

ELECTROCHEMICAL TANTALUM-DOPED PIEZOELECTRIC POLYMER–CERAMIC COMPOSITES FOR EXTREME-COLD GEOPHYSICAL ROBOTIC SENSING

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Abstract

Piezoelectric sensors are well established in research, but commercial piezoelectric composites suffer electromechanical performance loss in cryogenic environments. Such material failures arise from oxygen-vacancy migration, depolarization, and mechanical failure or microcracking. Piezoelectric manufacturing for Arctic robotic sensing technologies presents a feasible solution for integration with sensing segments in Arctic robotics if the underlying material is doped with donor-type metal ions that produce cold-stable oxygen-vacancy structures, defect-engineering these composites into microstructures controlled distinctly for electromechanical performance for deployment without failure. The electrochemical doping of tantalum into the composite's ceramic phase will enhance its low-temperature (-40°C) fracture toughness. This improvement occurs as the large ionic radius of Ta induces compressive lattice strain, and its high charge state creates oxygen vacancies for charge compensation. These vacancies are predicted to pin ferroelectric domain walls, thereby impeding microcrack propagation and creating measurable increases in mechanical resilience compared to baseline undoped samples. Ultimately, controlled by electrochemical doping, these engineered composites have chemical and physical characteristics at a microstructural level suitable for direct integration into Arctic robotic geophysical exploration and sensing systems, with robust resistance to failure and degradation.