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# Narrow gas gap in cryogenic heat switch

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## HIGHLIGHTS

- We present a novel conception of a high-performance cryogenic heat switch with a very narrow gas gap.
- We propose a methodology for building such heat switch devices in a simple and sturdy assembly.
- The narrow gap was obtained by differential thermal expansion of the construction materials.
- The high conductance was measured with from 20 K (He) or 75 K ($N_2$) up to room temperature.
- The switch was characterized along its extreme conductance states matching an analytical model.

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## ABSTRACT

A gas gap heat switch reaches its high conductance state when the gap between two exchange surfaces is filled with a conducting gas. The broader the surface and the narrower the gap the higher the conductance achieved. In this paper we describe how to leverage the differential of the thermal expansion of construction materials to narrow the gas gap in a heat switch, while overcoming the intricacies of the manufacturing process of the switch.

We designed and evaluated a prototype of a narrow gap heat switch built using our new methodology. The high conductance was measured with both helium and nitrogen, and at temperatures ranging from 20 K (He) or 75 K ($N_2$) up to room temperature. The inferred gap opening at low temperature ($\approx 17$ μm) showed up to be slightly larger than expected, which allowed us to reinterpret the design calculations performed. Using a sorption pump the switch was also characterized along its extreme conductance states, and its performance was compared with a previously developed model.

As a proof of concept, we built a prototype and the results obtained in the testing phase support our claim that the design we propose allow the development of high-performance customized cryogenic switches while keeping the assembly very simple and sturdy, hence widening the scope of the applicability of these devices.



## 1. Introduction

A heat switch shall let the user choose between a high and a low heat conductance link between two sites. In cryogenics it is commonly integrated in several architectures, such as in redundant space cryocoolers [1]. The process of designing and building a heat switch makes use of a variety of material properties and construction techniques. The control of the gas pressure in a narrow gap between two immobile blocks leads to the so called gas gap heat switch [2]. A supporting shell encloses the gas in a definite volume and holds the blocks securely steady and apart (Fig. 1). The lowest heat conductance state ("OFF state") is obtained by pumping out the gas from the gap between the blocks. Because these blocks are hold by an enclosing shell, the conductance properties of this shell influences the performance of the switch. Hence the supporting shell should be a bad thermal conductor: long, thin and made in a weak conducting material such as stainless steel.

For a gas gap switch, the highest value of heat conductance ("ON state") is established by the gas conductivity in its viscous regime and by a high exchange surface to gap width ratio. The ON conductance obtained in a gas gap heat switch is essentially pressure independent: once the gas is in the viscous regime, i.e., with the mean free path ($\lambda$) much smaller that the gap width, the gas conductance in the gap reaches its highest value. When the gas is pumped out the mean free path increases and the conductance

*Abbreviation:* SSSS, stainless steel supporting shell.

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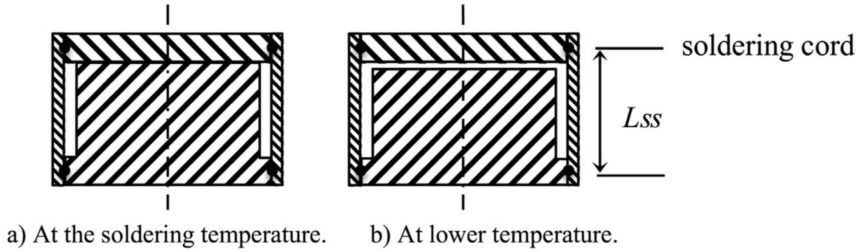


**Fig. 1.** Schema of the gas gap heat switch evidencing the gap opening between two conducting blocks held by a dissimilar supporting shell. The length $L_{ss}$ represents the distance between soldering cords and is the common length between the dissimilar materials at the soldering temperature: the inner blocks are touching face to face when the soldering is performed. The left schema represents the device at the high soldering temperature while the right schema depicts the gap opening at low temperature.

through the gas gap decreases. This decrease is linear with pressure if the molecular regime is reached [3]. The isolating supporting shell soon becomes a more efficient conducting path than the gas, hence defining the minimum of the switch overall conductance at low temperature. Hence the switch heat conductance is short-range pressure dependent and varies between two extreme values (ON and OFF).

Improving the high conductance characteristics of a narrow gap heat switch can be achieved either by choosing a higher thermal conductivity gas, or by using a higher exchange surface to gap width ratio, and both are challenging approaches. Helium is the most competitive exchange gas at cryogenic temperatures due to its high thermal conductivity, but in a sorption pumped device it might be inconvenient to be used in temperatures higher than about 15 K [4]. A switch with a large exchange surface may lead to an undesirably large and heavy device and/or to an intricate mechanical fabrication [5]. Narrowing the gap by mechanical construction is also a hard task and requires a quite delicate alignment assemblage.

In this work we explored a new idea for assembling the blocks of a cryogenic gas gap heat switch with a very narrow gap between them while keeping high the simplicity of its manufacture. The key insight is on leveraging the use of the differential thermal contraction of the building materials, such that when the switch is assembled the blocks are in physical contact and when the device is cooled down it opens a very narrow gap between the blocks.

Other authors have previously published on differential thermal expansion switches, but suggesting the physical contact [6,7] upon thermal actuation: cooling down one of the parts brings the two blocks in contact with each other. In our concept the differential thermal expansion leads to a low temperature gap opening that is to be filled with gas in order to promote the good thermal conduction state. Our approach obtains very narrow gaps and eliminates the need of complex fabrication [8].

This paper reports on the evaluation of the ON conductance characteristics of the built prototype, using both helium (20–270 K) and nitrogen (75–250 K) gases. The real opening of the gap between blocks was inferred from comparing our results to a simpler model and the original calculation is reinterpreted for matching the "measured" gap.

For the tests with nitrogen gas, a miniaturized sorption pump was attached to the switch so it could pump the gas in and out of the gap in order to produce the switch ON and OFF states. By cooling down the charcoal in the sorption pump the gas is adsorbed, emptying the gap space (OFF state). By heating it up, the gas is released to the gap space and the ON conductance is reached. Then, scanning the temperature of the sorption pump allows varying the gas pressure and assessing the whole conductance range of the switch. A scan of conductance measurement made at different gas filling conditions led to the wide characterization of the prototype as reported in this paper. This experimental characterization performed on the prototype switch is in good agreement with the results obtained by a previously validated model [9].

## 2. Experimental setup and results

The switch is composed of two blocks, each with one planar face in contact with the other while the device is at the "high" temperature in which the assembly process takes place. These two blocks are kept in place by soldering them to a stainless steel supporting shell (Figs. 1 and 2) and will naturally set apart upon cooling down the device if the materials are selected properly. The distance between the blocks once the device is cooled down is the gap width. The building of the supporting structure requires materials with poor heat conductivity and with a thermal expansion smaller than the highly conducting inner blocks. Stainless steel was found convenient for the supporting structure and copper for the blocks. Because these are non-expensive materials and can be easily joined by soldering, they were naturally chosen. The copper

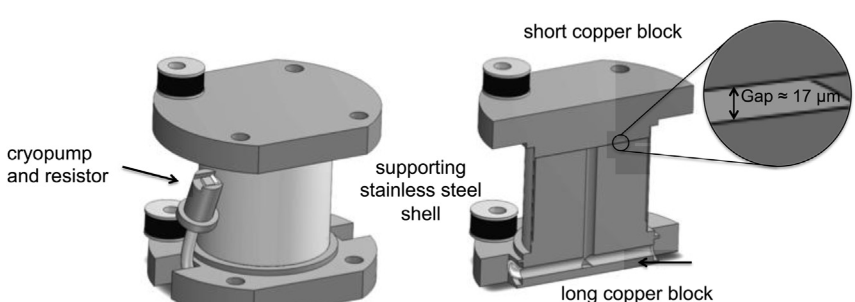


**Fig. 2.** The switch prototype as designed and built: the inner copper blocks contracting by cooling down more than the outer stainless steel supporting shell leads to a narrow gap opening between the blocks. Locations of the thermometers at the two copper blocks are indicated.