Hydrogen gas gap heat switch working in 150-400 K temperature range

J. Barreto[1], D. Martins[2] , M.B.C. Branco[2], J. Branco[3], A. Gonçalves[3], G. Bonfait[1]

CHMT 2019 – Enschede, The Netherlands
5th November 2019

[1] FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA
LIBPhys-UNL

[2] activespace technologies
making space a global endeavour

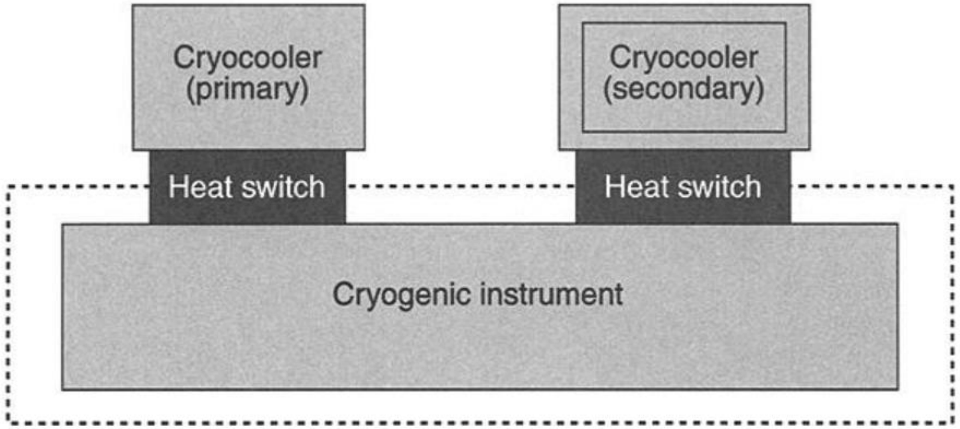
[3] C2TN
CENTRO DE CIÊNCIAS E TECNOLOGIAS NUCLEARES
TÉCNICO LISBOA

Overview

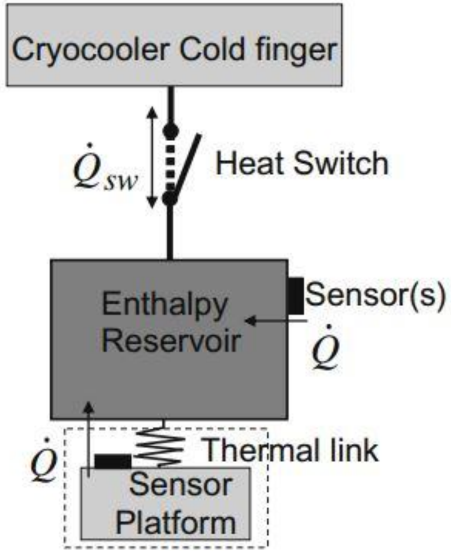
- Thermal heat switches
- Gas gap heat switch: working principle
  - Heat transfer in gases
  - Adsorption pump
  - Thermal model
- Hydrogen gas gap heat switch
  - Design
  - Sorbent characterization
  - Results
- Conclusions

Thermal heat switches

- Device with the ability to make or break a thermal contact between two ends.
- Heat switches are categorized by its physical mechanism:
  - Mechanical: usually the switching is obtained by a mechanical action (e.g. electromagnetic valve, differential CTE).
  - Fluid-loop: variation of a fluid’s flux in a closed loop
  - Gas-gap: Thermal switching is obtained by the presence or absence of gas in a narrow gap between two exchange surfaces.
- Gas-gap heat switch (GGHS) offers high reliability without any moving parts (very good for space applications).



Gilmore, David. 2002. Spacecraft Thermal Control Handbook. Vol I: Fundamental Technologies

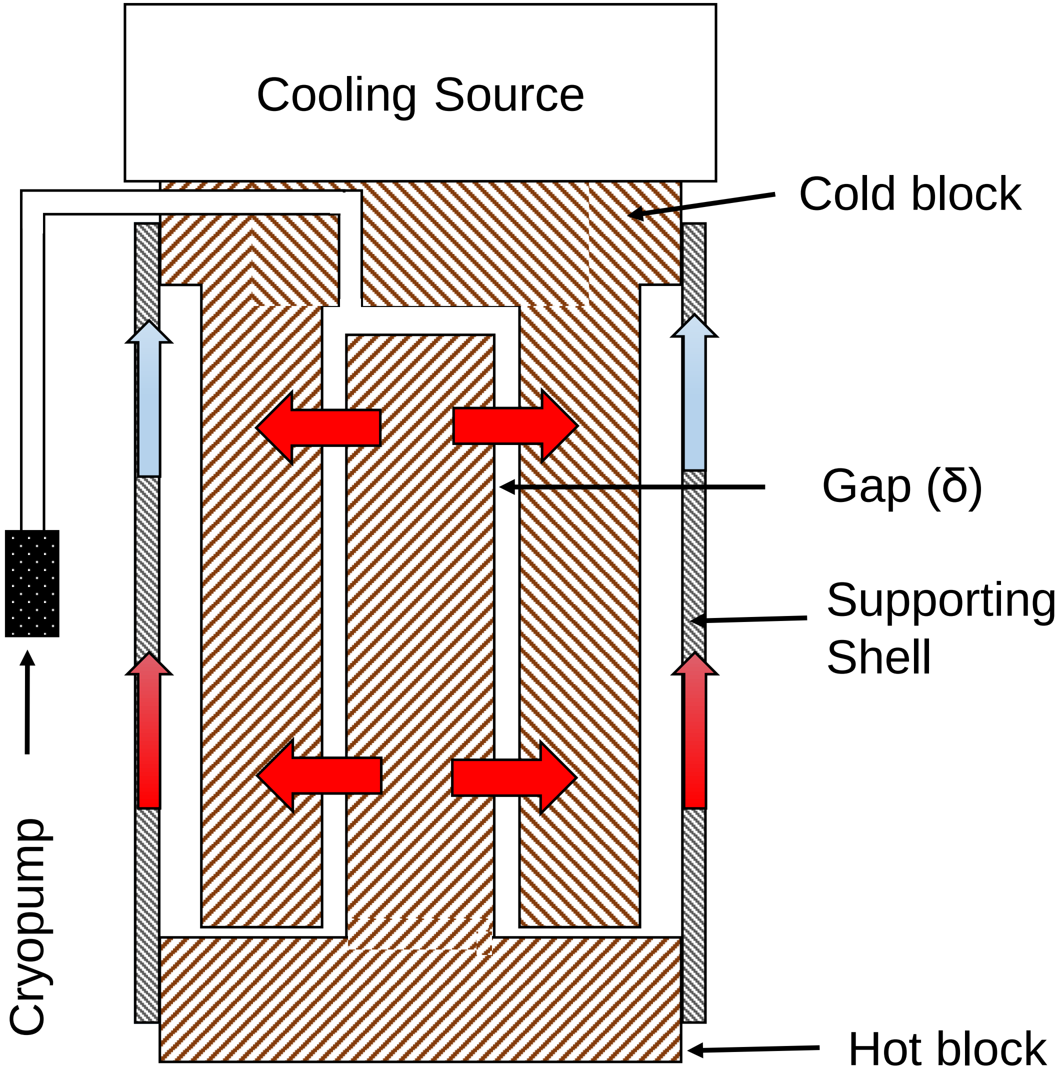


Bonfait, G. et al. 2009. “20K Energy Storage Unit.” *Cryogenics* 49(7): 326–33. https://linkinghub.elsevier.com/retrieve/pii/S0011227509000459.

GGHS

Working Principle

- Hot and cold terminals of the GGHS are two coaxial copper blocks separated by a thin cylindrical gap *δ*.
- The gap is filled or emptied of gas to achieve the switching action.
- A supporting shell encloses the gas and mechanically supports these two blocks.
  - To minimize the thermal short-circuit between them, it must be a thin-wall tube of low *k* material (eg.100 µm, SS304)
- The presence or absence of gas is controlled by a miniature adsorption pump (referred as "cryopump")



GGHS

Heat transfer in gases

- Mean free path λ is the average distance travelled by a molecule between successive collisions.

- Viscous regime (ON state):
  - Gas particles collide with each other, thus, making the heat transfer more effective (high conductance state)

$$\dot{Q} = k\frac{S}{\delta}(T_h - T_c)$$

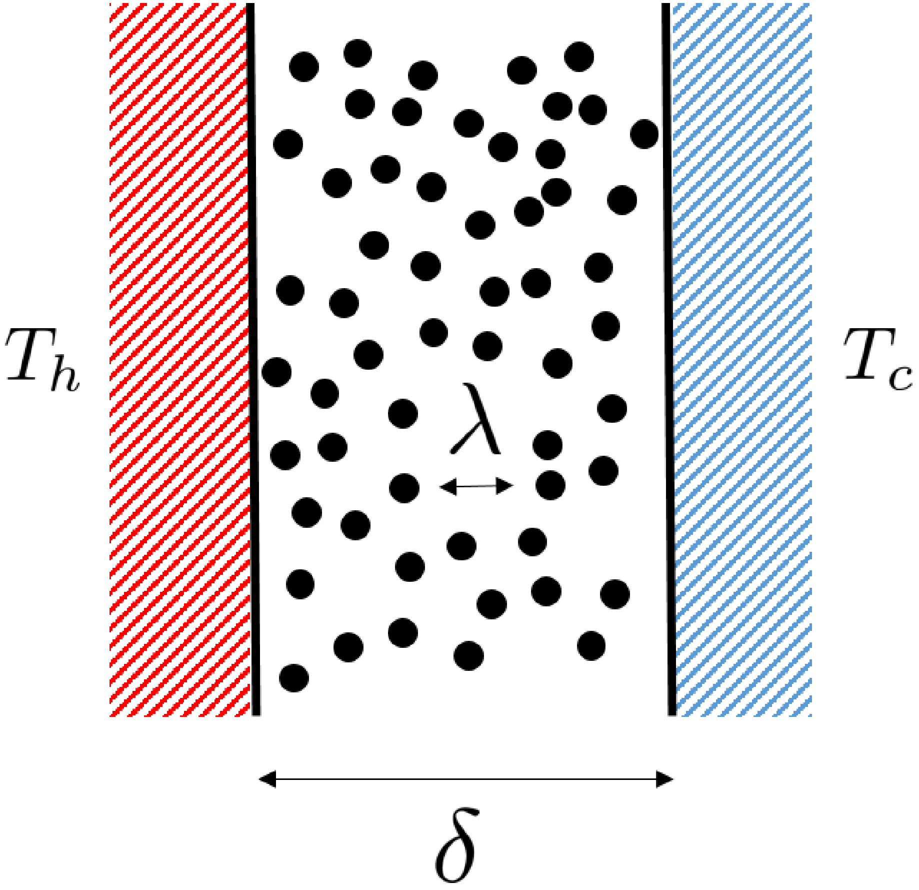
- From kinetic theory of gases, the thermal conductivity for an ideal gas is **pressure independent**:

$$k(T) = \frac{1}{3N_A\sigma}\sqrt{\frac{3RT}{M}}C_{\mathrm{mol}}$$

σ collisional cross section, C molar heat capacity

Viscous Regime

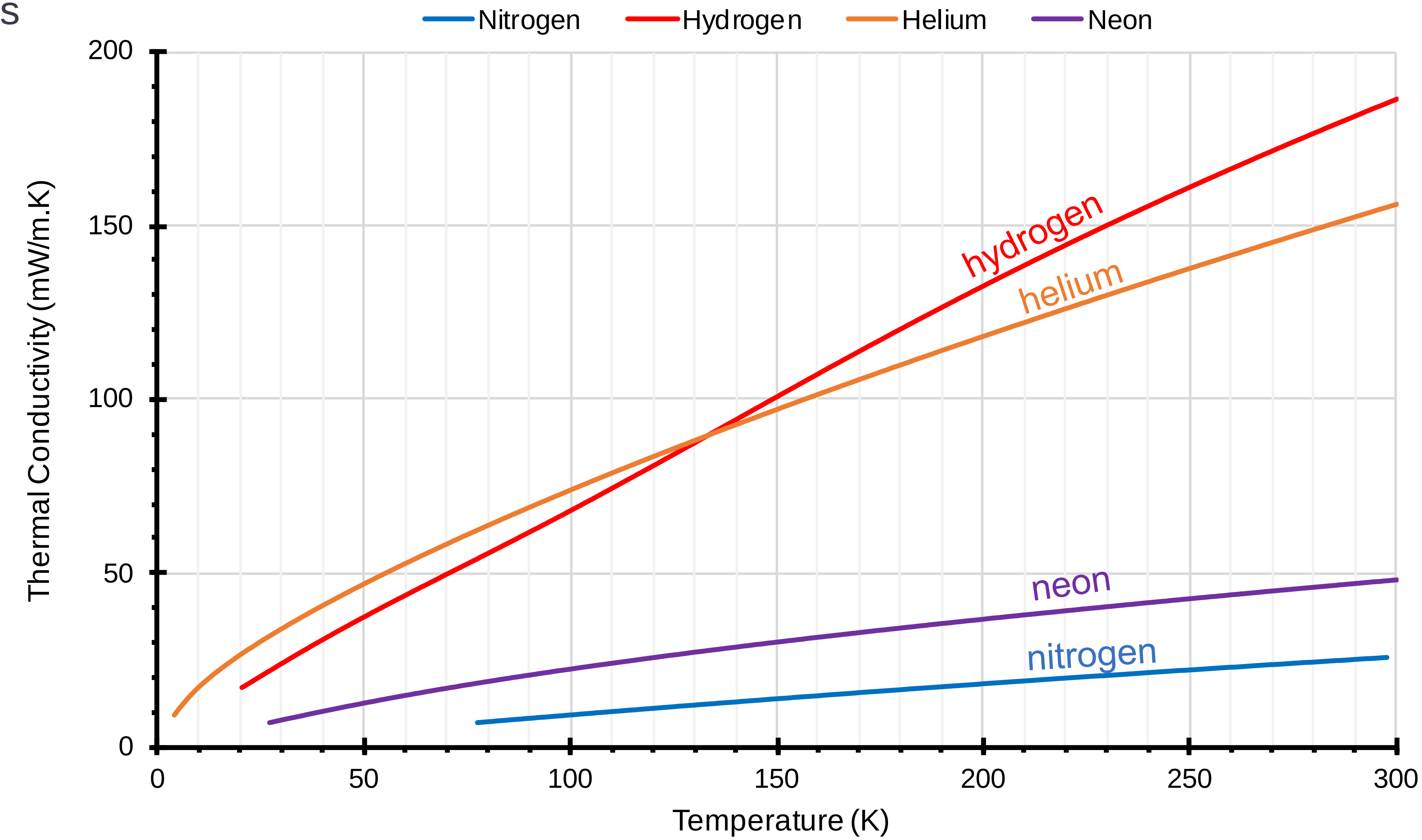
$\lambda \ll \delta$



GGHS

Heat transfer in gases

- **Pressure independent**
- Lighter molecules have higher thermal conductivity (H_2, He)



GGHS

Heat transfer in gases

- Molecular/ballistic regime (OFF state):
  - Gas particles mostly collide with the walls, the conduction is ineffective (low conductance state)
- The approximation $\lambda \approx \delta$ shows that the heat flux rate becomes **pressure dependen**t:

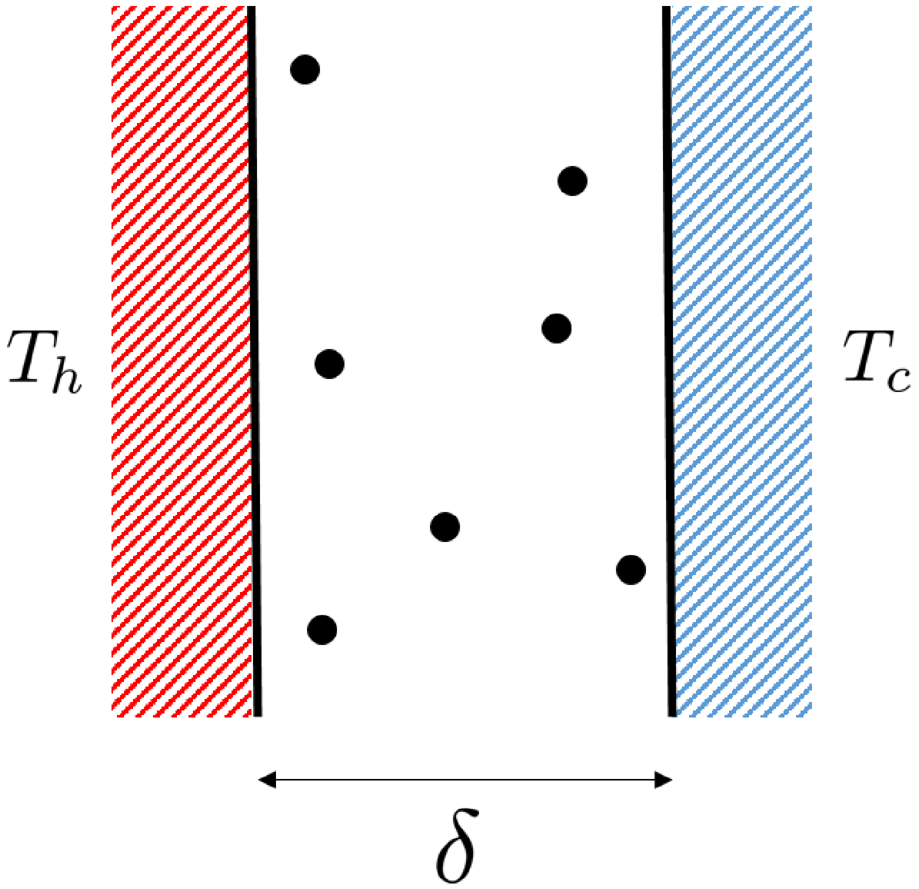
$$\dot{Q} = \alpha S \left(\frac{\gamma + 1}{\gamma - 1}\right) \sqrt{\frac{R}{8\pi M T}} P \Delta T$$

α accommodation coefficient, γ heat capacity ratio

- If the pressure is sufficient low, a very low conductance state can be achieved.

Molecular Regime

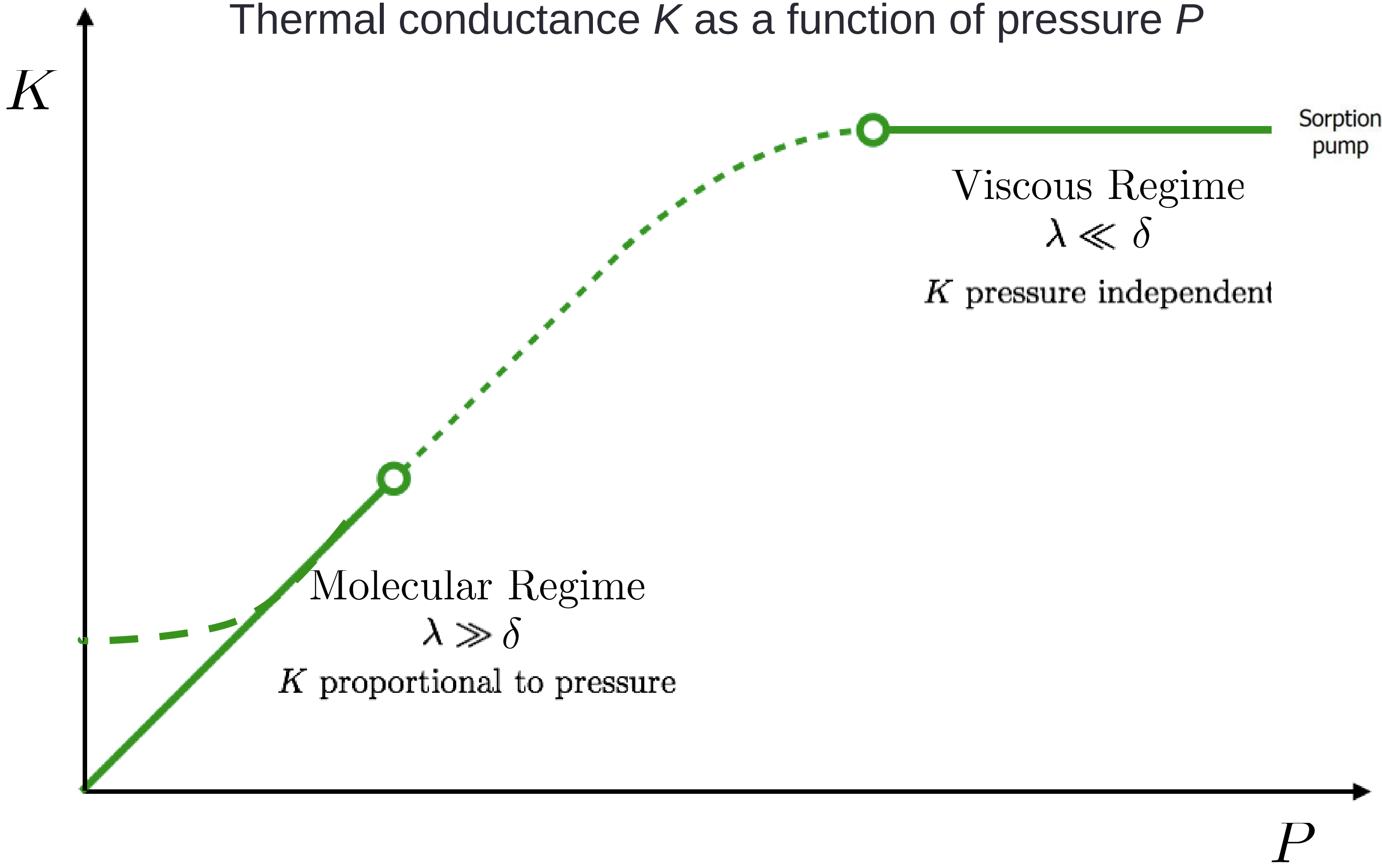
$\lambda \gg \delta$

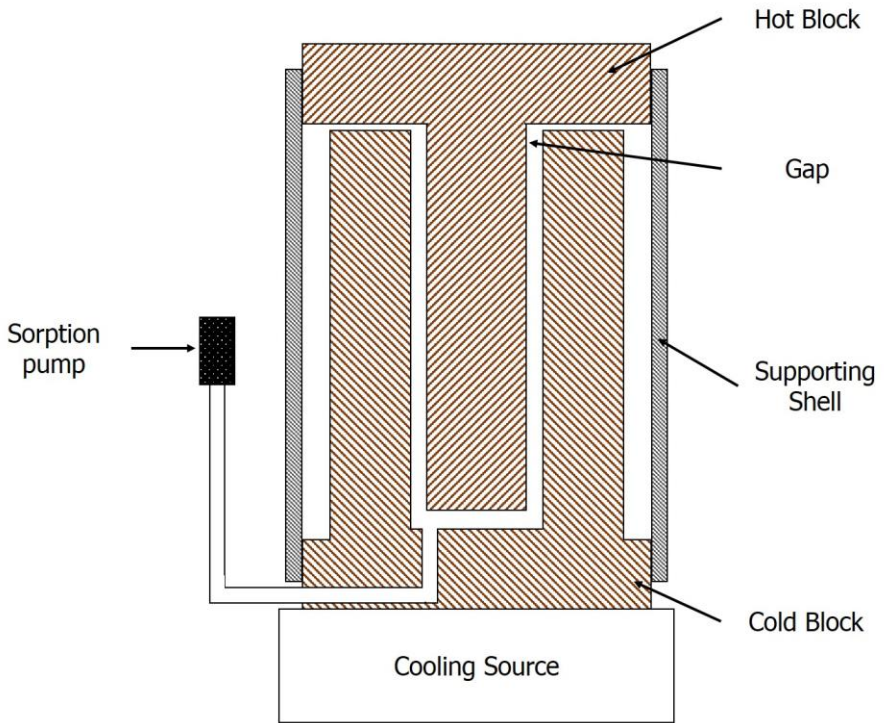


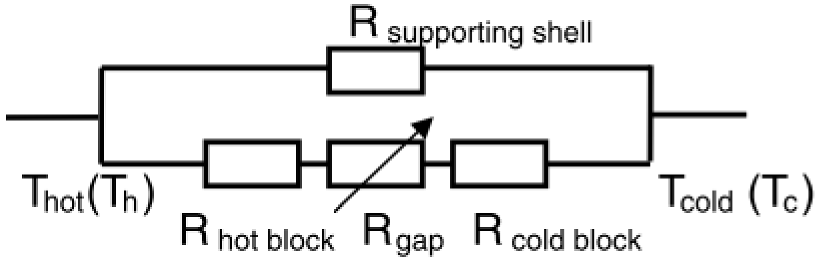
GGHS

Global conductance

Thermal conductance *K* as a function of pressure *P*







Catarino, I., Bonfait, G., & Duband, L. (2008). Neon gas-gap heat switch. Cryogenics, 48(1-2), 17–25. doi:10.1016/j.cryogenics.2007.09.002

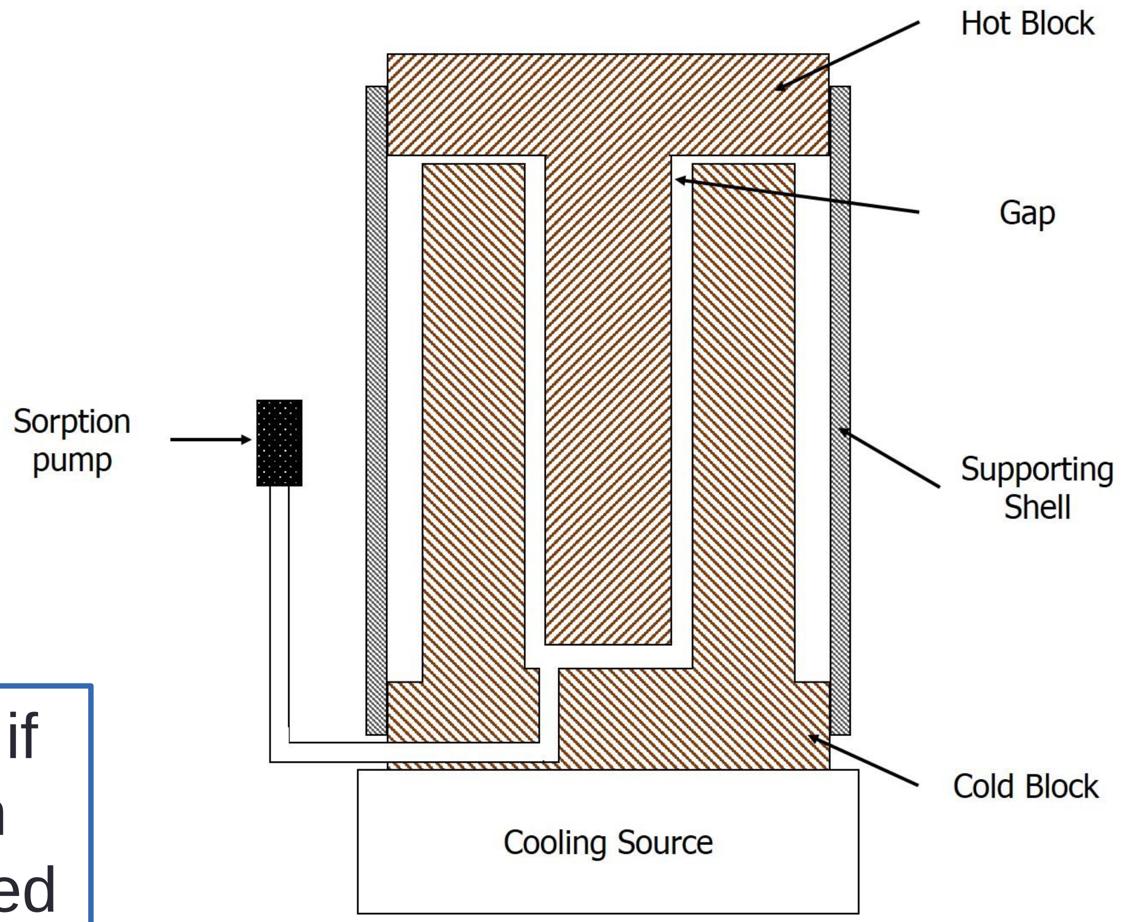
GGHS

Adsorption Pump – “cryopump”

- When this cryopump is cooled down:
  - Adsorption is effective
  - High vacuum can be achieved
  - Molecular regime ➞ OFF state

- On heating:
  - The adsorbed gas is desorbed leading to a pressure increase
  - Viscous regime ➞ ON state

However, this good behaviour only exists if the selected gas matches the adsorption capabilities of the adsorbent for the required temperature range

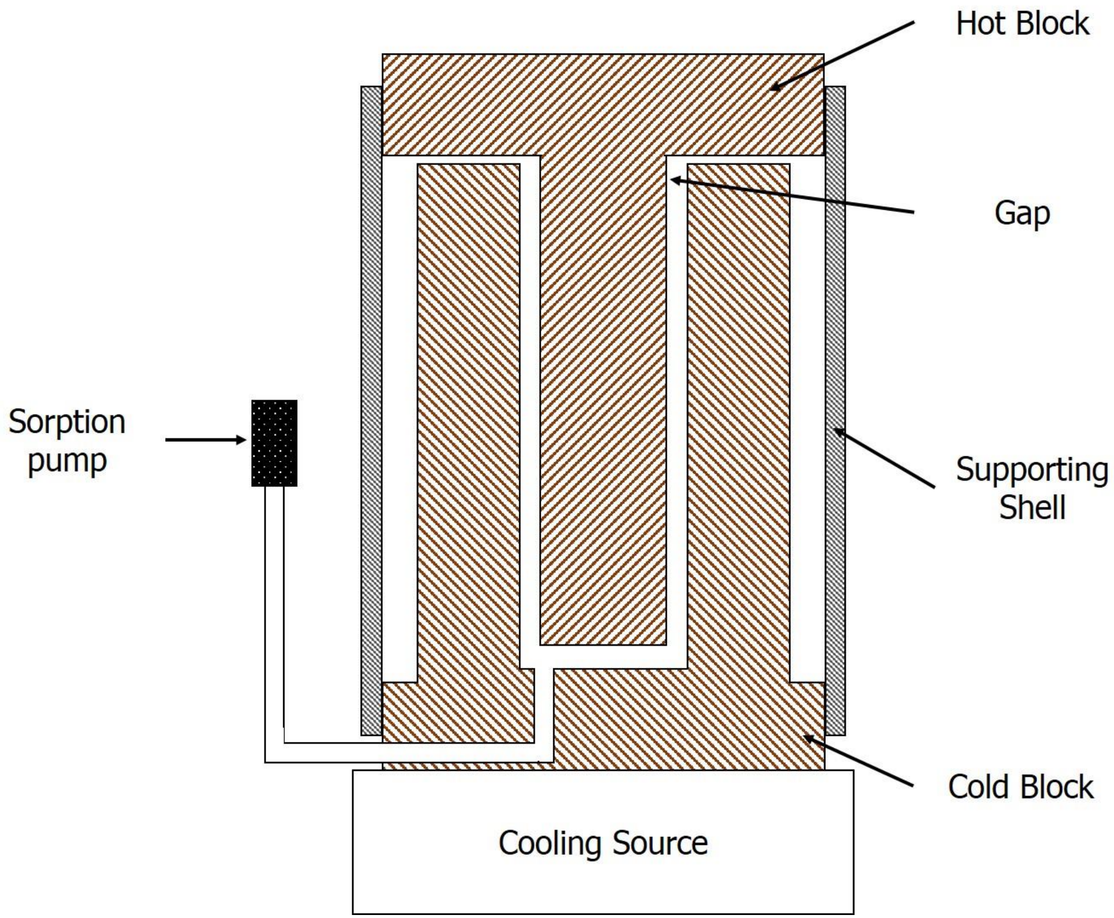


GGHS

Adsorption Pump – “cryopump”

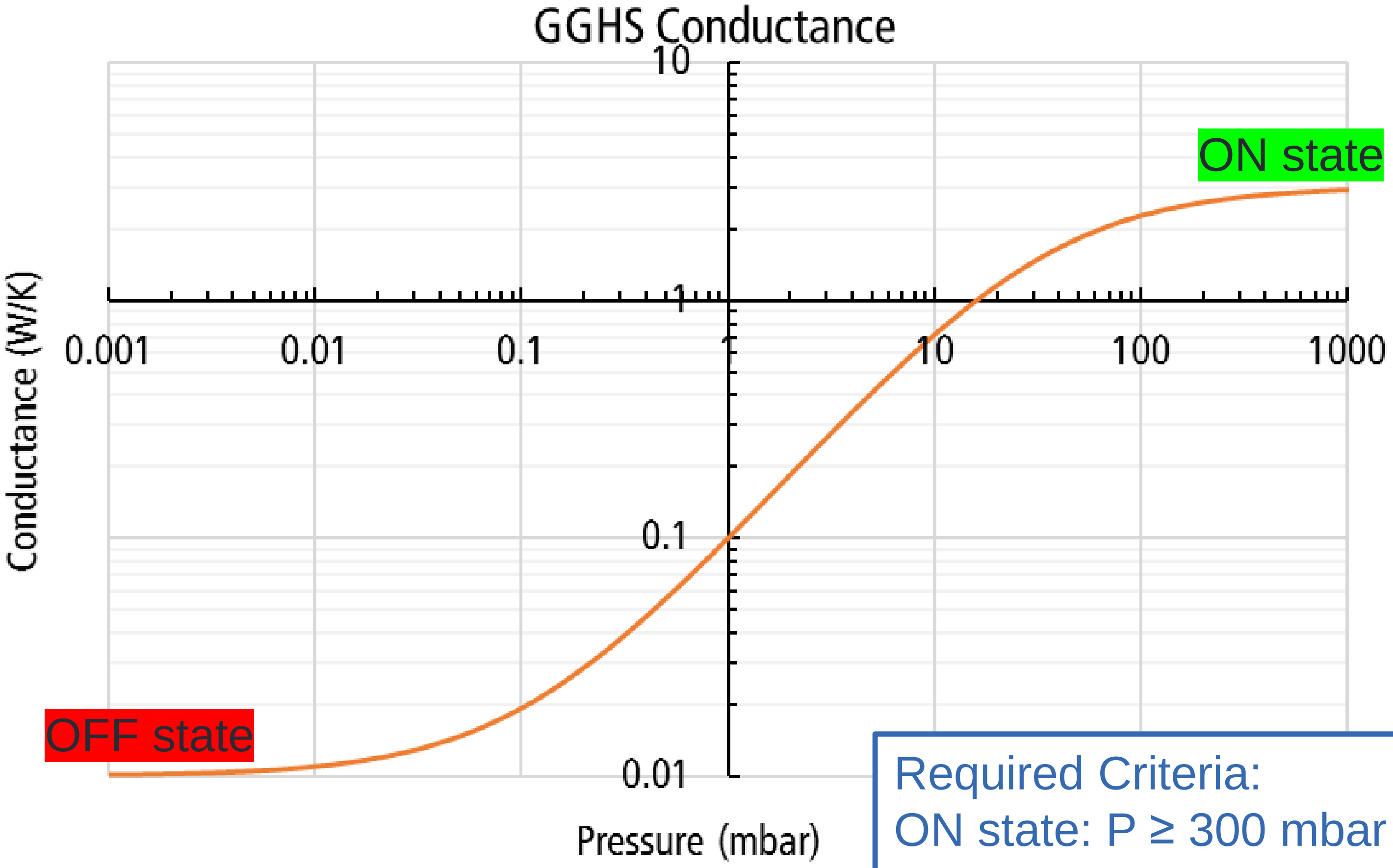
- The good conductive gases (He,H_2) need low T to be adsorbed.
- For instance, the pair helium + activated charcoal, the cryopump needs to be cooled below approximately 15-20 K.
- Very good if a heat sink is available in this temperature range. Otherwise it is a limiting parameter.

- For higher temperatures (T>120 K)??
  - Nitrogen can be adsorbed in the range of 120 K, but reduced thermal conductivity ✕
  - **Hydrogen can be chemically adsorbed with metal hydrides: ZrMn2**



Hydrogen GGHS

Design

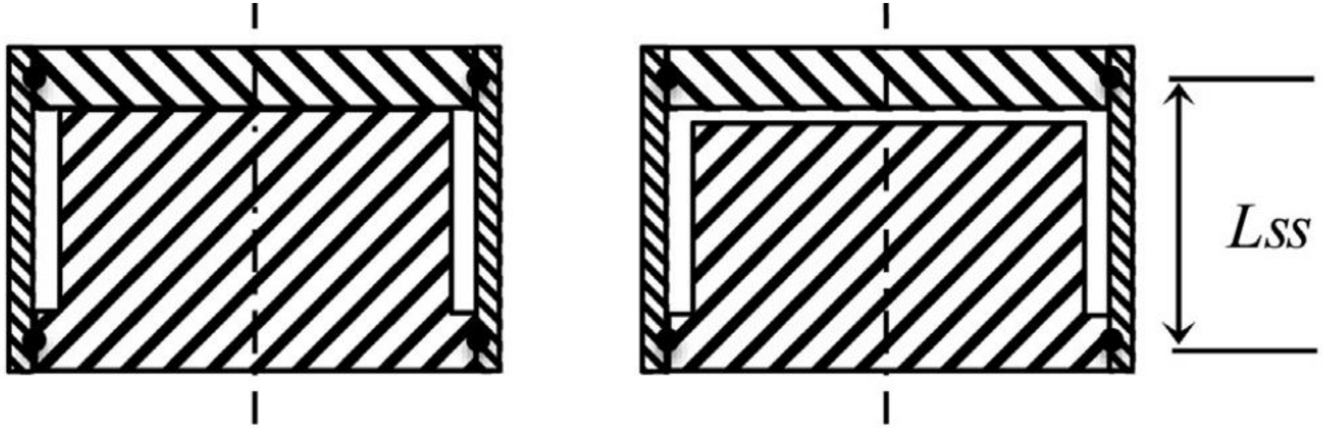


Required Criteria:
ON state: P ≥ 300 mbar
OFF State: P ≤0.01 mbar

- Temperature range: 150 to 400 K
- Expected performance
  - ON: < 3 W/K (gap: 15 µm)
  - OFF: 8 mW/K @ 150 K

Hydrogen GGHS

Manufacture



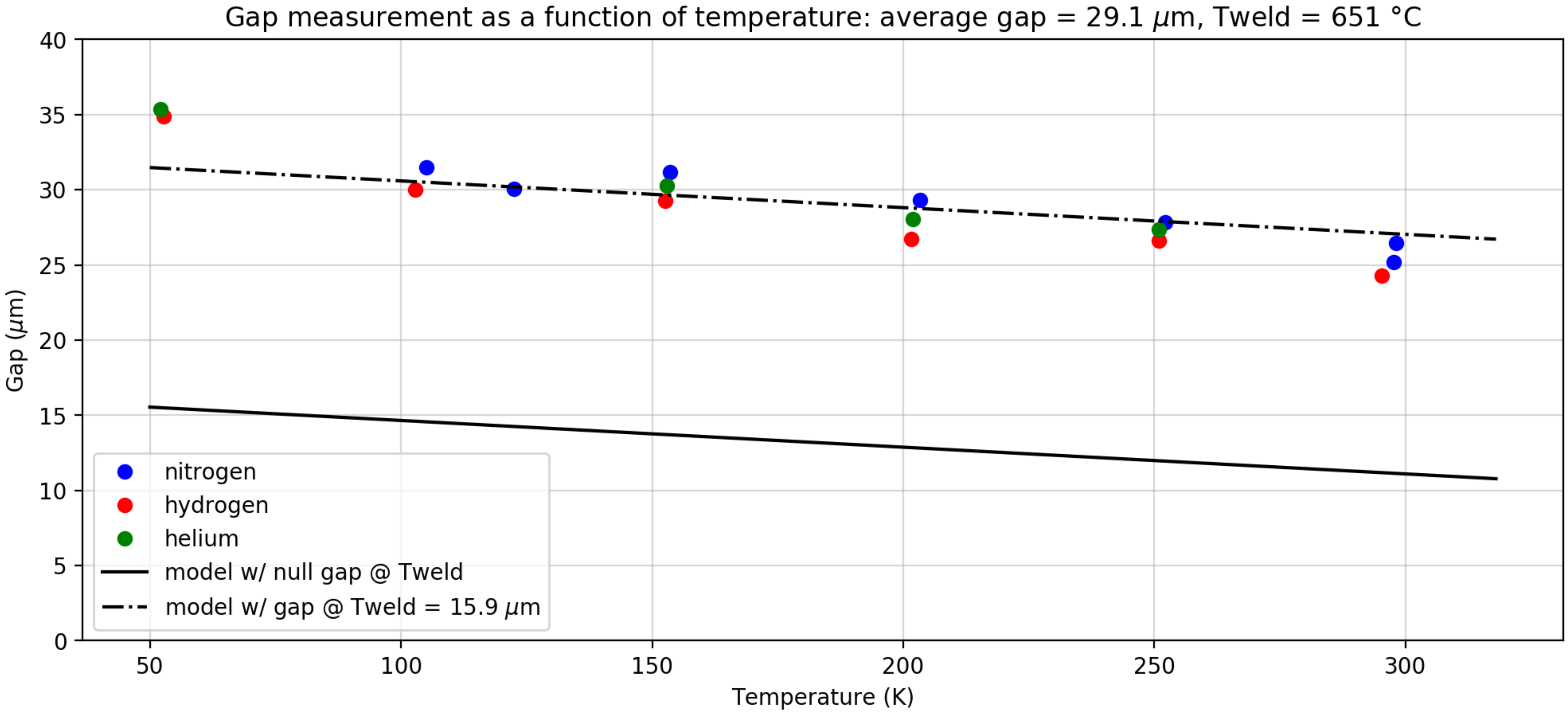
a) At the soldering temperature. b) At lower temperature.

Franco, J., D. Martins, I. Catarino, and G. Bonfait. 2014. “Narrow Gas Gap in Cryogenic Heat Switch.” *Applied Thermal Engineering* 70(1): 115–21. http://linkinghub.elsevier.com/retrieve/pii/S1359431114003263 (October 21, 2014).

- Gap obtained by the differential thermal expansion of copper and stainless steel (SS):
  - The two copper cylinders are in contact at the welding temperature (Ag brazing ~651ºC).
  - During the cooldown, copper contracts more than stainless and the gap naturally grows.
  - Very small gap can be obtained without complicated machining and alignment process!

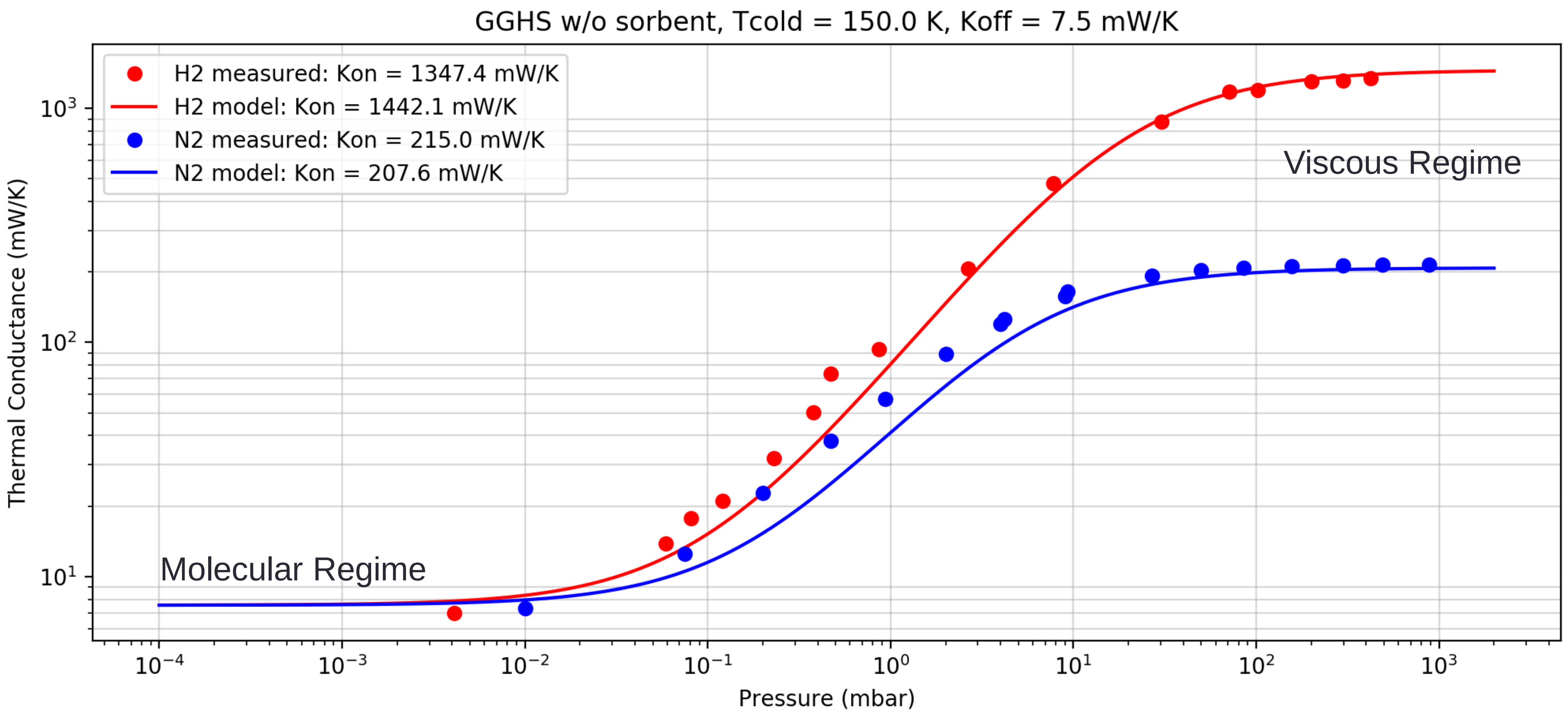
Hydrogen GGHS

Results: gap measurement



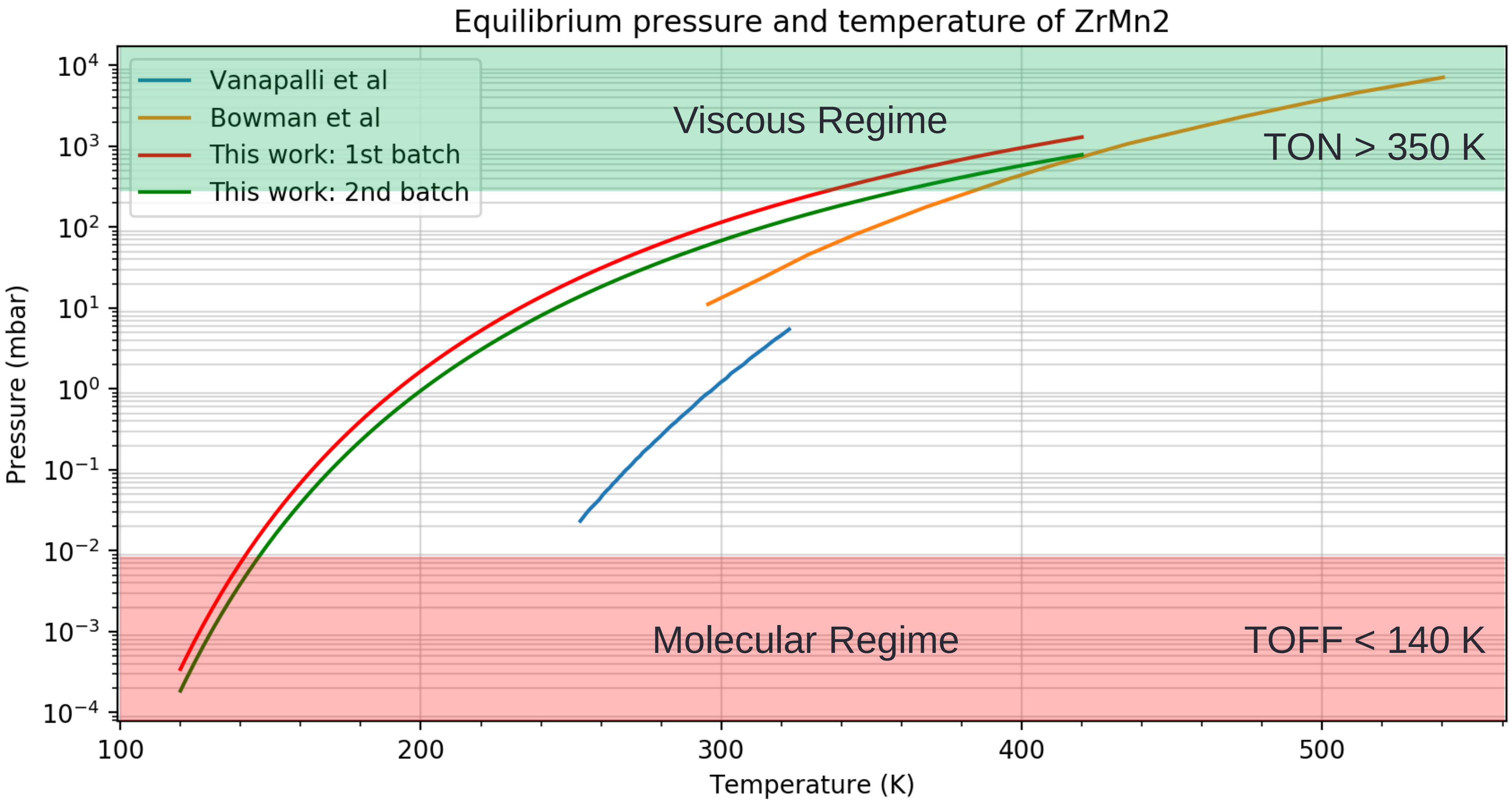
Hydrogen GGHS

Results: thermal conductance w/o cryopump



Hydrogen GGHS

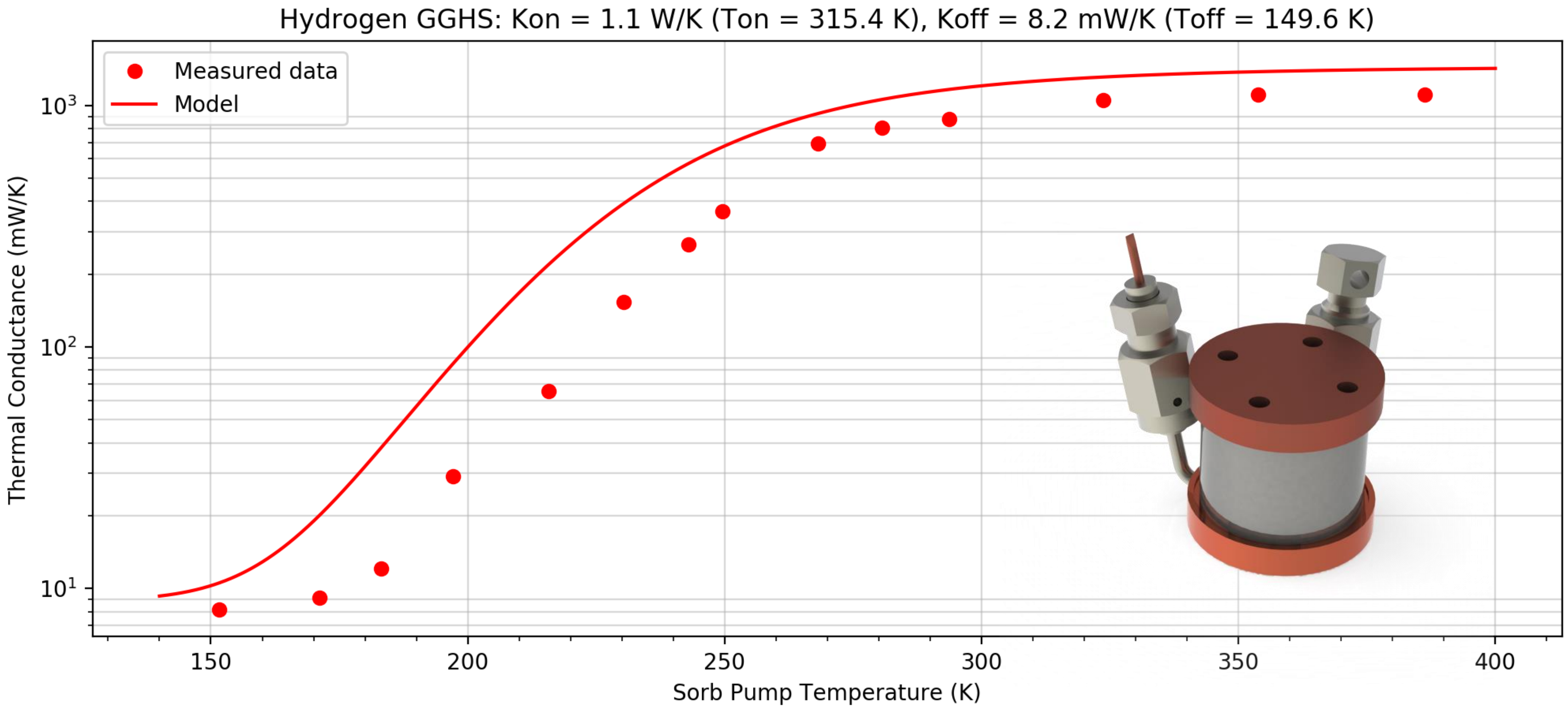
Results: $ZrMn_2$ metal hydride characterization



Vanapalli, Srinivas et al. 2015. “A Passive, Adaptive and Autonomous Gas Gap Heat Switch.” *Physics Procedia* 67: 1206–11. http://dx.doi.org/10.1016/j.phpro.2015.06.191.

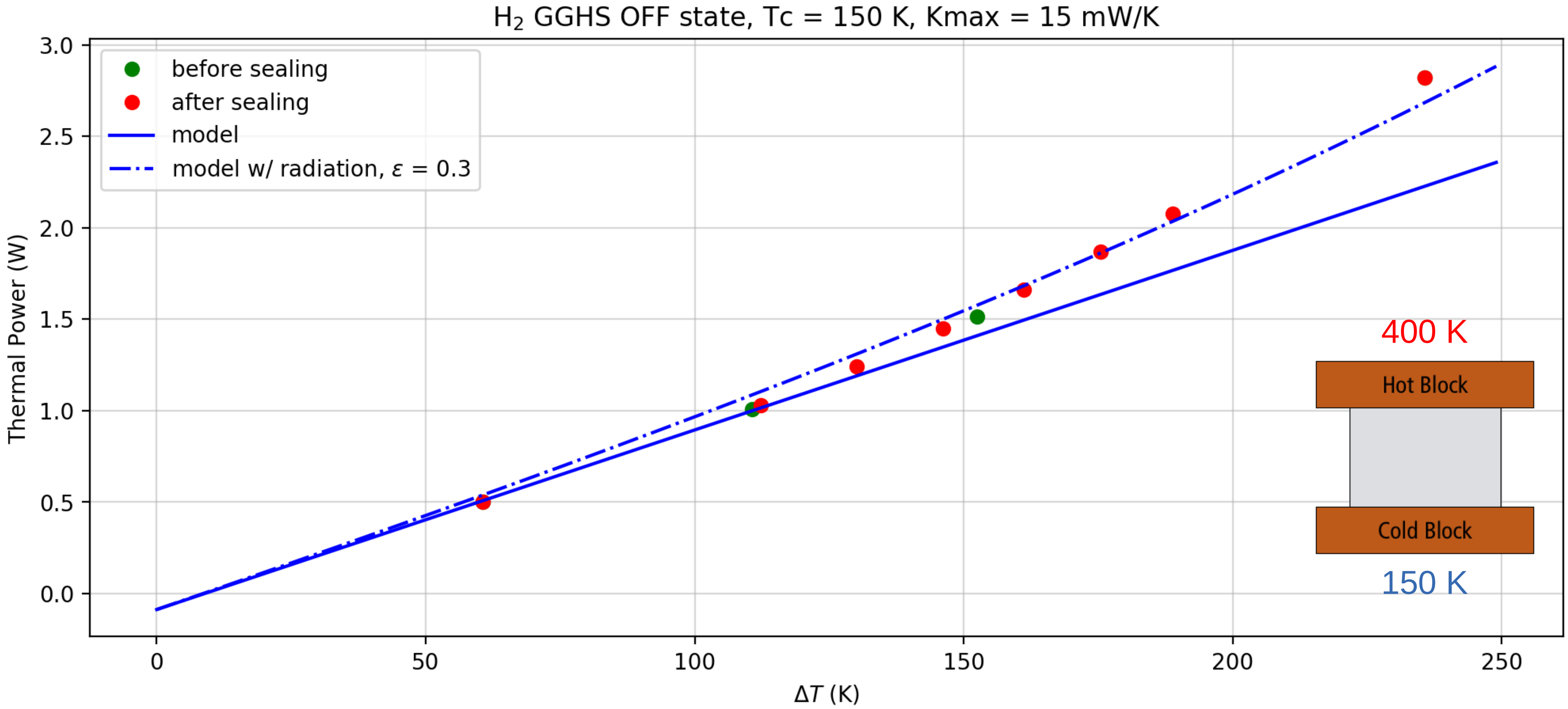
Hydrogen GGHS

Results: thermal conductance w/ $ZrMn_2$



Hydrogen GGHS

Results: OFF state radiation effect



Conclusions

- A hydrogen GGHS was designed and built to operate in the temperature range of 150 to 400 K:
  - With an expected ON conductance up to 3 W/K @ 150 K.
  - Expected OFF conductance of 8 mW/K @ 150 K.

- A preliminary characterization of the $ZrMn_2$ metal hydride has shown that is possible to have a GGHS working with hydrogen in this temperature range.
  - Expected ON / OFF switching temperatures of 140 K and 350 K respectively.

- The GGHS was loaded with 2.6 mg of $ZrMn_2$ and successfully achieved both hydrogen operating states:
  - Measured ON state: 1.1 W/K (switching temperature: 345 K, gap: 29 µm)
  - Measured OFF state: 8.2 mW/K (switching temperature: 155 K)
  - ON/OFF ratio: 134
- The latest GGHS (under characterization) showed a ON state up to 2 W/K (gap = 15 µm).

Acknowledgements

LIBPhys-UNL

- Jorge Barreto
- Grégoire Bonfait

activespace technologies making space a global endeavour

- Daniel Martins(1)
- Moritz Branco(2)

C2TN

- António Gonçalves
- Joaquim Branco

esa

(1)Currently at ASML
(2)Currently at ESA