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Lattice deformation in an axially strained BiSrCaCuO/Ag tape conductor investigated by X-ray diffraction

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Abstract

The lattice deformation of a Bi-2212/Ag tape conductor is investigated as a function of an externally applied strain at 300 K. This macroscopic strain is applied in the same direction ("axial") as where the current is normally passed through the conductor. A small but significant shift is observed in the position of the 00$\underline{20}$ diffraction peak. In a limited strain regime this shift is proportional to the applied strain. The deformation of the *c*-axis that corresponds to the observed peak shift can be described well with an elastic grain deformation. For tensile axial strains above 0.2% and below −0.1% strain, the *c*-axis deformation is limited to an almost constant value. These two limits in the elastic behaviour divide the axial strain range into three regimes. A good correlation with the axial strain dependence of the critical current at 77 K, is obtained when the thermal contraction is taken into account. In the central strain range, where an elastic lattice deformation is observed, the critical current remains almost constant. Any tensile or compressive deformation that exceeds the elastic limits causes a more severe and irreversible reduction of the critical current.

Keywords: Superconductivity; X-ray diffraction; BiSrCaCuO; Deformation; Critical current; Polycrystalline

1. Introduction

The transport critical current (I_c) in a Bi-based superconductor with Ag matrix can be significantly reduced if the conductor is strained in the axial direction. This reduction in I_c has been investigated in various tape and wire conductors and in different types of strain set-ups. [1–3]. So far every strain induced I_c reduction is found to be irreversible. Also it appears that the shape of the I_c versus axial strain relation is not influenced by temperature or magnetic field. Based on this behaviour it is generally concluded that the changes in I_c are mainly caused by strain induced fractures in the polycrystalline structure.

The relation between macroscopic strain and lattice deformation can be studied experimentally with X-ray diffraction. For instance by tilting the sample surface relative to its position inside the diffractometer. This technique is already successfully applied to a polycrystalline layer of Nb_3Sn with random oriented grains [4]. A good correlation is obtained between the lattice deformation and the strain applied on a macroscopic scale. In BiSrCaCuO/Ag tape conductors the *c*-axis alignment of the grains is an important factor that effects the transport critical

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current density. The required grain-alignment makes it impossible to investigate the lattice deformation by tilting the superconducting sample. Only an accurate value for the c-axis can be obtained in a c-axis oriented BiSrCaCuO layer. This parameter is therefore selected to study the lattice deformation as a function of the applied strain.

2. Sample material

A mono-core Bi-2212 tape is soldered with indium on a brass sample holder (see Fig. 1). After that the Ag sheath is cut at the edges and the central part of the Ag layer is pealed of. This enables a free access to the central 8 mm of the Bi-2212 core. The length of the tape on the flat part of the sample holder is about 25 mm. A typical diffraction pattern that is obtained by a 2θ scan with Cu-Kα radiation, is depicted in Fig. 2. The important peaks are classified as 0-0-2N with a c-axis of 3.080 nm.

For a good accuracy in the c-axis measurement it is important to select a diffraction peak at a high 2θ angle and a reasonable intensity. For the strain measurements on Bi-2212 the 00<u>20</u> peak near $2\theta = 60°$ is selected. A second important condition for the accuracy in the c-axis determination is the alignment of the sample. In this case the height of the sample (y-axis) is aligned by cutting a thin X-ray bundle (1/32 degree) to half its intensity at $2\theta = 0$. The angular alignment is adjusted by tilting the sample at $2\theta = 0$. In an iterative procedure for the angle and the y-axis position, the sample can be aligned with a

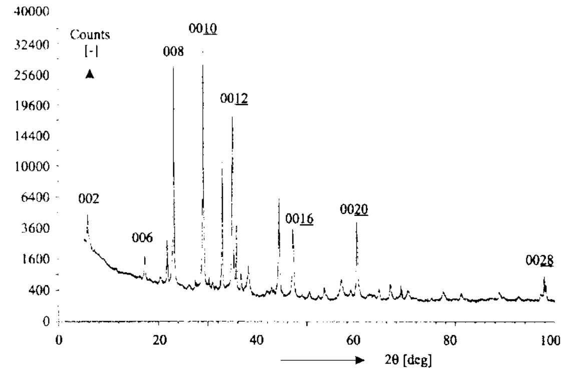

Fig. 2. The diffraction pattern with Cu-Kα radiation on polycrystalline Bi-2212 at 300 K, on a non-deformed sample holder.

2θ reproducibility in the 0020 peak of $\pm 0.002°$ (± 6 μm in the y-axis).

3. Tensile strain

The investigated Bi-2212 layer is deformed by a sample holder and the applied strain is measured by a strain gauge adjacent to the sample. A similar set-up is applied in the strain experiments on Nb_3Sn [4]. The strain gauge measures the applied tensile strain in the z-direction, which is parallel to the "axis" of the tape conductor. The 2θ measurement determines the c-axis of the grains in the y-direction. The initial value for 2θ is at 60.019°, in this layer on an non-deformed sample holder. An elongation of 0.15%, determined by the strain gauge leads to a small shift in the 2θ peak to 60.037°. This corresponds to a small compression of the c-axis with

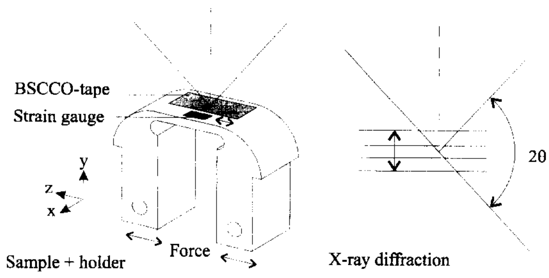

Fig. 1. Bi-2212 sample on the brass sample holder for the X-ray diffraction experiment.

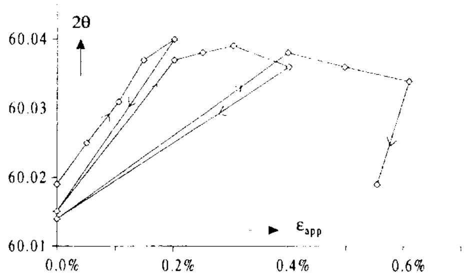

Fig. 3. The position of the diffraction peak of the 00<u>20</u> reflection as a function of the applied axial strain as measured with the strain gauge at 300 K.

0.027%. The observed shift in 2θ is small but significant compared to the reproducibility of 0.002°.

The observed change in the 2θ peak as a function of the applied strain is presented in Fig. 3. Two different strain ranges can be distinguished with a transition between 0.15% and 0.20% applied strain. In the first range, for small strains, the 2θ peak shifts proportionally with the strain, indicating a compression of the c-axis. For a larger applied strain the 2θ peak remains almost constant, indicating that the c-axis is not further compressed. The proportional compression of the c-axis in the first range can be described by an effective Poisson"s ratio of 0.18, for this polycrystalline Bi-2212 structure on a brass substrate. The measured value is in good agreement with other experimental results [5].

The proportional relation between the deformation of the c-axis and the macroscopic strain indicates that the Bi-2212 grains are deformed elastically in the first strain regime, at least for the major part. The non-linearity between 0.15% and 0.20% applied strain shows that a certain elastic limit in the polycrystalline structure is exceeded. The most probable cause for the non-linearity is the breaking of grain boundaries at strain values above 0.15%. Reducing the applied strain to its initial state, from a certain value in the second strain regime, shifts the 2θ peak almost back to its original position.

4. Compressive strain

The c-axis is investigated by means of X-ray diffraction in the compressive strain range too. For this experiment the brass sample holder is (plastically) deformed before connecting the sample and the sample is soldered onto the holder. After this procedure the sample can be compressed until -0.3% strain, before the sample edges touch the X-ray bundle in the alignment procedure (at $2\theta = 0$). This implies that the sample can be accurately aligned for a 2θ measurement in the strain range from 0 to -0.3% compressive strain.

The observed change in the 2θ peak of the $00\overline{20}$ reflection in a compressed sample is presented in Fig. 4. For compressive strain it appears that the first elastic strain regime is somewhat limited. The c-axis remains constant for a compression of 0.1% and

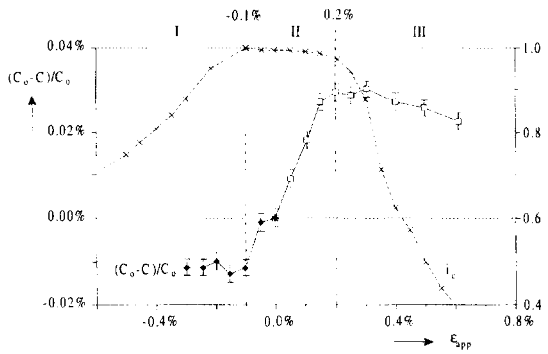

Fig. 4. The deformation of the c-axis as a function of the applied strain at 300 K, compared with the normalised I_c measured at 77 K on a deformed Bi-2212 mono-core wire [4].

higher. Again the slope of 2θ versus applied strain fits with an effective Poisson's ratio of 0.18, within the limited measuring accuracy. It is assumed that the limit of the elastic regime is due to a similar mechanism in both the compressive and tensile strain regime. If the thermal contraction of the Bi-2212 in this system is close to 0.05% strain then the experimental results can be described with a similar elastic strain limit for both compressive and tensile strains.

5. The correlation with the critical current in Bi-2212

A sample holder similar to the one described here is also applied to investigate the I_c in Bi-2212/Ag conductors as a function of the applied strain in both the tensile and the compressive regime [6]. For tensile axial strains the I_c remains nearly constant up to a certain limit, usually between 0.2 to 0.4% axial strain, and a drastic reduction in I_c occurs for larger strains. In axially compressed conductors there is a more gradual I_c reduction that starts immediately, even for the smallest compression. Note that all these I_c reductions are completely irreversible, which means that after unloading the I_c degrades even further. A similar I_c strain dependence is also reported for Bi-2223 conductors [7].

Comparing the strain dependence of the $00\overline{20}$ diffraction peak and the I_c shows two important strain levels in both curves. In the strain dependence of the diffraction angle two characteristic points occur at −0.1% and +0.2% axial strain and in I_c near 0 and +0.3% strain. These strain values can be scaled to similar values if the thermal contraction is taken into account. A good correlation is obtained for a reasonable value of 0.1% additional thermal contraction in the Bi-2212 during the change from room-temperature down to 77 K. This value is acceptable with the limited knowledge of the thermal contraction properties of Bi-2212 and the other materials involved.

A comparison between the strain dependence of the $00\underline{20}$ diffraction peak and the I_c is presented in Fig. 4, including a 0.1% strain correction for the thermal contraction difference. In this representation the strain dependence of both I_c and c-axis deformation is described with three strain regimes (I, II, III). In the middle (II) for small deformations is the regime where the grains are deformed elastically and the I_c is almost constant (but usually not perfect). For both compressive and tensile strains there is a limit in the elastic deformation of the grains. For strong tensile strains this leads to a drastic reduction in I_c where the grain boundaries start to break (regime III). A similar process occurs for a strongly compressed material, but then the reduction in I_c is less severe (regime I).

6. Conclusions

1. The lattice deformation of a poly-crystalline Bi-2212 tape conductor is determined by measuring the shift of the $00\underline{20}$ diffraction peak. This shift is studied as a function of the strain that is applied to the conductor on a macroscopic scale. The technique enables a qualitative interpretation of the lattice deformation in grains of deformed polycrystalline Bi-2212.

2. An elastic deformation is observed in Bi-2212 grains for a small strain in the conductor. Two limits are observed corresponding to an elongation of 0.2% and a compression of −0.1% in the polycrystalline structure at 300 K. For strain values beyond these limits the c-axis deformation remains nearly constant.

3. The observed limits in the elastic deformation of the grains can be scaled to the I_c versus strain behaviour that is determined on Bi-2212 conductors at 77 K, when the thermal contraction is taken into account. The strain regime where the grains are deformed elastically can be correlated with the regime where the I_c remains nearly constant. The I_c is strongly reduced when the elastic limit of the polycrystalline structure is exceeded.

4. The results presented here can be understood qualitatively very well. For a more quantitative interpretation in terms of strain, it is required to measure the diffraction pattern and the transport current I_c in a single deformation cycle in the same specimen.

5. The results presented here support the hypothesis that braking grain boundaries are the major I_c reduction mechanism in deformed polycrystalline Bi-2212 conductors. There is a strain regime where an elastic deformation occurs, but the small and permanent I_c reduction for a small tensile strain suggests that a certain non-elastic deformation is present in this regime too.

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