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Magnetic Properties of GaMnAs Diluted Magnetic Semiconductor Grown in S-K Mode

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Epitaxially grown GaMnAs thin film, which is a typical diluted magnetic semiconductor (DMS), has attracted lots of research interests because of its potential applications in spintronics [1]. The growth of GaMnAs follows a layer-by-layer two-dimensional (2D) growth mode [2], however, in the present work, we report a finding of Stranski-Krastanov (S-K) mode growth (2D to 3D) in GaMnAs system. And the magnetic properties of this GaMnAs system is investigated.

The samples were grown on expiready (001) semi-insulating GaAs substrates by a Varian Modular GEN-II MBE system. *On a 250 nm HT-GaAs (T_s = 580℃) buffer, 0.8-1.2ML InAs wetting layer was first grown at T_s = 500℃, Ga1-xMnxAs* (x=0.08-0.17) was subsequently grown at T_s = 250℃ with 2 mins interval per 10 seconds. During the growth, surface reconstruction was monitored in situ with the reflection high-energy electron diffraction (RHEED). Usually, GaMnAs thin films are single crystals or polycrystalline, dependent on Mn doping and substrate temperature. However, for the growth of $Ga_{0.88}Mn_{0.12}As$, RHEED pattern was observed to be gradually spotty with the disappearance of 2D (1×2) streaky lines after the initial 6nm growth. This change indicates a transition from 2D growth to 3D growth. This is a typical S-K mode growth which *commonly appears in the growth of InAs nanodots. Surface morphology observed with AFM shows monodisperse,* self-assembled $Ga_{0.88}Mn_{0.12}As$ nanodots were formed on the samples' surface. Epitaxial growth is further confirmed by HRTEM. The size and height distribution and their dependence on the growth time are further discussed.

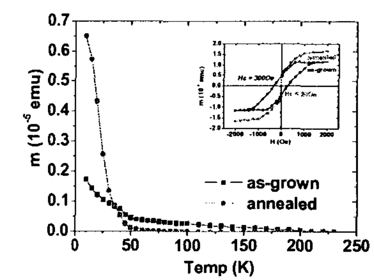

Fig. 1. Temperature dependences of magnetization for as-grown and annealed samples and the magnetic hysteresis curves (see the inset).

Magnetic properties of as-grown and annealed 12nm-$Ga_{0.88}Mn_{0.12}As$ sample were measured by a Quantum Design MPMS2 Superconducting Quantum Interference Device (SQUID) *magnetometer. As shown in Fig. 1, before annealing, there seems to be* a low T_c phase and a high T_c phase. And after annealing, however, only the low T_c phase was found. And the magnetization was enhanced by annealing. A possible explanation is that the interstitial Mn atoms were eliminated by annealing. In as-grown samples, a large amout of interstitial Mn atoms form antiferromagnetic coupling with substitutial *Mn atoms, therefore the magnetization was greatly reduced. After* annealing, the elimation of interstitial Mn actually enchanced the whole magnetization. As for the high T_c phase, it should come from the 3D growth. AFM images indicate after annealing the distance between nanodots was enlarged. And this change of the morphology could be the reason for the disappearance of high-T_c phase.

REFERENCES
[1] H. Ohno: Science, Vol. 281 (1998), p. 951
[2] V. Avrutin, D. Humienik, S. Frank, A. Koeder, W. Schoch, W. Limmer and R. Sauer: J. Appl. Phys., Vol. 98 (2005), 023909

PD09

Electric and Magnetic Properties of Precipitated GaMnAs

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Ferromagnetic semiconductors have received great attention because of their possible application to spintronics with high injection efficiency. Homogenous GaMnAs as a diluted ferromagnetic semiconductor with Curie temperature (T_c) lower than 110 K has been studied much by many groups [1,2]. In the previous work of our group, we havesucceeded in growing GaMnAs codoped with Be via MBE with solid source at low substrate temperature T_s = 300℃, and T_c is higher than room temperature due to MnAs precipitate. Further more, magnetic transport property is also realized at room temperature. But the high crystal tension due to the big difference of radius between Ga atom and Be atom in crystal at high Be flux, would become a obstacle for the activity of Be as a acceptor. Here, another acceptor Mg, with a larger atomic radius than Be, has been selected as a additional dopant to enhance Mn concentration.

The background pressure for growth was as low as 10^{-10} Torr with LN_2, and the growth pressure was 1.4×10^{-6} controlled by solid As source. Growth was done at low substrate temperature 300℃. Mn flux was set at 890℃ and 910℃ with/without a fixed Be flux 1175℃. In addition to Be, Mg was codoped in GaMnAs at the flux 360℃ and 380℃. Samples were examined by EPMA, X-ray diffraction, SQUID and Hall effect measurement.

With EPMA measurement, high Mn concentration due to Mg codoping is examined at a fixed Mn flux. We found that Mg flux point exists for the maximum Mn concentration. From X-Ray diffraction measurement, MgAs peak, Mn_2As peak andMnAs peaks are obviously observed in the samples with Mg codoping. Corresponding Mn concentration, magnetization value is enhanced greatly with additional Mg codoping, and also there exists a Mg flux point for maximum magnetization same Mn flux. Magnetization value of samples with Mg codoping is 10 times higher than those without Mg codopingat same Mn flux. Here, the most interesting thing we found is anisotropy phenomena observed in temperature dependence resistivity measurement measured with Hall effect measurement equipment. Samples were measured with van der Pauw geometry. Semiconducting behaviour is observed in transverse direction while metallicbehaviour is observed in longitudinal direction in the same sample. It means the change of mobility with temperature is very different in different direction.

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REFERENCES
[1] A. Shen, Y. Horikoshi, H. Ohno, and S.P. Guo, Appl. Phys. Lett. 71, 1540 (1997)
[2] H. Shimizu, T. Hayashi, T. Nishinaga, and M. Tanaka, Appl. Phys. Lett. 74, 398 (1999)