

PhD Dissertation Defense Announcement
Mechanical and Aerospace Engineering Department
University of Texas at Arlington

Reliability Assessment of Power Modules & Thermal Interface Materials in
Single-Phase Immersion Cooling Environment: Thermal, Electrical and
Materials Degradation Analysis

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Abstract

The escalating thermal demands of data center IT systems, driven by artificial intelligence, high-performance computing, and parallel processing, have rendered conventional air-cooling solutions increasingly inadequate. Single-phase liquid immersion cooling (SPLIC) has emerged as an innovative strategy, offering superior heat dissipation by submerging entire server assemblies in dielectric fluids. Despite its promise, the adoption of immersion cooling necessitates a comprehensive assessment of the reliability and performance of critical power electronics and materials under prolonged exposure to immersion environments. This dissertation systematically investigates the thermal, electrical, and reliability characteristics of power modules and associated packaging materials subjected to single-phase immersion cooling. The research comprises four core chapters. First, baseline thermal and electrical performance of power modules is established through benchmarking and in-situ testing across a suite of immersion fluids, supplemented by extended thermal aging to gauge long-term operational impacts. Second, a high temperature operating life (HTOL) study subjects power modules to 1000-hour cycling in immersion conditions, monitoring for electrical and thermal degradation that could impede large-scale data center deployment. Third, through dynamic and thermogravimetric analyses, the thermal and mechanical integrity of molded and unmolded substrates is compared after exposure to both air and immersion fluids, with results affirming the enhanced modulus retention of molded substrates but highlighting the persistent vulnerability to fluid-induced property shifts. Fourth, the dissertation addresses a critical gap in the literature by quantifying the degradation behavior of two immersion-compatible thermal interface materials (TIMs) during extensive power cycling within immersion environments, elucidating trends in thermal resistance and long-term reliability. Taken together, these studies provide a multiscale perspective on the performance and durability of power electronics and thermal interface solutions in immersion-cooled data centers. The findings advance fundamental understanding of component and material stability, serving as a pivotal reference for the safe and reliable deployment of immersion cooling technologies in next-generation high-density computing infrastructure.