Di.S.Co.L.I. sensor for local magnetic field mapping

E. Mezzetti1, R. Gerbaldo1, G. Ghigo1, L. Gozzelino1, F. Laviano1, G. Lopardo1, B. Minetti1, R. Cherubini2, S. Gerardi2

1 Politecnico di Torino and INFN, Torino, 2 INFN, Laboratori Nazionali di Legnaro

INTRODUCTION

As it is well known, when a transport current is applied to a homogeneous superconductor in the flux-flow state, vortex energy overcomes the pinning potential of crystal defects and vortices move due to the Lorentz force and generate a transverse electric field along the transport current direction. When the transport current is applied to the sample with a microscale modulated nanostructuring by means of high-energy heavy-ion lithography, it turns out that the critical state pattern is affected [1, 2]. At low magnetic field vortices are still strongly focused on the interface regions, as demonstrated in the magneto-optical imaging (MOI) measurements under the transport current presented in the past LNL annual report [3]. At higher magnetic field vortices occupy the whole nanostructured regions, leaving the electromagnetic properties of the virgin regions unchanged. In both cases the nanostructured region presents magneto-resistive local properties which detect the electrodynamical status of the local environment. In this paper we present a targeted summary of next milestones as well as updated results coming out from previous steps.

EXPERIMENTAL SET-UP

Thin films of high temperature superconducting YBa2Cu3O7−x (YBCO) were grown by thermal coevaporation on yttria stabilized zirconia (YSZ) substrates with a 40 nm thick CeO2 buffer layer. The critical current density sets over 3x1011 Am−2 at T=4.2 K, for the chosen film thickness of 300 nm (Tc onset is around 88.5 K). Strip-shaped YBCO samples (width ranging from 20 to 1000 μm), obtained by UV photolithography and wet etching, were irradiated with 0.25 GeV Au ions at the LNL-INFN Tandem accelerator facility. The high-energy heavy-ion (HEHI) beam was collimated by means of laser-cut stainless-steel masks of 150 μm thickness, with one or more micrometric slits lateral aperture ranging from 30 to 300 μm, in order to produce a microscale modulated region inside the virgin part of the superconductor, as depicted in the scheme of Fig. 1(a). 0.25 GeV Au ions produce well correlated columnar defects in the superconducting film, and afterwards they implant in the YSZ substrate around a depth of 13 μm (estimated by means of SRIM simulations). The structural analysis performed by atomic force microscopy has shown that such local irradiation causes a nanometric step across the interface between pristine and irradiated regions (Fig. 1(b)). The defect density is finely tuned by the HEHI fluence, as monitored by the online measurement of the HEHI beam current onto the sample holder.

RESULT SUMMARY

i) We used the HEHI irradiation collimated on microscale areas (Fig. 1) to produce finely controlled modulations of the superconducting properties without destroying the superconductivity in the material (Fig. 2).

ii) We observed that microscale modulations made by means of local HEHI irradiation across continuous superconductors generate interfaces where focusing of the energy dissipation, induced by vortices occurs also under current transport (Fig. 3).

iii) We demonstrated by magneto-resistive measurements that such tailored modulation of the superconducting properties acts as a local magnetic field sensing unit (Table 1) [1].

![FIG. 1](image-url)

Our approach was finally applied to develop planar arrays of local magnetic field detectors: they at last are exploiting the performance of the high-temperature superconducting materials in a fully planar and single-
compound device (Fig. 4). The radiation hardness of this device is under investigation [4].

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FIG. 2: Transverse channel carved by 0.25 GeV Au-ions into a virgin strip-shaped YBCO film. The increased vortex density is shown. \(\mu_0H_{app}=29.5\) mT. Brighter colors correspond to higher magnetic flux density, while the black zones inside the sample correspond to regions where the shielding Meissner currents still flow. Current streamlines are also shown [5].

FIG. 3: Magneto-optical images of a strip-shaped YBCO film with a 70 \(\mu\)m wide irradiated region. The images were taken after zero field cooling, at a temperature of 70 K and in an applied field of 50 Oe directed perpendicular to the film plane. In (a) no external bias current was injected, while in (b) a constant external bias current of 50 mA was applied. Ion fluence was \(5.0 \times 10^{11} \text{ ion cm}^{-2}\). The bias current causes the shift of the critical state flux front and a Meissner-zone deformation which is higher in the irradiated channel.

FIG. 4: Arrays of local magnetic field detectors (superconducting YBCO film shaped as a meander).

TABLE 1 – Di.S.Co.L.I. magnetic field detector characteristics of the single bit.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>low magnetic field range, (B=0)÷0.2 T: (1.6 \text{ m}\Omega/\text{Oe} (\phi = 2 \times 10^{11} \text{ ion/cm}^2)); high magnetic field range, (B) up to 4.1T: (0.4 \text{ m}\Omega/\text{Oe} (\phi = 10^{11} \text{ ion/cm}^2))</td>
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<tr>
<td>Spatial Resolution</td>
<td>&lt; 70 (\mu)m down-scalable with dedicated technology</td>
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<tr>
<td>Time Response</td>
<td>&lt; 10 ns (on 100 (\mu)m wide strip – downscalable of one order of magnitude in dependence on the strip width scalability)</td>
</tr>
<tr>
<td>Radiation hardness</td>
<td>(&gt; 2 \times 10^{13} \text{ protons/cm}^2) (proton energy: 3.5 MeV)</td>
</tr>
<tr>
<td>Saturation field</td>
<td>(&gt; 4)T</td>
</tr>
<tr>
<td>Cryogenic environment</td>
<td>(&gt; 77)K</td>
</tr>
<tr>
<td>Electrical power consumption</td>
<td>(&lt; 1 \text{ nW/} \Omega)</td>
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