Above Room Temperature Ferromagnetism in Mn-ion Implanted Si$_{0.75}$Ge$_{0.25}$

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Abstract. Ferromagnetic behaviour above room temperature has been observed in Mn-ions implanted Si$_{0.75}$Ge$_{0.25}$. The 900°C annealed sample with Mn dosage of $2 \times 10^{16}$ cm$^{-2}$ exhibit saturation magnetization, saturation field and coercive field of $\sim 9$ emu/cm$^3$ and $\sim 1500$ Oe and $\sim 60$ Oe respectively at 300K.

Keywords: Magnetic semiconductor, Manganese, Silicon

PACS: 75.50.Pp

INTRODUCTION

“Spintronic” is an emerging technology, where not only the electron charge but the electron spin as well are exploited. This could offer opportunities of a new generation of devices that are nonvolatile, with high data processing speed, large integration capabilities and low power consumption. In order to realize “spintronic” applications in current semiconductor technology, there is a need to develop Si-based magnetic semiconductors that is ferromagnetic (FM) above room temperature. Recently, it has been predicted [1] and experimentally [2] shown that Si can be made FM with Mn-doping. The reported Curie temperature above 400 K is encouraging. Since Si$_{1-x}$Ge$_x$ is a promising material for future CMOS technology, this aroused our curiosity whether Mn-doped Si$_{1-x}$Ge$_x$ can be made FM above room temperature as well. It has also been shown theoretically that for $x \geq 0.16$ in Si$_{1-x}$Ge$_x$, substitutional Mn in Ge-rich neighborhoods is more stable than interstitial Mn, and that Mn-doped Si$_{1-x}$Ge$_x$ can be a potential FM semiconductor. [3]

EXPERIMENTAL PROCEDURES

Ion implantation is known to be useful to screen particular combinations of magnetic dopants and host semiconductors for their FM properties, and may have applications in forming selected area contact regions for spin-polarized carrier injection in device structures. Thus, we employed this method to synthesis Mn-doped Si$_{0.75}$Ge$_{0.25}$. Two different dosages of Mn-ions (W1: $1 \times 10^{16}$ and W2: $2 \times 10^{16}$ /cm$^2$) were implanted at 100 keV into the relaxed Si$_{0.75}$Ge$_{0.25}$ layers that were grown by chemical vapour deposition on SiGe graded buffer layer on Si(100) substrates. Rapid thermal annealing (RTA) were performed at temperatures ranged from 700 °C to 900 °C for 20s. Characterizations were carried out with the use of x-ray photoelectron spectroscopy (XPS), x-ray diffraction (XRD), Raman spectroscopy, superconducting quantum interference device (SQUID), and Hall measurements.

EXPERIMENTAL RESULTS

Mn peaks concentrations (determined from XPS sputter depth profiles) of the as-implanted W1 and W2 are, $\sim 8$ % and $\sim 12$ %, respectively. The Raman spectrum of the RTA sample W2, as shown in Fig. 1 shows the characteristic phonon frequencies of Si-Si, Ge-Ge and Si-Ge modes. The as-implanted sample shows a curve characteristic of an amorphous material, with all the characteristic peaks being smeared out. After annealing, the crystalline quality has been recovered.

Field dependent magnetization ($M$-$H$) curves in Fig. 2 show hysteresis for all of the samples, evidence of FM behaviour. The magnetization strength
increases with increasing annealing temperature, which can be related to improved crystal quality (Raman peak intensity). After RTA900 °C, sample W2 exhibits saturation magnetization, saturation field and coercive field of ~9 emu/cm³ and ~1500 Oe and ~60 Oe respectively at 300K.

It can be seen from Fig. 3 that clear FM behaviours are observed at 300 K, and the magnetization strength is increased by 2X as the implantation dosage doubled. The temperature-dependent magnetization curves (M-T) show that the magnetization persists up to 350 K and the critical temperature can be well above 400 K. The measured coercive field decreases with increasing temperature, as shown in Fig. 4.

CONCLUSION

FM behaviour above device operating temperature has been observed in Mn-implanted Si₀.₇₅Ge₀.₂₅ alloys, and the magnetizations strength increases with increasing Mn-dosage and annealing temperature. This material can be suitable candidates for spintronic applications, due to the presence of Si which guarantees the desired integrability with the well-assessed Si technology.

ACKNOWLEDGMENTS

This work is supported by Singapore Agency for Science, Technology and Research (A*STAR), under Grant No. 022 105 0053.

REFERENCES