Ferromagnetism and localization in Ga$_{1-x}$Mn$_x$As, Ga$_{1-x}$Mn$_x$P, and in between$^1$

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Because of their potential as both injectors and filters of spin-polarized carriers, ferromagnetic semiconductors may play an important role in spin-based electronics, or spintronics. Ferromagnetic semiconductors are formed by the substitution of a relatively small fraction of host atoms with a magnetic species. Ga$_{1-x}$Mn$_x$As has been the most thoroughly studied material among these, and ferromagnetism in it arises from hole-mediated inter-Mn exchange. The Curie temperature $T_C$ in Ga$_{1-x}$Mn$_x$As has been shown to increase with increasing concentration of substitutional Mn acceptors. However, room temperature ferromagnetism in this canonical system has been elusive due to challenges in materials synthesis—namely, raising $x$ while avoiding the formation of second phases or compensating defects. Increasing $p-d$ exchange by modifying the host semiconductor via anion substitution (e.g., replacing As with P) is a significantly less explored route by which $T_C$ may be raised. We are investigating the effect of anion substitution in ferromagnetic Ga$_{1-x}$Mn$_x$As$_{1-y}$P$_y$ formed by ion implantation followed by pulsed-laser melting. In the endpoint compound Ga$_{1-x}$Mn$_x$P $T_C$ is found to vary linearly with $x$, and non-metallic transport is observed for $x$ up to $\sim$4.2%, corresponding to a $T_C$ of $\sim$62 K compared to $\sim$112 K for Ga$_{1-x}$Mn$_x$As with a similar $x$. Dilution of the endpoint compound Ga$_{1-x}$Mn$_x$As with P results in a precipitous decrease in $T_C$ to below 60 K for $y=2.8%$. Remarkably, Ga$_{1-x}$Mn$_x$As$_{1-y}$P$_y$ films undergo a metal-insulator transition between $y=1.5\%$ and 2.3\% even as $x$ is held approximately constant indicating that alloy disorder in the anion sublattice induces hole localization, which in turn may be responsible for a strong suppression of $T_C$. Thus, while anion substitution may enhance $p-d$ exchange, localization effects must be considered when developing a suitable picture for ferromagnetism in these materials.

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