Time Resolved Spectroscopy in Narrow Gap MOVPE Grown Ferromagnetic Semiconductors

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Abstract a We report on time resolved experiments that provide insight into the time scales and the nature of the interactions in ferromagnetic InMnAs and InMnSb. Theoretical calculations are performed using an 8 band **k·p** model including non-parabolicity, band-mixing, and the interaction of magnetic Mn impurities with itinerant electrons and holes.

Introduction

Carrier-induced ferromagnetism in magnetic III-V semiconductors has opened up new opportunities for device applications, as well as fundamental studies in material systems in which itinerant carriers interact with the localized spins of magnetic impurities. A low temperature MBE technique is nearly always used to prepare thin ferromagnetic films, although MOVPE, an alternative technique, allows single phase magnetic InMnAs and InMnSb compounds to be deposited at 500° C, much higher than that used in MBE. Films with hole densities of 1018 cm-3 can have T_c above room temperature [1].

In this work, we perform time resolved differential transmission (TRDT) studies to obtain insight into the dynamics in MOVPE grown ferromagnetic films on the picosecond time scale. To understand the effects of ferromagnetic order on the electronic structure and subsequent relaxation dynamics, we calculate the electronic structure for bulk InMnAs and InMnSb. By calculating the electronic band structure, we can determine where photoexcited carriers are generated by the pump pulse and which regions of the electronic structure are sampled by the probe pulse. The calculations are based on an 8 band **k·p** model which includes the conduction and valence band mixing [2]. We use **k** = 0 Bloch basis states for the conduction bands, heavy-holes, light holes and split-off holes for a total of 8 states in-

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cluding spin. In our model, we include the effects of the spontaneous magnetization of the Mn ions and the sp-d coupling of this magnetization to the electrons and holes [2]. Figure 1 shows an example of the calculations for ferromagnetic InMnSb at 77 K in the absence of an externally applied magnetic field.

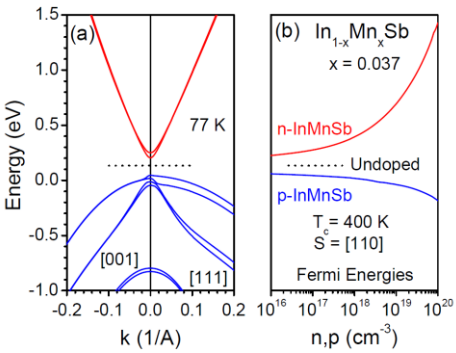

Fig. 1. The band structure and the Fermi energies as a function of carrier density for InMnSb at 77 K as a function of n and p carrier concentrations. The Fermi energy for the undoped semiconductors is indicated by the dotted line. The Curie temperature is taken to be 400 K.

Experimental Approach

By probing the dynamical behavior of the nonequilibrium carriers created by intense laser pulses, we gain valuable information about the band structure and different scattering mechanisms. Using TRDT in the MID-IR, we achieved tunability of carrier dynamics and relaxation times with characteristics unobtainable in MBE grown ferromagnetic structures [2]. The MOVPE grown InMnAs structure is an 800 nm thick film with a Mn content of 4%, and the InMnSb film is a 200 nm film with a Mn content of 3.7%. Both samples, demonstrated T_c above room temperature. The laser pulses were tuned in NIR and MIR using different sources with repetition rates of 1 KHz and pulse durations of ~ 100 fs.

As shown in Fig. 2 for InMnSb, we observe the sensitivity and tunability of the carrier dynamics to the initial excitation. The initial increase in the differential transmission is due to free carrier Drude absorption where the fast component of the temporal evolution is attributed to the relaxation of hot electrons and the slower component is due to electron-hole recombination. Exploiting the selection rules for interband transitions, spin-polarized carriers are created using circularly polarized pump beams. By monitoring the transmission of a weak delayed probe pulse that has the same circular polarization (SCP) or opposite circular polarization (OCP) as the pump pulse, as shown in Fig. 3, the optical polarization can be extracted. Figure 3b shows the exponential fit to the SCP-OCP in the TRDT signal which gives a spin relaxation time of ~ 6.0 ps, which is much higher than the reported time scale for other narrow gap ferromagnetic semiconductors. This fact is due to much higher hole mobilities in these material systems.

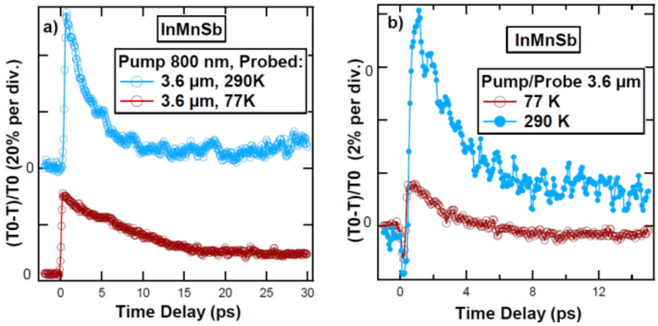

Fig. 2. TRDT a) in a non-degenerate scheme, b) when the pump and probe are the same wavelength. Both the magnitude of the TRDT and the time scale of the relaxations vary by tuning the initial excitation wavelength.

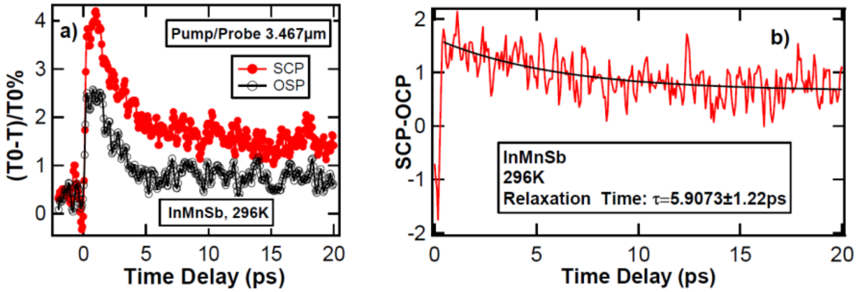

Fig. 3. a) Spin Polarized Time Resolved Differential Transmission b) Exponential fit to the SCP-OCP, to extract the spin relaxation time.

References

[1] C. E. Feeser, L. Lari, V. K. Lazarov, J. A. Peters, and B. W. Wessels "Structural and magnetic properties of epitaxial In1-xMnxSb semiconductor alloys with x > 0.08" J. Vac. Sci. Technol. B **30**, 032801 (2012).

[2] M. Bhowmick, T. R. Merritt, and G. A. Khodaparast, Bruce W. Wessels, Stephen A. McGill, D. Saha, X. Pan, G. D. Sanders, and C. J. Stanton , "Time-resolved differential transmission in MOVPE-grown ferromagnetic InMnAs" Phys. Rev. B **85**, 125313 (2012).