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Superconductivity of compressed iron: Low temperature electrical transport behaviour

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Abstract. Resistivity of iron under pressure ($p < 17$ GPa) has been measured in a new type of Bridgman cell adapted to trap Daphne oil as pressure medium. Here we have done detailed studies on the T -exponent of $\rho(T)$ in the low p -region of the superconducting phase ($13 \leq p \leq 31$ GPa) under magnetic field (≤ 8 kOe). Very large drop and quasi-complete $\rho(T)$ transition were observed for the first time in the low- p region of SC-dome. With the increase of magnetic field we obtained, below T_{SC}^{onset} , a trend that the T -exponent is increasing and reached to 1.82 at the highest applied field. Attempt has also been made to estimate the critical current density, which appears to be quite high compared to our earlier work.

1. Introduction and background

The discovery of superconductivity (SC) in iron under pressure [1] raises questions about the mechanism for its pair-formation. The results of recent experiments [2] have led to suggest an unconventional nature of its origin: The SC appears to be quite sensitive to disorder and it develops only when the electronic mean free path is above a threshold value ($\ell > 20$ nm). The normal state resistivity exhibits the characteristics of a nearly ferromagnetic metal and varies as $T^{5/3}$ at considerably high temperature over the entire superconducting pressure domain [3]. All these findings point towards triplet pairing symmetry of SC.

In this respect, the normal state properties of the low temperature ($< T_{SC}^{\text{onset}}$) region have not been fully studied. Here we will present the result of our work on the behaviour in the normal state of compressed Fe below 2 K and around 17 GPa. The normal state can be achieved by destroying the SC by applying magnetic field ($B_c > 8$ kOe). We performed the measurement in a newly developed clamped Bridgman-anvil cell [4] adapted to use a liquid pressure medium, Daphne oil (7373). Some modifications have been done in the previous set up [4] to extend the pressure range up to 17 GPa. Smaller anvil (2 mm in diameter) made of sintered-diamond was used. The pressure was determined *in situ* by the SC transition of lead (Pb). We have used a single crystal of iron whisker, prepared in the group of Prof. Y. Onuki [5]. The whisker cross-section was 1.6×10^{-6} cm² and with a length of 350 μ m. Four 10 μ m gold wires were spot-welded to the sample to make the contacts for the four-probe DC resistivity measurement.

2. Results and discussions

The Figure 1 shows resistivity at zero and 8 kOe magnetic field and under the highest applied pressure, 16.8 GPa, measured during this studies. At zero magnetic field, a large drop was obtained in $\rho(T)$ below 2 K. For the first time we have observed a larger - more than 80% of the normal state value, nearly-complete superconducting transition at this low pressure range. The width of the T_{SC} of the lead-manometer, which was placed very close to Fe-whisker, is only 0.05 K, corresponding to 0.3 GPa pressure gradient. In previous experiments with steatite as pressure medium, such quasi-complete transitions were obtained only above 22 GPa. So this large drop at lower p -range might be related to better hydrostaticity inside the pressure cell. Given the better hydrostatic-conditions, the unusual broad nature of the superconducting transition seems to be intrinsic to the high pressure phase of Fe, probably due to phase coexistence associated to the martensitic transition [6]. The inset of figure 1 shows, at two different applied magnetic fields, the value the T -exponent of the resistivity, n , below 1.5 K. At 4 kOe, the $n = 5/3$ normal state value is still depressed by superconducting traces, while at 8 kOe n is approaching closer to 2 and entering the FL regime. This is because the application of magnetic fields pushed the system further away from its hypothetical QCP.

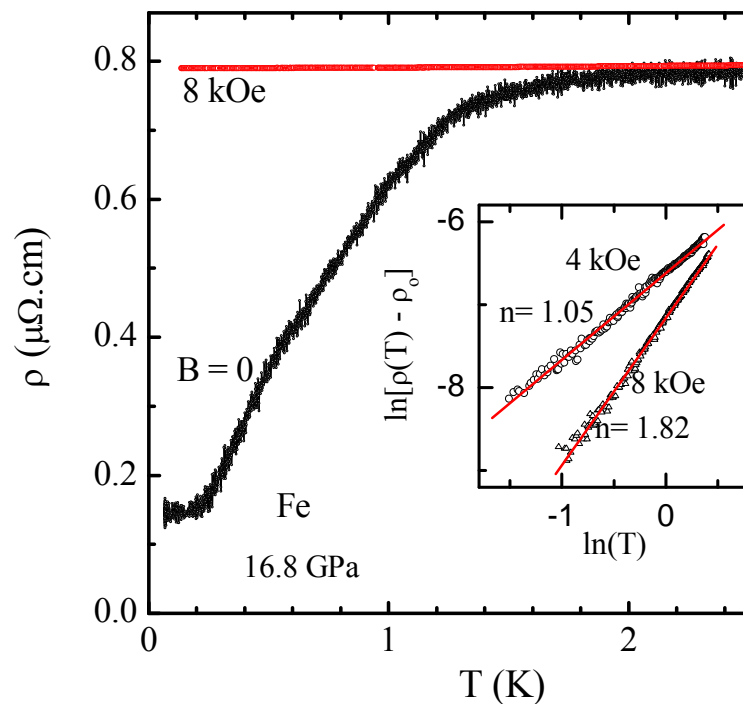


Figure 1. (color online) Resistivity of iron under pressure 16.8 GPa. Inset shows the values of n , in $\rho(T) = \rho_0 + AT^n$, at two applied magnetic fields.

One may also notice, from the figure 2a, that to obtain a large drop in $\rho(T)$, a small current density is required. However, a partial transition could be observed for current densities $j \approx 6.3 \times 10^5 \times I \sim 10^4 \text{ A}\cdot\text{cm}^{-2}$, with $I = 15 \text{ mA}$. This value is several orders of magnitude higher compared to the lowest value (at $5 \mu\text{A}$). The deviation in the $\rho(T)$ drop at different currents is more pronounced at lower

temperature. Figure 2b shows plot of R vs. I at $T = 70$ mK. This R - I behaviour resembles the flux-flow resistivity in type-II superconductor at zero magnetic field [7]. Considering the coexistence of superconducting and normal phases [6], it is difficult to determine the precise value of critical current (I_c) from the DC resistivity measurement. But qualitatively one may estimate that the superconducting phase can sustain large current density (larger than $80 \text{ A}\cdot\text{cm}^{-2}$).

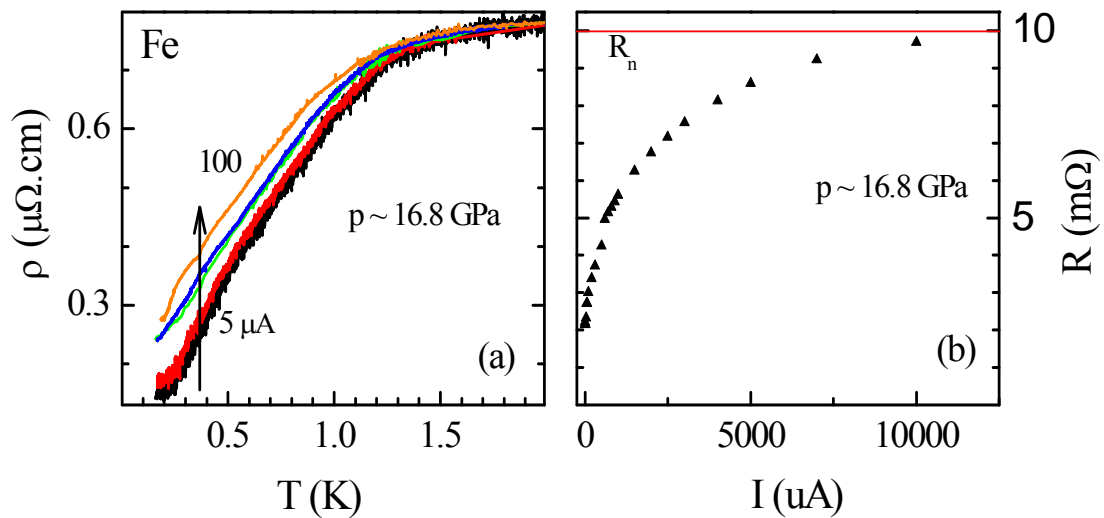


Figure 2. (color online) (a) $\rho(T)$ vs. T at different applied currents and (b) $R(I)$ at base temperature $T = 70$ mK with a sample self-heating below 50 mK at 1 mA. R_n represents the normal state resistance.

3. Summary

In summary, we have reported our preliminary results on electrical transport at low T and p regions of superconducting iron. The superconducting drop is found to be quite sensitive to hydrostaticity of the pressure medium. Further measurements with higher magnetic fields (> 8 kOe) are already in progress.

References

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