GaMnAs and Its Application Toward Spintronics

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Moore's Law predicts the number of features on a chip to double approximately every eighteen months. As industry struggles to maintain this pace, alternatives to size reduction of charge-based devices are being sought out in both industry and academia. These alternatives to charge-based functionality include the processing of photons, spin states, or plasmon resonance. Of these alternatives, spintronics, or spin-based electronics, show a great deal of promise. The advantages of using spin processing, with, or in place of, charge, include nonvolatility, decreased power consumption, and perhaps most intriguingly, an integration of logic and memory onto the same device.[1,2] Current hard disk drive (HDD) technology is based on spintronics, which is responsible for the 80% average annual growth rate in storage density over the last ten years.[3] Other devices based on spin include spin LEDs[4] (Figure 1) , spin FETs[5], spin-dependent resonant tunneling diodes[6], magneto-optical modulators[7], and ferromagnetic heterojunction bipolar transistors.[8]

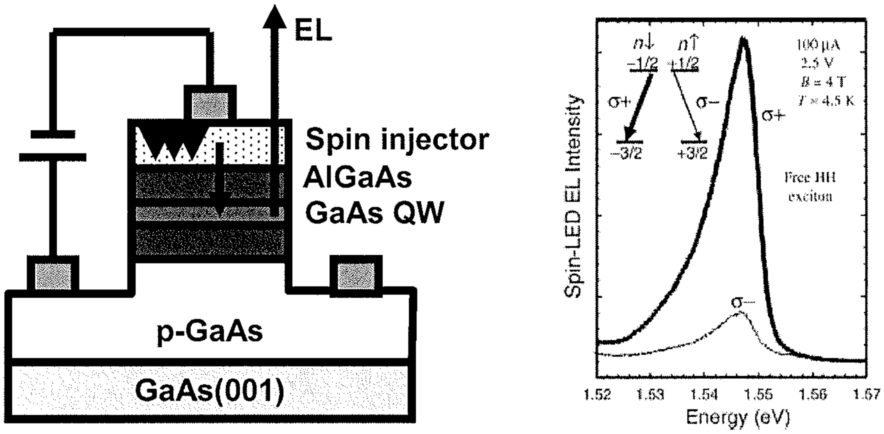

Figure 1 Spin LED and electroluminescence data showing polarization.[4]

The advent of spintronics was the discovery of "giant" magnetoresistance (GMR) in superlattices composed of alternating layers of Fe and Cr.[9] The remarkable change of resistance in these structures is derived from the spin-dependent conductivity of magnetic materials. If the splitting of states in the presence of a field is large enough, then all the majority spin states will be filled, allowing conduction only by carriers of the minority spin.[10] This selectivity would serve as the basis for logic operation in spintronic devices.

While ferromagnetic metals are still the most commonly used materials in current spintronic devices, an interesting new class of materials has garnered much attention from researchers in device physics and materials science. The ferromagnetic semiconductors, such as GaMnAs, are comprised of conventional semiconductors doped with low concentrations (3-6%) of magnetic ions such as Mn. The interaction between the highly localized d-electrons on the metal ion, and the delocalized s- and p- like electrons in the conduction and valence bands, respectively, results in a ferromagnetic coupling between Mn centers, which is mediated, in the case of GaMnAs, by itinerant holes.[11,12,13] This hole-mediated coupling gives rise to some remarkable materials properties. Since the Mn ions act as an acceptor, the hole concentration is roughly proportional to the Mn ion concentration. In addition, the degree of ferromagnetic coupling is hole mediated, thus by varying the hole concentration, the Curie temperature of the material can be controlled.[12,14](Figure 2) These unique properties, along with the direct band gap of GaAs, allow for optical, electrical, or magnetic control of ferromagnetism. In addition, GaMnAs also posses unique ferromagnetic properties, exhibiting a change in the easy axis at approximately $T_c/2$.[15]

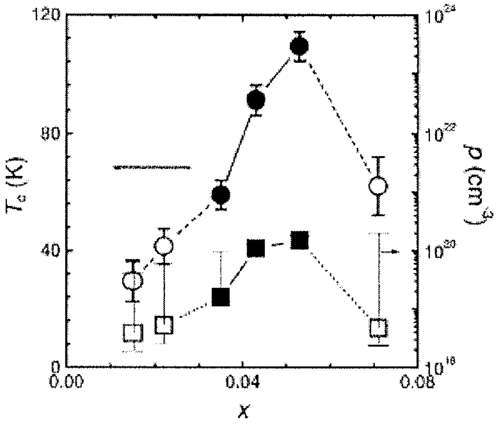

Figure 2. Relation between T_c, [Mn], and $[h^+]$[12].

While some refinement of the materials processing of GaMnAs remains to be done, there is little doubt that the use of alternatives to charge-based functionality will increase.[8,16] It is certain that the breadth of applications for spintronic devices will expand as researchers continue to study the fundamentals of spin-based phenomena.

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