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Lower critical fields in BKBO single crystals

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ABSTRACT

We performed dc-magnetization measurements in low magnetic fields on single crystals of $Ba_{1-x}K_xBiO_y$ (BKBO) with the different potassium content. The single crystals reveal the superconducting transition at 29 – 31 K. It is shown that the lower critical fields H_{C1} in crystals amount to 104 Oe (x = 0.34), 126 (x = 0.37) and 112 Oe (x = 0.4). The values of the penetration depth λ (0) are equal to 2530 A, 2430 A and 2670 A for x = 0.34, 0.37, and 0.4, respectively.

Keywords: superconductivity, BKBO, single crystals, lower critical field, the penetration depth.

1. INTRODUCTION

The BKBO high-T_c system shows promising features for the possible application in the devices based on Josephson electronics because of its relatively long coherence length (ξ = 45 – 70 A).[1,2] It is important to note that the most successful superconductor – insulator – superconductor (SIS) and superconductor – insulator – normal conductor (SNS) structures using BKBO have been already obtained (see, p. ex.,[3] and the references therein). On other hand, BKBO with $T_c \approx 30$ K is intermediate system between high-T_c and usual superconductors, and at present the origin of superconductivity in the copperless bismutate materials is not fully understood. It is necessary to know the critical parameters of BKBO both for the understanding of the mechanism of superconductivity and for the creating superconducting devices. The critical fields, the lower critical field, H_{c1} and the upper critical field, H_{c2} are important characteristics of the type-II superconductors providing us the information in order to evaluate the main characteristic lengths, the coherence length, ξ and the penetration depth, λ. Both critical fields can be determined from magnetization measurements. The purpose of present work is to measure the lower critical field H_{c1} in single crystals of $Ba_{1-x}K_xBiO_y$ with different potassium content. The data on these characteristics obtained for ceramic, polycrystalline or single crystals are markedly contradictory. The values of $H_{c1}(0)$ obtained only for single crystals and ranging from 100 Oe to 300 ÷ 420 Oe indicate that the sample to sample variations are usual both for single crystals and polycrystalline materials. The determination of this fundamental parameter and comparison with results obtained on BKBO in previous works are the aims of our work.

2. EXPERIMENTAL

The single crystals of $Ba_{1-x}K_xBiO_y$ with x = 0.34 ÷ 0.4 were grown using the electrochemical deposition method from KOH flux melt.[8] The potassium concentration in the samples was determined by using a calibration curve for pseudocubic cell according to the approximation formula reported by S. Pei et al.[9] obtained by neutron diffraction experiments. The high quality of single crystals with potassium content x = 0.34; 0.37; 0.4 was confirmed by X-ray diffraction analysis.[10] The sample of practically cubic shape with average size ~ 1 mm^3 were cut from the central part of as-grown large single crystals. All faces of the samples are oriented (100) surfaces. The critical temperature values T_c were obtained at fields ~5 (Oe) and were equal to 30 K (x = 0.34), 29 K (x = 0.37) and 31 K (x = 0.4). The transition width ΔT did not exceed 2 – 3 K. The magnetization measurements were taken using an automatic vibrating sample magnetometer with the sensitivity of 10^{-6} emu over the temperature range from 4.2 K to ~T_c. For all measurements we waited about 20 min at the temperature of sample above T_c, subsequently we cooled the crystal at zero field down to temperature where performed a virgin magnetization curve. The M(H) curves were recorded at continuously varying magnetic fields up to ~1 kOe of an Al-solenoid.

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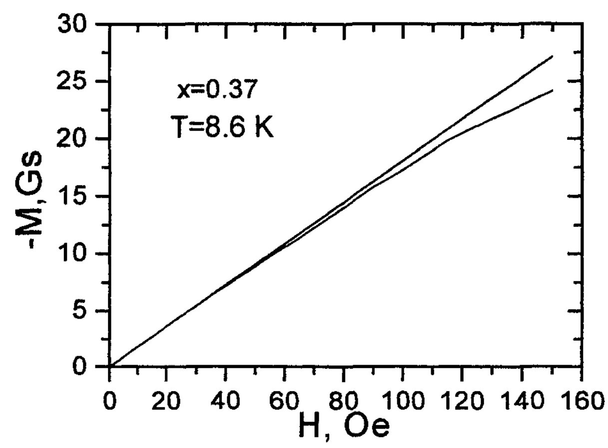
More than ten different methods exist for measuring lower critical field H_{c1}.[11] For present work we choose the standard method[12] which consists of determining H_{c1} from the first deviation of M(H) from linear behavior at $H_a = H_{c1}(1 - n)$, where H_a is external magnetic field, n is the demagnetization factor.

Typical magnetization data for BKBO single crystals are shown in Fig. 1 (single crystal with x = 0.37). Also shown is a straight line fit to the low-field diamagnetic regime. The values of H_{c1} were obtained from the field at which the flux first enters the sample by correcting for demagnetizing effects obtained from the initial slope of the magnetization curve assuming $M/H = -1/[4\pi(1 - n)]$. The value of n, deduced from the initial slope of the curve M(H) is in good agreement with the calculated value based on the sample dimensions: $n \approx 0.56$ for single crystal with x = 0.37.



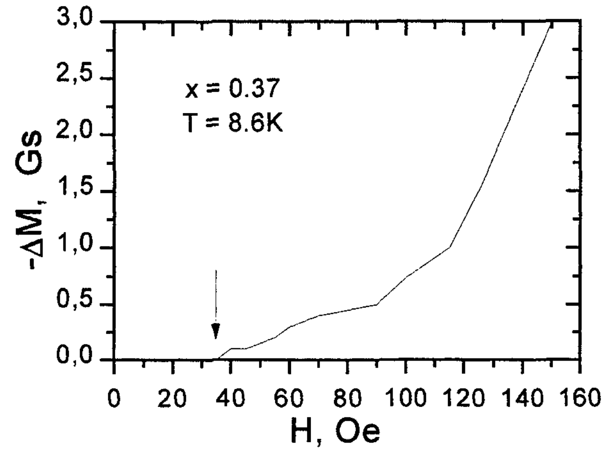


Fig. 1. Magnetization data M(8.6 K, H) for a $Ba_{1-x}K_xBiO_y$ single crystal with x = 0.37. The straight line is a least-squares fit to the first ten data points (perfect screening).

Fig. 2. The deviation ΔM(8.6 K, H) from linear behavior (perfect screening) as in Fig. 1. The value for the lower critical field, H_{c1} was estimated as the field were ΔM starts to deviate from zero. The arrow denotes H_{c1} uncorrected for demagnetization factor.

In order to observe the deviation from linearity (perfect screening) of M(H) we use the plot the curve (Fig. 2) corresponding to the curve in fig. 1 after the linear fit extrapolation of the low-data was subtracted. The transition from the Meissner state (B = 0) to the mixed state (B > 0) is easily seen, and the entry field H_{c1} was determined as the field at which the deviation ΔM from perfect screening starts to deviate from zero. The arrow at Fig. 2 indicates the H_{c1} at 8.6 K uncorrected for demagnetization factor for single crystal with x = 0.37. Similar magnetization-versus-field data were also obtained for determination of the first entry field, H_{c1} values corrected for demagnetization factors are plotted versus temperature in Fig. 3 for single crystals with x = 0.37. The line depicting $H_{c1}(T)$ dependence was obtained using the expression:

$$H_{c1}(T) = \varphi_0/[4\pi(\lambda(T))^2] \cdot \ln[\lambda(T)/(\varphi_0/2\pi H_{c2}(T))^{1/2}]$$

where φ_0 is the flux quantum, $\lambda(T)$ is the penetration depth.

Note that Werthamer, Helfand and Hohenberg (WHH) or linear extrapolations are usually assuming for the evaluation of temperature dependence of upper critical field, $H_{c2}(T)$, but we rely on the values of $H_{c2}(T)$, obtained from the direct magnetic measurements. The $H_{c2}(T)$ dependence was determined by means QUANTUM DESIGN MPMS-5 SQUID near T_c at the magnetic fields up to 5 T[13] and at lower temperatures by the NHMFL cantilever force magnetometer at fields up to 33 T.[14] The results for x = 0.37, e. g., can be described by relation $H_{c2}(T) = 46.2 - 2.8T + 0.04T^2$. The values of $\lambda(T)$ determined from the reversible magnetization data[13] with the superconducting volume correction (f = 0.8) were used for the approximation of $H_{c1}(T)$ dependence. We obtained for the penetration depth $\lambda(0) = 2430$ A and $H_{c1}(0) = 126$ (Oe).

Similar measurements and calculations were performed for other single crystals of BKBO (with x = 0.34 and 0.4). We can summarize the data by $H_{c1}(0)$ = 104 Oe and $\lambda(0)$ = 2530 A for x = 0.34, and $H_{c1}(0)$ = 112 Oe and $\lambda(0)$ = 2670 A for x = 0.4.

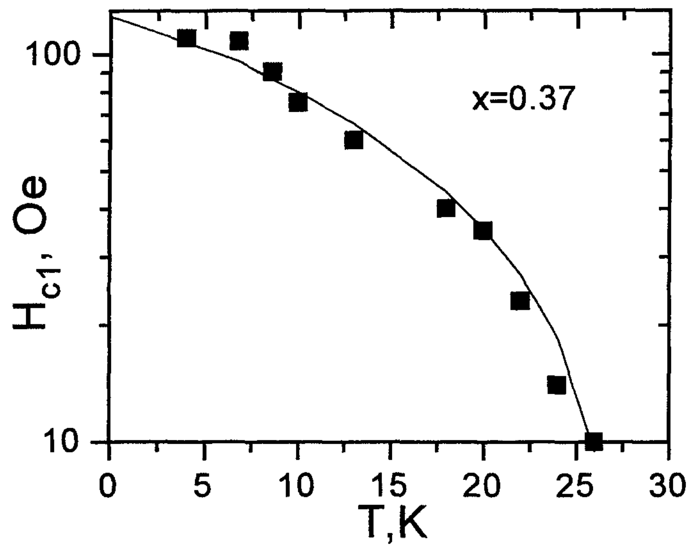


Fig. 3. The temperature dependence of lower critical field for single crystal with x = 0.37. The solid line represent fit of the data to theoretical expression as described in the text.

Analysis of the results of magnetization measurements on the three single crystals of BKBO shows that we find significantly lower values of H_{c1} compared to the values obtained in [5,7]. Qualitatively our data are in agreement with data [4].

3. CONCLUSION

We report measurements of the field of first magnetic flux entry and determined values of the lower critical field $H_{c1}(T)$ on the three single crystals of BKBO with the different potassium content. The obtained Hc1(0) values amount to 104 Oe (x = 0.34), 126 (x = 0.37) and 112 Oe (x = 0.4).

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