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Annealing of deep level defects in GaAs nanostructures by ion beam irradiation

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ABSTRACT

Present study reports the fabrication of Gallium Arsenide (GaAs) nanostructures on silicon (Si) substrates with the help of GaAs ions produced by hot and dense argon plasma in a modified dense plasma focus device. The fabricated nanostructures are further irradiated by Ar^{2+} ion beam having energy of 100 keV and fluences of 1×10^{13} ions/cm^2, 5×10^{14} ions/cm^2 and 5×10^{15} ions/cm^2 in a ion beam accelerator. The morphological, stoichiometric and optical properties of as-fabricated and ion beam irradiated nanostructures have been compared to study the presence of defect states. As-deposited GaAs nanodots were found to be modified as nanostructured films upon ion irradiation. Excess arsenic present in as-deposited nanodots as deep level defect, is removed from ion irradiated nanostructured films. Thus, we found that the deep level defect states i.e., arsenic antisite (EL2) were annealed out in ion irradiated samples as is evident from Raman and photoluminescence spectra. It is found that ion irradiation reduces the EL2 defects in nanostructured films which have immense potential applications in enhancing efficiency of optoelectronic and electronic devices.

1. Introduction

Gallium arsenide (GaAs) nanostructures are the potential candidate for making high efficient optoelectronics and electronic devices [1–3]. The efficiency of these devices can be further increased by using defect free GaAs nanostructures. In general, GaAs nanostructures possess structural and electronic defects such as dislocations, stacking fault, Arsenic antisite etc [4–6]. Defects introduced due to arsenic antisite introduce a deep level in the middle of the band gap which is commonly known as EL2 defect. EL2 is main native defect found in GaAs nanostructures, which reduces the performance and efficiency of electronic and optoelectronic devices [7]. Earlier reports [8–13] suggest that the origin of EL2 defect is arsenic (As) antisite (As_{Ga}) present in the GaAs nanostructures due to excess of As. Thus, it is necessary to remove the excess As from nanostructures, which passivates the EL2 defect and enhance the efficiency of devices.

In an earlier study [14], it was observed that the as-deposited GaAs nanostructures when fabricated using high fluence and highly energetic ions in a modified dense plasma focus (DPF) device, possesses excess of Arsenic which is the main cause of EL2 defects. The irradiation of GaAs nanostructures by low energy ion beam (having energy from few keV to hundreds of keV) can reduce such deep level defects and increase the efficiency of device fabricated on the irradiated nanostructures. Thus, in present study, as-deposited GaAs nanostructures were ion irradiated and its effect on the morphological, stoichiometric and optical properties of nanostructures has been reported.

2. Experimental details

The GaAs nanostructures were fabricated on silicon substrates. GaAs wafer of purity 99.99% was cut in the form of a disc of diameter 17 mm and fixed on the top portion of the modified anode of DPF device. The details of modification and formation of high temperature, high density and extremely non-equilibrium plasma in modified DPF device has already been reported earlier [14–17]. The hot, dense and extremely non-equilibrium plasma formed at top of the modified anode ablates GaAs target and subsequently GaAs is deposited on silicon substrates kept at an optimized distance of 5.0 cm from the top of central anode. Previous studies indicated that two bursts of plasma of duration ~100 ns (shot) were needed for the formation of nanodots [14–17]. The thickness of as-deposited films was found to be ~30 nm measured using

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ellipsometry. The as-deposited nanostructures were further processed using Argon ion beam irradiation at ion beam facility available at Inter University Accelerator Centre (IUAC), New Delhi having beam size of the order of few mm. Ion beam energy of 100 keV was chosen with fluence varying from 1×10^{13} ions/cm^2 to 5×10^{15} ions/cm^2 and samples were irradiated by raster scan. The MIRA3 TESCAN field emission scanning electron microscope (FE-SEM) was used to analyze surface morphology. Energy dispersive X-ray spectroscopy (EDX) measurement was done on an Environmental SEM model Quanta 200 FEI with Oxford-EDS system IE250 X-MAX 80.Raman spectra were recorded using the in-Via Reflex (Renishaw) spectrometer equipped with Ar–Ne laser. The room-temperature photoluminescence (PL) were measured on a Fluorolog (HORIBA JOBIN-YVON) spectro-fluorometer with excitation wavelength of 470 nm (2.638 eV).

3. Results and discussion

The surface morphology of as-deposited sample has been reported [14] and shows the formation of nanodots with average diameter ~22 nm. The SEM images of GaAs nanodots ion irradiated at energy of 100 keV with ion fluences of 1×10^{13} ions/cm^2, 5×10^{14} ions/cm^2 and 5×10^{15} ions/cm^2 are shown in Fig. 1(a), (b) and (c), respectively. The surface morphology of these nanodots irradiated with ion fluence of 1×10^{13} ions/cm^2 is similar to the morphology of as-deposited nanodots whereas for higher ion fluences nanodots agglomerated to form nanostructured films. The size distribution of respective nanodots are presented in inset of their SEM images showing increase in average diameter of nanodots from 22 nm (as-deposited) to 30 nm (for 1×10^{13} ions/cm^2), 50 nm (for 5×10^{14} ions/cm^2) and 80 nm (for 5×10^{15} ions/cm^2).

The change in morphology of GaAs nanostructures on irradiation with different ion fluences can be understood as follows: Ion irradiation of as-deposited nanodots causes the local heating of the sample, which partially melts the as-deposited material. This material subsequently recombines to produce overall agglomeration of nanostructures which is evident from decrease in the surface density of nanostructures. The irradiation of nanodots, by ion beam is affected by both the electronic and nuclear energy losses with the nuclear energy loss playing a dominant role as per the SRIM calculations. The electronic and nuclear energy losses estimated from SRIM calculations are 37.25 eV/Å and 65.23 eV/Å, respectively, which suggest nuclear energy loss is more than electronic energy loss ($S_n > S_e$). It is well known that in the energy range from few eV to few hundreds of keV nuclear energy loss is dominant whereas in the energy range 10 MeV and above electronic energy loss is dominant. This has been observed in the present experiment also. The loss in nuclear energy results in breaking of Arsenic from its antisites which are loosely bound and this is evident from EDX result.

A typical EDX spectrum of ion irradiated nanostructures is shown in Fig. 2(a) indicating the presence of Ga and As only. The observed atomic percentage of Ga is 2.53% and As is 2.44% with an error of 0.05%. The ratio of elemental compositions of Ga and As after ion irradiation is ~1:1. This is due to restructuring of nanostructures and subsequent evaporation of excess As from as-deposited nanodots. Thus, the ion beam irradiated samples have standard equiatomic composition in the nanostructures.

A typical XRD spectrum of ion irradiated nanostructured film is shown in Fig. 2(b) having diffraction peaks at 2θ values of 27.3°,

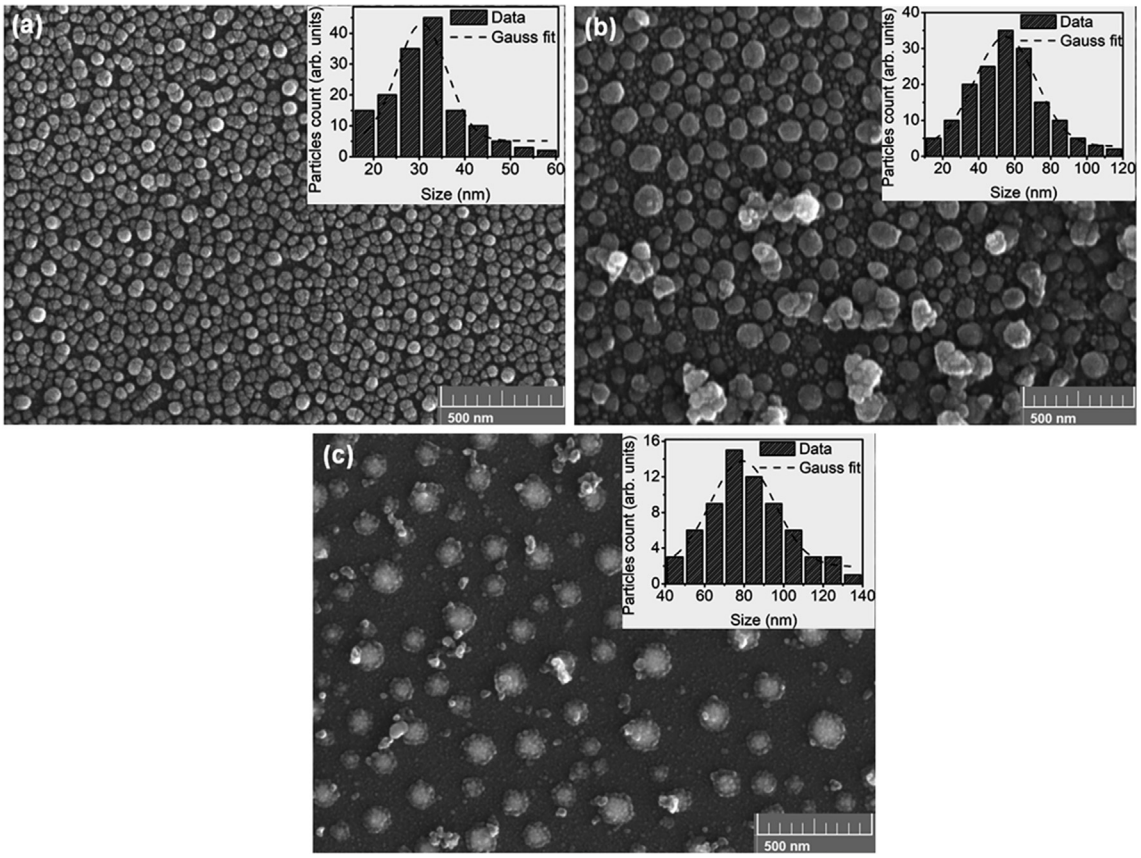

Fig. 1. SEM images of GaAs nanostructures irradiated with ion fluences of (a) 1×10^{13} ions/cm^2, (b) 5×10^{14} ions/cm^2 and (c) 5×10^{15} ions/cm^2. The size distribution of nanostructures is shown in inset.