Light-Activated Nuclear Spin Relaxation in Dilute Ferromagnetic (Ga,Mn)As

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Introduction

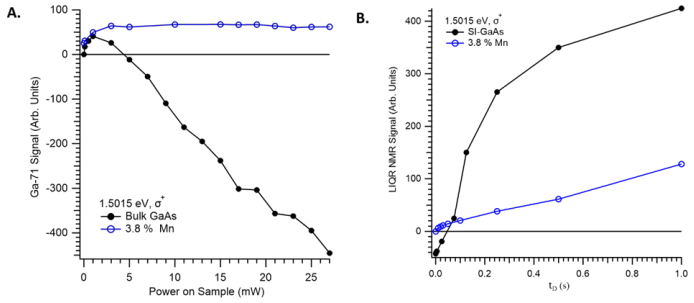
At Mn concentrations >1%, (Ga,Mn)As is a dilute ferromagnetic semiconductor (DFS) supporting high Curie temperatures.[1] However, a fundamental understanding of the band structure and the origin of free holes in this material is still debated. Nevertheless, this material a promising candidate for semiconductor spintronics applications. Few studies have examined the nuclear spin interaction in this DFS, and to our knowledge, light-induced nuclear spin dynamics in (Ga,Mn)As was not previously reported until now.

Experimental

Two different $Ga_{1-x}Mn_xAs$ films with x=0.01 and x=0.04 were grown on [001] oriented semi-insulating GaAs by low temperature (LT) molecular beam epitaxy (MBE). Using a low temperature polarization optics, samples were illuminated with circularly polarized light from a Ti:Sapphire laser in the 1.48 – 1.56 eV range. Experiments with gated light were performed using a Pockel cell. Ga-71 NMR spectra were collected at 39.19 MHz (3 T) in pumped He-4 (1.5 K).

Results and Discussion

Light-activated NMR signals were observed in the Mn-doped films. However, the signatures of ONP that are present in GaAs at high illumination intensities, i.e. dependence on the helicity of the circular polarized light, an emission phase NMR signal for high intensity σ^+ illumination, and modulations in the photon energy response of the light induced NMR signals,[2,3] were absent. To examine the interplay of the light-activated nuclear spin relaxation and nuclear spin diffusion, experiments with gated illumination were performed. As shown in a previous literature report, gated illumination can facilitate a greater efficiency in the number of spin-flips per photon, particularly for deep defects where light-induced quadrupolar relaxation is fast and the spin-diffusion blockade is most effective.



Light-induced Ga-71 nuclear polarization in the GaAs (open blue symbols) and $Mn_{0.04}$ (filled black symbols) samples by illuminations with σ^+ light at 1.5015 eV, B_0=3 T and T_{bath}=1.5 K. **A.** Laser power dependence of NMR peak area for 120 s continuous illumination. B. Gated laser illumination study for 12000 cycles consisting of 2.5 ms illumination followed by a variable dark delay, t_D, for a constant total illumination of 30 s prior to NMR acquisition.

Conclusions

A monotonic increase in the light-induced NMR signal is observed in both the GaAs and $Mn_{0.04}$ samples when the dark delay in gated light experiments is increased at a fixed total illumination time, which is consistent with light-activated relaxation centers with strongly localized charge distribution.[2] Furthermore, the absence of quadrupole splitting of the Ga-71 resonance in light-activated spectra in strained films suggests strong charge localization at the light-activated relaxation centers, where the spin-diffusion is significantly hindered by strong electric field gradients. However, further work is needed to identify the relaxation centers and elucidate the mechanistic details in this complex material.

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