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C3Po1E-03: Design and fabrication of CPA salt pill for adiabatic demagnetization refrigerator

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As interest in quantum-related research continues to grow, so does the demand for ultra-low temperatures below 1 K. Cooling systems designed to achieve such ultra-low temperatures include Dilution Refrigerators (DR), Pulse-Tube cryocoolers with Joule-Thomson modules (PT-JT), and Adiabatic Demagnetization Refrigerators (ADR). Unlike DR and PT-JT systems, ADRs do not rely on fluids but instead utilize the magnetocaloric effect of paramagnetic salts. This approach offers advantages such as miniaturization and high efficiency due to the absence of mechanical moving parts. A critical component of ADRs, the salt pill, significantly influences system performance, with its design, fabrication process, and the material properties of the salt playing key roles. Chromium Potassium Alum (CPA), a representative magnetocaloric material for ADR, has a Curie temperature of approximately 9 mK. However, due to its low thermal conductivity at ultra-low temperatures, a dedicated thermal bus and a sealed cylinder for vacuum environment stability are required. Copper wires used as thermal buses are subject to eddy current losses in varying magnetic field environments. To reduce such losses, multiple thin wires are employed, providing the required heat transfer area while effectively minimizing eddy current losses.

This study presents the design of a single-stage ADR capable of achieving ultra-low temperatures below 100 mK, as well as the design and fabrication process of a CPA salt pill. The single-stage ADR was designed to reach temperatures below 100 mK by exchanging heat with the second stage of a two-stage 4 K cryocooler. The specifications of the CPA salt pill were determined based on the ADR cooling cycle, and its performance was evaluated using FEM analysis. Subsequently, a fabrication method for the CPA salt pill was proposed, and basic evaluations were conducted. The results of this study are expected to provide foundational data for the development of multi-stage continuous ADR (cADR) systems.

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