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Characteristicsofsinglecrystallinedilutedmagneticsemiconductor$Ga_{1-x}Mn_xN$nanowires

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Introduction

Theoretical studies indicate that transition metal doped gallium nitride (GaN) possesses a ferromagnetic transition temperature higher than room temperature by hole mediated ferromagnetism, which would be advantageous for many proposed spintronic applications[1]. While many experiments have already been carried out in efforts to validate this hypothesis, significant controversy exists over the possible magnetic impurity phase separation for many of these thin-film studies[2]. Moreover, many intrinsic defects in these films originating from the nonequilibrium molecular beam epitaxial growth process constitute an Achilles' heel toward attaining a fundamental understanding of the ferromagnetism in these materials[3]. Among many others, nanotubes and nanowires are currently being actively explored as possible building blocks for electronic devices of sub 100 nm or smaller[4-6]. Recently, we reported on single crystalline Mn:GaN nanowires with Curie temperature above room temperature, magnetoresistance near room temperature, and spin-dependent transport.

Experiment

GaN:Mnnanowires were grown using a Ni catalyst deposited on sapphire by chloride based transporting under flow of ammonia (NH_3) at 700°C. Our CVD system was similar to halide vapor phase epitaxy, which is hot-well horizontal quartz tube chemical vapor deposition growth system.

Resultsanddiscussion

Fig. 1 shows transmission electron microscopy (TEM) images of the nanowires. Perfect single crystalline nature without defects or secondary phases can be readily seen from these high resolution TEM images (Figs. 1A,B). Selected area electron diffraction (SAED) pattern recorded on the wire can be indexed according to the wurtzite GaN structure. Fig. 2C shows the representative Mn concentration in the $Ga_{1-x}Mn_xN$ nanowires determined by an energy dispersive X-ray spectroscopy (EDS) analysis with an x value of ~0.08. It was found from the line profile analysis and compositional mapping in the EDS analysis that Mn is distributed homogeneously within the nanowire lattice. Importantly, our process produces single crystalline Mn doped GaN nanowires without any secondary phases, which are frequently observed in GaMnN thin film studies. Thorough TEM and high resolution TEM observations of the $Ga_{1-x}Mn_xN$ nanowires showed no evidence of secondary phases, such as Mn_xN_y or Ga_xMn_y. And the magnetic properties of the nanowires were determined using a superconductor quantum interference device (SQUID) magnetometer. Temperature dependence magnetization (M-T curve) of the $Ga_{1-x}Mn_xN$ nanowires with 0.08 showed ferromagnetism up to room temperature (Fig. 2 B). Significant controversy exists with regard to the ferromagnetic origin of $Ga_{1-x}Mn_xN$ phases[5]. Some investigation suggests a high-temperature intrinsic ferromagnetism of $Ga_{1-x}Mn_xN$. We believe that the ferromagnetism of nanowires originates from the intrinsic ferromagnetism of $Ga_{1-x}Mn_xN$, since we could not observe ferromagnetic secondary phases at the interior or the surface of the nanowires through in-depth structural analyses by TEM and HRTEM.

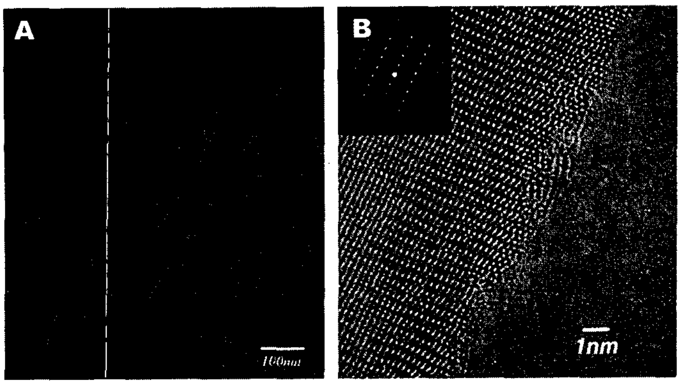

Fig. 1. HR-TEM images show the GaMnN nanowires (A)low magnification image of nanowires, (B) high resolution images a nanowire, inset is SEAD patterns which was taken along the <100> zone axis, followed by growth direction is (001).

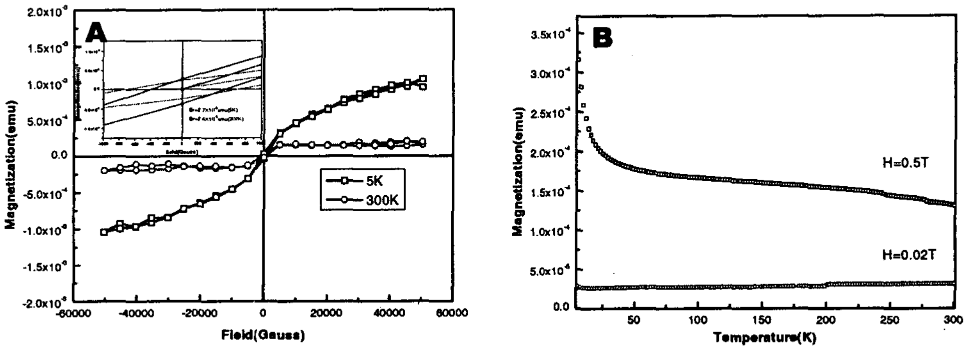

Fig. 2. Magnetic properties of GaMnN nanowirs using the SQUID (A) Magnetization loops of the nanowires at 5K and 300K.(B) magnetization as function of temperature (under 0.5 and 0.02 Tesla) for 8 at% Mn doped GaN nanowrires.

Conclusion

we successfully prepared room temperature ferromagnetic semiconductor Ga1-*x*Mn*x*N nanowires by a chemical vapor transport process. Importantly, our chloride-based transport approach enables controlled doping of Mn in the single crystalline GaN nanowires. Our characterization of the nanowires, ferromagnetism up to room temperature, and no evidence of secondary phases. The availability of such ferromagnetic semiconductor nanowires should be helpful toward attaining understanding of the fundamental aspects of magnetism in diluted magnetic semiconductors.

Acknowledgements

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