EXCHANGE COUPLING IN THE FERROMAGNETIC SEMICONDUCTOR GaMnAs

Abstract

by

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The study of ferromagnetic semiconductors continues to be of great interest because of their potential for spintronic devices. While there has been much progress in our understanding of FMS materials particularly of the canonical III-V system $Ga_{1-x}Mn_xAs$ many issues still remain unresolved. One of these is the nature of interlayer exchange coupling (IEC) in GaMnAs-based multilayers, an issue that is important from the point of view of possible spintronic applications. In this connection, it is important to establish under what conditions the IEC between successive GaMnAs layers is antiferromagnetic (AFM) or ferromagnetic (FM), since manipulation of such IEC can then be directly applied to achieve giant magnetoresistance (GMR) and other devices based on this material. In this thesis I describe magneto-transport, magnetization, and neutron reflectometry experiments applied to GaMnAs-based tri-layer structures, consisting of GaMnAs layers separated by non-magnetic GaAs spacers. These measurements serve to identify conditions under which AFM coupling will occur in such GaMnAs/GaAs multilayer systems, thus providing us the information which can be used for manipulating magnetization (and thus GMR) in structures based on the ferromagnetic semiconductor GaMnAs.

In addition, I describe results regarding vertically graded magnetic anisotropy in GaMnAs. Controlled vertical grading of magnetization of the ferromagnetic semiconductor GaMnAs represents a significant step toward optimizing its magnetic properties for device applications. We show that vertical magnetization gradients in GaMnAs layers can readily be achieved by appropriate growth strategies, although quantitative control of such grading is difficult in the growth of such layers due to various competing effects, such as Mn diffusion, self-annealing, and diffusion of charge carriers. Furthermore, there also are several surface effects that can influence the magnetization profile, which should be considered in designing and fabricating graded GaMnAs specimens. Polarized neutron reflectometry provides direct evidence that vertical grading of Mn concentration has been successfully achieved in our GaMnAs samples, and that the samples exhibit magnetic "hardening" near the surface.

Finally, I describe results from efforts to carefully engineer the hole concentration in GaMnAs both after and *during* growth. When Ge is grown on GaMnAs, the incorporation of Mn has already been fixed during its growth, but the holes are drained off into Ge. SQUID measurements show T_C in GaMnAs drops rapidly when layers of Ge are deposited over it, the decrease in T_C scaling roughly with the thickness of the Ge layers. Based on our current understanding of impurity band behavior in GaMnAs, this precision control over hole concentration may be important for efforts to optimize T_C. In addition, I describe efforts (and their unintended consequences on magnetic anisotropy) to control the incorporation of Mn in substitutional and interstitial positions of GaAs via increasing the Fermi level of GaMnAs during the growth by growing GaMnAs over Ge layers.