FORMATION OF LIGHT-EMITTING Si:Er LAYERS BY ION IMPLANTATION AND PULSED ANNEALING

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In this work the formation of Si:Er solid solutions and erbium silicide layers by means of Er ion implantation and pulsed annealing by nanosecond ion and laser beams was carried out. The dependence of Er atoms redistribution in Si and also the microstructure and phase composition of Si:Er layers on the implanted fluence and regimes of pulsed annealing was determined. It is shown that Si:Er layers obtained using pulsed and thermal treatments have photoluminescent properties in the near infrared region at 77 K. These properties are manifested by the intensive signals at λ = 1.13 and 1.54 μm.

Introduction

The method of ion implantation is widely applied for the formation of thin film Si:Er solid solutions emitting light in the 1.5-1.6 μm region [1] and also for the synthesis of erbium silicide layers which are perspective in microelectronics as Schottky barriers [2]. The significant disadvantage of this method is the severe damage of Si matrix during implantation of heavy erbium ions (Er^+). In order to eliminate the radiation-induced defects the high-temperature annealing (T > 900 ^{0}C) is usually carried out. However, the elimination of simple kinds of defects is accompanied by the creation of extended defects (dislocations, dislocation loops) [3] and erbium ion clusters which decrease the luminescence efficiency.

Pulsed treatments of the implanted layers by nanosecond laser, ion and electron beams can be alternative to the traditional thermal annealing. Pulsed nanosecond treatments allow one to localize heating of amorphous material for its area and depth. Moreover, due to high velocities of heating, melting and crystallization defect-free epitaxial layers can be formed as a result of pulsed treatments [4]. It is necessary to note that pulsed treatment practically did not apply to Er-Si thin film systems. In this work the characteristic features of the pulsed annealing of Er-implanted Si layers were studied.

Experimental

In order to form Si:Er solid solutions and erbium silicide layers the implantation of n-Si (100) wafers was carried out at room temperature by Er^+ ions with energy E = 100 keV and fluencies $\Phi = 10^{15}$, 10^{16} and 10^{17} cm^{-2}. Separated Si crystals were firstly implanted by 40-keV O^+ ions with fluence $\Phi = 10^{17}$ cm^{-2} before Er^+ implantation. To eliminate radiation defects and to synthesize erbium silicides, Si samples were subjected to pulsed annealing by high-power ion (C^+, E = 300 keV, τ = 50 ns, W = 1.4-2 J/cm^2, N = 1-10) or laser (λ = 0.69 μm, τ = 80 ns, W = 1.1-2 J/cm^2) beams.

The distribution of implanted Er ions in Si after ion implantation and pulsed treatments was studied by Rutherford backscattering spectrometry (RBS) using 2 MeV He^+ ions The microstructure and phase composition of Si:Er layers were investigated by transmission electron microscopy (TEM) and microdiffraction. The dynamics of structure-phase transitions during pulsed laser annealing (PLA) was studied by measuring of sample reflectivity during laser pulse at two wavelengths (λ_1 = 1.06 μm and λ_2 = 0.53 μm). Photoluminescence (PL) of Si:Er layers was studied in the near infrared region (λ = 1-1.7 μm) at the temperature T = 77 K. In order to excite the PL signal Si samples were irradiated by Ar^+ laser (λ = 514.5 nm, P = 200 mW). Registration of PL was performed by BOMEM Fourier-spectrometer equipped with liquid nitrogen cooled Ge photodetector.

Results and discussion

RBS spectra of Si samples measured after ion implantation show that due to low energy (E = 100 keV) Er atoms are located in the narrow peak near the surface with thickness of about 80 nm (Fig. 1). PIBT of a Si layer implanted with the fluence Φ = 10^{16} cm^{-2} leads to the epitaxial recrystallization of amorphous layer that seen by the channeling of He^+ ions between 450 and 500 channels and also to redistribution of some part of Er atoms closer to the surface (segregation) and into Si crystal. Segregation effect of Er atoms is due to low solubility of Er in Si (~ 10^{16} cm^{-3}) and trapping of impurity by front of liquid-phase crystallization. Compared to Si the channeling in Er peak (750-800 channels) is absent that indicate interstitial position of Er atoms in Si lattice.

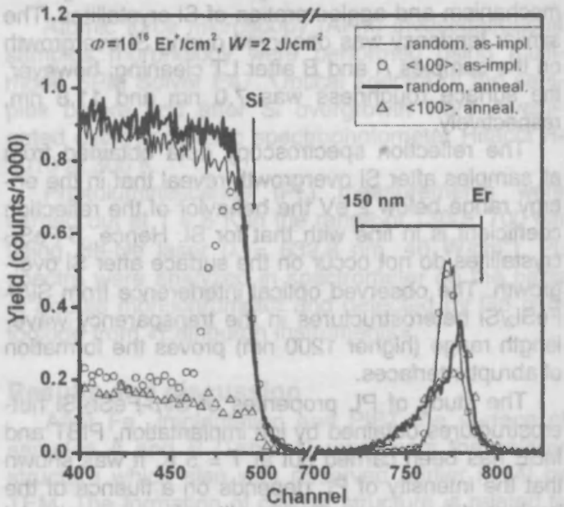

Fig. 1. RBS/Channeling spectra of Si (100) sample after ion implantation (Φ = 10^{16} cm^{-2}) and PIBT (W = 2 J/cm^2).

In the case of high-fluence implantation (Φ =10^{17} cm^{-2}) PIBT results in to significant suppression of Er segregation due to achieving of high Er concentration in the implanted layer ($N \sim 10^{22}$ cm^{-3}). At such a fluence Er profile expands into Si crystal up to depth of 0.15-0.2 μm depending on the number of pulses. A similar redistribution of the implanted Er atoms in Si was observed after PLA but in this case the diffusion tail of Er atoms was not so extended due to significantly lower melt depth.

Figure 2 shows the bright-field plan-view TEM image of a Si layer implanted with the fluence $\Phi = 10^{16}$ cm^{-2} and subjected to PIBT. It can be seen that PIBT leads to the formation of cellular structure of the implanted layer characteristic of liquid-phase crystallization. These cellular structures are columns of Si 0.15–0.2 μm in diameter surrounded by walls of erbium silicide precipitates with sizes of 10-20 nm. Electron microdiffraction patterns demonstrated the presence of spot reflexes belonging to Si and ErSi that indicate the formation of single-crystalline Si and ErSi. This result agrees with RBS data (Fig. 1) which showed the channeling of He^+ ions in the implanted layer after PIBT (450-500 channels). A similar cellular structure was observed by TEM in Fe-implanted Si layers after pulsed annealing [5]

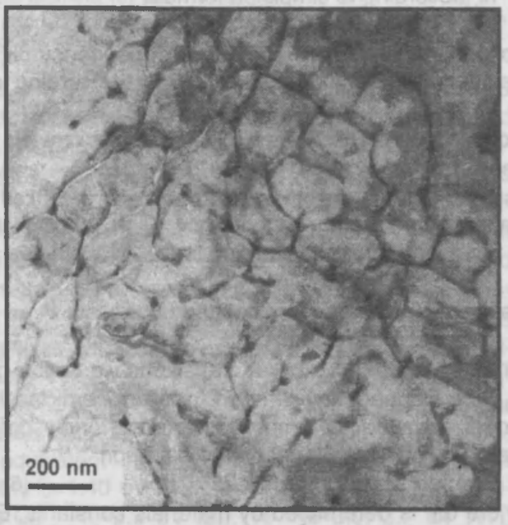

Fig. 2. Bright-field TEM image of Si layer after ion implantation ($\Phi = 10^{16}$ cm^{-2}) and PIBT (W = 2 J/cm^2).

In the case of high-fluence implantation ($\Phi = 10^{17}$ cm^{-2}) the formation of larger erbium silicide precipitates with sizes of 30-50 nm is observed. Electron microdiffraction pattern showed the presence of large number of rings (up to 20) related to the formation of polycrystalline Si and erbium disilicide ($ErSi_2$). The synthesis of $ErSi_2$ layer agrees with the data of [2] and correlates with our RBS data which showed decrease of maximum Er concentration from 50 % to 25-30 % during rapid diffusion of Er atoms in molten Si.

Before low-temperature PL measurements, Si:Er samples prepared by ion implantation and PIBT were thermally annealed (T = 800 ^{0}C, 30 min). PL spectrum of medium-fluence ($\Phi = 10^{16}$ cm^{-2}) implanted sample (Fig. 3) shows two intensive peaks at 0.807 and 1.1 eV. PL peak at 0.807 eV is related to the optical transitions between $^4I_{13/2} \rightarrow {}^4I_{15/2}$ energy levels of Er^{3+} ion. For our opinion, the main contribution to this peak gives the tail regions of Er depth profile, where the concentration of Er atoms significantly lower than that in segregation peak (Fig. 1) that leads to the formation of light-emitting Si:Er solid solutions. The second PL peak at 1.1 eV is related to Si band edge luminescence emitting from the depth of about 1 μm which corresponds to the penetration depth of Ar laser radiation. Relatively high intensity and small width of this PL peak is probably due to low defectivity of a Si layer after liquid-phase epitaxial recrystallization followed by thermal annealing. The PL spectrum of Si sample implanted by the highest Er fluence ($\Phi = 10^{17}$ cm^{-2}) also showed two above mentioned peaks, however in this case a broad defect band in the range of 0.7-0.9 eV was observed. This PL band probably relates to the formation of extended defects due to high-fluence implantation and thermal annealing. So, in spite of significant precipitation of Er in Si the formed layers emit light in the near IR region that allows one to fabricate light-emitting diodes on its base.

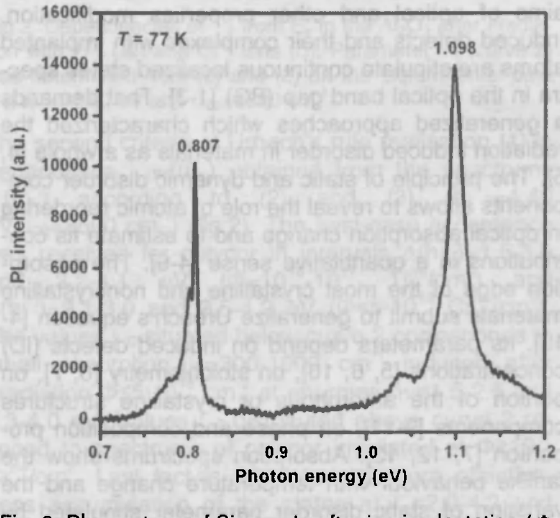

Fig. 3. PL spectrum of Si sample after ion implantation ($\Phi = 10^{16}$ cm^{-2}), PIBT (W = 2 J/cm^2) and thermal annealing (T = 800 ^{0}C, 30 min).

Acknowledgments

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