CURRENT-INDUCED DYNAMIC NUCLEAR POLARIZATION IN GaAs AND InSb

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The dynamic polarization of nuclei (DNP) by optical or R. F. "pumping" (Overhauser effect) was established long ago, but in certain cases a fundamental understanding of the microscopic mechanism of the transfer of the polarization from the electrons to nuclei is not fully understood. Recently there have been a number of proposals for application of highly polarized nuclei in spintronics and quantum computing, leading to renewed interest.[1] An additional method of polarizing nuclei which has received no attention since its prediction and initial observation by Feher and Clark[2,3] involves "hot electrons" produced by appropriate DC currents in semiconductors. The original experiments of Clark and Feher on InSb, doped by neutron transmutation, gave polarizations enhanced by about a factor of seven. We have carried out detailed experiments on GaAs and InSb to further elucidate the mechanism and develop methods for further enhancement of the polarization. The GaAs ($5.9\times10^{15}/cm^3$ just below the MI transition) and InSb ($2.4\times10^{15}/cm^3$ metallic) samples were bars 8×2×0.4 mm with ohmic In contacts at the ends. The results for a typical GaAs experiment are shown in Fig.1. The DNP is negative with the signal decreasing to zero and then increasing by about a factor of two. A sample doped into the metallic phase gave no DNP. At currents greater than 25 mA the resistance becomes negative through breakdown processes and the DNP decreases rapidly. Since carriers in the conduction band of GaAs have essentially zero hyperfine coupling, we developed a model in which the translational non-equilibrium of the conduction band carriers is transferred via the localized impurity states, which have large hyperfine coupling. Spin diffusion smoothes the nuclear polarization. At higher field the breakdown occurs at lower currents. At higher currents there was some increase in sample temperature. It is difficult at this stage to differentiate between these effects. Experiments on InSb (4×10^{14} cm^3, semiconducting) gave qualitatively similar results but with smaller DNP. However, surprisingly, when the metallic InSb was driven to the semiconducting state with increasing magnetic field, an appreciably larger DNP than in GaAS was observed, as shown in Fig. 2. At low field, 1.5T, InSb (2.4×10^{15}, metallic) gave no DNP. These phenomena are currently being investigated. It seems likely that different mechanisms operate in the two materials. In GaAs, the conduction band wave function provides no measurable hyperfine coupling, while in InSb the hyperfine coupling is very large. It is likely that the DNP in GaAs is through the localized donor states in the gap, while in InSb the DNP occurs directly through the hot conduction electrons. Further work is in progress to elucidate this behavior. It should also be noted that T_1 in these systems is very long, of the order of hours. These experiments were performed by saturating the NMR line, establishing the current and then sampling the signal after 10 minutes. It is likely that the polarization would evolve in time on the order of T_1, although, due to present inability to control the temperature over long periods of time this has not been demonstrated. The absolute magnitude of the nuclear polarization for times >> T_1 may be much larger than observed here in times << T_1.

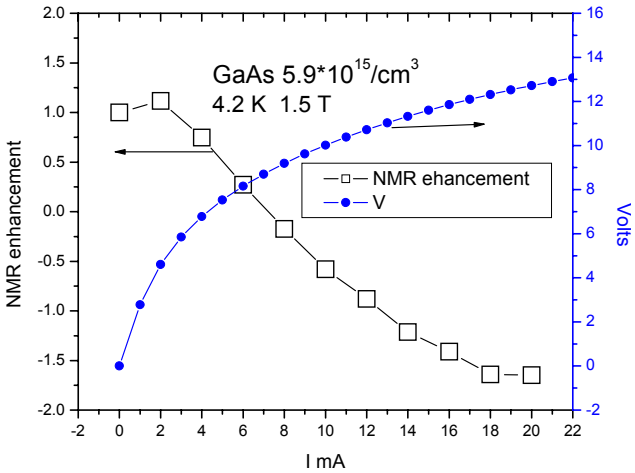

Figure 1. DNP in GaAs as a function of current (left axis) and the corresponding I-V curve (right axis).

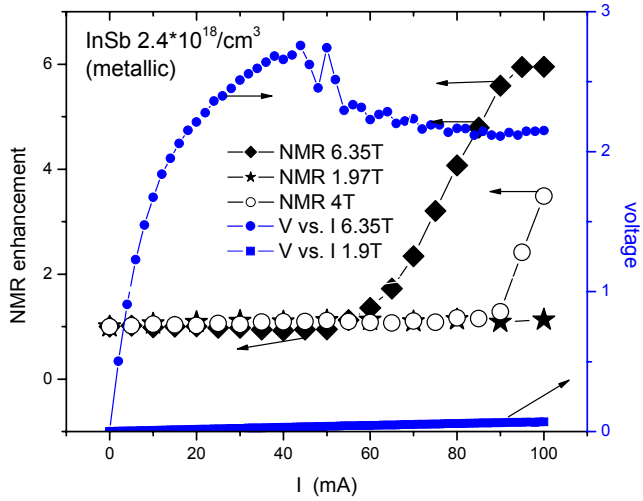

Figure 2. DNP in InSb (metallic) as a function of current for three fields (black, left axis) with the corresponding I-V curves (blue, right axis) at T= 2K.

References

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[3] W.G. Clark and G. Feher, Phys. Rev. Lett. **10**, 134 (1963).