Experimental study on single-stage adiabatic demagnetization refrigerator (ADR) with Chromium Potassium Alum (CPA)

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1.Abstract

As an excellent paramagnetic material with low magnetic ordering temperature, CPA is often used in the ADR to achieve extremely low temperature. A typical ADR consists of many components, such as a salt pill, a superconducting magnet, a heat switch, etc. An experimental system was built to test the performance of a designed single-stage ADR. It used a two-stage GM refrigerator to provide ADR with a low-temperature environment of less than 4 K. A superfluid helium bath was connected to the ADR, and they were controlled by a mechanical heat switch to turn on and off. A superconducting power supply is used to magnetize and demagnetize the crystal. In the experiment, CPA salt pill can be pre-cooled to 1.35 K by a superfluid helium bath. Applying a 1 T magnetic field, the single-stage ADR can obtain a lowest temperature of 318.5 mK.

2.Cryogenic system

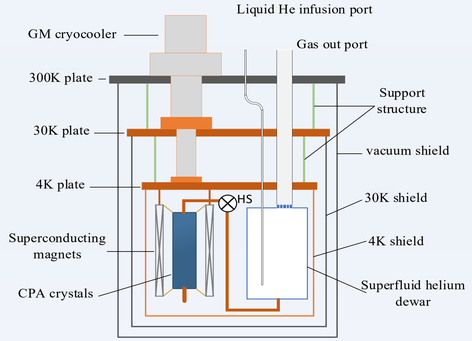

Fig.1 The schematic diagram of the cryogenic system

3.Pre-cooling stage

A superfluid helium bath was designed to pre-cool ADR. Superfluid helium has a creeping film effect. It leads to difficulty in obtaining lower temperature by reducing the pressure. This cold bath uses small pore structure to suppress the creeping film effect. Then, the results obtained by the decompression method are basically consistent with the standard saturated vapor pressure of helium-4.

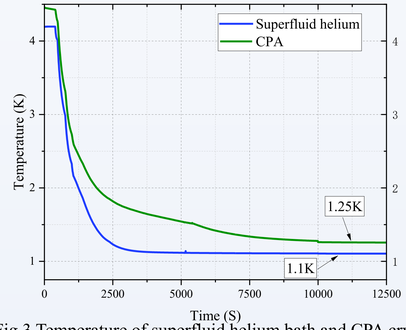

Fig.3 Temperature of superfluid helium bath and CPA crystal

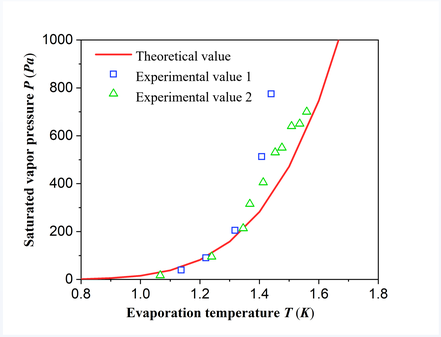

Fig.2 Curve of saturated vapor pressure to evaporation temperature of helium-4

The CPA can be gradually pre-cooled to 1.25K after turn on the heat switch. Demagnetization usually begins when the CPA is cooled to 1.35 K to reduce the experiment time. The temperature of the superfluid helium bath is stable at 1.1 K. The temperature difference between them is due to the heat leakage of the heat switch and thermal resistance.

4.ADR stage

Here mainly introduce the salt pill of ADR. It contains CPA crystals and thermal bus. The thermal bus is composed of oxygen free copper wires interspersed in parallel between the two plates, and the ends are vacuum-brazing with the copper rods. The function of the thermal bus is to reduce the temperature gradient of the CPA crystal. A cylindrical wall made of FRP material encloses the thermal bus inside. There are slits in the cylindrical sidewall that are used to allow the solution to flow into it when CPA crystals are grown. After completing the growth of CPA crystals, seal the seam with epoxy resin glue to prevent it from losing water and thus losing its cooling capacity.

5.Results

Turn on the heat switch and start magnetizing. Due to the heat of magnetization, the temperature of the CPA rises at this part. The superfluid helium bath absorbs this heat. After the magnetization is completed, the CPA is gradually cooled down to the bath temperature. Then turn off the heat switch to start demagnetization. The whole process is shown in the Fig. 4. The lowest achievable temperature is 318.5mK. Fig. 5 shows the temperature change of CPA after the lowest temperature is reached. An increase in temperature means there is a leakage heat, estimated to be an average of 40 μW. Through analysis, this part of the leakage heat may mainly come from the vibration of the GM cryocooler.

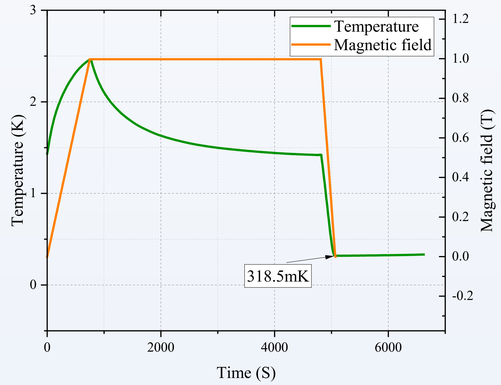

Fig.4 Temperature changes in CPA during magnetization and demagnetization

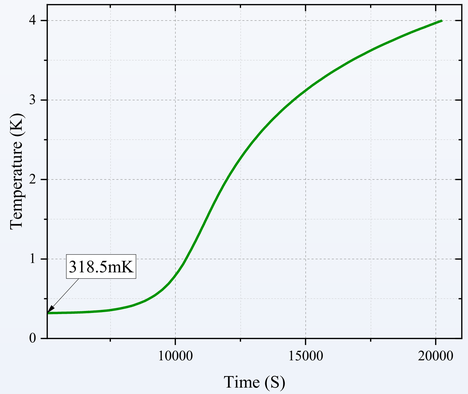

Fig.5 CPA temperature changes with time after the end of the demagnetization

6.Conclusion

This paper designs a single-stage ADR and uses CPA as the paramagnetic salt. An experimental system is set up for testing. It includes a 1.1 K superfluid helium bath that can pre-cool CPA to 1.35 K. The preliminary experimental results show that CPA can cool down to 318.5 mK from 1 T demagnetization. Parasitic losses caused by vibration in cryogenic system, especially GM cryocooler, affect the holding time of ADR. In the future, the vibration absorption optimization of the cryogenic system will be carried out.

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