Formation and Growth of Oxide Nanoparticles During Nb-Sn Diffusion and Implications for Flux Pinning and Critical Current in APC Nb_3Sn

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***Abstract*—To meet the need for superconductors with higher values of critical current density in order to build the next generation of particle accelerators, internally oxidized Nb_3Sn wires have been developed. These 'APC' wires are made according to a modified powder-in-tube process, by which a Nb-Ta-Zr tube is filled with a mixture of Cu, Sn, and SnO_2 powders. Upon heat treatment, Nb_3Sn is formed by diffusion, while ZrO_2 precipitates in the form of particles a few nanometers in size. These non-superconducting particles are of such a size and spacing as to add an additional point-based flux pinning mechanism, working in addition to the grain-boundary based flux pinning already seen in all Nb_3Sn conductors. Optimization of the wire recipe has given these conductors a non-Cu critical current density ($J_{non\text{-}Cu}$) exceeding CERN's specification for the Future Circular Collider (FCC). In addition, replacing the Zr with Hf to form instead HfO_2 has also been shown to enhance flux pinning and J_c. However, the precise mechanism of the formation and growth of the oxide nanoparticles is not fully understood. Herein we investigate the thermodynamic and kinetic driving forces driving the formation of new ZrO_2 and HfO_2 particles, their growth behavior over time, and their effect on the movement of Nb_3Sn grain boundaries during heat treatment. The implications of the size and number density of nanoparticles on flux pinning and critical current density are discussed.**

***Keywords (Index Terms)*—Nb_3Sn, internal oxidation, nucleation, diffusion, flux pinning**

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