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James Tufnail
Rebecca Nicholls[1], Chris Smith[2], Chris Grovenor[1], Susannah Speller[1]
[1]Department of Materials, University of Oxford, 16 Parks Rd, OX1 3PH, Oxford, UK
[2]United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, OX14 3DB, UK

james.tufnail@materials.ox.ac.uk

Evidence for Cu-O chain breaking in ion-irradiated high temperature superconductors for magnetic confinement fusion

Compact tokamak concepts, to achieve magnetically confined nuclear fusion, are facilitated by the use of rare-earth barium copper oxide (REBCO) superconducting coated conductors (CC) for their magnets. REBCO offers a comparatively high transition temperature (T_c), upper critical field (B_{c2}), and current carrying ability in high fields relative to conventional Nb_3Sn or Nb-Ti [1]. However, a drawback of compact tokamak designs is the reduced space available for neutron shielding, exposing the magnets to larger high-energy neutron and gamma fluxes than in less compact reactor designs [2]. Radiation damage produces a combination of nanometre cascades and point defects, particularly in the Cu-O chain anion sites [3], [4]. This leads to a degradation in the critical parameters of the materials and consequently its performance [5]. Raman spectroscopy is an underutilized method to investigate the local disorder in irradiated REBCO. Historical experimental and ab-initio computational work on thin films and bulks has proven the effectiveness in identifying the characteristic REBCO modes, as well as specific defects and impurity phases [6], [7], [8].

Irradiation damage in REBCO primarily produces two types of oxygen sub-lattice damage: displacement of oxygen from the O1 chain site [9], [10], and formation of Frenkel pairs in the CuO_2 planes [11]. In this work, evidence for the irradiation-induced breaking of Cu1-O1 chains in REBCO is shown for the first-time using Raman spectroscopy. Experimental Raman spectra of pristine 2 MeV He^+ ion-proxy irradiated samples from commercial CC manufacturers are presented, and modelling with the ab-initio density-functional theory code CASTEP is used to identify the modes. Additional spectra of lab-grown pulsed laser deposition REBCO thin films are presented in their pristine state, following a 300 keV He^+ ion irradiation to damage levels that completely suppressed superconductivity, and following a post-irradiation oxygen anneal. The spectra changed significantly by broadening, hardening, and softening of specific peaks. Most interestingly, the oxygen sublattice is seen to change during this process, showing an increase in the relative intensity of the Cu1-O1 chain mode following irradiation, indicating a breaking of the Cu-O chains, which are essential to the transfer of superconducting charge carriers to the CuO_2 superconducting planes. A 24-hour O_2 anneal appeared to replenish the oxygen in the chains, indicated by the disappearance of the defect chain modes. Meanwhile the cation lattice appears unchanged following the anneal. This work supports previous studies that show the displacement of O1 site oxygens to be a key factor in the degradation of superconducting performance.

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