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

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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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