3RD Year Report- Michela Iebole

Study of the irradiation effects on superconducting films of Iron Based Superconductors.

Abstract:

My PhD thesis is inserted in the Project 4 of the JRC Fusion "High Tc superconductors for magnetic confinement fusion: development of materials and production processes" within the Joint Research Agreement between CNR and Eni. The partners of this Project are Eni itself, and the two CNR Institutes SPIN (Genova and Salerno) and IMM (Catania). Moreover, a significant part of my project has been carried out in collaboration with the PRIN project HIBISCUS (PI Marina Putti).

The magnetic fields needed for applications such as nuclear fusion plants are in the range between 8 T and 20 T. In such conditions, superconducting materials are needed in order to build magnets for plasma confinement. Magnets developed and manufactured for nuclear fusion up to now are in Nb-Ti and Nb3Sn, but there are materials which can be better candidates for these applications such as the High temperature superconductors like REBCO, which show better performances in field, but are very complicated to be manufactured as conductors in long lengths. One of the main difficulties is due to the fact that REBCO needs to be grown epitaxial in order not to suffer from weak link grain boundaries which limit the current flow. Therefore, REBCO wires must be fabricated as coated conductors, i.e. highly textured, biaxially aligned films deposited on a metal tape substrates covered with suitable buffer layers.

Iron Based Superconductors (IBS) since their discovery in 2008 have grown to become a new class of high magnetic field superconductors. At low temperature, their upper critical fields are high, proving that they are very promising for fusion magnets. Although not yet considered "technological" conductors, the investment in terms of research worldwide on IBS is large. IBS are semi-metallic materials with transition temperatures up to 55K. The combination of extremely high upper critical fields, moderate anisotropies and high critical field, makes this class of superconductors particularly appealing for high-field applications. Moreover, they are less sensitive to grain boundaries and therefore they can be grown as coated conductors on less textured substrates and with architectures and buffer layers much simpler than those required by REBCO. There are different IBS families, each deriving from a common parent material. FeSe (so-called 11 family) is very interesting because it is the only not containing arsenic, and it has the simplest structure. FeSe has a critical field up to 50 T and a critical temperature of 9K, but an enhancement of the T_C was observed with the substitution of Te for Se, for which the T_C increased up to 75%, while 21 K can be reached upon strain induced by substrates.

The aim of my project is to improve the growth of FeSeTe thin films, to be able to grow this phase on coated conductors with superconducting properties appealing for conductors for fusion applications. Inside a fusion plant, our material would be subjected to many particles radiation, so an important stage of this study is to understand how irradiation affects the phase. As we could imagine, a too high dose of radiation will ruin its superconducting properties, but, actually, radiation could bring some positive effects too, creating defects that can increase the upper critical field and pin the flux lines, that allows to reach higher critical current density J_C. Although many irradiation experiments on IBS single crystal have been reported, only few studies report on the effects of irradiations in thin films: a complete understanding of the effects of irradiation with different particles and energies is foreseen.

Activities carried out in the third year:

- During the first and second year I optimized the growth of FeSeTe thin films via PLD on different substrates, starting from single crystals (such as CaF_2, $SrTiO_3$, $LaAlO_3$, MgO...), moving to single crystals with a chemical CZO buffer layer, aiming the deposition on an oriented metallic substrate with a chemical buffer layer. Several samples, either with and without buffer layers, were irradiated with different particles (protons, Au ions, neutrons). I participated to the irradiation experiment on neutrons and protons. I characterized the superconducting properties with transport and magnetic measurements.
- During the third year, I optimized the growth of FeSeTe thin films on metallic substrates with chemical buffer layer, obtaining a superconducting samples series which has been characterized in terms of transport properties;
- In order to better understand the role of the CZO buffer layer for obtaining the superconductivity, we implemented XPS analysis on different samples, with and without the superconducting film deposited, and in that case, with superconducting and non-superconducting samples.
- We irradiated several samples (both on single crystal and on single crystal with buffer layer) with Au ions, with different doses, in order to find a link between the irradiation dose and the change in the properties. We found that the effect of the heavy ion irradiation is strongly substrate-dependent: pure single crystal as CAF and STO do not present an improvement in the properties, while single crystal with buffer layer present an improvement in critical current density after irradiation;

- We started irradiation experiment with 3.5 MeV protons also on films deposited on metallic templates: this work is on going;
- I was awarded with a Fellowship at Shibaura Institute of Technology in Tokyo, where I spent 3 months. At SIT I learned to use the Spark Plasma Sintering (SPS), a technique that allows to make very dense bulks, starting from the powder of the phase, to make targets for PLD;
- I fabricated targets of the FeSeTe phase with the SPS, either pure and, in order to improve pinning in the phase, with different doping. In particular, one doped with 4% wt. $BaZro_3$ and one with 2% wt. of carbon nanopearls. I characterized such targets with SEM, XRD and magnetic measurements;
- Using the targets made with SPS, I deposited thin films on CaF_2 single crystal, which I'm characterizing now through transport and magnetic measurements.

Supervisors:

- Valeria BRACCINI (CNR-SPIN)
- Marina PUTTI (Università degli Studi di Genova)

Publications:

- A Traverso, A Leveratto, A Angrisani Armenio, G De Marzi, G Celentano**, M Iebole** and A Malagoli "*Study of the Rutherford cabling process effects on Bi2212 round wires through the analysis of the mechanical deformation behaviour*", Submitted to: Superconductor Science and Technology
- G. Grimaldi, M. R. Khan, A. Leob, M. Scuderi, F. Rizzo, A. Augieri, G. Celentano, A. Galluzzi, **M. Iebole**, M. Polichetti, A. Nigro, V. Braccini "*The Iron-Based Fe(Se,Te) Can Mimic High Temperature Superconductors*", Submitted to Advanced Functional Materials
- L. Piperno, A. Vannozzi, A. Augieri, A. Masi, A. Mancini, A. Rufoloni, G. Celentano, V. Braccini, M. Cialone, **M. Iebole**, N. Manca, A. Martinelli, M. Meinero, M. Putti, A. Meledin "*High-performance Fe(Se,Te) films on chemical CeO2-based buffer layers: understanding the role of the seed layer*", Scientific Report, (2023) 13:569
- D. Torsello, M. Fracasso, R. Gerbaldo, G. Ghigo, F.Laviano, A. Napolitano, **M. Iebole**, M. Cialone, N. Manca, V. Braccini, A. Leo, G. Grimaldi, A. Vannozzi, G. Celentano, E. Silva, M. Putti and L. Gozzelino *"Proton irradiation effects on the superconducting properties of Fe(Se,Te) thin films",* IEEE Transactions of Applied Superconductivity 32 (2022) 7500105
- L. Piperno, A. Vannozzi, V. Pinto, A. Augieri, A. Angisani Armenio, F. Rizzo, A. Mancini, A. Rufoloni, G. Celentano, V. Braccini, M. Cialone, **M. Iebole**, N. Manca, A. Martinelli, M. Putti, G. Sotgiu, A. Meledin *"Chemical CeO2-based buffer layers for Fe(Se,Te) films"*, IEEE Transactions of Applied Superconductivity 32 (2022) 7300205

Courses attended:

1ST Year

- Design of Superconducting Magnets
- Applied Cryogenics
- Technology of wires, tapes and superconducting cables
- Microscopic and spectroscopic techniques for the analysis of surface and interfaces.

2ND Year

- Nanophotonics and Nanofabbrication;
- Advanced Crystallography: theory and experiments.

Conferences / Workshops attended:

- I participated as a speaker in the roundtable "SCIENCE: WHERE MAGIC HAPPENS" organized by Ulisseus European University on 11 February 2022, on the International Day of Women and Girls in Science.
- I participated to the yearly Workshop of the Eni-CNR JRA (June 28-29, 2022) and presented the activity of the Project 4 of the JRC Fusion.
- I partecipated at ASC2022 Applied Superconductivity Conference in Honolulu (Hawaii). I presented a poster "Irradiation Effects on FeSeTe Thin Films Grown on Different Substrates" and a talk on "Nanoscale analysis and relationship with pinning properties in superconducting Fe(Se,Te) conductors".
- I participated to "PHD_DAYS", an event organized by ENI in Milano, presenting my PhD work.
- I participated at EUCAS2023 European Conference of Applied Superconductivity in Bologna, with an oral on "Synthesis and characterization of high-quality $BaZrO_3$-doped Fe(Se,Te) thin films".