2D Hole System Characterization by T/T_F Dependence of Electrical Resistivity

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Abstract ***–The paper presents an experimental setup design for two-dimensional (2D) systems characterization at ultra low-temperature. The electrical resistivity can be measured for variable density of carriers. The resistivity measurements were done for different densities and shows the influence of finite-temperature over the behavior for an 2DHS confined in GaAs.***

Keywords: ***measurements, materials***

I. INTRODUCTION

The competition to produce progressievly higher 2D systems helped select a particular group of materials well-suited to the task: the GaAs/$Al_xGa_{1-x}As$ lattice-matched system. The elements themselve – Al, Ga, As, and the dopant of choice, Si – were relatively easily evaporated or sublimed at reasonable temperatures, lattice matching resulted in high-quality epitaxy, and the band offsets allowed for convenient confinement of either electrons or holes depending on the structure and doping. Moreover, the relatively low vapor pressures of the constituent elements meshed particularly well with the ultra-high vacuum requirements for Molecular Beam Epitaxy [1].

The study of 2D holes has lagged somewhat behind progress in electron systems. The higher effective masses and lower motilities of holes in most semiconductors render quantum effects in reduced-dimensional systems fabricated with *p*-type material more difficult to observe. These barriers notwithstanding, early progress was made using *p*-type inversion layers of various semiconductors, with Si again as the paradigm [2, p. 594-607]. However, following the initial fabrication of a two-dimensional electron system at the GaAs/$Al_xGa_{1-x}As$ interface [3, 4], the first observation of a 2DHS at the same interface was reported soon thereafter by Stormer and Tsang [5]. With the promise again proffered by the GaAs/$Al_xGa_{1-x}As$ system, subsequent experimental efforts sought in part to improve mobilities in the same fashion as modulation-doped electron systems.

Up to now, the resistivity has been by far the main tool to characterize the behaviors in 2D carrier systems. Despite the considerable body of experimental evidence accumulated, a thorough and consensual understanding of the 2D metalliclike phase is still missing, partly due to the lack of information on other physical properties. While scattering is central to some of the proposed explanations, the resistivity is of limited help to distinguish between different scattering mechanisms. The thermopower is also a very sensitive probe of single and many body properties of the 2D systems [6-9] and is usually complementary to resistivity. For example, diffusion thermopower has opposite *T* dependencies for a mobility gap than for a real (energy) gap, while resistivity shows an insulating behavior in both cases.

II. EXPERIMENTAL SETUP AND RESULTS

The experiment was performed on Si modulation doped GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells, 200 Å wide, grown on (311)*A* GaAs substrates by molecular-beam epitaxy. Measurements were done on rectangular $7 \times 2\ mm^2$ piece cut along the [233] direction with In(5% Zn) Ohmic contacts deposited on the edges parallel to the length of the sample. Resistivity was measured using van der Pauw geometry with current and voltage contacts along the [233] high mobility direction (Fig 1).

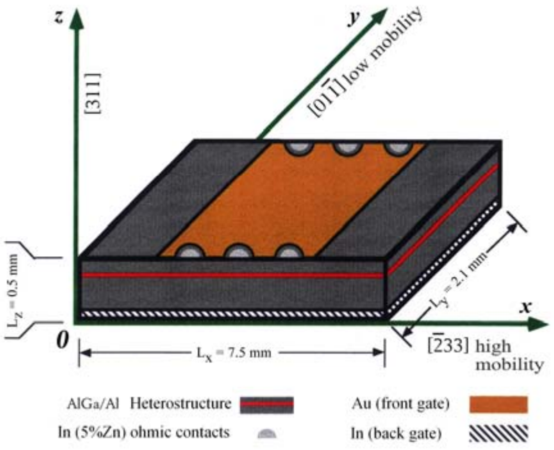


Fig. 1. Sample design

The sample had metal front and back gates that allowed tuning of the 2D hole density (*p*) from 1.49 to

0.86×10^{11} cm^{-2} (Fig. 2) by settings the front gate (V_{FG}) and back gate (V_{BG}) voltages.

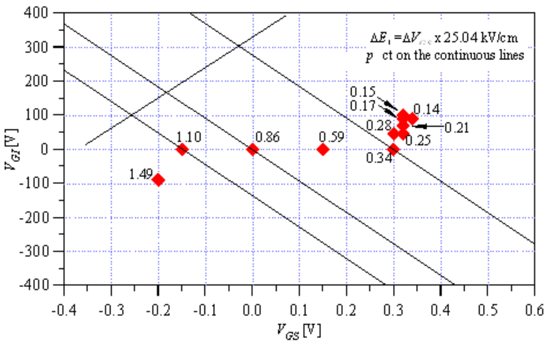
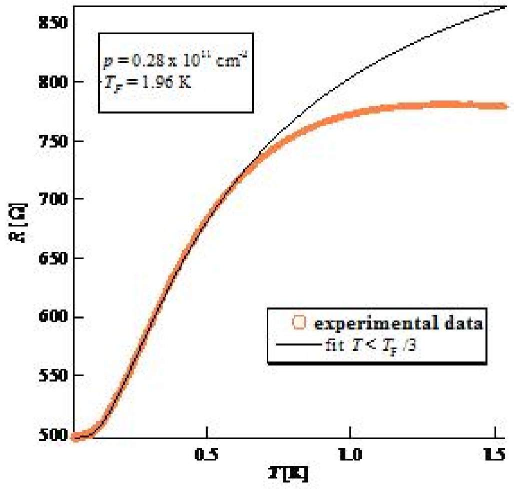
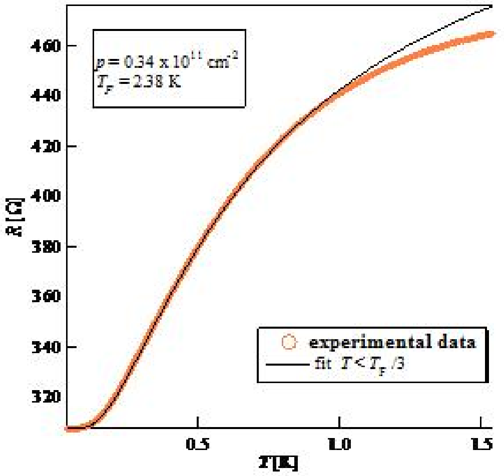


Fig. 2. V_{FG} and V_{BG} map

While for the low densities a mixed behaviour is observed, in the range $0.28 \leq p \leq 0.59 \times 10^{11}$ cm^{-2} of density it was finded a metallic behavior characterized by a dramatic and monotonic drop in resistivity (ρ) as T is lowered. The $\rho(T)$ data was fitted at these densities, for $T \leq T_F/3$, to the empirical formula $\rho = \rho_0 + \rho_1 \exp(-T_0/T)$ [10], where ρ_0, ρ_1, and T_0 are free fitting parameters and T_F is the Fermi temperature (Fig. 3).





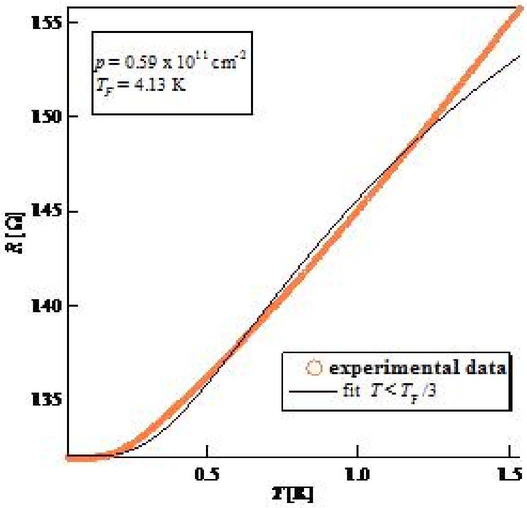


Fig. 3. Experimental data for $0.28 \leq p \leq 0.59 \times 10^{11}$ cm^{-2} density range, fitted with $\rho = \rho_0 + \rho_1 \exp(-T_0/T)$

The extracted T_0 obeys a linear dependence on p (Fig. 4) that indicate a metallic behaviour in agreement with the theoretical or experimental previous studies [11-13].

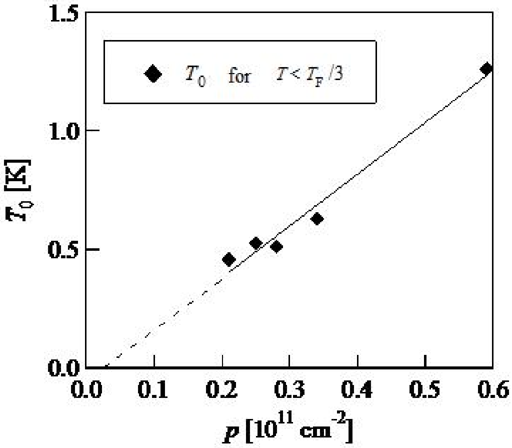


Fig. 4. Linear dependence between T_0 and resistivity

In $0.86 \leq p \leq 1.49 \times 10^{11}$ cm^{-2} density range, the behavior can be ilustrated by classical temperature dependence of electrical conductivity (Fig. 5), but a interesting pesrspective is offered by T/T_F dependence of electrical resistivity (Fig. 6). These data are very similar qualitatively to the results of previous experiments done in other 2D systems [14-17] and suggest the finite-T effect as causing of the metal-insulator transition. All the data are taken in the absence of a magnetic field.

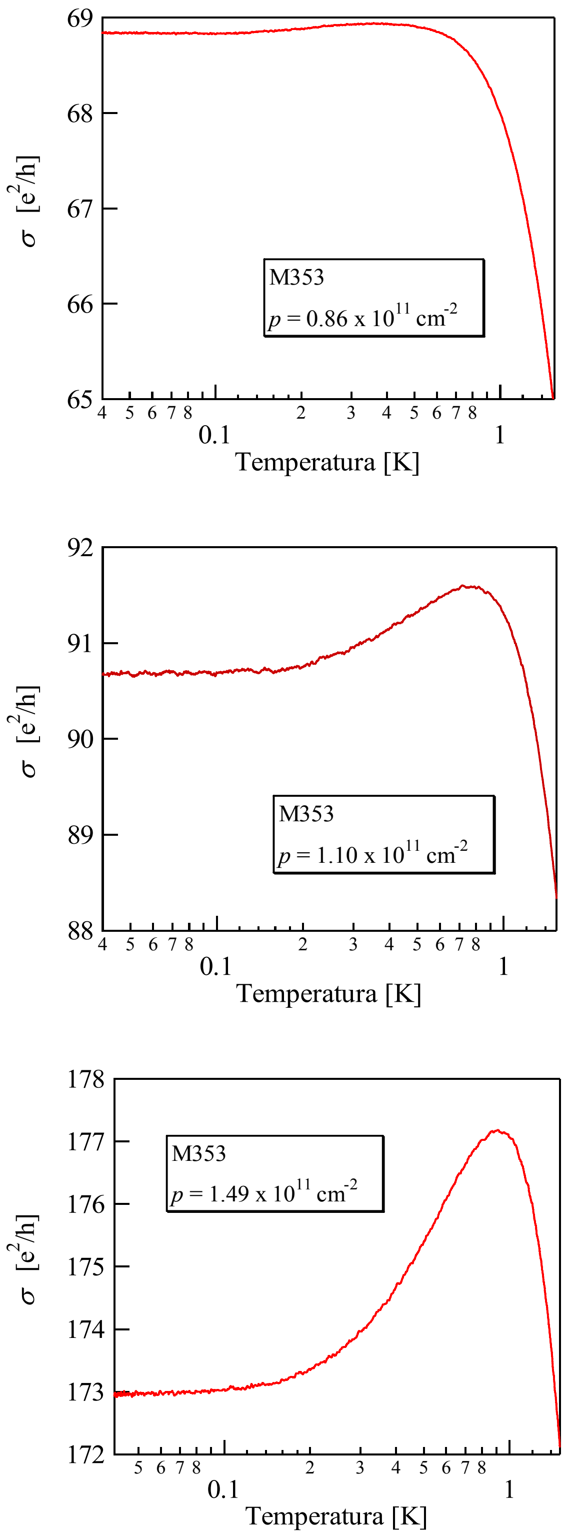


Fig. 5. Temperature dependence of electrical conductivity for $0.86 \leq p \leq 1.49 \times 10^{11}$ cm^{-2} density range

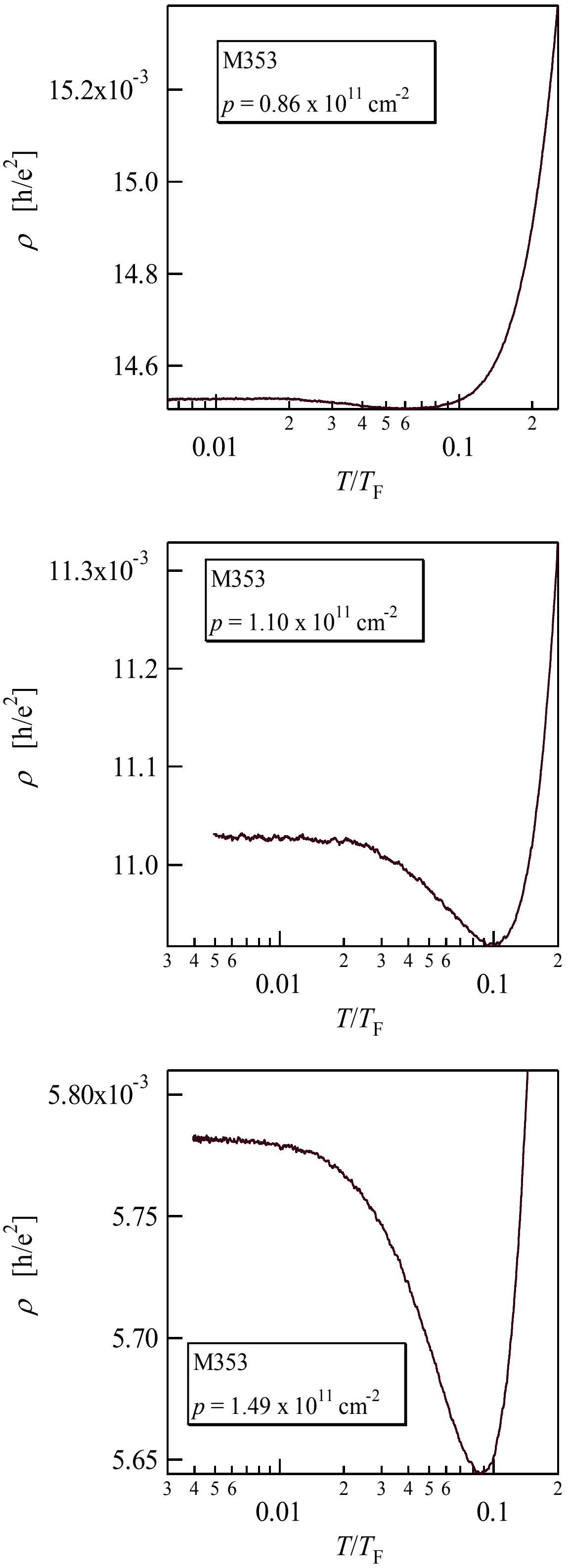


Fig. 6. T/T_F Dependence of electrical resistivity

III. CONCLUSIONS

In summary, the presented results shows that T_F might be an important parameter for understanding the metal-insulator transition in 2DHSs. Measurements and calculations for samples grown along various crystal axes might be interesting.

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