MODIFICATION OF SI-RELATED MATERIALS BY HIGH ACCELERATED HEAVY IONS

Ch.Angelov, INRNE, Sofia, Bulgaria
M.Kalitzova, S.Simov, ISSP, Sofia, Bulgaria
C.Pizzuto, Universita di Roma “La Sapienza”, Italy
J.Faure, P.Bonhomme, University of Reims, France

Abstract

The present paper describes a comprehensive study of the ion-beam induced crystallization in amorphised (a)-Si layer by high-dose implantation of low solubility heavy ions, Pb^+ and Bi^+. These species are important dopants in Si due to their potential application in the production of long wave infrared detectors. (100)Si wafers of device quality have been implanted at RT with 50 keV Pb^+ and Bi^+ in the dose range $5x10^{13}$ – $1x10^{18}$ cm^{-2}, using an ion current density of $10\mu A.cm^{-2}$. Conventional Transmission Electron Microscopy (TEM) as well as High Resolution Transmission Electron Microscopy (HRTEM), combined with Rutherford Backscattering Spectroscopy (RBS) and computer simulations have been applied. The kinetics of ion beam induced crystallization of new phases and precipitate evolution in the a-Si layer have been studied as a function of ion dose. It has been established that the front of new phase crystallization (cubic Pb and hexagonal Bi – nanocrystals) starts at positions in the a-layer, corresponding to the peaks in the Pb^+ and Bi^+ implant profiles. As the dose increases, the formation of Pb and Bi precipitates occurs closer to the surface. By computer processing of the HRTEM images of the nanocrystals so formed, the Nygren theoretical model for recrystallization by precipitation in liquid phase of elenents with low melting temperature has been confirmed experimentally for the Bi:Si system.

1 EXPERIMENTAL RESULTS

A (100) oriented, p type, 17 Ω cm, Cz silicon wafer was cleaved into samples which were implanted with 50 keV Pb^+ or Bi^+ ions at room temperature (RT). All the implants were performed at an angle of 7^o with respect to the surface normal to minimize channeling. Samples were heated during implantation solely by the incident ion beam whose density was kept at 10 μA cm^{-2}. The implant doses for the two species were in the range of $5x10^{13}$ to $1x10^{18}$ cm^{-2}.

TEM specimens were prepared using standard techniques for mechanical thinning and ion beam etching [1] as a final thinning procedure. In the course of TEM sample preparation, pre-surface treatment was deliberately omitted to avoid modification of the implanted layers. Specimens for both plan-view (PVTEM) and cross-sectional transmission electron microscopy were accordingly prepared. The <110> cross-sections from (100) implanted Si were obtained using a technique similar to that described in Ref. [2]. TEM observations were performed in diffraction (CTEM) and phase contrast (HRTEM) modes. All CTEM investigations were carried out in a Philips CM30 electron microscope operating at 200 kV, and under “two strong beams” (220) Bright Field (BF) conditions. HRTEM microscopy was done on cross-sectional (XHRTEM) specimens only. HRTEM observations were made in a JEM 2010 electron microscope operating at 160 kV in a “seven beams” BF mode. Small area electron diffraction (SAED) patterns were taken from selected areas of about 100 nm in diameter, with an approximately parallel electron beam (convergence beam about $5x10^{-5}$ rad) [3]. HRTEM images recorded with a LESA LH72LL - TEM camera were subsequently digitalized and processed. Histograms showing the size distribution of precipitate nanocrystals within the a-Si layer were derived on the basis of the PVCTEM micrographs.

The Pb and Bi profiles were analyzed by RBS. Measurements were performed using a beam of 1.7 MeV He^+ and a scattering angle $\Theta = 170^o$, with an overall resolution of 15 keV FWHM. The implant doses were estimated from the RBS experimental data by means of a RUMP/thick operator. Depth distributions of both the displaced target atoms and the implanted atoms were calculated by SRIM2000 and compared with the XTEM experimental results.

2 MAIN CONCLUSIONS

Single-crystal Si has been implanted with 50 keV low solubility heavy ions with low diffusion coefficients and with low temperature simple eutetics with Si, namely Pb^+ and Bi^+. Ion implantation was performed at RT, with current density of $10\mu A.cm^{-2}$ and in the dose range $5x10^{13}$ – $1x10^{18}$ cm^{-2}. Under the experimental conditions used in this study the obtained results enable us to draw the following conclusions.

1. The microstructure of implanted layer depends critically on the combined effect of implant dose, substrate temperature and sputtering. With varying the dose the processes of Ion Beam Induced Amorphization (IBIA) and Ion Beam Iduced Crystallization (IBIC) are competitive as a result: a complete amorphization, a

clustering behavior and amorphous-policrystal (a-p) transition arise in the a-Si layer.

2. An attempt was made to explain the mechanism of phase transformation in the formed a-Si layer at used experimental conditions. For this reason the kinetics of precipitate evolution and crystallization of new phases induced in a-Si layer have been studied as a function of ion dose. The process of solid phase epytaxial growth (SPEG) is inhibited at used experimental conditions by the IBIC process of nanocrystals of Pb or Bi. The analysis of SAED patterns from regions containing nanocrystals of Pb or Bi, as well as elaboration of the interplanar distances in the corresponding nanocrystal structures visualized by XHRTEM show that Bi crystallizes in hexagonal phase and Pb – in cubic phase. The crystallization of the new phases appears to be a bulk effect most probably initiated at the peaks off the Pb and Bi distributions. As the dose increases, the front of Pb and Bi precipitation moves to the specimen surface. This behavior is explained by us with defect-defect interactions. The presence of radiation defects maximum at a depth below the surface corresponding to about 0.75 of the R_p position of the implanted impurity creates conditions favoring the heterogeneous nucleation. With increasing the dose a coalescence of the nanocrystals appears.

3. The Nygren theoretical model for recrystallization of Si mediated by liquid phase of In precipitates (in our experiments Pb and Bi) has been confirmed experimentally. By computer processing of some HRTEM images of the crystallized clusters in the a-layer in the Si:Bi system we established the appearance of crystal planes with distances characteristic for Si, included in the interplanar (012) distances of the crystallized Bi.

REFERENCES

[1] L.M.Bharadwaj. J.Faure, P.Bonhomme and G.Balossier, Microsc.Microanal. Microstruct. 2, 89 (1991).

[2] T.T.Sheng and R.B.Markus, J.Electrochem. Soc. 127, 737 (1980).

[3] M.Tanaka, M.Terauchi, T.Kaneyama, in Convergent Beam Electron Diffraction II, Jeol LTD, Tokyo, (1987).