BC02

Room temperature magnetic semiconductors based on (In, Mn)As quantum dots

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Diluted magnetic semiconductors (DMS) have drawn a substantial attention for more than a decade due to their potential applications in spintronics and memories. Among them, epitaxially grown III-V materials based on (Ga, Mn)As have been rigorously studied. However, the drawback of low Curie temperature (Tc), below 200 K, has cooled down enthusiasm of many groups. Instead, other materials with Tc potentially above room temperature, such as doped ZnO, TiO_2, GaN, among others became very attractive. We in this report disclose III-V quantum dots showing Tc higher than 300 K.

(In, Mn)As quantum dots (QD) have been grown by MBE on GaAs (100) substrate by a low-temperature process with a suitable wet layer. These QD samples were then analyzed by using a SQUID, Grazing-angle X-ray diffractometry, EXAFS, and high-resolution TEM.

Microstructure analyses revealed that the uniformly distributed $In_{1-x}Mn_xAs$ dots have a zinc-blende structure as $x \leq 0.38$. The EXAFS measurements performed at Beamline 01C of National Synchrotron Radiation Research Center, Taiwan, on one sample that exhibits irregular-type islands, i.e., In0.60Mn0.40As, showed that on average the Mn atoms in the sample are surrounded by a nearest neighbor shell of 6 Mn atoms at a distance of 2.53Å. Based on the local structural information, Mn atoms in the sample are found to form Mn-Mn clusters and the possibility of forming MnAs, which has a Tc around 318 K, can be excluded. The cross-sectional HR-TEM image of the $In_{0.79}Mn_{0.21}As$ QD sample also shows no signs of MnAs nor magnetic GaMn phases (Fig. 1). All samples exhibit ferromagnetic state at 5 K, and their Curie temperatures range from 260 to 340 K varying with x (Figs. 2 and 3). Details of TEM structures and variation in magnetic properties versus x values of the QD samples will be given.

Fig. 1. HR-TEM of a QD of the $In_{0.79}Mn_{0.21}As$ sample

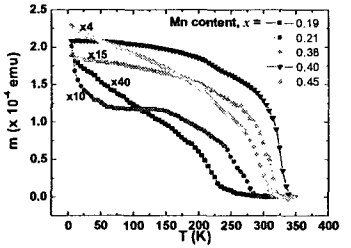

Fig. 2. M-T curves of $In_{1-x}Mn_xAs$ QD samples

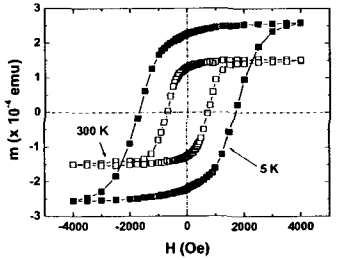

Fig. 3. M-H loops at 5 K and 300 K of $In_{0.60}Mn_{0.40}As$

BC03

Transition of Percolative Ferromagnetism in Co-doped ZnO by Multilayer Growth Technique

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Transition metal (TM)-doped oxide materials have been investigated as a promising diluted magnetic semiconductor (DMS) for implementing spintronic device owing to the discovery of room temperature (RT) ferromagnetism. For example, there are reports suggest the absence of magnetic clusters or secondary phases in some DMSs with evidence supporting carrier mediated ferromagnetism,[3-5] which has been successfully proposed to explain the ferromagnetism in Mn doped GaAs systems. But the poor conductivity of other systems such as oxide DMS disagrees with the carrier mediated mechanism. For oxides DMS, structure defects such as oxygen vacancies or interstitials have also been considered as the origins of diverse magnetic behavior. More and more findings suggest that the magnetism of oxide DMSs is generally consistent with a bound magnetic polaron (BMP) description. However, the origin of ferromagnetism remain ambiguous in oxide DMSs.

In this work, we develop a well-controlled multilayer (ML) δ doping technique to modulate the ferromagnetic properties of Co-doped ZnO diluted magnetic semiconductor. We study a series of ion-beam sputtered [Co(1 Å)/ZnO(d_{ZnO})]25 MLs with d_{ZnO}=10, 15, 20, 25, 30, 40 and 60 Å. By varying the thickness (d_{ZnO}) of ZnO layers, the average spacing between adjacent Co sub-monolayer (1 Å) can be controlled. The mixed structure of a minor component of DMS and a major component of Co clusters appears for d_{ZnO}=10 Å film, in contrast, the MLs for $d_{ZnO} \geq 15$ Å show DMS dominated phase and intrinsic RT ferromagnetism. The saturation magnetization (Ms) decrease rapidly for increasing d_{ZnO} from 15 to 20 Å, and remain almost at a constant value of ~0.4 μB/Co for d_{ZnO}>20 Å. The exponential decay to a constant term of the Ms can be interpreted as the transition from three-dimensional (3D) interlayer interaction of bound magnetic polarons (BMPs) magnetic interactions with reduced d_{ZnO}($\leq$ 20 Å) to quasi two-dimensional (2D) BMPs with increasing d_{ZnO}. In addition, the coercive field (Hc) shows an interesting non-monotonic dependence on d_{ZnO}. The Hc shows a maximum at about d_{ZnO} =30 Å. The Hc peak corresponds to a transient behavior from 3D-connected BMPs to quasi 2D connected BMPs in the intermediate d_{ZnO} regime. Our results support a BMP percolated model and provides a new way to tailor the ferromagnetism for oxide DMSs.