# Ferromagnetism in Manganese Implanted GaAs

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**Abstract**

In the present work, 325 keV $Mn^+$ ions were implanted into GaAs with various fluences varying from 1 $x10^{15}$ to $1x10^{16}$ ions $cm^{-2}$.The magnetic properties of $Mn^+$ implanted GaAs samples were studied using super conducting quantum interference device (SQUID) techniques. M-H curves exhibit the hysteresis loops indicated the presence of magnetic behavior. To investigate the influence of the residual implant damage upon the structural and magnetic properties of $Mn^+$ implanted GaAs was obtained from RBS experiment on implanted wafers.

**Keywords:** Ion Implantation, GaAs, SQUID, RBS.

## Introduction

(GaMn)As is very important dilute magnetic semiconductors because of its potential application in electronics and optoelectronics devices. In general only limited success has been achieved. Some studies on the effects of Mn ion implantation in GaAs with various fluences at different energies have been reported [1]. p-type GaAs wafers were implanted with different energies (70, 120, 170,250 and 350 keV) with various fluences (0.9, 0.88, 0.61, 1.3, 0.63 x $10^{16}$ ions $cm^{-2}$) at room temperature and after implantation, the samples were irradiated with 350 keV $He^+$ ions with fluence of 1 x $10^{16}$ ions $cm^{-2}$.for Recrystallization [2] . Semi-insulating GaAs implanted with 1MeV $Mn^+$ with fluence of 3 x $10^{15}$ ions $cm^{-2}$ were studied using the high resolution X-ray diffraction and vibrating sample magnetometer [3]. Implantation damage study in ferromagnetic Mn-implanted Si [4].

In the present work, we studied the magnetic properties of gallium arsenide after implantation with 325 keV Mn+ ions with various fluences varying from 1 x $10^{15}$ to 2 x $10^{16}$ ions $cm^{-2}$ using Superconducting Quantum Interference Device and Rutherford Backscattering Spectroscopy.

## Experimental Details

In this study, un-doped gallium arsenide samples were implanted with 325 keV $Mn^+$ ions for 1 $x10^{15}$ to $1x10^{16}$ ions $cm^{-2}$ at 350 $^0$C substrate temperatures using 1.7 MV Tandetron accelerators at IGCAR, Kalpakkam. The implantation energy of 325 keV was selected on the basis of the SRIM code calculations. Projected range (Rp) and standard deviation (ΔRp) of the 325 keV $Mn^+$ ions in gallium arsenide were found to be 170.50 nm and 78.00 nm respectively. The beam current density was about 50 nA $cm^{-2}$ during implantation. The scanned beam was further collimated through a collimator of diameter 12.5 mm for uniform implantation over the entire area of the sample. During implantation, the vacuum in the target chamber was maintained at $10^{-7}$ mbar. The sample implanted with $Mn^+$ ion for the fluence of 1 x $10^{16}$ ions $cm^{-2}$ was irradiated with 5 MeV $Si^+$ ions for ion fluences of 1 x $10^{16}$ $cm^{-2}$ at 350 $^0$C substrate temperatures. The magnetic measurements were performed by using superconducting quantum interface devices (SQUID). The magnetization of each sample was measured as a function of an applied magnetic field and the temperature to determine the Curie temperature, the coercive field and magnetic properties and Rutherford Backscattering Spectroscopy techniques have been used to investigate properties of $Mn^+$ ion implanted samples.

## Result and Discussions

### *Magnetic Properties*

The magnetization of each sample was measured as a function of an applied magnetic field (H) and the temperature to determine the Curie temperature, the coercive field and other magnetic properties. The magnetizations were obtained with the applied field parallel to the surface of the samples. All the samples showed the ferromagnetic behaviors at room temperature only after the irradiation with 5 MeV $Si^+$ ions for ion fluence of 1 x $10^{16}$ $cm^{-2}$ at 350 $^0$C substrate temperature. The shape of the hysteresis loops were found to be depends on the ion fluence and the hysteresis loop indicates the presence of magnetic behavior [5]. The temperature dependence magnetization (M-T) curves and Hc - T are plotted from the data of the sample implanted with $1x10^{16}$ ions $cm^{-2}$ (after post annealing) are presented in Figure 1,2. It is seen from the table that the width of the hysteresis loops changed with temperature and the coercivity of the sample was found to be decrease with increase in temperature and The Curie temperature (Tc) estimated from the M-T curves was found to be 281.17 K.

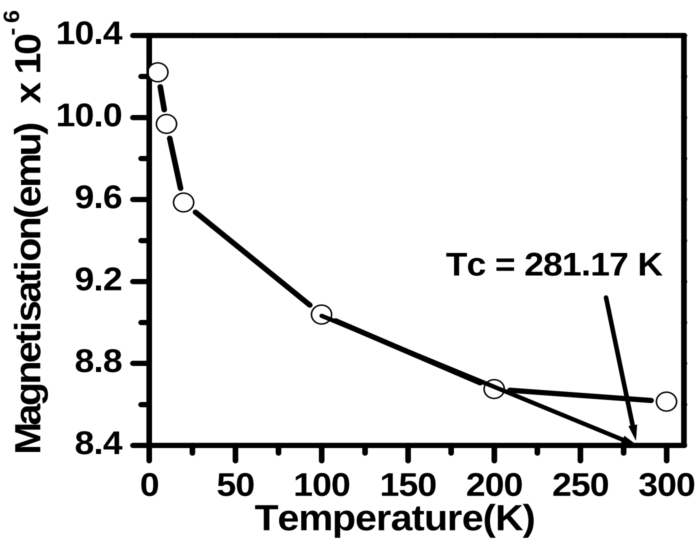


**Figure 1** Magnetization Versus Temperature (M-T) Curves Of GaAs $+Mn^+$ +Si

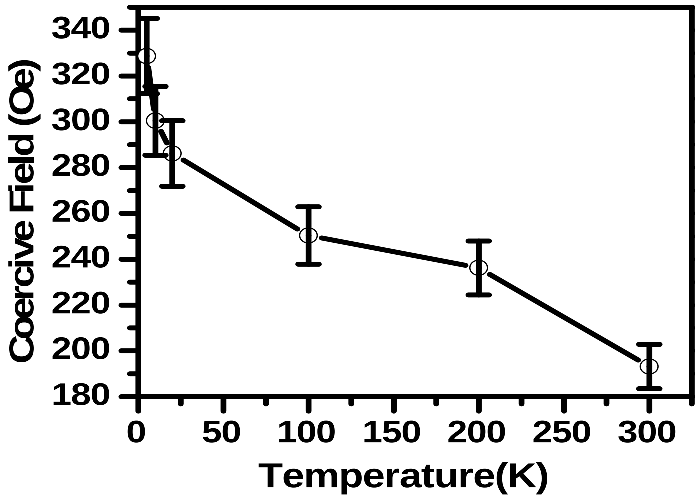


**Figure 2.** Hc-T Curve Of GaAs $+Mn^{+}$ +Si

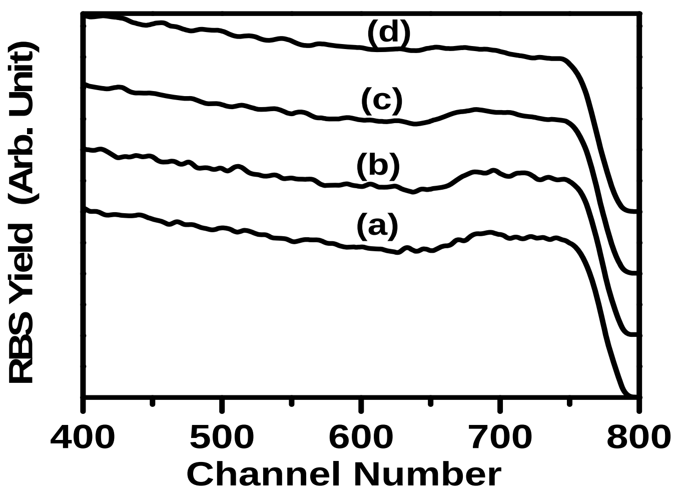


**Figure 3.** RBS Spectra of The GaAs Samples Implanted With 325 Kev $Mn^{+}$ Ions Implanted Gaas For The fluence of (a) $1x10^{15}$ (b) $5x10^{15}$ (c) $1x10^{16}$ (d) $2x10^{16}$ ions $cm^{-2}$.

## Rutherford Backscattering Spectroscopy (RBS) Studies

Fig.3 shows the RBS spectra of the GaAs samples implanted with 325 keV Mn+ ions at room temperature. The decreasing scattering yield between the channel numbers 650 to 750 with smooth falling edge shows reduction in the volume concentration of the GaAs due to the presence of implanted Mn ions in the region and the presents GaAs in the buried layers. It shows that the Mn+ ions has distributed to form a buried GaMnAs layer with well defined boundaries between GaAs and Mn .The yield height is found to decrease with increase in the Mn fluences levels, showing the decrease in the thickness of the buried layer with increase in theionsfluences.

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