Magnetic Doping and Characterization of n-type GaN

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Abstract. n-type GaN films grown on sapphire by MOCVD were doped with Mn and Cr by solid state diffusion and characterized by various methods. Hall measurement shows that the samples still remain n-type after the diffusion. Secondary Ion Mass Spectroscopy (SIMS) results show a good diffusion of Mn and Cr inside GaN. X-ray diffraction (XRD) reveals no secondary phases in the samples. Superconducting quantum interference device (SQUID) results show that the samples are ferromagnetic up to room temperature. The possible origin of ferromagnetism is discussed.

INTRODUCTION

GaN has been applied in conventional optical and electron charge based devices. In electron spin based devices [1], GaN will continue to play a key role since GaN samples doped with transitional metals like Mn or Cr were predicted to be ferromagnetic with a high Curie temperature [2,3]. Though much work [2-7] has been done about Mn and Cr doped GaN, many important issues like the origin of ferromagnetism, the change of c-lattice constant etc. remain open. In this paper, MOCVD grown GaN were doped with Mn and Cr by thermal diffusion. The doped samples were characterized and the origin of ferromagnetism was briefly discussed.

EXPERIMENTS

The unintentionally doped GaN wafers were grown at the same condition of 1100°C by MOCVD on sapphire (0001) substrates. Mn (100 nm) and Cr (51 nm) thin films were deposited on the wafers by standard thermal evaporation under the vacuum of 10^{-6} torr. The coated wafers were then sealed in separate quartz tubes under the vacuum of 10^{-3} torr and annealed at 500 °C for 6 hours in a furnace. After annealing, the wafers were washed by HCl solution of 2 mol/L. The Mn doped wafer was labeled sample 1 and the Cr doped was labeled sample 2. The samples were characterized by X-ray fluorescence (XRF), SIMS, XRD, Hall measurement and SQUID.

RESULTS AND DISCUSSION

XRF results show that the Mn concentration is 0.02% for sample 1 and the Cr concentration is 2.68% for sample 2. SIMS results demonstrate that both Mn and Cr diffuse deep into GaN layer and their concentrations decrease gradually with increasing depth without accumulation inside GaN layer.

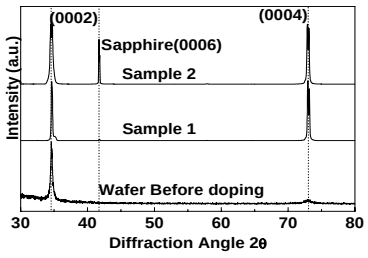

FIGURE 1. XRD θ-2θ curves for the two samples and the wafer before doping.

Fig. 1 shows the XRD results for the two samples and the wafer before doping. It can be observed that only the peaks related to h-GaN and sapphire appear.

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This indicates that no secondary phase or phase separation is detected. This result agrees with other reported results [5]. In addition, there is no obvious change in the peak positions after doping, which implies that doping causes no obvious change in c-lattice constant and this also agrees with the results in the literature [8].

Fig. 2 shows the magnetization as a function of applied field measured at 5K and 300K. The magnetic field was applied parallel to the sample surface. The data shown in Fig.2 are the values extracted from the raw data by deducting the diamagnetic contribution of the substrate. Therefore, those data are more qualitative than quantitative. The curves in Fig.2 are typical for a ferromagnetic material, indicating that the Curie temperature is around or over 300K. The saturation magnetization decreases as the temperature increases to 300K. The obtained Curie temperature is within the range of the values reported in the literature which vary from 10-25K [6] to 940K [7].

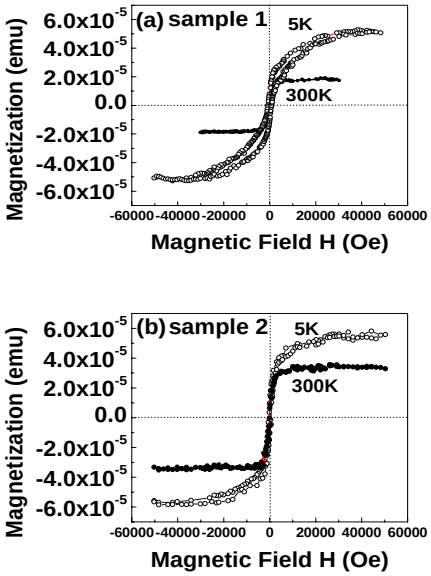

FIGURE 2. The magnetization versus magnetic field curves for sample 1 (a) and sample 2 (b) at 5K and 300K.

Since SIMS and XRD results do not show any phase separation, it is possible that the observed ferromagnetism originates from an alloy of GaN and magnetic elements (Mn and Cr respectively). Hall measurement shows that the samples are still n-type after doping. Other groups also reported that n-type GaN:Mn [6,7,9] and GaN:Cr [4] show ferromagnetism. Obviously these results can not be explained by the theory based on hole mediation [2]. The ferromagnetism in n-type GaN:Mn and GaN:Cr is possibly induced by the s-d exchange interaction, i.e. interaction of electron spins and localized moments of the transition metal, as previously proposed [10].

CONCLUSION

GaN doped with Mn and Cr by solid state diffusion shows room temperature ferromagnetism which comes from an alloy of GaN and magnetic elements (Mn,Cr). The observed ferromagnetic properties are possibly due to the s-d exchange interaction.

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