An optical cryostat for use in Microscopy cooled by Stirling-type pulse tube cryocooler

Chen Liubiao[1], Zhou Qiang[1,2], Zhu Xiaoshuang[1,2], Zhou Yuan[1] , Wang Junjie[1,*]

[1]Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, CAS, Beijing 100190, China

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

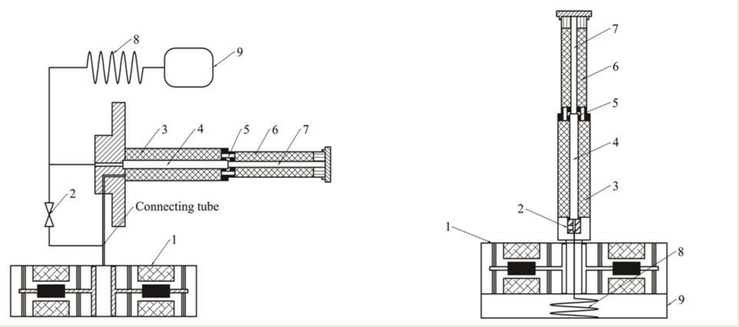
Technical Institute of Physics and Chemistry, CAS

Introduction

➢At present, the cryogenic environment needed for microscopy is generally provided by two ways, the first one is by cryogens, and the second one is by cryocoolers.
➢The application of cryogens has many advantages in low vibrations and low noise, but it's operate process is relative more tedious; in some places, liquid nitrogen, especially liquid helium, is not easily available.
➢The application of cryocoolers for microscopy, usually G-M cryocooler or G-M type pulse tube cryocooler, can reduce the operating difficulties, but there are also some disadvantages for cryocooler-based microscopes, such as the vibrations, noise, and long-term stability.
➢In this paper, an optical cryostat for use in microscopy cooled by a Stirling-type pulse tube cryocooler will be introduced. the main advantages of SPTC are small sizes, low noise and vibrations, reduced electric powers etc.

Configuration design

➢The developed optical cryostat for use in microscopy is cooled by SPTC. The most remarkable feature of pulse tube cryocooler is that there are no moving parts in the cold head. For the absence of moving parts in low temperature, PTC has the advantages of low vibration and long-life..
➢The pressure wave is generated by a dual-opposed linear compressor, which can reduce the vibration significantly.
➢For simplification and compactness, single-stage configuration with coaxial arrangement was employed.
➢In the process of SPTC development, two kinds of configuration have been developed, one is named as the separating type, whose compressor and pulse tube are connected by a connecting tube, and the other one is named as the integrated type, whose compressor and pulse tube are coupled together.
➢The cold head orientation of PTC has a very obvious effect on the cooling performance. The performance will be much deteriorated when it is tipped with the pulse tube's cold end above its hot end due to natural convection. The no-load temperature will be 5-10 K higher when it is tipped with the pulse tube's cold end above its hot end.
➢In order to arrange the cold head down, the integrated type will be not applicable because of the structure limitations of the microscopy. However, the integrated type generally achieves a little better performance than that of the separating one. In the process of development, an integrated type SPTC has been reconstructed to the separating one, and the no-load temperature increased from15.9 K to17.0 K
➢The separating type has been employed.

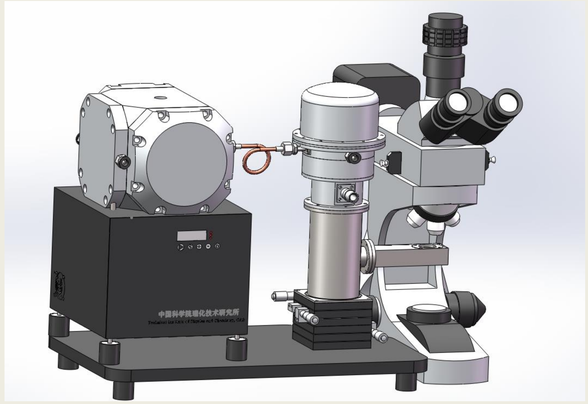


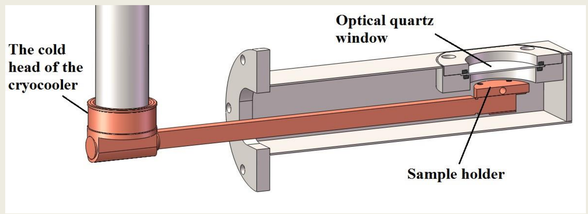
Schematic of the two types of the developed SPTCs. 1: linear compressor; 2: double-inlet; 3: regenerator I; 4: pulse tube I; 5: multi-bypass; 6: regenerator II; 7: pulse tube II

Vibration reduction

➢ The main vibration source of the SPTC is the compressor. The vibration of the PTC is so low that has little effect on the observation.
➢Two ways to reduce the vibration. One is to install the vibration isolation system between the sample platform and cold head of the cooler. The other one is to install the vibration isolation system between compressor and the PTC
➢As to the first way, for example, to employ a flexible connection by copper pigtail, the heat transfer difference and the heat loss from the support are inevitable. However, compared to G-M type PTC, the cooling power of the developed SPTC is much smaller. The typical cooling power is about 300mW/20K with the input electric power 240 W; it is important to reduce the heat loss. The first way is not applicable when very low temperature is required.
➢As to the second way, it is very convenient by using the separating type SPTC. However, the sizes of the flexible connection tube between the compressor and the PTC also have some effect on the cooling performance. The no-load temperature increased from 17.0 K to 17.3 K when the length of connection tube extended from 15 cm to 25 cm while the same diameter of 4 mm is employed.
➢ At present, when connected the compressor and the PTC with a 25 cm copper tube, there is still a little vibration at the position of the sample holder, so the length and the kinds of connection tube should be optimized further.

CAD view of the microscopy

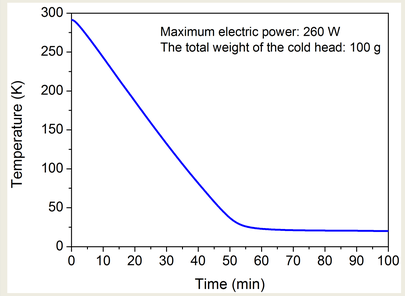




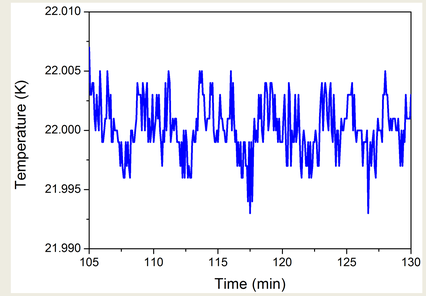
The connection of the sample holder and the cold head of the SPTC

Temperature control

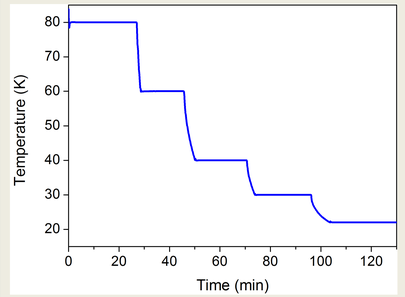
➢The general temperature control method for cryocooler is to directly control the DC electric power of the heater through PID (proportion, integral and derivative) adjustor control; the cryocooler is still running at full capacity during the whole process of the temperature control.
➢As to the developed SPTC, we control the temperature of the cold head by adjusting the input electric power to the compressor. Different temperatures can be approached by adjusting the input: a lower temperature needs a higher voltage and vice versa.
➢The cryocooler will not be required to keep running at full capacity during the whole process of the temperature control, it is energy-efficient and it contributed to long life.
➢The temperature fluctuation can be controlled at ±10 mK.



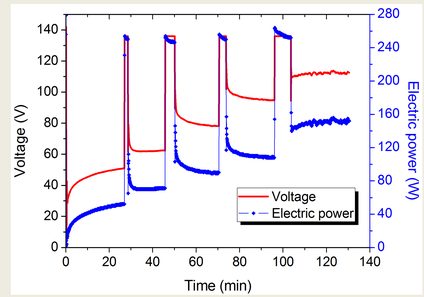
Cooling curve



A detail temperature control curve



Temperature control curve at different temperature



The corresponding voltage and electric power with different set temperature

Conclusions

An optical cryostat for use in optical microscopy cooled by stirling-type pulse tube cryocooler has been designed, built and tested. In order to lower the vibration, the separated configuration was adopted; its compressor and pulse tube are connected with a flexible connecting tube. At present, a lowest temperature of 20 K could be achieved. The temperature fluctuations can be controlled at ±10 mK by adjusting the input electric power to the compressor.

Acknowledgements

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