Room Temperature Ferromagnetism in Novel DMS $CdMnGeP_2$

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High concentration of Mn atoms was successfully introduced into the surface layer of the ternary compound semiconductor $CdGeP_2$. The crystal structure before and after introduction of the Mn atoms belongs to the same crystal system: tetrahedral chalcopyrite structure. No traces of binary compounds were found in the XRD pattern. The magnetization curve measured by VSM clearly shows a hysteresis loop that is characteristic of a ferromagnetic material. The Curie temperature was determined to be 320 K. This is the first report of room temperature ferromagnetism in any of diluted magnetic semiconductors.

Key words: diluted magnetic semiconductor, Mn-$CdGeP_2$ system, chalcopyrite structure, ferromagnetism

Researchers of magnetic semiconductors have been dreaming of realizing a room-temperature ferromagnetism from the early days of studies in 70's, when spinel type chalcogenides (e.g., CdCr2Se4 with Tc=130 K) and Eu-chalcogenides (e.g., EuO with Tc=69 K) were intensively studied and were finally discarded because of the lowness of their magnetic transition temperature. In 80's diluted magnetic semiconductor (DMS) based on II-VI semiconductors came on stage. However, most of them did not show ferromagnetism but showed paramagnetic or spin-glass behavior.

The revival of magnetic semiconductor boom in 90's was brought about by the break-through in the crystal growth technology that enabled incorporation of high concentration of transition elements into III-V materials, which in turn introduced carrier-induced ferromagnetism in III-V based DMS. However, despite a lot of studies, the Tc remained far below the room temperature. The highest Tc obtained to date was 110K observed in GaMnAs.[1)]

Recent theoretical works suggest possibility of ferromagnetism in DMS due to double exchange mechanism by hole doping into the 3d band of Mn. [2)] We focused on II-IV-V_2 type ternary semiconductors as a host, since Mn^{2+} may easily occupy the group II-site and high concentration of acceptors may be introduced by substitution of Mn at the group IV site. The present study aims at making a new DMS by using the ternary II-IV-V_2 with considerable content of a transition element, as well as observing their possible magnetic properties.[3)]

As a host material we adopted a single crystal of $CdGeP_2$, which was prepared at the Ioffe Institute by directional crystallization. Thin Mn layer of about 30 nm in thickness was deposited on the $CdGeP_2$ crystal in a MBE chamber, followed by the thermal treatment at about 500°C for 30 minutes. Details of preparation techniques will be published elsewhere. During the preparation the surface was monitored using RHEED technique. Before the Mn-deposition, RHEED pattern close to that of (112) was observed indicating the high perfection of the crystal surface. The deposition of Mn layer leads to disappearance of the atomic order. After finishing the reacting process the original RHEED pattern is recovered with a trace of typical texture reflections.

XRD pattern showed no traces of extraneous phases of magnetic compounds such as MnP. EDX studies revealed that Mn/Cd is 53.4% at the surface, while it is 12.7% at 0.6 μm in depth. Calculated from the profile average Mn concentration is determined to be 20% for effective thickness of 0.5 μm in depth. PL spectrum measured at 20K showed emission peaks around 3.2 eV, which means that the layer is semiconductor with the band gap higher than that of the host $CdGeP_2$ (Eg=1.83eV at 20K).

The VSM measurement clearly showed a hysteresis loop with *Hc*=0.5kOe and *Hs*=2kOe due to the novel DMS, superposed on the diamagnetic term due probably to the host semiconductor. The Curie temperature (Tc) of the $CdMnGeP_2$ was determined to be 320 K by the measurement of temperature dependence of magnetization as shown in Fig. 1. The surface magnetization studied by MFM clearly showed a stripe-domain pattern. Magneto-optical spectrum showed a peak Kerr ellipticity of 0.14 deg around 1.7eV, which is just Eg of the host material.

All of these experimental results point to the first realization of room-temperature ferromagnetic semiconductor.

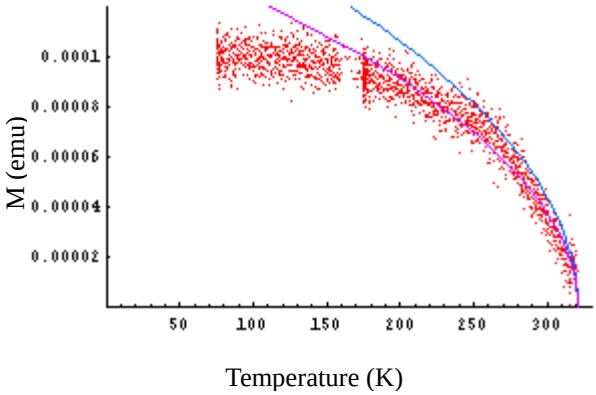

Fig. 1 Temperature dependence of Magnetization

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