ELSEVIER
Physica B 312–313 (2002) 795–796
PHYSICA B
www.elsevier.com/locate/physb

Magnetoresistance scaling in $BaRuO_3$

S. Levy[a], Y. Kats[a], M.K. Lee[b], C.B. Eom[b], L. Klein[a,*]

[a] *Physics Department, Bar-Ilan University, Ramat-Gan 52900, Israel*
[b] *Department of Materials Science and Engineering, University of Wisconsin-Madison, Madison, WI 53706, USA*

Abstract

We present measurements of electrical resistivity (ρ) and magnetoresistance ($\Delta\rho/\rho$) in epitaxial thin films of $BaRuO_3$ with a hexagonal four-layer structure. The low-temperature resistivity ($3\ K < T < 20\ K$) shows a quadratic temperature dependence $\rho = \rho_0 + aT^2$. Measurements of magnetoresistance in the temperature range of $5\ K < T < 50\ K$ and fields up to 8 T reveal a failure of the conventional Kohler's rule. On the other hand, we find that the magnetoresistance data can be scaled if one assumes that the resistivity ρ is related to the scattering time τ as $\rho \propto 1/\tau^{\alpha}$ with $\alpha \simeq 0.25$.

PACS: 72.15.Gd; 75.50.Jt; 73.61. − r

Keywords: Ruthenates; Magnetoresistance; Non-Fermi-liquid behavior

Ternary ruthenates have attracted much attention due to their intriguing electronic properties which give rise, among others, to exotic *p*-wave superconductivity (Sr_2RuO_4) [1], itinerant ferromagnetism with intriguing characteristics ($SrRuO_3$) [2], and itinerant antiferromagnetism ($Ca_3Ru_2O_7$) [3]. While many of the Ruddlesden–Popper series of $Sr_{n+1}Ru_nO_{3n+1}$ and $Ca_{n+1}Ru_nO_{3n+1}$ ($n = 1, 2, 3$, and infinity) have been extensively studied, very little is known about the transport properties of $BaRuO_3$ whose structure belongs to the family of hexagonal perovskites. Here, we present transport and magnetotransport measurements of epitaxial thin films of *c*-axis oriented four-layered hexagonal $BaRuO_3$ and discuss possible interpretations of our results.

$BaRuO_3$ films in the four-layer hexagonal structure were grown on (1 1 1) $SrTiO_3$ by a 90° off-axis RF-sputtering technique [4]. The film whose measurements are presented here has a resistivity ratio of $\rho(300\ K)/\rho(3\ K) \sim 5$, which is similar to values obtained for single crystals [5].

The resistivity ρ as a function of temperature is shown in the inset of Fig. 1. At low temperatures ($3\ K < T < 20\ K$) a quadratic behavior is observed: $\rho = \rho_0 + aT^2$, as shown in Fig. 1. This form of the resistivity, which was also reported previously [5,6], is typical of Fermi-liquid metals. In the following, we examine whether the magnetoresistance of $BaRuO_3$ is consistent with Fermi-liquid behavior.

We measured the magnetoresistance between 5 and 50 K, in fields up to 8 T. The field was applied perpendicularly to the plane of the film. The magnetoresistance of $BaRuO_3$, reported here for the first time, is small and positive. In the low-temperature limit and a field of 8 T $\Delta\rho/\rho \sim 0.2\%$, and it decreases as a function of temperature, which made it difficult to obtain accurate data above 50 K.

An ubiquitous behavior in Fermi-liquid metals is the scaling of the magnetoresistance by Kohler's rule [7] which states that the magnetoresistance $\Delta\rho/\rho$ is a function of $H\tau$ alone (where $\Delta\rho = \rho(H) - \rho(0)$, H is the magnetic field and τ is the scattering time). In conventional metals $\rho \propto 1/\tau$, which results in a scaling law of the form $\Delta\rho/\rho = f(H/\rho)$. Fig. 2a shows our data as $\Delta\rho/\rho$ vs H/ρ. Clearly, the data do not fall on a single curve, indicating a violation of Kohler's rule.

*Corresponding author. Tel.: +972-3-531-7861; fax: +972-3-535-3298.

E-mail address: kleinl@mail.biu.ac.il (L. Klein).

0921-4526/02/$ - see front matter
PII: S0921-4526(01)01227-3

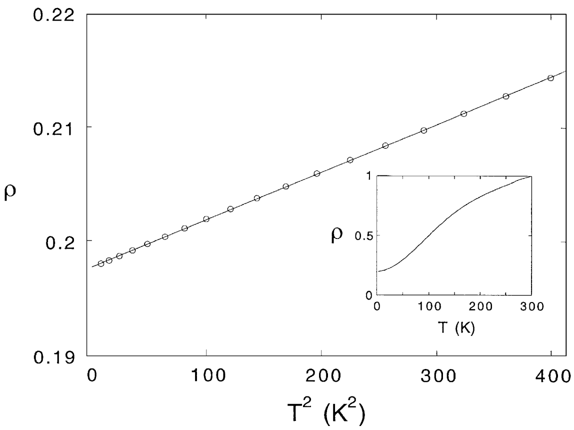

Fig. 1. Plot of ρ vs T^2 at low temperatures, where ρ is the resistivity normalized to its value at $T = 300$ K. Inset: ρ vs T up to room temperature.

The failure of Kohler's rule may imply that charge carriers from different parts of the Fermi surface have different scattering times. On the other hand, it may also be a result of an unusual relation between the conductivity and the scattering time. For instance, optical measurements of $SrRuO_3$ [8] suggest that its electrical resistivity might not be inversely proportional to τ as expected for Fermi-liquid metals, but instead $\rho \propto 1/\tau^\alpha$ with $\alpha \simeq 0.4$. If a similar fractional power-law relation exists here, then instead of Kohler's rule we might expect: $\Delta\rho/\rho = f(H/\rho^{1/\alpha})$ with $\alpha \neq 1$. In order to examine this possibility we plotted $\Delta\rho/\rho$ as a function of $H/\rho^{1/\alpha}$ for various trial values of α, and obtained the best data collapse with $\alpha = 0.25$. As shown in Fig. 2b, data-points obtained at different temperatures and fields fall on a single curve. It should be noted that when α is changed by more than 0.03 from this value, the scaling becomes significantly worse.

The failure of the conventional Kohler's rule might be a sign of non-Fermi-liquid behavior in $BaRuO_3$. Various signs of non-Fermi-liquid behavior have been reported before for similar compounds $SrRuO_3$ [2,8,9] and $CaRuO_3$ [10]. The possibility of a non-trivial relation between the scattering time and the resistivity in $BaRuO_3$ can be directly tested by measurements of optical conductivity similar to those performed in Ref. [8] for $SrRuO_3$.

This research was supported by the Israel Science Foundation founded by the Israel Academy of Sciences and Humanities, and by National Science Foundation Grant No. DMR 980244 and DMR 9973801.

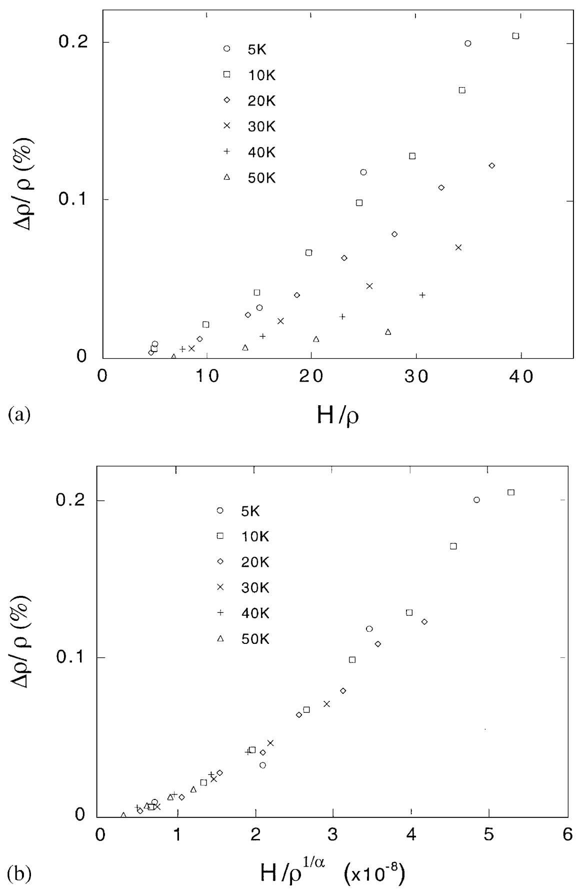

Fig. 2. Scaling of the magnetoresistance data ($\Delta\rho/\rho$ in percent) obtained with fields up to 8 T at temperatures $T = 5, 10, 20, 30, 40$ and 50 K: (a) Scaling assuming Kohler's rule; namely, $\Delta\rho/\rho = f(H/\rho)$. The wide spread of the data points clearly indicates the failure of the scaling; (b) Scaling assuming $\Delta\rho/\rho = f(H/\rho^{1/\alpha})$ with $\alpha = 0.25$. In both plots, the field H is in teslas and the resistivity is normalized to its value at $T = 300$ K.

References

[1] Y. Maeno, et al., Nature (London) 372 (1994) 532.
[2] L. Klein, et al., Phys. Rev. Lett. 77 (1996) 2774.
[3] G. Cao, et al., Phys. Rev. Lett. 78 (1996) 1751.
[4] C.B. Eom, et al., Appl. Phys. Lett. 55 (1989) 595.
[5] J.T. Rijssenbeek, et al., Phys. Rev. B 59 (1999) 4561.
[6] M.K. Lee, et al., Appl. Phys. Lett. 77 (2000) 364.
[7] J.M. Ziman, Principles of the Theory of Solids, Cambridge University Press, Cambridge, 1972, pp. 250–254.
[8] J.S. Dodge, et al., Phys. Rev. Lett. 85 (2000) 4932.
[9] P. Kostic, et al., Phys. Rev. Lett. 81 (1998) 2498.
[10] L. Klein, et al., Phys. Rev. B 60 (1999) 1448.