as-implanted optical observations do not showed any change in the surface morphology with respect to un-implanted InP samples. Hence, our implanted samples can be used directly for wafer bonding in order to transfer thin InP layers [12].

In the case of hydrogen implanted InP samples at LN_2, the damage band had a width of about 400 nm and started at a depth of about 560 nm from the implanted surface. But in the case of helium implanted InP samples at same implantation temperature, the width of damage band was about 250 nm and was started at a depth of about 400 nm from the implanted surface. This implantation-induced damage band was also reported in our earlier work and by some other groups also [5-7]. It is worth mentioning here that in those works the implantation was either carried out at RT or − 20 °C with ion current density of 2 to 2.5 μm cm^{-2}. Since layer transfer is done by wafer bonding technique, hence these implantation parameters are very important in order to decide the role of implanted hydrogen and helium ions within the damage band so that layer splitting time and annealing temperature should decrease to practical level, which is a major requirement for heterogeneous wafer bonding.

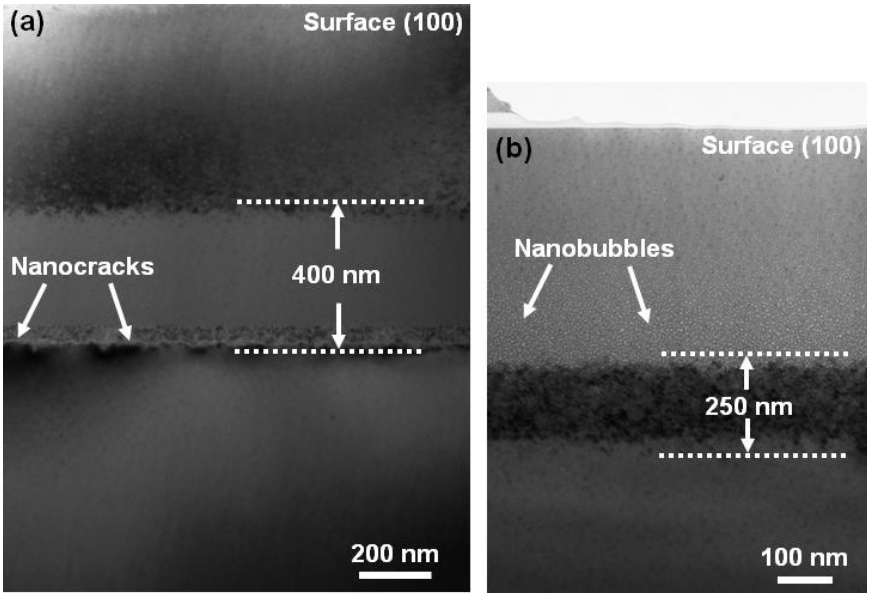

***Fig. 2** – XTEM image of as-implanted InP samples with* 100 *keV* (*a*) H^+ *and* (*b*) He^+ *ions, for fluence of* 1×10^{17} cm^{-2} *at implantation temperature of* LN_2

As mentioned earlier, the InP is very sensitive towards implantation temperature, hence the effective diffusivity of light hydrogen ions is more sensitive towards implantation temperature in comparison to heavy helium ions. As a result, the layer transfer of InP assisted with helium ion implantation at RT is much easier than hydrogen ions, which was also endorsed by our earlier work [6]. But in this work, the hydrogen implanted InP samples at LN_2 resulted in a controlled diffusion of hydrogen within the damage region, which may be governed by the trapping-detrapping phenomena and hence was effectively trapped by the implantation-induced defects within the wide damage band [6]. The remaining hydrogen either diffused out from the damage lattice or may agglomerates together and resulted in the formation of hydrogen-induced nano/microcracks near to the end of damage region as shown by Fig. 2a. These hydrogen-induced microcracks may preferably be filled with molecular hydrogen which may assist in the easy transfer of InP layers at lower post-implantation annealing parameters.

However, in the case of helium implanted InP samples at LN_2 resulted in the formation of diffused helium filled nanobubbles from the narrow damage band towards the implanted surface (Fig. 2b). Such type of helium filled nanobubbles was also reported by Chicoine et al. at RT implantation in the form of nanocavites but after thermal annealing [11]. However, this diffusion of helium from narrow damage band is not useful for layer splitting process [6]. The diffusion of helium ions from narrow damage band at LN_2 is may be because of inert behaviour of helium ions in comparison to much chemical reactive hydrogen ions, which may helps in the passivation of internal damage surface mainly by hydrogen atoms. Moreover, high helium concentration (about six times of hydrogen peak) along with high longitudinal straggling at shallow implantation depth may further assist in the diffusion of helium ions from the narrow damage band. The remaining helium within the damage band was unable to migrate in creating extended defects in as-implanted InP samples due to the too defective nature of lattice per unit depth within the narrow damage band in comparison to previous case, as shown by Fig. 2b in a dark contrast damage band. This makes layer transfer of InP assisted with He ions is very difficult at lower thermal budget [6]. However, layer splitting is also decided by the dynamics of implantation-induced defects during implantation and annealing process, which significantly depends upon the implantation-induced strains and mechanical behaviour of the InP towards implantation-induced damage. Further details studies are needed in these directions in oder to understand the detail layer splitting mechanisms in InP at LN_2 implantation temperature. Hence we concluded that, layer splitting of InP at LN_2 may be easier with hydrogen ions.

4. CONCLUSIONS

We have investigated the hydrogen and helium implantation-induced damage in as-implanted InP samples at LN_2. The cross-sectional TEM analysis showed the formation of implantation-induced damage band in both cases. The formation of nanocracks within the damage band in hydrogen implanted InP samples was attributed to molecular hydrogen. The diffused helium filled nanobubbles from the damage band were reported in helium implanted InP samples. These extended defects in the form of nano/microcracks in hydrogen implantation at LN_2 may assist in the easy transfer of InP layers at lower post-implantation annealing temperature and time in comparison to helium implantation.

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