Programmable magnetic anisotropy in ferromagnetic semiconductor films with graded composition

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Developing strategies for manipulating magnetic properties of ferromagnetic semiconductors such as $Ga_{1-x}Mn_xAs$ is of interest both because of the basic science involved and of its potential for spintronic applications. In this presentation we explore the effects of compositional grading of such alloys on their ferromagnetic properties using MBE. For this purpose, we chose the quaternary alloy $Ga_{1-x}Mn_xAs_{1-y}P_y$ grown by molecular beam epitaxy on a GaAs substrate, with Mn concentration kept constant at $x \approx 0.06$, while the concentration of P is graded along the growth direction, increasing stepwise from $y \approx 0.0$ to $y \approx 0.28$.

Note that in a graded $Ga_{1-x}Mn_xAs_{1-y}P_y$ film, grading the P concentration will result in a gradient of the concentration of holes that mediate the Mn-Mn exchange, and in a gradient of the strain in the film due to lattice mismatch with the substrate. Importantly, the existence of interfaces between layers in the graded sample will also lead to removal of inversion symmetry between successive layers along the gradient. One thus expects that the properties arising from graded strain and composition will result in an entirely new magnetic system, with novel ferromagnetic behavior. In fact, in an earlier study of magnetic domains in this system, it has already been found that domain walls in such a graded structure display an entirely new behavior [1], giving rise to speculation that Dzyaloshinskii-Moriya interactions may play a key and novel role in such systems.

Our magneto-transport studies of this graded structure revealed a series of new effects, the most conspicuous being the following: (1) Despite the fact that the specimen consists of distinct layers with different magnetic properties due to differences in the content of P, the entire structure behaves as a single magnetic domain; and (2) applying a strong magnetic field changes the magnetic anisotropy of this system by “imprinting” an internal field onto the system that persists after the initial field is removed, thus permanently changing the magnetic anisotropy of the graded specimen. While the mechanism causing such internal field to form is not presently understood, we speculate that its formation may be related to the removal of inversion asymmetry due to grading, which (along with spin-orbit coupling) leads to pronounced Dzyaloshinskii-Moriya interactions. On a practical end, such ability to permanently manipulate magnetic anisotropy of a ferromagnetic semiconductor holds out the possibility of novel magnetic memory applications.

[1] V. K. Vlasko-Vlasov, et al., Phys. Rev. B 98, 180411 (2018).

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Supplementary Pages

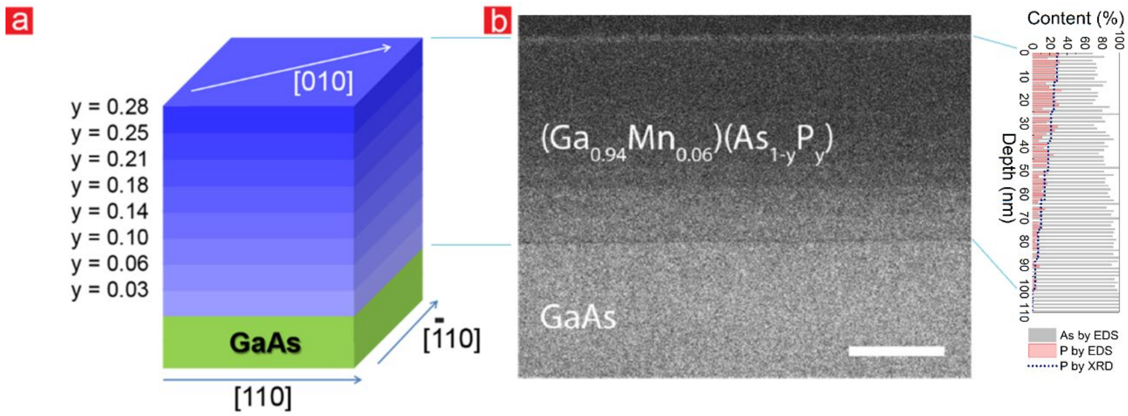

Figure 1: **Structure of the graded GaMnAsP film.** a. Design and schematic diagram of the 8-layer graded sample. b. Cross-section of dark field TEM image of the sample (the scale bar indicates 50 nm). EDX and XRD analyses are plotted on the side.

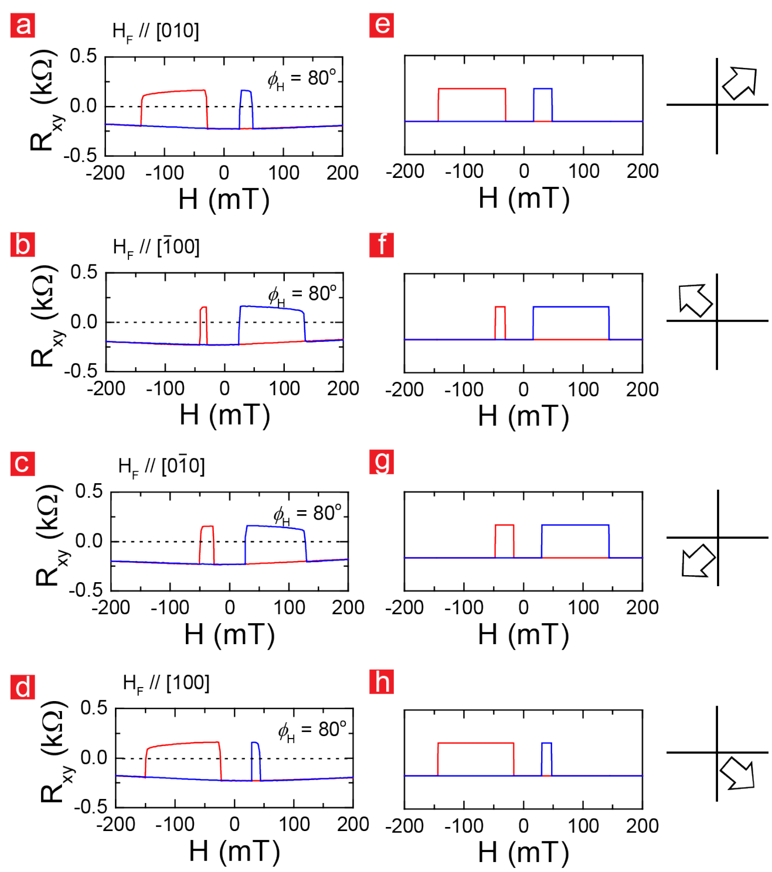

Figure 2: Isothermal tunable asymmetric planar Hall effect obtained by selected "initial" field. a-d. Asymmetric planar Hall effect at 1.8 K after an initial field H_i of 400 mT is applied along [010], [-100], [0-10], [100] directions, respectively. e-h. Related simulation curves for imprinted field of 22.0 mT aligned with easy axes nearest to H_i orientations. Blue and red curves show data obtained by sweeping the field up or down, respectively.