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Evidences of room temperature ferromagnetism in substitutionally Mn network-doped GaN nanowires

Tae-Eon Park[1,2]*, Han-Kyu Seong[1], Ungkil Kim[1], Joonyeon Chang[2], Heon-Jin Choi[1†]
[1]Department of Materials Science and Engineering, Yonsei University, Seoul 120-749, Korea
[2]Center for Spintronics Research, Korea Institute of Science and Technology, Seoul 136-791, Korea
(† To whom correspondecne should be addressed. Email : hjc@yonsei.ac.kr)

Magnetic-doped semiconductors, known as diluted magnetic semiconductors (DMSs), are the most promising candidates for spintronics. Room temperature ferromagnetism in the DMSs has primarily focused on wide band-gap Ⅲ-Ⅴ semiconductors, particularly Mn-doped GaN and ZnO, as theoretical calculations indicates that a Curie point is higher than the room temperature[1]. Numerous experiments have reported on the room temperature ferromagnetism with DMSs. However, the distribution and chemical state of doped Mn elements play an important role to address the magnetic ordering and its origin in DMSs, because it remains a point of controversy, due to the possibility of ferromagnetic secondary phases and the uncertainty related to the magnetic interaction between the charges and the magnetic dopant. Therefore, understanding of magnetism in transition metal doped semiconductors requires structural information of Mn site distribution and their magnetic interaction.

In the previous study, we reported on preparation of Mn-doped GaN nanowires and their ferromagnetism[2]. Here, we report on evidences of truly room temperature ferromagnetism in substitutionally Mn network-doped GaN nanowires. In these single crystaline nanowires, doped Mn atoms substitutionally doped with 2+ states for the Ga sites and largely take part in the wurtzite network of host GaN from anomalous x-ray scattering and x-ray absorption fine structure measurements.

The nanowires in this study were prepared by a transitional chemical vapor deposition process[2]. $Ga_{1-x}Mn_xN$ nanowires were grown by transporting gallium chloride ($GaCl_3$) and manganese chloride ($MnCl_2$) onto sapphire substrates under a flow of ammonia (NH_3) at 800 ℃. They were single crystalline, approximately 100 nm in diameter, several μm in length and were doped with 7% of Mn.

In order to investigate whether Mn dopants are incorporated in the crystalline lattice of GaN nanowires, we measured anomalous x-ray scattering (AXS) for the $Ga_{0.93}Mn_{0.07}N$ nanowires around Mn K-edge. The spectrum of AXS exhibits the intensity cusps at (0002) reflection, whose magnitude is directly related to the Mn composition. It indicates that the doped Mn atoms substitutionally participate in the wurzite network of host GaN. We further confirmed that the doped Mn is primarily in 2+ charge state and substitues for Ga from the Mn and Ga K-shell XAFS.

X-ray absorption spectroscopy (XAS) spectrum shows that the electronic configuration of doped Mn is mainly $3d^5$, suggesting that the divalent bonding nature of Mn $3d$ orbital with surrounding

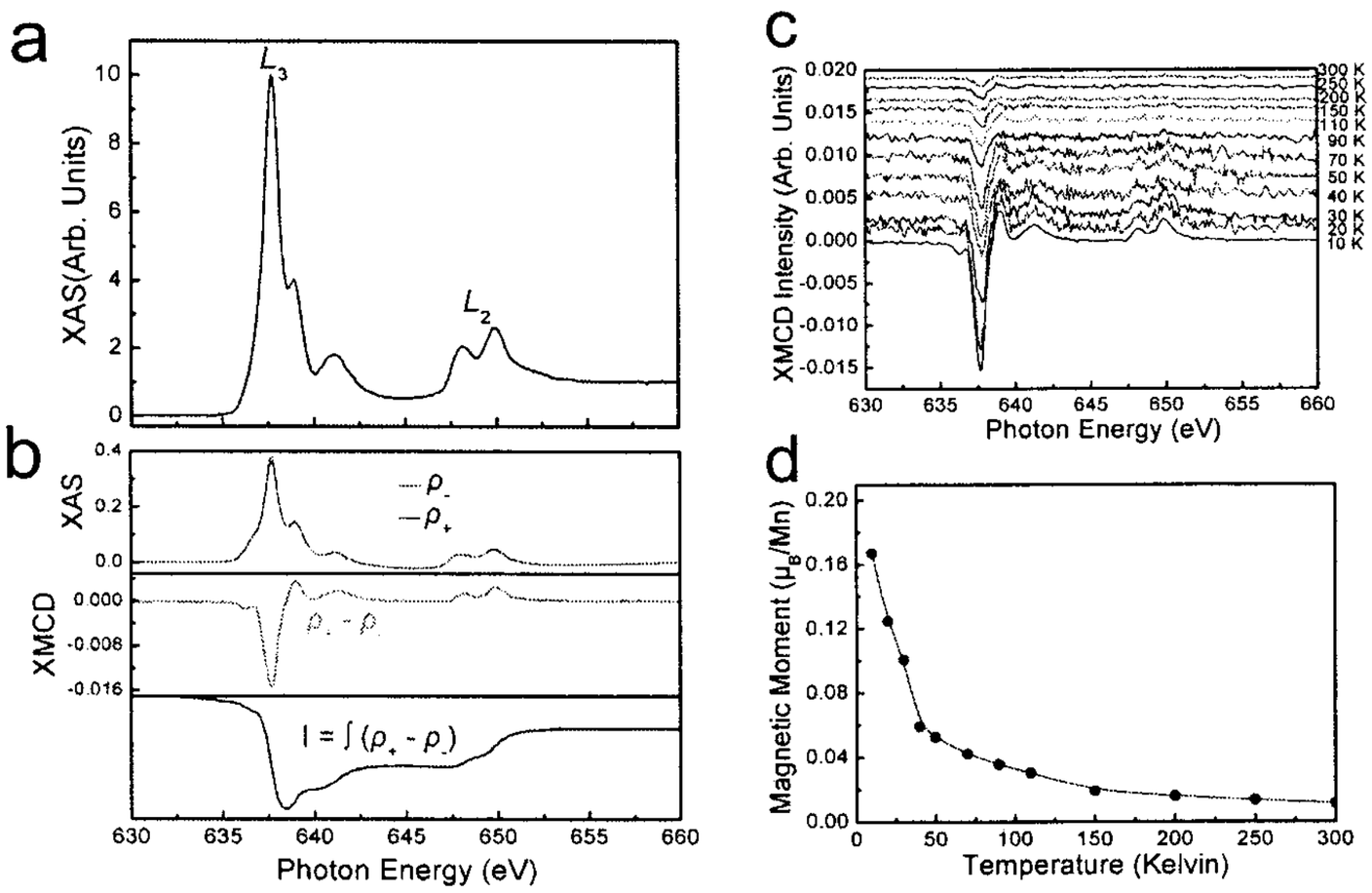

Fig. 1. (a) Typical Mn $L_{2,3}$-edge XAS spectrum of $Ga_{1-x}Mn_xN$ nanowires at 300K. (b) XMCD spectra at 5000 Oe taken with parallel (ρ_+) and antiparallell (ρ_-) alignment of light helicity and their integration measured at 10K. Temperature dependence of the dichroism (c) and magnetic moment per Mn atom (d) for the same sample.

semiconductor medium makes Mn atom a electron configuration in the GaN structures. In order to check whether the local spin moments align ferromagnetically or not, we also masured at x-ray magnetic circular dichroism (XMCD) spectra at Mn $L_{2,3}$-edges. The XMCD signal was observed in the $Ga_{0.93}Mn_{0.07}N$ nanowires and shows nearly identical line shapes for MCD spectrum ($\rho_+ - \rho_-$) and its integration (I) of the nanowires doped with Mn atoms, indicating that magnetic origin is the Mn^{2+} ($3d^5$ configuration).

In summary, we observed that the doped Mn atoms substitutionally doped with 2+ states for the Ga sites and largely take part in the wurtzite network of host GaN from AXS and x-ray absorption fine structure measurements. XAS and XMCD spectra at Mn $L_{2,3}$-edges showed that doped Mn has local mangeic moment and the electronic configuration of it is mainly $3d^5$. These experimental evidences supports the contention that $Ga_{1-x}Mn_xN$ is room temperature ferromagnetic semiconductor.

References

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