THE EFFECT OF THIN SURFACE OXIDE LAYERS ON ION BEAM SYTHESIS OF InAs NANOCRYSTALS IN Si

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Nanosized crystallites have been synthesized into Si and SiO_2/Si structures by means of As (170 keV, 3.2×10^{16} cm^{-2}) and In (250 keV, 2.8×10^{16} cm^{-2}) implantation at 25 °C and 500 °C and subsequent annealing at 1050 °C for 3 min. RBS, TEM and PL techniques were used to analyse the impurity distribution and the structural and optical characteristics of the implanted layers. It was found that oxidation of samples before thermal treatment significantly reduces the As and In losses. A broad band in the region of 1.2 – 1.5 μm was detected in the photoluminescence spectra.

Experimental

We used two sets of samples in this paper. The samples from the first set were cut from thermally oxidized n-type Si (100) wafer. The thickness of thermal SiO_2 was equal to 40 nm. The samples from the second set were cut from p-type Si (111) wafer. After that, two sets of samples were implanted with As^+ (170 keV, $3.2\cdot10^{16}$ cm^{-2}) and then In^+ (250 keV, $2.8\cdot10^{16}$ cm^{-2}) ions at 25 and 500 °C. After implantation a part of Si (111) samples was electrochemically oxidized (thickness of oxide layer was 100±30 nm) in order to prevent impurity loss during subsequent annealing. Finally, a rapid thermal annealing at 1050 °C for 3 min in an inert ambient has been carried out in order to restore crystalline structure of implanted samples.

Rurtherford backscattering spectrometry in combination with the channelling technique (RBS/C) with 1.5 MeV and 2.5 MeV He^+ was used to analyse a depth distribution of the implanted atoms as well as to evaluate a damage of implanted material. A structure of the implanted samples was studied by TEM in plan-view (PV) geometry. The TEM investigations were performed using a Hitachi H-800 instrument operating at 200 keV. The optical properties of samples were investigated by low temperature photoluminescence (PL).

Results and discussion

We measured RBS spectra with 2.5 MeV He^{+} ions at two angles of the incidence beam onto the sample (0° and 50°) to improve accuracy of fitting spectra. The depth profiles were calculated by simulation of the spectra using HEAD DOS code until the simulated spectra coincided completely with the experimental spectra. An embedded species redistribution was experimentally observed at "hot" implantation conditions. It is resulted from non-equilibrium radiation-enhanced diffusion caused by the migration of "impurity atom – radiation defect" complexes. The impurity which is bounded in nanoclusters becomes inactive to diffuse. And the most effective cluster formation takes place in the area of overlapping depth profiles of different impurities. The calculated from RBS spectra losses of As and In atoms after implantation at T_{imp} = 500 °C and annealing are equal to 30 % and 60 %, respectively. Also, As pile up at the interface of SiO_2/Si layer was revealed.

RBS spectra were measured also for As and In implanted in p-doped Si (111). Calculated from RBS spectra depth distributions of As and In show that oxidation of samples before annealing reduces impurity losses. Indeed, such calculations reveal that in the case of T_{imp} = 25 °C and subsequent annealing the oxide film presence reduces the loss of As to 25 % and In to 35 %. In the case of implantation at 500 °C and annealing, the oxide surface layer reduces the loss of As to 50 % and In to 10 %. Moreover, one can observe, that the oxide film decreases the broadening of implanted depth profiles of implanted species. In the case of implantation at room temperature an oxidation leads to bimodal distribution of In: the first peak was formed in SiO_2 layer because of non-equilibrium diffusion during "hot" implantation and post-implantation annealing, another one is located in Si near In ions projected range R_p. There was not detected In atoms at all for samples without oxide film at the surface under these treatments.

Fig. 1 shows TEM-images of the precipitates for the annealed samples. One can see the presence of faceted nanocrystals with the sizes from 2 to 600 nm. The crystalline nature of the precipitates is proved by the presence of Moiré fringe patterns in the TEM images (Fig. 1e). In our previous work /1/ we have analyzed the distance between the Moiré fringes and got good agreement for the superposition of InAs and Si {220} planes. Thus, a layer with InAs crystallites is formed in the annealed samples. It should be noted that implantation at the elevated temperature results in narrower size distribution of nanocrystals from about 2 to 115–140 nm (depends on presence of surface oxide film) (insets in Fig. 1c,f,h). The implantation at T_{imp} = 25 °C (inset in Fig. 1f) leads to a broader nanocrystal size distribution and larger average nanocrystal sizes in comparison with T_{imp} = 500 °C (insets in Fig. 1c,h).

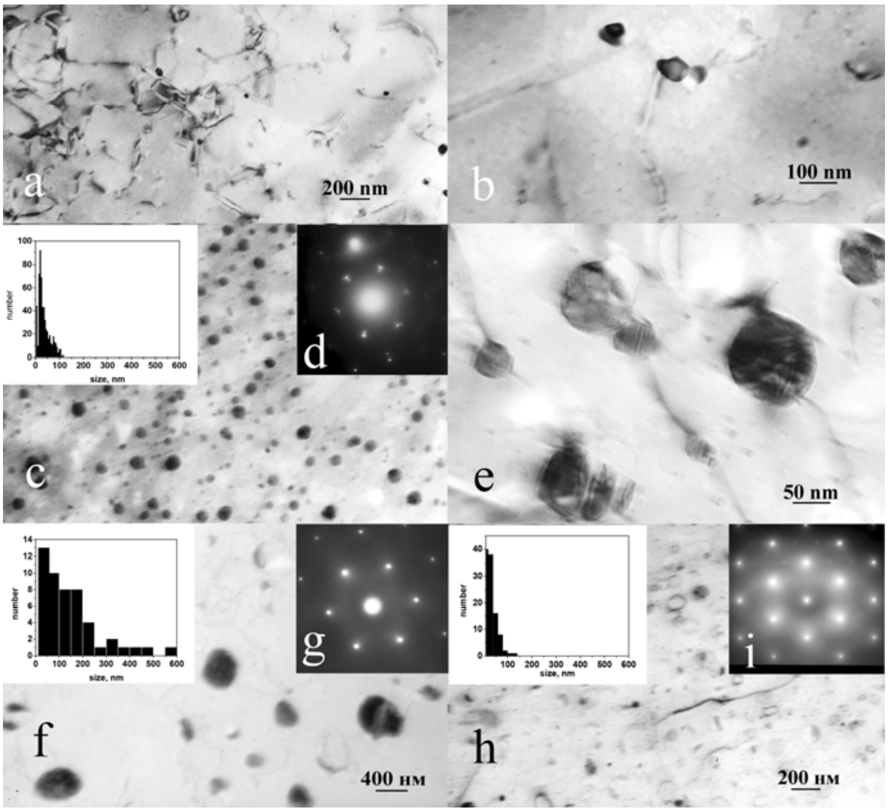

Figure 1. Bright-field TEM-images (a, b, c, e, f, h) and microdiffraction patterns (d, g, i) from Si (a,b,c,e) and SiO_2/Si (f,h) after implantation at 25 °C (a,b,f) and 500 °C (c,e,h), anodic oxidation (f,h) and annealing

It is possible to estimate crystalline structure quality and to evaluate the percentage of impurity embedded into silicon lattice sites by comparing random and aligned RBS spectra of implanted samples. Our calculations show that only 16 % of implanted impurity atoms are incorporated into silicon lattice sites in the case of a sample after "hot" implantation and annealing. Oxidation of this sample before thermal treatment results in 65 % of As and In atoms incorporated into regular lattice sites of silicon. It indicates that the presence of an oxide film on the sample top before thermal treatment leads to more intensive impurity embedding into the silicon regular lattice sites. Impurity atoms incorporated into silicon lattice sites do not participate in the cluster formation and that's why the average nanocluster size is smaller in the case of samples with oxide layers (insets in Fig. 1c, h).

The surface region of the "hot" implanted, oxidized and annealed sample contains a lot of dislocation loops, microtwins and little size precipitates (Fig. 1h,i). However, photoluminescence yield from this sample is maximal in comparison with others samples. All the PL spectra of implanted samples can be characterized with a narrow line of exciton emission in Si at 1.135 μm and a broad band at 1.15–1.6 μm (Fig. 2). A similar band was observed earlier in the PL spectra of InAs nanocrysals grown on Si wafers by MBE /2/ or synthesized by high-fluence ion implantation of In and As into Si /3,1/. That band was ascribed to InAs nanocrystals. One can see in Fig. 2 that “hot” implantation of Si samples results in more effective luminescence in comparison with room temperature implantation.

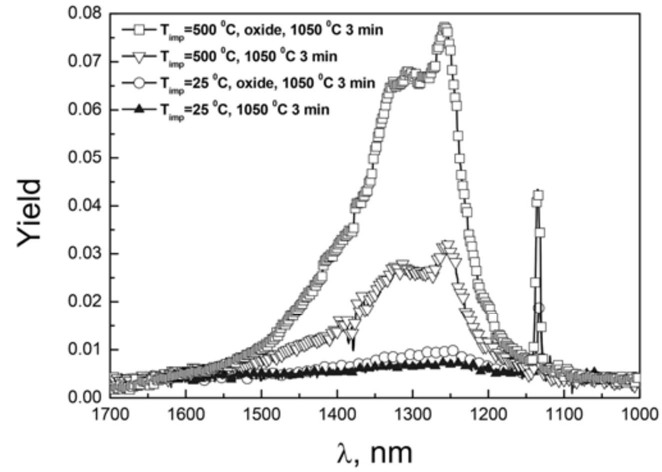

Figure 2. PL spectra of SiO_2/Si and Si samples after implantation at 25 and 500 °C and annealing

Conclusions

We have demonstrated a possibility to produce InAs nanocrystals with sizes from 2 to 600 nm in Si and SiO_2/Si structure by means of implantation of As^+ (170 keV, $3.2\cdot10^{16}$ cm^{-2}) and then In^+ (250 keV, $2.8\cdot10^{16}$ cm^{-2}) with subsequent thermal processing at 1050 °C for 3 min. It has been shown that oxidation of samples before thermal treatment results in an impurity loss reducing, brings down a broadening of depth concentration profiles, increases incorporation of impurity into silicon lattice sites and enhances photoluminescence yield in PL spectra.

For all samples a broad band in the region of 1.15 – 1.6 μm is registered. “Hot” implantation as occurs leads to more effective light emission in this spectral range of PL spectra in comparison with room temperature implantation. Oxidation of a sample before thermal treatment results in increasing luminescence yield in the 1.15–1.6 μm spectral range.

References

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