Critical Current in YBCO Coated Conductors in the Presence of a Macroscopic Defect

Milan Polak, Paul N. Barnes, Pavol Mozola, and George A. Levin

Abstract— **We have studied the effects of localized defects in the YBCO coated conductors on the critical current. The artificial defects were introduced into 4, 10 and 12 mm wide tapes as cuts of various lengths made either by laser ablation or mechanical means. Transport measurements were carried out in an external variable magnetic field to obtain the I-V characteristics of the damaged areas. The distribution of the magnetic field in the vicinity of the defects has been mapped as well. The reduction of the critical current by the defects, with and without an external DC magnetic field are discussed and compared with existing theories. A criterion for determining the critical current in the area containing a defect is suggested.**

Index Terms— **Coated Conductors, Defects, HTS, YBCO**

I. Introduction

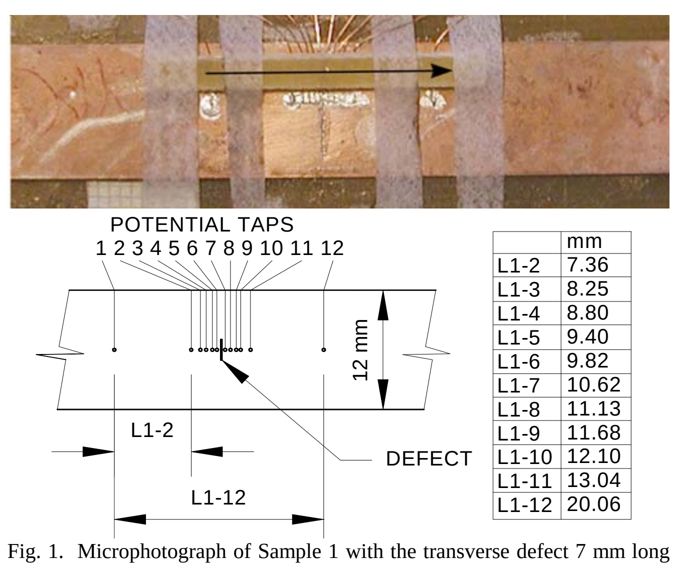
CURRENT-BLOCKING obstacles such as grain boundaries, second phase precipitates, pores, micro-cracks, etc. in $YBa_2Cu_3O_{7-x}$ (YBCO) reduce the critical current density [1] and give rise to an inhomogeneous current distribution in the vicinity of these defects. Cracks and porosity in the YBCO layer produced during the fabrication process of the high temperature superconductor (HTS) YBCO coated conductors can limit the critical current density (J_c) considerably [2]. Additional defects that can reduce J_c may be introduced during the handling of the tape, for example, due to excessive tensile stress [3] or tape bending. If the superconducting tapes exhibit a “bowing,” then additional damage can occur when the conductor is wound onto cylindrical formers to make pancake coils.

Magneto-optical imaging (MOI) and scanning laser microscopy (SLM) are frequently used to characterize HTS samples [4-8]. For MOI, the samples are often quite short (centimeters) and narrow (to reduce the currents). It may be difficult to investigate samples from the tapes without their modification. The sensitivity of the method is ~10^{-4} T and limited by saturation of the indicator film. Koyanagi et al. [5] measured the local current flow around transverse artificial defects in YBCO deposited on $SrTiO_3$. The sample carried various bias currents and the current distribution in the longitudinal direction was affected in the distance smaller than 100 μm. Abraimov *et al*. [6] used low temperature laser scanning microscopy and magneto-optical imaging to study the influence of transverse defects and showed the existence of flux flow channels with electric fields well above those used in the definition of the critical current (I_c).

In this work, we studied the effect on I-V curves and critical currents caused by artificial linear defects oriented perpendicular to the current flow. Using a sequence of voltage taps we also measured the distribution of the electric field in the vicinity of the defect to determine how far from the defect the field is distorted and whether the reduction of the I_c is proportional to the size of the defect. We also measured the magnetic field in the vicinity of the defects due to magnetization currents induced in the tape by ramping up and down an applied magnetic field.

II. Experimental

To study the influence of defects we used YBCO coated conductors manufactured by SuperPower, Inc. Sample 1 was made from a 12×90 mm^2 tape stabilized by a 20 μm thick electroplated copper layer. Transverse defects of various lengths (1.9 mm, 3.5 mm, 5 mm and 7 mm) were successively made in the tape center using a micro-drill. Several potential taps were attached to the tape at various distances from the defect. Figure 1 shows Sample 1 with a 7 mm long defect and



	mm
L1-2	7.36
L1-3	8.25
L1-4	8.80
L1-5	9.40
L1-6	9.82
L1-7	10.62
L1-8	11.13
L1-9	11.68
L1-10	12.10
L1-11	13.04
L1-12	20.06

Fig. 1. Microphotograph of Sample 1 with the transverse defect 7 mm long and the 6 pairs of the potential taps (taps 1-6 on the left side, 7-12 on the right side of the defect). The table shows the distances between the taps.

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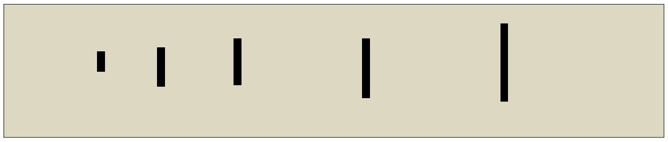

Fig. 2. A sketch of Sample 2 with the 5 artificial defects made by laser cutting. The tape width is 10 mm, the length is 65 mm.

the 12 potential taps. As a note, the location of potential taps changed for the different lengths of the defect as the taps were reapplied several times.

Sample 2 (Fig. 2) was a 10×65 mm^2 tape, covered by a 3 μm thick layer of Ag. Five artificial defects (cuts 1 mm, 2 mm, 3 mm, 4 mm and 5 mm long) were made using laser ablation. The width of each cut was about 0.01 mm.

Sample 3 was a 4 mm wide YBCO coated conductor covered by a ~ 3 μm thick silver layer. A defect 1 mm long in the tape center oriented perpendicular to the tape axis was made by micro-drill. A pair of potential taps distanced by 19 mm was attached to the tape with the defect between them. Results and Discussion

A. I-V Curves and Critical Currents

For Sample 1, we measured the I-V curves between the reference tap 1 and tap 2, 1 and 3, 1 and 4, etc., up to 1 and 12 for each of the defect lengths. As an example, in Fig. 3 we show the I-V curves measured for Sample 1 with the 3.5 mm long defect. From these measurements we obtained the profiles of the potential drop V_{1_n} as a function of distance from the reference tap 1, L_{1_n}. In Figs. 4 (a-c) the profiles V_{1_n} are shown for different lengths of defects and at several values of current. As depicted, the voltage rapidly changes only in close proximity to the defect. This indicates that the electric field is strongly localized around the defect. The difference in the voltages measured, for the 7 mm defect of Fig. 1, between taps 6 & 7 (0.65 mm apart) and taps 1 & 12 (20 mm apart) is very small.

As a consequence, the usual criterion for critical current I_c - the magnitude of the *average electric field* between the voltage taps - is not applicable to the situation where I_c is determined by a localized defect. Another empirical criterion needs to be chosen. As the data in Figs. 4 indicate, the potential drop across the defect, or its derivations such as resistance r(I)= V/I,
can be an objective criterion defining I_c, because it is independent of the distance between the voltage taps. The critical current I_c defined by the new criterion in the area around a defect has to be related to the critical current I_c^0 in the undamaged sections of the same conductor. The latter is determined by the commonly accepted criterion of the electric field $E_0 = 1\mu V / cm$, according to the relationship:

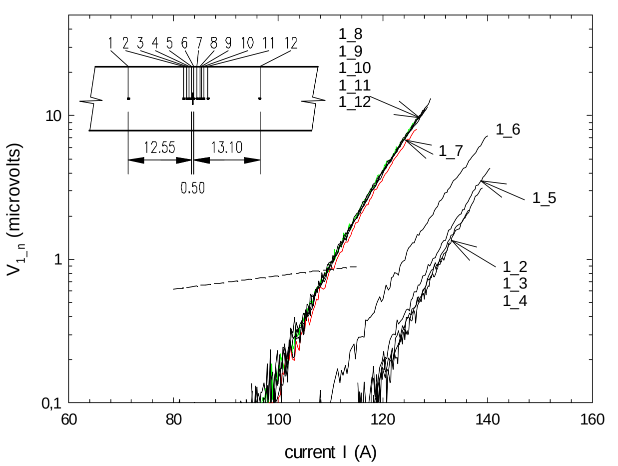

Fig. 3. I-V curves measured between the reference tap 1 and other taps (see inset) in Sample 1 with defect 3.5 mm long in external magnetic field of 74 mT. The dashed line corresponds to the relationship (5), $V=r_0I$. The intersection point determines the critical current of the damaged section.

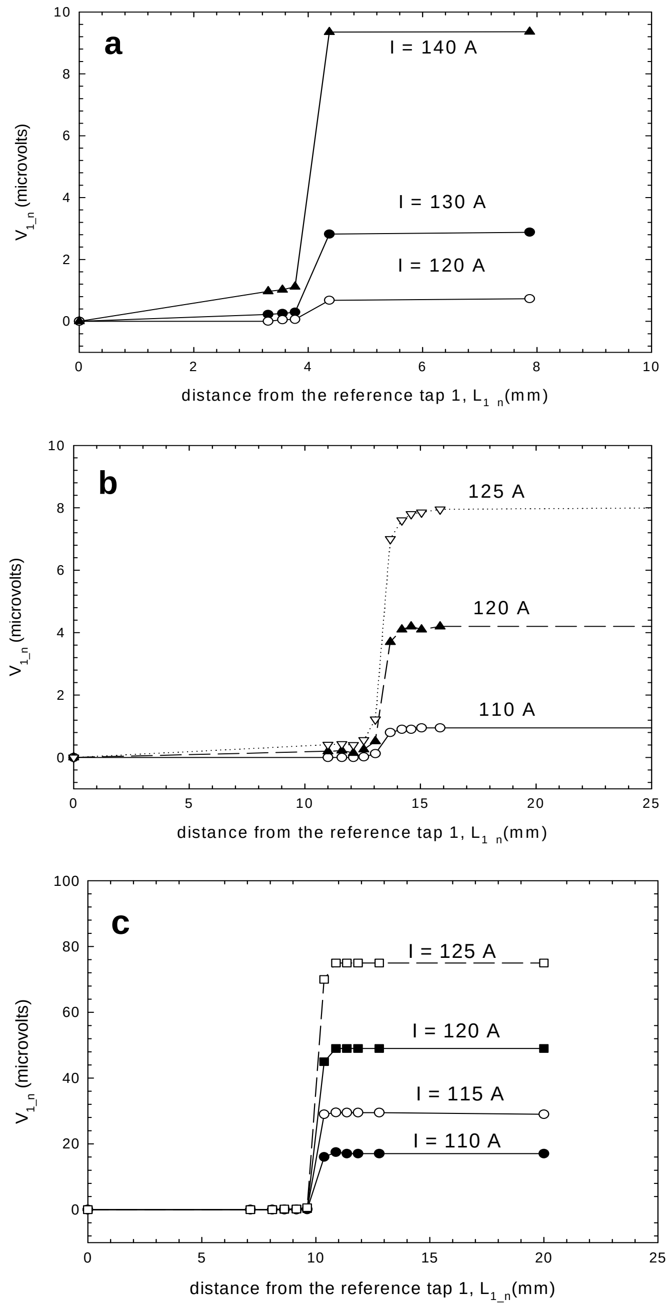

Fig. 4. The voltages measured for Sample 1 between Reference Tap 1 and other taps vs. the distance from Tap 1, L_{1_n}, measured at the different currents indicated in the figures where Sample 1 has a defect length of: a) 1.9 mm long (only 6 potential taps were used in this measurement) b) 3.5 mm long, and c) 5 mm long.