Experimental progress of a 4K VM/PT hybrid cryocooler for pre-cooling 1K sorption cooler

Changzhao Pan[1], Tong Zhang[1, 2], Jue Wang[1, 2], Liubiao Chen[1,2], Jia Guo[1], Yuan Zhou[1,2] , Junjie Wang[1, 2, *]

1 CAS Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing, 100049, China

2 University of Chinese Academy of Sciences, Beijing, 100049, China

C2PoK-04

panchangzhao@mail.ipc.ac.cn

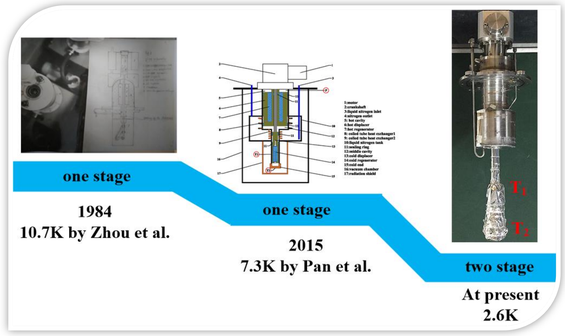
Abstract

Sub-kelvin refrigerator has many applications in space detector and manned space station, such as for the transition-edge superconducting (TES) bolometers operated in the 50 mK range. In order to meet the requirement of space applications, the high efficient, vibration free and high stability refrigerator need to be designed. VM/PT hybrid cryocooler is a new type cryocooler capable of attaining temperature below 4K. As a low frequency Stirling type cryocooler, it has the advantages of high stability and high efficiency. Combined with the vibration free sorption cooler and ADR refrigerator, a novel sub-kelvin cooling chain can be designed for the TES bolometer. This paper presents the recent experimental progress of the 4K VM/PT hybrid cryocooler in our laboratory. By optimizing of regenerators, phase shifters and heat exchangers, a lowest temperature of 3K was attained. Based on this cryocooler, a preliminary sorption cooler could be designed.

Structural parameters

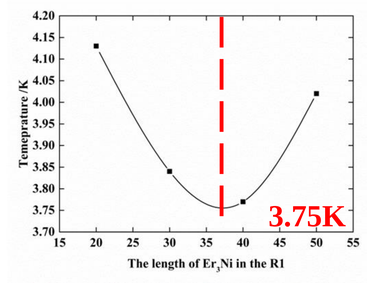
Components	Parameters
displacer	Diameter of 26 mm, length of 190 mm, stroke distance of 20 mm
regenerator	Diameter of 23.6 mm, length of 125 mm, layer 1 filling 45 mm200# SS with porosity of 70.7%, layer 2 filling 50 mm Lead sphere(diameter of 0.4–0.45 mm) with porosity of 36%, layer 3 filling 30 mm Er_3Ni sphere(diameter of 0.4–0.45 mm) with porosity of 36%
Regenerator	Annular structure, inner diameter of 8.9 mm, outer diameter of 18 mm, layer 1 filling 30mm Er_3Ni sphere (diameter of 0.2–0.25 mm) with porosity of 36%, layer 2 filling 40mm $HoCu_2$ sphere (diameter of 0.2–0.25 mm) with porosity of 36%,
Pulse tube	Diameter of 8.5 mm, length of 70 mm
Capillary tubes	0.4 mm*80 mm + 0.8 mm*0.2 m, connecting PTC hot end and cold reservoir
Reservoir	Volume of 1 L

HISTORY

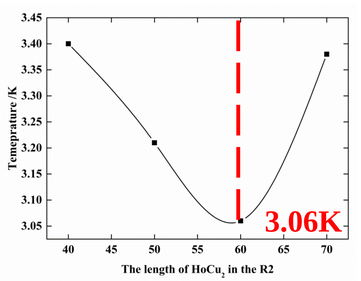


- 1987：**10.7K** —lead sphere
- 2015: **7.35K** —rare earth material
- 2016: **4.4K** —VM/PT hybrid
- 2017: **2.6K** —VM/PT hybrid

REGENERATOR



The lowest temperature appeared its optimal value at the 40mm length of Er_3Ni



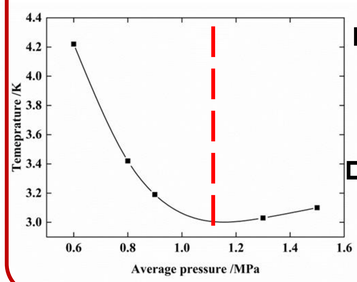
The lowest temperature appeared its optimal value at the 60mm length of HoCu2.

PHASE SHIFTER

Case	Parameters /mm	T1 /K	T2 /K	Opt. Frequency
1#	Φ0.4*200+Φ0.8*200	4.68	15.0	1.06
2#	Φ0.4*150+Φ0.8*200	4.55	15.8	1.38
3#	Φ0.4*120+Φ0.8*200	**4.21**	16.3	1.53
4#	Φ0.4*100+Φ0.8*200	4.41	18.0	1.61

- **The temperature of the first stage would decrease but the temperature of the second stage had its optimal value because of the performance of regenerator**
- **The optimal operating frequency was influenced by the resistance of capillary tubes. With the increasing of the resistance of capillary tube, the optimal operating frequency would decrease**

AVERAGE PRESSURE



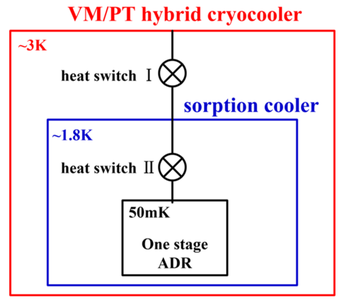
- **The average pressure decreased with the cooling**
- **The optimal operating pressure was about 1.2MPa**

FURTURE DEVELOPMENT

- **By optimizing the diameter of $HoCu_2$, a lowest temperature of 2.6K has been obtained!**

Cooling chain for TES

- **Optimization of the regenerator or using the Helium-3 to hit the lower temperature for directly precooling the ADR.**
- **Based on the present experimental results, combining with a sorption cooler to precool the ADR**



This work was supported by the National Key Research and Development Program of China (No. 2016YFB0901403) and Postdoctoral Innovation Talent Support Program of China (Foundation No. BX201600173)