

# Ge film thermometers at ultralow temperatures in high magnetic fields

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## Abstract

The conduction mechanisms and effect of magnetic field for Ge-film thermometers in the 25 mK to 4.2 K temperature range and magnetic fields up to 6 T are studied. At low temperatures, the variable-range hopping conductivity prevails. At temperatures below 0.3 K, a gigantic negative magneto-resistance (up to 100%) is observed. The temperature dependence of resistance and magneto-resistance shows that localization behavior near the mobility edge exists. To explain experimental results, we adopt a phenomenological model based on variable-range hopping below the mobility edge. We also use a scaling theory of localization with a localization length depending on the mobility edge location. © 2000 Published by Elsevier Science B.V. All rights reserved.

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Investigation of transport properties of heavily doped and compensated semiconductors at ultralow temperatures is important for understanding localization phenomena near the mobility edge. Ge films simultaneously doped with Ga and As also have many applications. Several types of miniature thermometers, based on Ge films on GaAs substrates, have been produced. They are intended for use in the 25 mK to 500 K temperature range [1].

Here we present results of our measurements of conductivity and magneto-conductivity of Ge film thermometers (model TTR-1D [2]) in the temperature range from 25 mK to 4.2 K and magnetic fields up to 6 T. An explanation of these experiments is presented using a scaling theory of localization, which is confirmed by numerical calculations.

The thermo-resistive films have been prepared by thermal evaporation of Ge in vacuum on semi-insulating GaAs substrates. At temperatures below 0.3 K, a gigantic

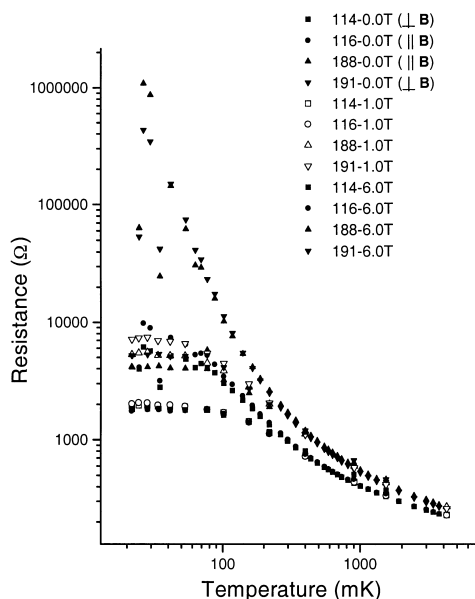


Fig. 1. Temperature dependence of resistance for several samples at three different magnetic fields and two orientations.

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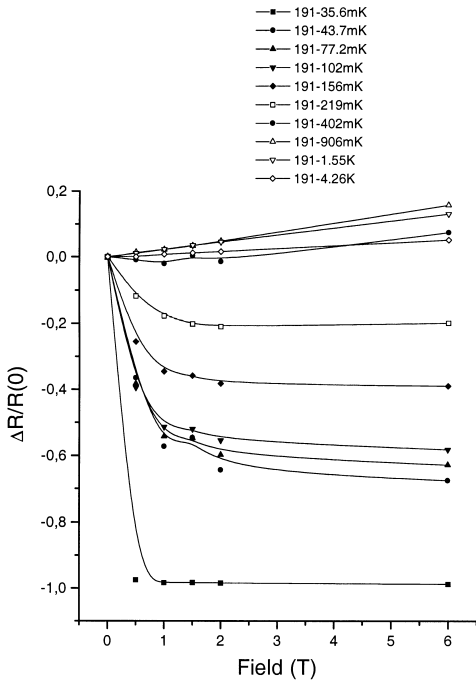


Fig. 2. Magneto-resistance of a film at different temperatures. B-spline fits are an aid to the eye only.

negative magneto-resistance, up to 100%, has been observed (Figs. 1 and 2). This magneto-resistance saturates for fields above 1 T. The temperature dependences of the resistance and magneto-resistance demonstrate a localization behavior near the mobility edge.

We believe that these results can be explained in the framework of localization theory in the vicinity of the mobility edge of conductivity. To verify this, we performed numerical calculations, taking into account a scaling dependence of localization length  $L_{loc} = a_0 [(ε_c - ε)/ε_c]^{-ν}$  where [3]  $ε_c = ε_{c0}[1 - A(a_0/l_H)^{1/ν}]$ , and  $l_H$  is the magnetic length. The dependence of conductivity on temperature in the insulating phase is assumed to be

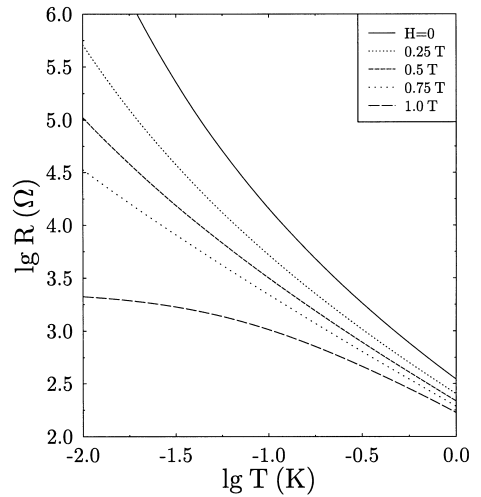


Fig. 3. Dependence of resistance on temperature near mobility edge (theory).

described by the variable range hopping [4]  $σ(T) = σ_0 \exp[-(T_0/T)^{1/4}]$  where  $T_0$  depends on the localization radius of the electron wave function  $r_0$ ,  $T_0 = 16/(\rho_0 r_0^3)$ , and  $\rho_0$  is the density of states. In the scaling region we take  $r_0 = L_{loc}$ . To fit the metallic region, we take  $σ = (e^2/2π^2ħa)[(ε - ε_c)/ε_c]^ν$  and  $a = \sqrt{3ħ/(4\sqrt{mε_c})}$ .

We used the parameters of the Ge films and found rather good qualitative agreement with experiments when  $ν \approx 0.8$ . The results of calculations are presented in Fig. 3.

**References**

[1] V.F. Mitin, Mol. Phys. Rep. 21 (1998) 71.  
 [2] V.F. Mitin, J. Phys. IV France 8 (1998) 193.  
 [3] D.E. Khmel'nitskii, A.I. Larkin, Solid State Commun. 39 (1981) 1069.  
 [4] V. Ambegaokar, B.I. Halperin, J.S. Langer, Phys. Rev. B 4 (1971) 2612.