1ST Year Report- Michela Iebole

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

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).

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 structur. 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

<u>Techniques learned and Experiments performed:</u>

- My first year of PhD was mostly focused on improving the growth of FeSeTe thin films using Pulsed Laser Deposition, at CNR-SPIN laboratories. This technique consists in positioning a substrate on a heater, and exciting a target (made of the interested phase) with a pulsed laser. The target, under excitation, releases atoms that re-arrange on the substrate. I grew up samples both on single crystal substrate - mainly CaF_2, which up to now gave the best results - and on single crystals covered with buffer layers. 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). This step was needed in order to understand the growth of FeSeTe on such buffer layers which will be then deposited on metallic oriented substrates.
- To evaluate the orientation of the phase on films, I performed XRD analysis in order to check the epitaxiality of the films, their in- or out-of-plane orientation and when possible the thickness.

- To understand the quality of the films, I measured resistance vs temperature to evaluate the critical temperature (which is for this phase around 16-18 K), and the sharpness of the transition. We gradually cool down the sample in a helium cryostat, and with a 4-wire measurement we record the resistance from room temperature to 4.2 K.
- In order to have a desired geometry on the films, selected samples were patterned through standard optical photolithography, and the etching was performed by water-cooled argon ion milling (with argon ion energy of 500 eV). After the milling process, the photoresist was removed with acetone at 50°C for a few tens of seconds and dried in nitrogen air. Hall bar-shaped micro-bridges 0.25x1 mm2 in size were realized, typically 9 per sample. Such patterns allow both selective irradiation (in the same sample we can evaluate the effects of different doses of irradiation) and a measurement of the critical current.
- I partecipated to irradiation of some of the films either on CaF_2 and on YSZ + CZO with 3.5 Mev protons at "Laboratori Nazionali di Legnaro-INFN" in Legnaro, in collaboration with Politecnico di Torino. In this collaboration some samples have been irradiated with 250 MeV gold ions as well.
- The irradiated patterns were then characterized in a PPMS system up to 9T in order to extract the upper critical field from R vs T curves at different fields, and the critical current density from the V vs I characteristics at different temperatures.

Supervisors:

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

Publications:

- 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*", submitted to IEEE Transactions of Applied Superconductivity (Sept. 2021)
- 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*", submitted to IEEE Transactions of Applied Superconductivity (Sept. 2021)

Course attended:

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

I have already taken the exam for "design of superconducting magnets", and I plan on taking "applied cryogenics" and "Microscopic and spectroscopic techniques for the analysis of surface and interfaces" in the end of September and "Technology of wires, tapes and superconducting cables" in October.

Conferences attended:

- Workshop on State-of-the-Art in High Field Accelerator Magnets, 14-16 April 2021
- EUCAS 2021, 5-9 September 2021