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Signle crystalline Cu doped GaN nanowires and their magnetism

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1. 서론

The concept of simultaneously manipulating both charge and spin in a single semiconductor medium leads to the exciting area of spintronics. Semiconductors doped with transition metal, so called diluted magnetic semiconductors (DMSs), are the most promising candidates for such applications. According to the principle of mean field theory, transition metals such as Sc, Ti, V, Cr, Mn, Fe, Co, and Ni that have partially filled *d* states can be doped for transforming spin-frustrated semiconductors to ferromagnets. It has also been predicted that room temperature ferromagnetism, which would be advantageous in many applications, could be achieved in magnetic doped wide band-gap semiconductors. Indeed, room temperature ferromagnetism has been reported from Cr, Mn, Fe and Co doped GaN, ZnO, and TiO_2. However, these transition metals with local magnetic moments may not be the best choice for the doping elements. Magnetic secondary clusters have been shown to be ferromagnetic, arguing the motivation that the ferromagnetism of the DMS sarises frommagnetic secondary clusters. Namely, the origin of ferromagnetism in these DMSs is still controversial, due to the possibility of magnetic secondary phases and uncertainty of magnetic interactions. Herein, we report magnetism in *nonmagnetic* Cu doped single crystalline GaN nanowires.

2. 실험방법

Single crystalline diluted magnetic semiconductor $Ga_{1-x}Cu_xN$ nanowires for x = 0.01 and 0.024 were synthesized using a Ni catalyst deposited *c*-plane sapphire substrates in a horizontal hot-wall chemical vapor transport system. Solid metallic Ga (purity 99.99%) and CuCl (purity99.99%) powder were inserted into the center of a quartz tube at intervals of 2 inch, respectively. The substrates were placed at a distance of 1 inch away metallic Ga. The temperature of the furnace was increased at a heating rate of 50 ℃min^{-1} to 800 ℃ under flow of NH_3 at a rate of 20 cm^3min^{-1} and kept for 10 through 60 min and then cooled down to room temperature.

3. 실험결과

The $Ga_{1-x}Cu_xN$ nanowires (x=0.01,0.024) were grown by transporting gallium (Ga) and copperchloride (CuCl) onto anickel coated sapphire substrate under flow of ammonia (NH_3) at 800°C. The diameter and length of these nanowires were from 10 nm to 100 nm and tens of micrometers, respectively, and they had a triangular structure. The $Ga_{1-x}Cu_xN$ nanowires (x=0.01,0.024) with Curie point above room temperature indicate that Cu atoms substitute the Ga sites and they largely take part in the wurtzite network of host GaN. X-ray absorption and x-ray magnetic circular dichroism spectra showed that doped Cu have local magnetic moment and the electronic configuration of doped Cu is mainly $3d^9$ with a small portion of $3d^8$ component. The room temperature ferromagnetic $Ga_{1-x}Cu_xN$ system is expected to open a pathway toward a new class of nonmagnetic doped diluted magnetic semiconductors.

4. 고찰 및 결론

Ferromagnetism was achieved from Cu doped wide band gap GaN semiconductor nanowires. As shown in our magnetic measurements, the Curie point of this magnetic semiconductor is much higher than room temperature. Importantly, magnetic secondary phases are not responsible for the observed room temperature ferromagnetism since no such phases exist in the system. Instead, it may be attributed to *p-d* hybridization between Cu and N ions, which induces delocalized magnetic moments and long range coupling. It should be noted that theoretical calculations and limited experiments involving Cu doped oxide systems (e.g., ZnO and TiO_2) have also shown room temperature ferromagnetism. In these systems, however, the Cu ions are strongly localized and hybridized with oxygen 2*p*orbitals, suggesting that carrier-induced ferromagnetism for manipulating the spin and charge of a single semiconductor medium may be difficult to realize without additional doping for the carrier generation. In the Cu doped GaN system, on the contrary, Cu^{+2} ions induce long range coupling of unpaired spins, and thus the system can be regarded as a new class of DMSs tha trealize room temperature ferromagnetism by coupling between carriers and local moments of nonmagnetic spins.

5. 참고문헌

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