Materials for damping the PTC-induced thermal fluctuations of the cold-head

I. Catarino[1], D. Martins[1], R. Sudiwala[2]

1. Departamento de Física, Faculdade de Ciências e Technologia, Universidade Nova de Lisboa, 2829-516 Monte de Caparica, Portugal
2. School of Physics and Astronomy, Cardiff University, 5 The Parade, Cardiff, CF243AA, UK

Background

The 4 K cooling using regenerative cryocoolers is very attractive when compared to the liquid helium bath. Intrinsically to their use of thermodynamic cycles, there are oscillations associated to some extent, both thermal and mechanical.

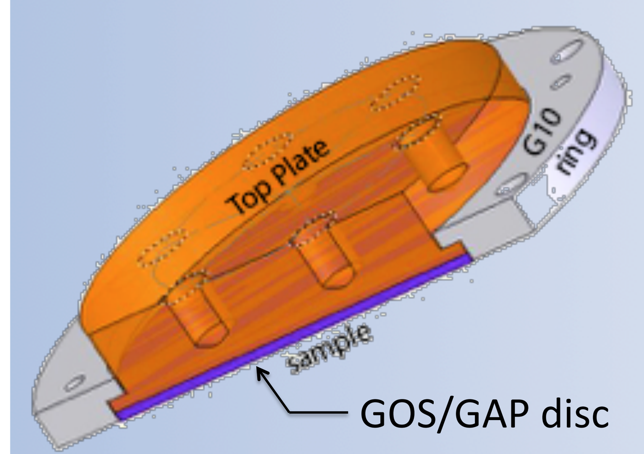
Pulse Tube Cryocoolers (PTC) having no moving parts at low temperature significantly reduce the mechanical issue, but not the thermal one. Typically thermal fluctuations at a level of 200 mK peak-to-peak at 1.4 Hz for a Cryomech Model PT405 cooler running at 4 K, are still present at the cold-head. Two materials, GOS and GAP, acting as low-pass thermal filters over the temperature range 3 K to 6 K, are used toattenuate the thermal fluctuations at a level of x0.1 at 0.01 Hz with a clean side temperature of 4 K.

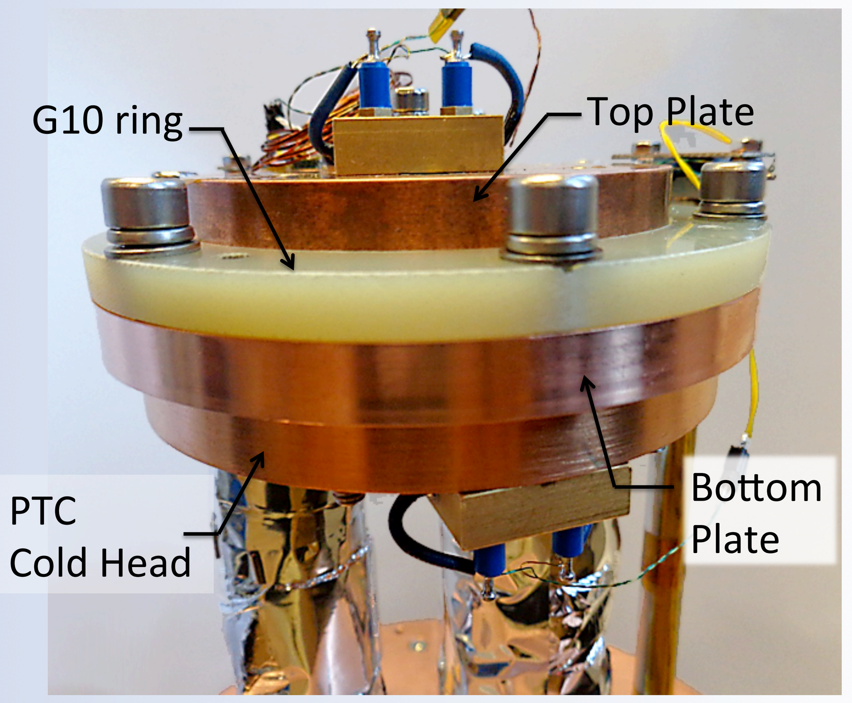
Objectives

- Measurement of the thermal attenuation levels using GOS and GAP discs at 0.01 – 0.1 Hz for the temperature range of 3 K – 6 K.
- Modelling a low pass RC filter
- Infering the thermal conductivity and specific heat capacity for GOS and GAP materials.

Experimental Setup

The sample (GOS or GAP disc) is sandwiched between two copper Plates (Top and Bottom Plates) and compressed by a G10 ring. The Bottom Plate is bolted directly to the cold finger of a cryocooler (Cryomech PT405). The Sample to Plate interfaces have a smear of vacuum grease. The Bottom Plate to PTC Cold Head is a grease-free interface.

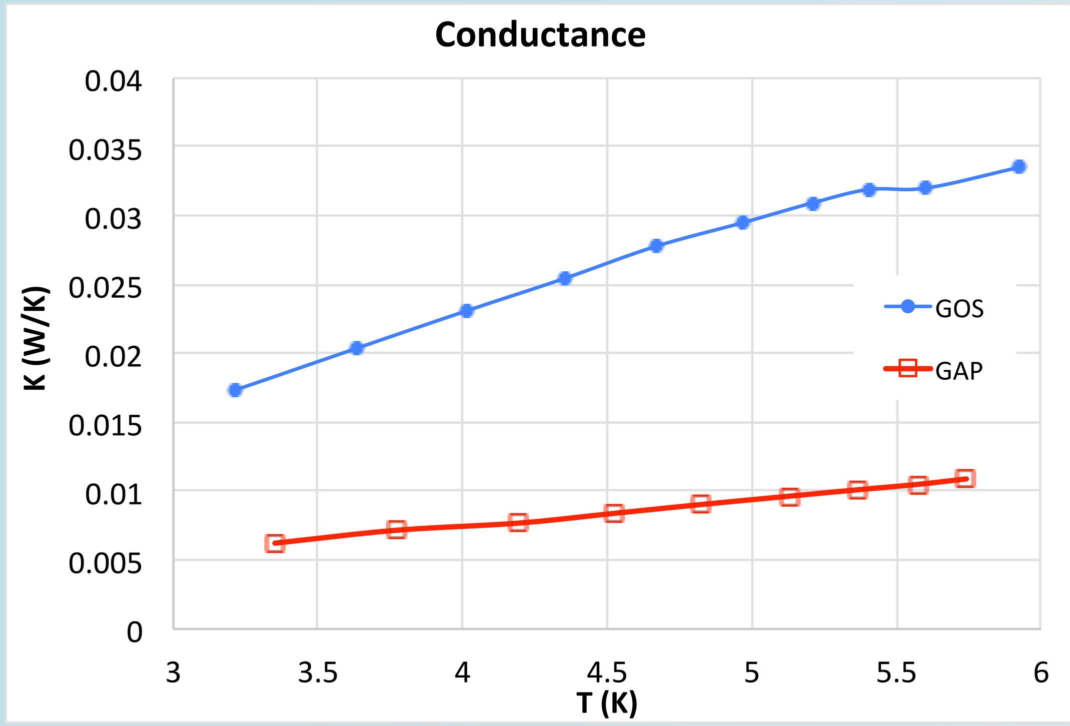




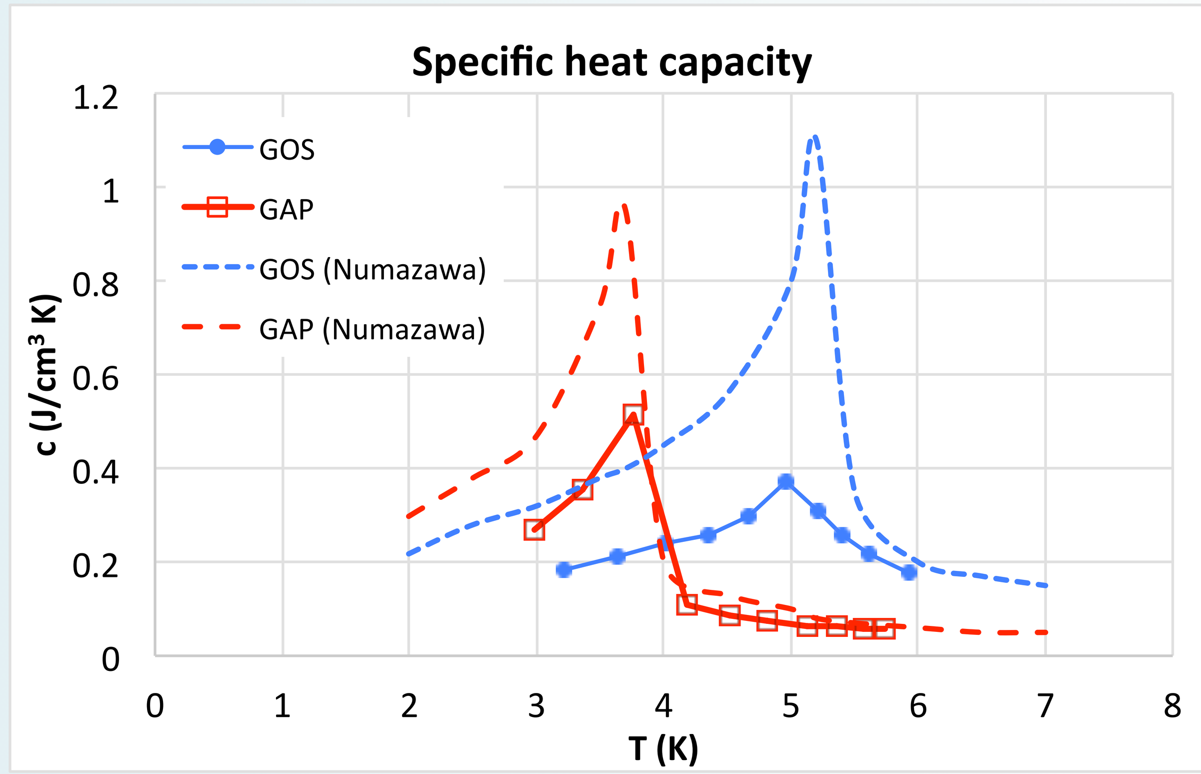
Sample Disc dimensions:
GAP: *t* =1.6 mm ∅75 mm
GOS: *t* =2.5 mm ∅75 mm

The effective thermal conductance is measured by applying a small power (0.02 W and 0.03 W) to the Top Plate and stepping the power in the Bottom Plate.
The frequency response of the thermometers is measured using the faster analog output port of the resistance bridge, while modulating the temperature of the bottom plate at a known frequency using the heater of the bottom plate.

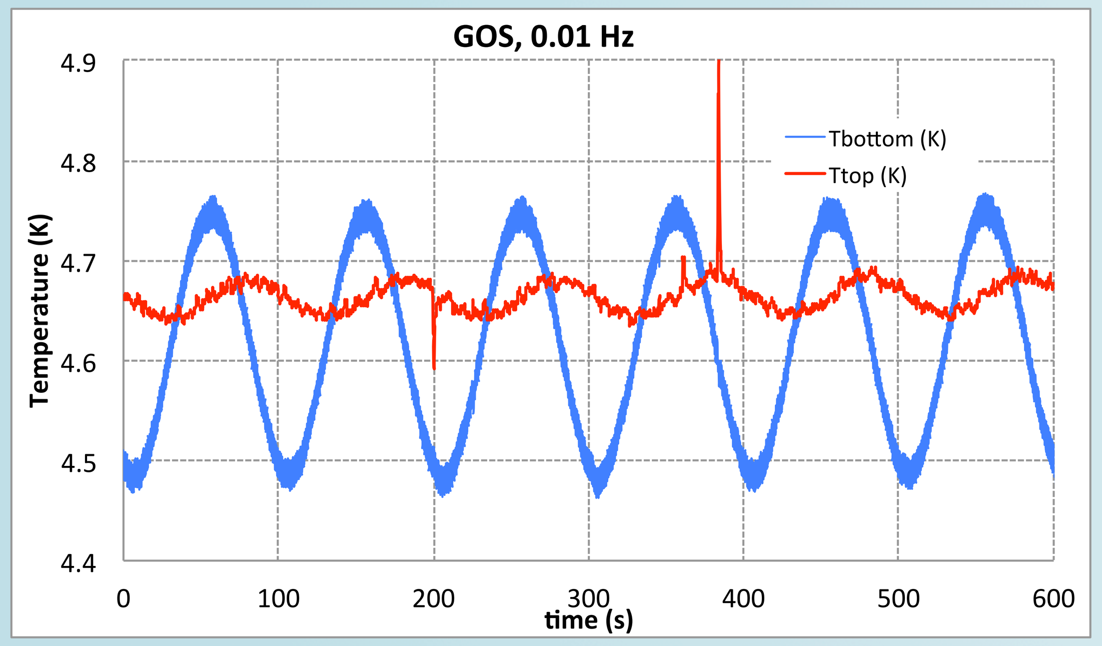
Experimental Results



Inferred conductance measured as the ratio of the applied power to the temperature difference between blocks. Turning this data into conductivity, with the geometry data for the discs, yields a two order of magnitude lower values when compared to the reference data [1].



Specific heat capacity for GOS and GAP materials obtained from cutoff frequency values and measured conductance, compared to the manufacturer data [1]. The reduction about one half of the expected values is assigned to the unavoible contact resistances.

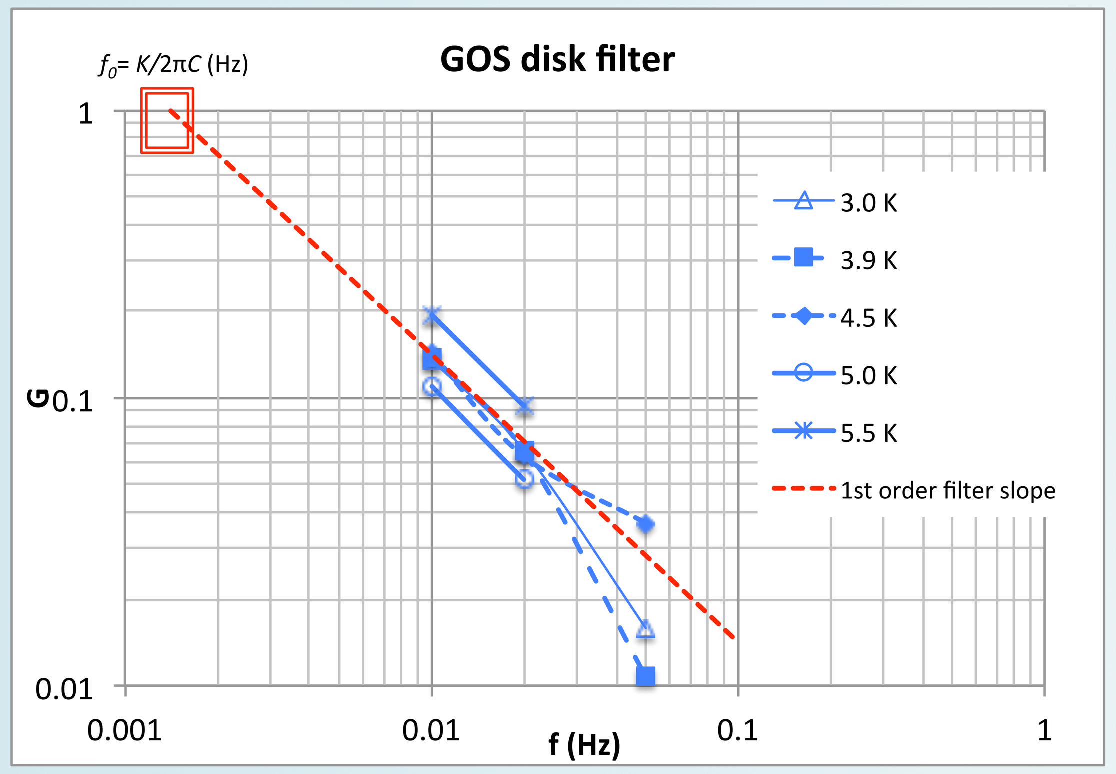


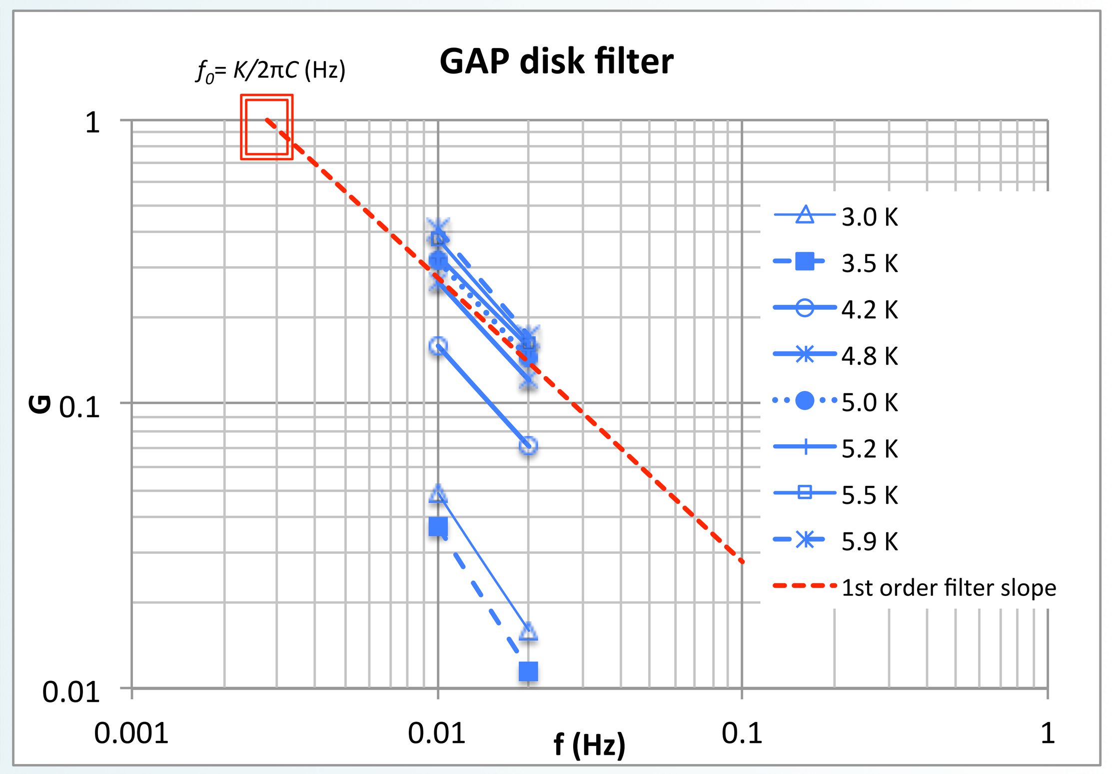
Example of Induced oscillating temperatures (0.01 Hz) logged on both sides of the assemblies.

T (K)	Cutoff frequency (Hz)	
	GAP	GOS
3	0.00048	0.00136
3.8	0.0003	0.00138
4.5	0.0023	0.00143
5	0.0033	0.0011
5.5	0.004	0.0019

Cutoff frequencies as fitted using the measured temperatures for the induced oscilation at 0.01 Hz, and used to infere the heat capacity.

Attenuation of the induced oscillations for GOS and GAP as a function of frequency in a Bode-type gain plot. The red dashed long line stresses out the expected slope for a first order filter – its fitting to each temperature points along with an extrapolation back to *G*=1 confirms the obtained cutoff frequency values.





In a single pole Butterworth filter: $\frac{T_{top}}{T_{bottom}} = \frac{1}{\sqrt{1+\left(\frac{f}{f_0}\right)^2}}$

[1] Numazawa T, Yanagitani T, Nozawa H, Ikeya Y, Li R, Satoh T. A New Ceramic Magnetic Regenerator Material for 4 K Cryocoolers. Boston, MA: Cryocoolers 12; 2003. pp. 473–81.

Conclusions

- The approximation to a first order Butherworth filter allows the assignment of a cutoff frequency and to infer the specific heat capacity.
- The disc geometry was designed to yield about 1W/K conductance at ~4 K but failed by two orders of magnitude. The conductance issue needs improvement, namely on the contact interfaces.
- The coupling of a thin disc of GOS or GAP materials to the cold end of a cryocooler brings several (>2) orders of magnitude reduction in the temperature oscillations induced by the normal operating frequencies of such machines (1.48 Hz).

This work was partially supported by:
PTDC/EMS- PRO/1065/2012

Presented at the Cryogenic Engineering Conference , 2015 June 28 – July 2, Tucson, Arizona