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Magnetic-Field-Induced Metal-Insulator Transitions in Degenerately Doped n-type Ge

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INTRODUCTION

Many possible ground states have been proposed to describe degenerately doped semiconductors in large magnetic fields. Most such proposals speculate that the ground state is a collective state[1] and all proposed states are insulating. Degenerately doped Ge has recently been shown to undergo a metal-insulator transition in large magnetic fields at low temperatures[2-4]. Thermoelectric power measurements were undertaken on degenerately doped Ge in this insulating state in order to gain insight as to the nature of the density of states for the carriers.

EXPERIMENT

The material used was an uncompensated Sb-doped Ge crystal obtained from Eagle-Picher. Careful checks of dopant homogeneity were performed as described in references[2-4]. Samples were cut to sizes ~1.1x3.3x24mm with all edges ‖ to the <100> directions. The samples were etched and contacts made as decribed in references 2-4. Two contacts were placed on the longitudinal ends for the thermopower measurements and for current injection during resistivity and Hall measurements. Three small voltage contacts were placed on the sides to permit virtual-contact Hall measurements[5,6] and four-terminal resistance measurements. The sample was cantilevered into the vacuum with one end heat sunk to the crystadt. A small heater was epoxied to the free end of the sample and a differential thermocouple was used to measure the temperature gradient produced when the heater was switched on and off. Au wires were mounted to ends of the sample thus forming another differental thermocouple composed of Au-sample-Au. This is a modified version of the apparatus of Geballe, et al.[7]. All measurements were take with H along the <100> axis. Thermopower measurements were taken with the temperature gradient ‖ and ⊥ to H.

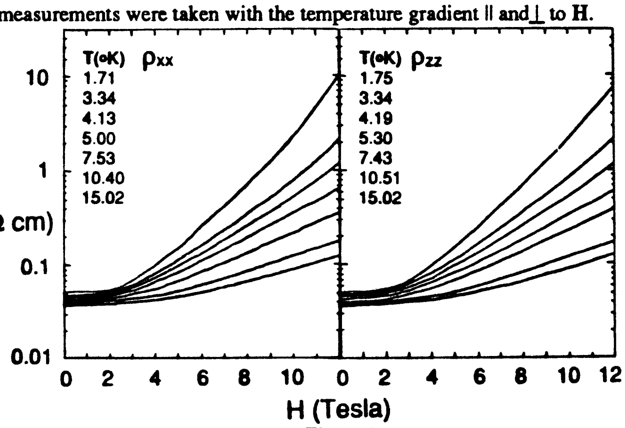

Figure 1

RESULTS

In figure 1 we show ρ_{xx}, ρ_{yy}, and in figure 2 the normalized Hall coefficient for a sample of donor density $N_D \sim 2.2 \times 10^{17} cm^{-3}$. Low field Hall measurements indicate $n \sim 1.7 \times 10^{17} cm^{-3}$ at 4.2°K. Figure 1 clearly shows a metal-insulator transition in ρ_{xx} and ρ_{yy} as H increases above ~4 Tesla, consistant with refs. 2-4. The Hall coefficient shows no sign of any transition, thus indicating that the apparent carrier concentration remains unchanged through the transition. Figure 3 shows the thermopower (S) plotted as 1/T. The thermopower was isotropic with respect to the field. The thermopower can often be naively considered as the entropy per carrier. For all systems σS --> 0 as T --> 0 is required by the third law of thermodynamics[8]. If σ stays nonzero as T-->0 then S-->0 as for any metal.

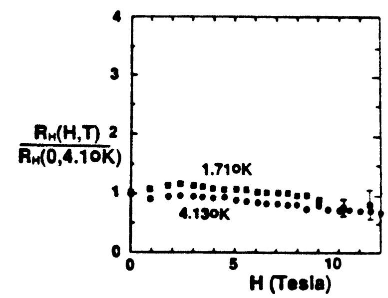

Figure 2

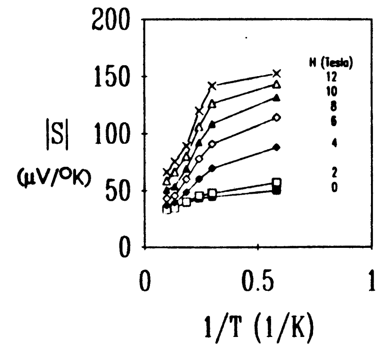

Figure 3

If σ -->0 as T-->0 then S can do anything. However, if S is nonzero at T=0, the density of states at the Fermi level must be zero[8,9]. In Mott type varaible range hopping, the denstiy of states, while localized, is finite, hence S-->0 as T-->0[10]. For Efros type interacting hopping, S may go to a nonzero constant as T-->0[11]. For systems with finite width gaps at the Fermi level such as intrinsic semiconductors, charge and spin density wave systems, the thermopower diverges as 1/T. If the Fermi level were in a energy gap (of finite width) in the density of states, S would display a 1/T dependence for $K_B T < E_{GAP}$[9].

Recent scaling theories which include both single-particle "localization" terms and the presence of disordered Coulomb interactions address the behavior of the conductivity near the metal-insulator transition in strong fields[12]. These theories indicate that at the field-induced metal-insulator transition the quasiparticle density of states remains non-zero while the quasiparticle diffusion constant vanishes. Unfortunately, neither the Hall effect or thermoelectric effects have been calculated in these models.

If the trend displayed in figure 3 does not change so that S is nonzero at T=0, the density of states for the carriers responsible for the transport must be vanishing as the system enters this high field insulating state.

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