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C3Or2D-03: Investigation of helium gas-gap heat switch for the cryogen-free dilution refrigerator

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The cryogen-free dilution refrigerator operating in the millikelvin temperature region has the advantages of no magnetic field interference, high reliability and long-term stability, which play an important role in providing the desirable cryogenic environment for the quantum computing. A cryogen-free dilution refrigerator generally operates over a broad range of temperatures, yet the large temperature difference between the precooling stage and the dilution unit may lead to serious heat leakage which would severely lower the cooling rate of cryogenic components. The gas-gap heat switches (GGHS) featuring high conductance and high switching ratio can control the thermal conductance between stages in the refrigerator and then accelerate the precooling. Furthermore, the GGHS can be designed without any moving part and thus significantly simplify the operation.

This paper presents the design of a passive GGHS which consists of multiple inter-leaved fins made of low-emissivity gold-plated coppers. The ON state is realized by introducing Helium into a gap between two conductors to provide the high thermal transfer, while the OFF state is achieved by removing the exchanging gas helium. An analysis model is established to optimize the switch geometry and discuss the effect of the cross section of fins. The switches with rectangular and triangular fins are modeled separately to value the thermal conductance, and the simulated results show that both switches can achieve the ratio of "on" to "off" conductance of greater than 10^4.

The experiments are then conducted to verify the theoretical analyses. It is found that the cross section of fins slightly affects the witching ratio, while narrowing the gas gap or enlarging the surface areas can greatly improve the switch heat transfer. The important parameters such as switching times and thermalization of the sorption pump are also focused on. A good agreement between theoretical analyses and experimental results are observed.

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