Japanese Journal of Applied Physics **50** (2011) 05FD02 **BRIEF NOTE**
DOI: 10.1143/JJAP.50.05FD02

Anomalies in Transport and Superconducting Properties of $Ba_{1-x}K_xFe_2As_2$ Single Crystals

Vladimir N. Zverev*, Alexey V. Korobenko, Guoli L. Sun[1], Dunlu L. Sun[1], Chengtian T. Lin[1], and Alexander V. Boris[1]

Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Region 142432, Russia
[1] *Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany*

Received October 2, 2010; accepted January 5, 2011; published online May 20, 2011

The transport and superconducting properties of $Ba_{1-x}K_xFe_2As_2$ single crystals were studied. Both in-plane and out-of-plane resistivity were measured by Montgomery method. The in-plain resistivity temperature dependence was found to be nonlinear with the tendency to saturate at high temperature. We have found that the resistivity anisotropy is almost independent of temperature and lies in the range 10–40 for the studied samples. We explain this result by the extrinsic nature of high out-of-plane resistivity, which may be due to the presence of flat defects along Fe–As layers. This statement is supported by comparatively small effective mass anisotropy, obtained from the upper critical field measurements.

After the discovery of high-temperature superconductivity in the iron arsenides,[1)] both experimental and theoretical activity was directed toward the study of the band structure, transport properties and the pairing symmetry in the superconducting state. Despite intensive studies, there is still controversy regarding many important physical issues concerning the properties of these new materials, in particular, anisotropy, which is a highly important parameter. This paper is devoted to the studies of transport properties and the anisotropy of hole-doped $Ba_{1-x}K_xFe_2As_2$ single crystals in normal and superconducting states. Unlike to the parent compounds, our K-doped samples did not have the anomalies in the temperature dependence of the resistivity due to the structural phase transition. This gives the opportunity to study and compare with theoretical models their transport properties in a wide temperature region.

The samples, obtained in two different growth processes, had the potassium content $x \approx 0.5$ and 0.4 and the superconducting transition temperatures T_c about 31 and 38 K, respectively. The growth method and the preliminary results were published in ref. 2. The experiments were carried out in the temperature range $4.2 < T < 300$ K and in magnetic fields up to 17 T. Both in-plane ρ_{ab} and out-of-plane ρ_c resistivities were measured by a Montgomery method. On some samples with the small thickness only ρ_{ab} value was measured by traditional four-probe method. Figure 1 demonstrates the temperature dependence of the in-plane resistivity component ρ_{ab} for two samples with different doping level. The difference in T_c values in Fig. 1 is determined not by the different potassium content, but mainly by the higher quality of the samples with $x = 0.4$. The elemental analysis of the sample with $x = 0.5$ shows that the potassium concentration is not uniform: it drops from the value about 0.5 near the surface to about 0.3 in the middle part of the sample.[3)] As seen from the Fig. 1, the resistance of both samples is characterized by anomalous T-dependence: $\rho_{ab}(T)$ curves are convex with the tendency to saturate at high temperature. Taking into account that iron-pnictides are characterized by multi-band energy spectrum, the saturation could be explained in the framework of a simple two-band model: in the case of two bands with different parameters, the conductivity of one band can "shunt" the conductivity of another, leading to the saturation of the total resistance at high temperature.[4)]

*E-mail address: zverev@issp.ac.ru

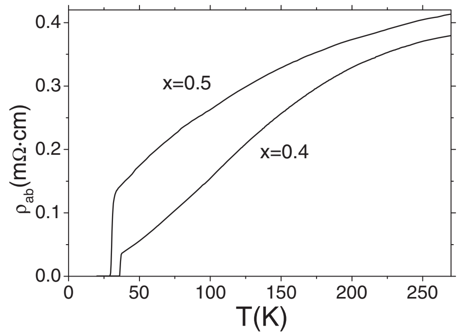

Fig. 1. The temperature dependence of the in-plane resistivity ρ_{ab} for two samples of $Ba_{1-x}K_xFe_2As_2$ with different doping level.

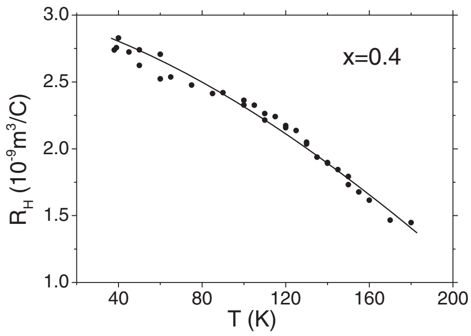

Fig. 2. The temperature dependence of the Hall constant R_H.

The results of the Hall-effect measurements are presented in Fig. 2 for the sample with $x = 0.4$. One can see that the Hall constant value R_H increases with the decreasing of the temperature. The temperature dependent R_H value was observed recently in $Ba(Fe_{1-x}Co_x)_2As_2$ and was treated as the consequence of the temperature dependent carrier concentration.[5)] We believe that, at least for our case, the temperature dependence $R_H(T)$ is more naturally to explain by the mobility changes, because in multi-band conductors R_H value is the function of both concentration and mobility and there are no physical reasons for the strong temperature dependence of the concentration.

The results for the resistivity anisotropy on the samples with $x = 0.5$ are presented in Fig. 3. We did not succeed in the measurements of the anisotropy on the samples with

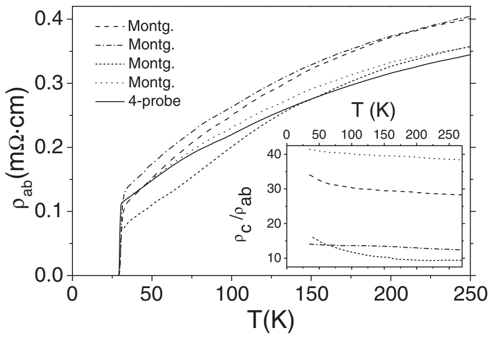

Fig. 3. Results of the resistivity ρ_{ab} measurements on five different samples with $x = 0.5$. The resistivity anisotropy is shown in the insert.

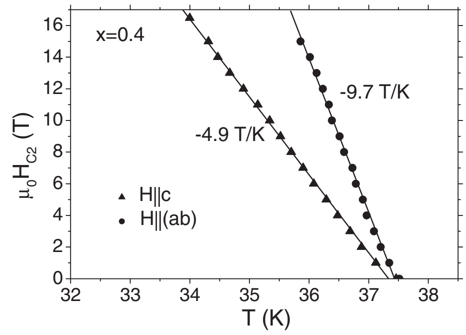

Fig. 4. The temperature dependence of the upper critical field $H_{c2}(T)$.

$x = 0.4$ because the thickness of these samples was too small for the Montgomery measurements. One can see that ρ_{ab} values for all studied samples proved to be similar to each other for both Montgomery and four-probe measurements. The results for the resistivity anisotropy are presented in the insert. On can see that ρ_c/ρ_{ab} values are almost temperature independent and lie in the range 10–40 for the studied samples. This means that, unlike to ρ_{ab} values, out-of-plain tensor components ρ_c differ considerably for different samples, probably owing to an extrinsic source. This phenomenon is well known for the layered systems (e.g., graphite, layered semiconductors) in which the out-of-plane conductivity is limited by the presence of flat defects.

In contrast to our dc measurements, the anisotropy extrapolated from our far-infrared conductivity data is lower by a factor of 2–3 even for the highly conductive sample (lowest curve in the inset to Fig. 3). The similar result was obtained from our measurements of the upper critical field anisotropy. The temperature dependence of the upper critical field H_{c2} was measured when the field was directed either along or perpendicular to Fe–As planes (see Fig. 4). In this experiment we have used the capacitor to measure the temperature to avoid the influence of the strong magnetic field on the temperature sensor. As seen from Fig. 4, $H_{c2}(T)$ dependence is linear in the vicinity of T_c. From dH_{c2}/dT values for $H \parallel (ab)$ and $H \parallel c$ one can get the effective mass anisotropy $\gamma_m = m_\perp/m_\parallel$. According to Ginzburg–Landau theory γ_m is equal to the square of the slope ratio of the lines, presented in Fig. 4. For the samples with $x = 0.4$ and 0.5 we have got $\gamma_m \approx 4$ and 3 respectively, which is in a good agreement with the results of the spectral investigations but is much smaller than that evaluated from dc resistivity measurements. This result confirms our statement about the extrinsic nature of the out-of-plane resistivity: the presence of flat defects parallel to Fe–As planes does not influence the effective mass but leads to the increase of the ρ_c value and, as the consequence, to the increase of the resistivity anisotropy ρ_c/ρ_{ab}. This statement is also supported by the observation[2)] of the so-called "Friedel transition" in our samples: the effect consists in distinction of superconducting transition temperatures, obtained from longitudinal and transversal resistance measurements, and occurs for a disordered layer array.[6)]

Acknowledgments We thank A. A. Golubov and O. V. Dolgov for valuable discussions and suggestions.

1) Y. Kamihara, T. Watanabe, M. Hirano, and H. Hosono: J. Am. Chem. Soc. **130** (2008) 3296.
2) V. N. Zverev, A. V. Korobenko, G. L. Sun, D. L. Sun, C. T. Lin, and A. V. Boris: JETP Lett. **90** (2009) 130.
3) V. A. Gasparov: Sov. Phys. JETP **111** (2010) 313.
4) O. V. Dolgov: private communication.
5) F. Rullier-Albenque, D. Colson, A. Forget, and H. Allaul: Phys. Rev. Lett. **103** (2009) 057001.
6) M. Dzierzava, M. Zamora, D. Baeriswyl, and X. Bagnoud: Phys. Rev. Lett. **77** (1996) 3897.