2^{ND} 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 is 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 second year:

- My first year of PhD was mostly focused on improving the growth of FeSeTe thin films using Pulsed Laser Deposition, at CNR-SPIN laboratories. In particular, I focused on templates consisting of YSZ single crystal covered with Zr-doped CeO2 epitaxial films chemically grown in ENEA via chemical routes (i.e. metal-organic decomposition, MOD and Polymer-assisted deposition, PAD). During my second year I optimized the growth of FeSeTe thin films on such templates, in particular through the presence of a seed layer of the FeSeTe phase deposited on the CeO2 buffer layers. After such optimization, I focused on deposition on oriented metallic templates (as NiW) using Zr-doped CeO_2 epitaxial films, previously studied, as buffer layers.
- In parallel, in collaboration with the PRIN project HIBISCUS, I also worked at the optimization of the process (mechanical deformation + heat treatment process) to fabricate a biaxially textured home-made substrate starting from a NiFe alloy (namely, INVAR).
- I prepared several samples, in particular FeSeTe thin films grown on different substrates: single crystals (CaF_2, $SrTiO_3$, $LaAlO_3$, MgO) and on YSZ single crystal covered with Zr-doped CeO_2 buffer layer.
- Some of those samples, in collaboration with the PRIN project HIBISCUS, have been irradiated using heavy ions in two facilities: at the JAEA tandem acceleratorat Tokai in Japan with 320 MeV Au ions, and in “Laboratori Nazionali di

Legnaro-INFN" in Legnaro at Tandem accelerator with 250 MeV ions. The films were previously patterned through standard optical photolithography in order to have up to 9 Hall bar-shaped micro-bridges on each sample to allow selective irradiation with different fluences – i.e. 0.97, 1.94, 2.90, 3.87 10^{11} ions/cm^2 - and the measurement of the transport properties. In particular, I measured transport properties (i.e. resistivity, critical fields and critical current) in a PPMS system up to 9 T and some samples were measured up to 12 T in collaboration with the Salerno Research Unit of CNR-SPIN.

- In order to simulate the irradiation that may occur inside a Tokamak, I went to Frascati Neutron Generator, a facility that allowed us to irradiate some samples (FeSeTe on single crystal CaF_2 and YSZ single crystal with Zr-doped CeO2) with 14.1 MeV neutrons and fluences of 0.4, 0.8 and 1.2 10^{14} n/cm^2. Also for this series of irradiated samples, I am carrying out transport measurement at low temperatures, in magnetic field. Moreover, a magnetic characterization is being carried out at ENEA with VSM.
- In order to be able to test the critical temperature of the various films without bonding wires on the surface, we developed a new measurement system, which is totally non-invasive. Using a little coil, we put a superconducting sample in a very small magnetic field. Then, we cool the sample down and we acquire the 3rd harmonic signal. As a result, we will be able to see a signal only when our sample is in the superconducting state. Using that system, we can understand superconducting properties of samples, such as critical temperature, and also to estimate the quality of our films, without touching (and so ruining) the sample's surface.
- In order to better understand the irradiation effects, and also the role of the substrate in our samples, I collected some of the irradiated films and series of films on different substrates and carried out structural analysis at BESSY II synchrotron in Berlin, using the very focused beam to make a spatial resolute analysis of the patterned samples.

Supervisors:

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

Publications:

- L. Pipern, 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*", under revision in Scientific Reports (August 2022).
- 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:

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

I have taken the exam either for the courses left last year, and for the courses of these year.

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.
- In October I will attend the ASC2022 Applied Superconductivity Conference in Honolulu (Hawaii). I will present 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"