High Magnetic Field Studies of Ferromagnetic Narrow Gap Semiconductors

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Carrier-induced ferromagnetism in magnetic III-V semiconductors has opened up several opportunities for device applications as well as for fundamental studies of a material system in which *itinerant* carriers interact with the *localized* spins of magnetic impurities. The origin of the carrier-induced ferromagnetism is still an open and exciting question. In order to begin to understand the hole mediated ferromagnetism, probing the band structure in these material systems is crucial. Here we present Cyclotron Resonance (CR) and Magnetic Circular Dichroism (MCD) studies on InMnSb and InMnAs films. The measurements were performed on samples with different Mn contents and external magnetic fields ranging up to 120 Tesla for the CR, and 31 Tesla for the MCD measurements. We compared Landau level and band structure calculations with our experimental measurements.

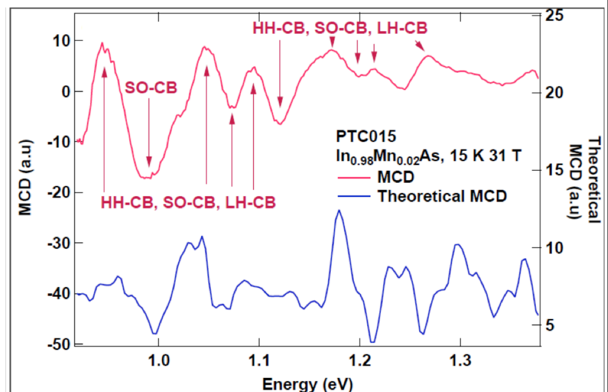

Fig. 1: A comparison between the theoretical MCD (blue) and experimental MCD (red) at 31 T. The theoretical MCD matches the observed MCD features.

To model the results, we used an 8-band Pidgeon-Brown model generalized to include the wave vector dependence of the electronic states along k_z as well as the *s-d* and *p-d* exchange interactions with the localized Mn *d*-electrons. The Curie temperature is taken as an input parameter and the average of the Mn spin is treated within a mean field theory [1,2] Our CR measurements and calculations on our MOVPE structures indicated that the lower hole densities can result in a much larger average spin. This fact could be responsible for the higher Curie temperatures in the MOVPE grown narrow gap ferromagnetic semiconductors with carrier densities of 10^{18} cm^{-3}, compared to the MBE grown structures, which have much higher hole concentrations [1]. In addition to our CR studies, comparison of our observed MCD with the theoretical calculations provided a direct method to probe the band structure including the temperature dependence of the spin-orbit split-off g-factors and gap, and to estimate the *sp-d* coupling constants.

[1] G. A. Khodaparast,Y. H. Matsuda, D. Saha, G. D. Sanders, C. J. Stanton, H. Saito, S. Takeyama, T. R. Merritt, C. Feeser, B. W. Wessels, X. Liu and J. Furdyna, Phys. Rev. B, **88**, 235204 (2013).
[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, Phys. Rev. B, **85**, 125313 (2012).

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