Improved Vortex Pinning and High Field Critical Current Density of Nb_3Sn Superconductor

Tarantini, C., Balachandran, S., Lee, P.J., Su, Y.F., Starch, W.L. (NHMFL-FSU); Kametani, F., Walker, B., Larbalestier, D.C. (NHMFL and FSU, College of Engineering)

Introduction

R&D superconducting Nb_3Sn wires were fabricated at the Applied Superconductivity Center employing new in-house fabricated alloys, in order to investigate the feasibility of wires with enhanced high field properties for future accelerator magnets for the proposed Future Circular Collider (FCC), as well as US-Magnet Development Program (MDP) projects. The target non-Cu critical current density, $J_{c,}$ at 4.2 K, 16 T for FCC is 1500 A/mm^2, value far out of sight of any prior Nb_3Sn conductor. Previous experiments used Nb-Zr precursor rods surrounded by SnO_2, which generates ZrO_2 precipitates in the reacted Nb_3Sn that act as pinning centers. However, the use of Zr leads to a suppression of the irreversibility field H_{Irr}. Here we show results obtained with 2 new ternary alloys, Nb4Ta1Zr and Nb4Ta1Hf, and compare them to the commercially used Nb4Ta (typical $\mu_0 H_{Irr}$=23.2 T with F_p maximum at $\mu_0 H_{Max}$=4.7 T). Ta-doping increases H_{Irr} whereas Zr or Hf are intended to enhance pinning force density F_p.

Experimental

The samples were measured by VSM in the DC facility at NHMFL in the 35 T magnet in the temperature range between 14 and 1.3 K. From the hysteresis loops, we obtained the layer J_c and the pinning force density, F_p.

Results and Discussion

Fig.1 compares the layer F_p curves obtained at 4.2 K while **Fig.2** reports the temperature dependence of H_{Irr}. We observed that adding SnO_2 is detrimental to the (standard) Nb4Ta sample, whereas it clearly increases the F_p maximum, shifting the F_p peak to 5.3 T for the Nb4Ta1Zr alloy. However, the Nb4Ta1Zr+SnO_2 sample has a reduced H_{Irr} (20.9 T at 4.2 K) that limits the J_c improvement at 16 T. To our surprise, the most striking results were obtained with Nb4Ta1Hf; with or without SnO_2 the F_p maximum is more than twice that obtained with the Nb4Ta alloy, reaching more than 150 GN/m^3. Because for Hf additions, H_{Irr}(4.2 K) is 23.1-23.6 T, the J_c(16T) values are not suppressed with respect to commercial wires and H_{Irr} is actually enhanced when SnO_2 is not used. The net result is that J_c(16T) more than doubles, achieving the hitherto thought impossible FCC target.

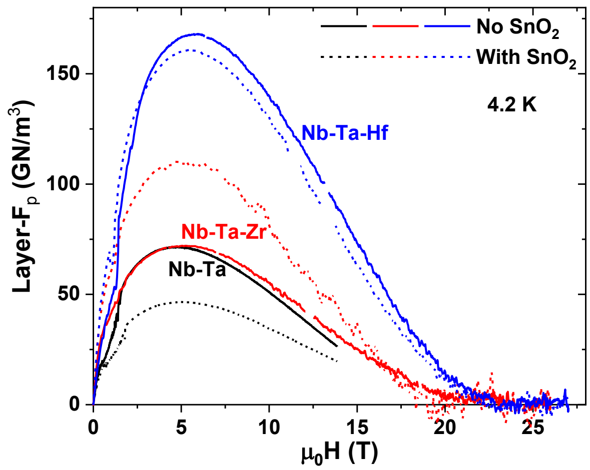

Fig.1 F_p curves for a in-house quaternary Nb_3Sn wires showing a significant F_p enhancement for wires made with Nb-Ta-Zr and Nb-Ta-Hf alloys instead of the standard Nb-Ta.

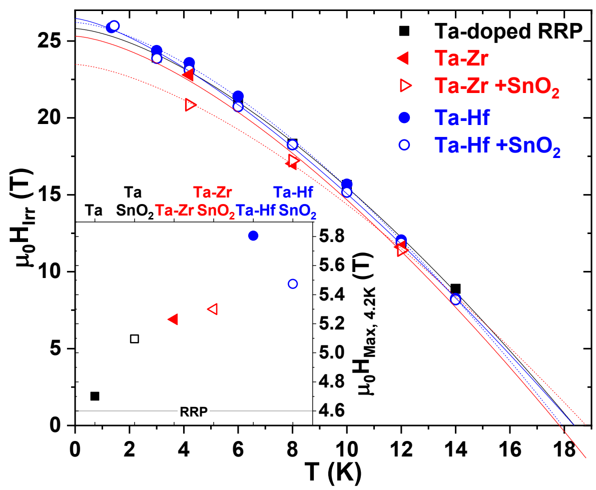

Fig.2 Temperature dependence of H_{Irr} of the wires prepared with new alloys compared to a commercial state-of-the-art RRP wire. In the inset the position of the F_p maximum for all home-made wires.

Conclusions

These findings for the Nb-Ta-Hf alloyed Nb_3Sn wires demonstrate that Nb_3Sn conductor performance can be greatly improved. We believe that this new alloy can easily be implemented into commercial wires without the difficulty of incorporating SnO_2. We estimate that a conventional (RRP®) wire using Nb-Ta-Hf alloy could attain a non-Cu J_c(16 T, 4.2 K) of over 2200 A/mm^2, well above FCC specification.

Acknowledgements

The National High Magnetic Field Laboratory is supported by the National Science Foundation through NSF/DMR-1157490/1644779 and the State of Florida. This work is funded by the U.S. Department of Energy, Office of Science, and Office of High Energy Physics under Award Number DE-SC0012083, and performed under the purview of the US-Magnet Development Program of the Office of High Energy Physics.

References

[1] Balachandran, S., *et al.*, arXiv: 1811.08867 (2018).