BIAS-DEPENDENT ELECTRON SPIN LIFETIMES IN n-GaAs AND THE ROLE OF DONOR IMPACT IONIZATION

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Introduction

The discovery of very long electron spin lifetimes τ_s in GaAs has helped motivate considerable interest in semiconductor-based spintronic devices. Studies of bulk *n*-GaAs have established that, in the absence of any applied electric field, long spin lifetimes in the range τ_s = 100 - 300 ns are associated with cryogenic temperatures and electron doping in the range of the metal insulator transition (n_{MIT} ~ 1 x 10^{16} cm^{-3}). This is, however, precisely the doping and temperature regime where carrier transport becomes highly nonlinear due to impact ionization of donor-bound electrons at quite modest electric fields, typically employed in prototype spin transport devices.

Experimental

We measure τ_s as a function of temperature and applied electrical bias, E_x, in a bulk epilayer of *n*-GaAs, grown by molecular beam epitaxy and doped near the metal insulator transition (n_{MIT} ~ 1 x 10^{16} cm^{-3}). τ_s is obtained from Hanle depolarization measurements using the magneto-optical Kerr effect. [1]

Results and Discussion

Figure 1 (a) shows *I-V* transport data from the n_{MIT} ~ 1 x 10^{16} cm^{-3} sample at 30, 20, 10, and 4 K. Strong nonlinearities at E_x ~ 11V/cm indicate the threshold of impact ionization in this epilayer. The corresponding average spin lifetime τ_s in this sample is shown in Figure 1(b). At 4 K, τ_s is long (175ns) ad relatively independent of electrical bias for E_x < 10V/cm. In the narrow bias range between 10 and 14 V/cm, just beyond the ionization threshold, τ_s drops rapidly by a factor of three. A similar, though less pronounced trend is observed at 10 and 20 K. By 30 K most donors are already thermally ionized so that electrons are predominantly free and only gradual changes in τ_s are observed.

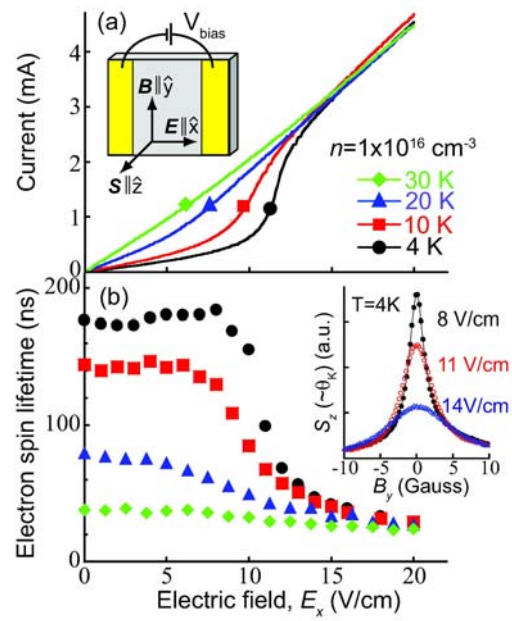

Figure 1: (a) Current vs. in-plane electric field, E_x in the n_{MIT} ~ 1 x 10^{16} cm^{-3} *n*-GaAs epilayer at T = 30, 20, 10 and 4 K. At low T impact ionization of donors occurs at E_x ~ 11V/cm. Inset: The experimental geometry (b) The corresponding electron spin lifetime τ_s measured via the Hanle effect. Inset: Hanle data at 4 K, in the regime of impact ionization.

Conclusions

In conclusion, the collapse of the electron spin lifetime at the onset of donor impact ionization marks the transition from an ensemble of largely localized spins to an ensemble of primarily free- and warm- electron spins subject to efficient Dyakonov-Perel spin relaxation. This collapse is very important for prototype spin transport devices which rely on the interplay between electron mobility and spin lifetime to achieve desired spin transport length.

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References

[1] M. Furis, D. L. Smith, S. A. Crooker, and J. L. Reno, Appl. Phys Lett. **89**, 102102 (2006).