Properties of ferromagnetic $Ga_{1-x}Mn_xP$ thin films synthesized by ion implantation and pulsed-laser melting

M. Scarpulla[1,2]; R. Farshchi[1,2]; B. Cardozo[1,2]; W. Hlaing Oo[4]; K. Yu[2]; H. Ohldag[3]; E. Arenholz[3]; M. McCluskey[4]; O. Dubon[1,2]
1. Materials Science & Engineering, University of California at Berkeley, Berkeley, CA, USA.
2. Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.
3. Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.
4. Physics, Washington State University, Pullman, WA, USA.

The study of other III-Mn-V ferromagnetic semiconductors in addition to $Ga_{1-x}Mn_xAs$ is crucial to elucidating the nature and details of ferromagnetism in these systems [1]. We have synthesized ferromagnetic $Ga_{1-x}Mn_xP$ films with nominal $x \leq 0.06$ and T_C up to 65 K using ion implantation and pulsed-laser melting (II-PLM). We have previously produced $Ga_{1-x}Mn_xAs$ films having T_C above 130 K and displaying behavior in line with well-annealed $Ga_{1-x}Mn_xAs$ films grown by molecular beam epitaxy [2-4].
These $Ga_{1-x}Mn_xP$ samples are insulating for $x \leq 0.06$ and ρ_{xx} shows a change in activation energy near T_C. The anomalous Hall effect is similar to but larger than that from ferromagnetic $Ga_{1-x}Mn_xAs$ and ρ_{xx} displays large negative magnetoresistance (up to -44% at 7 T). T_C and other properties scale both with Mn content and with carrier concentration. Transmission electron microscopy, X-ray diffraction, and ion-channeling demonstrate that these films are single-crystalline and epitaxial (unlike [5]) and analysis of the ion-channeling results demonstrates that no interstitial Mn is present. SQUID magnetometry reveals in-plane magnetization and anisotropy characteristics similar to $Ga_{1-x}Mn_xAs$ films. Mn $L_{2,3}$ X-ray absorption reveals a peak structure identical to that from properly annealed and etched $Ga_{1-x}Mn_xAs$ [6,7]. Magnetic circular dichroism at the Mn L_3 edge follows the sample hysteresis loop and reaches ~30% at 5 kOe.
These measurements establish the presence of a carrier-mediated ferromagnetic phase in $Ga_{1-x}Mn_xP$ similar to that observed in $Ga_{1-x}Mn_xAs$. Fascinating differences arise because of the deeper (400 meV) Mn acceptor level in GaP; far-infrared photoconductivity and resistivity reveal an excitation gap of ~25 meV and infrared absorption shows a peak near 400 meV. Based on these observations and the behavior of this gap with Te compensation and Mn content, we attribute it to a separation between the valence and Mn-derived impurity bands.
The implications of our work on the understanding of carrier-mediated ferromagnetic exchange in III-Mn-V diluted magnetic semiconductors will be discussed.

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