Transient Spin-gratings of Itinerant Electrons in Lightly-doped GaAs Quantum Wells

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Abstract: Spin gratings lasting longer than the carrier lifetime are measured in lightly *n*-doped quantum wells. In a magnetic field, precession of the grating is observed, and diffusion rates are determined by varying the grating period.

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The use of spins to store and transmit information requires an understanding of both spin relaxation and transport. In semiconductor systems, time-resolved optical pump-probe measurements are often used to study these phenomena, demonstrating long-lived (tens of nanoseconds) electron spin polarizations that can be transported over distances greater than 100 μm [1]. Transient spin grating experiments are similar to pump-probe measurements but two pump pulses are used to generate a grating of spins with alternating polarizations. For crossed-linear polarized pump pulses, the net polarization varies from right-circular to left-circular, which modulates the carrier spin orientation across the sample. (For co-linear polarized pump pulses, the intensity across the sample is modulated, leading to a population grating.) A delayed probe pulse is diffracted off of this grating until the grating decays due to spin relaxation and diffusion. These transient spin gratings have been measured in undoped GaAs quantum wells (QWs) [2,3], giving the electron spin relaxation times and diffusion rates. Recently, spin Coulomb drag in highly *n*-doped QWs was demonstrated by examining the decay of spin gratings [4]. In these experiments, the spin gratings typically decayed with a time constant on the order of 10 ps, before recombination of the optically generated carriers. This summary describes experiments in lightly *n*-doped GaAs QWs, in which spin gratings can last about 1 ns, long after carrier recombination. In the presence of a magnetic field in the QW plane, the spin grating precesses, leading to a signal that oscillates at twice the precession frequency. The results demonstrate the generation of a spin grating of itinerant electrons and give insight into spin dynamics in semiconductors.

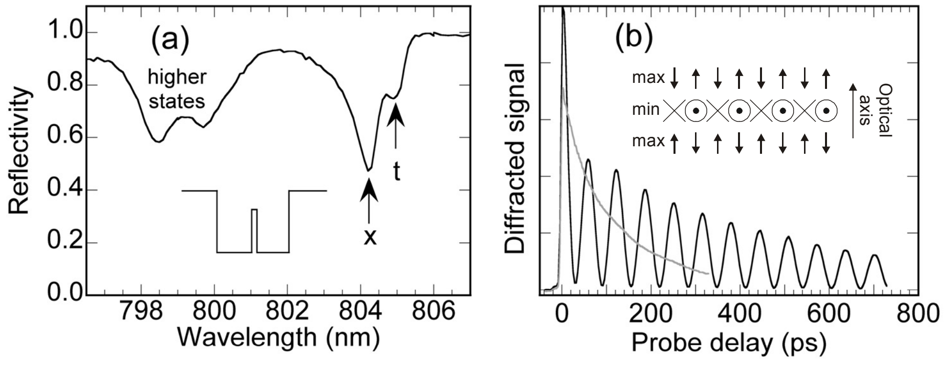

Fig. 1. (a) Sample reflectivity with the lowest exciton (x) and trion (t) states labeled. The QW profile is inset in the graph. (b) Transient population (grey line) and spin (black line) gratings vs probe delay taken with a magnetic field of 2 T. The probe was set to 804.8 nm. The inset displays the spin grating orientation for maximum and minimum signal.

The sample used for these measurements consists of 10 periods of coupled GaAs QWs, with Silicon modulation doping centered in the 41 nm $Al_{0.3}Ga_{0.7}As$ barriers. The coupled QWs are 10 nm and 12 nm in width, separated by a 2.5 nm $Al_{0.2}Ga_{0.8}As$ tunnel barrier [see inset of Fig. 1(a)]. The sample was designed to have an electron concentration of ~2×10^{10} cm^{-2} per pair of wells, with the electron wavefunction extending into both wells. A distributed Bragg reflector is behind the QWs, so the reflectivity of the sample [Fig. 1(a)] is essentially double-pass transmission. Transient grating experiments were performed with the pumps set to the exciton/trion resonance near 804 nm with a bandwidth of ~4 nm. The linear polarized probe was made spectrally narrow (~0.2 nm) using a pulse shaper and was typically set near the trion resonance.

Figure 1(b) displays transient population and spin gratings in the presence of a 2T magnetic field oriented in the QW plane. The population grating decays with a time constant of 280 ps [5]. For crossed-linear polarized pumps, spins are initially oriented perpendicular to the QW planes but precess about the magnetic field at the Larmour frequency. The inset of Fig. 1(b) displays the changing orientation of the spin grating relative to the probe optical axis. When the spin grating is aligned with the optical axis of the probe (perpendicular to the QW planes), the contrast in the optical susceptibility across the grating is at its maximum. When the spin grating is oriented in the QW plane, the optical susceptibility is uniform for the probe, thus giving no diffracted signal. The field of the diffracted beam oscillates at the Larmour frequency, so the intensity oscillates at twice this frequency. The oscillation frequency in Fig. 1(b), 15.5 GHz, was confirmed to be double the precession frequency by time-resolved Kerr rotation (TRKR) measurements. The spin grating signal can be fit to the square of a decaying cosine, $\left[A\cos(\omega t+\phi)\exp(-t/\tau)\right]^2$. This fit gives a decay time of 0.92 ns.

The population and spin gratings decay due to both relaxation and diffusion according to $\gamma_{pg,sg} = D_{p,s}q^2 + \Gamma_{p,s}$. The population (spin) grating decay rate is γ_{pg} (γ_{sg}), the diffusion rate is D_p (D_s), the relaxation rate is Γ_p (Γ_s), and the grating wavevector is q. The data in Fig. 1(b) was taken with a pump angle of ~4.3° (grating period $\Lambda = 10.7$ μm, $q = 0.59$ μm^{-1}). Measurements were taken for a series of grating spacings with the probe at the exciton (804.2 nm) and the trion (804.8 nm) resonances. The grating decay rate is plotted vs. q^2 in Fig. 2 for (a) the population gratings and (b) the spin gratings. The decay rate appears to be fairly linear with q^2, and the slope is not significantly different for the two probe wavelengths. The slopes give $D_p = \sim 28$ cm^2/s and $D_s = \sim 13$ cm^2/s, and the intercepts give $1/\Gamma_p = 148$ ps (350 ps) and $1/\Gamma_s = 880$ ps (1530 ps) for the probe at the exciton (trion). Since the spin grating decay time is much longer than the population relaxation time (*i.e.* the recombination time), we attribute the spin grating to the itinerant electrons. The dependence of the spin relaxation time on probe wavelength is not well understood. TRKR measurements also show an interesting dependence on probe wavelength with two precession frequencies appearing under some conditions. Further work must be performed to understand this unique behavior.

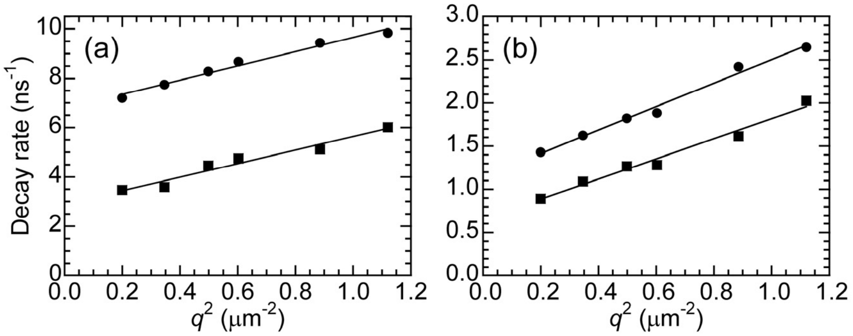

Fig. 2. Decay rate of (a) population and (b) spin gratings as a function of the grating wavevector squared.The probe was set to the exciton (trion) energy for the circles (squares). The lines are linear fits to the data points.

Transient grating experiments provide a useful tool in studying spin dynamics. The technique has a number of advantages over the more common method of TRKR in that the signal is background free and it allows easy measurement of spin diffusion. Until now, measurements have been in systems where the spin gratings decayed rapidly, before carrier recombination. The results in this summary demonstrate spin gratings that last longer than the carrier lifetime, indicating the formation of spin gratings of itinerant electrons. These measurements have also been performed for the first time in a magnetic field, exhibiting oscillations at twice the Larmour precession frequency.

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[5] Since the diffracted intensity is proportional to the square of the grating amplitude, the signal decays with time constants half of those given in the text.