Special Interest Group meeting
Thermal Issues
Eindhoven, The Netherlands, March 2024
www.euspen.eu

Thermal path optimization between cryocooler and sample

Marcel van Wensveen[1], Rens van Alebeek[1], Ron van den Boogaard[1], Ronald Lamers[1]

[1]*Thermo Fisher Scientific, Eindhoven, The Netherlands*

Marcel.wensveen@thermofisher.com

Abstract

Thermo Fisher Scientific (TFS) is currently developing a transmission electron microscope (TEM) which can cool the sample below 35 Kelvin. The thermal connection between the cryogenic cooler and the sample must be realized. The lower temperature compared to the current state of art, combined with the strict constraints of implementing the thermal path inside the TEM, brings new challenges to TFS. The development is started with modelling, and the complete design is validated using cryogenic testing. During testing it was found that the thermal contact resistances are much higher than initially validated. Via multiple design iterations, the contact resistances are reduced and the final goal to cool the sample below 35 Kelvin was achieved.

Cryogenic, thermal, contact resistances, conductivity, ultra-high-vacuum, modelling, cryostat

1. Introduction

In a new development of the TFS (Thermo Fisher Scientific) transmission electron microscope division, the sample needs to be cooled below 35 Kelvin. To do this, a cooler has been developed in collaboration with MI-Partners [1]. A thermal connection between the cooler and the sample must be realized. This brings new challenges. Firstly, the temperature is lower compared to the current state of art at TFS. This sets significantly more strict requirements on the thermal inleak and thermal conduction between and through components. Secondly, the thermal connection must be made in such a way that the dynamic performance of the microscope is guaranteed. Meaning the spectral content of the vibrations need to be within certain limitations. Lastly, the environment, e.g., UHV (Ultra High Vacuum), electrical isolation, motion performance in 5 degrees-of-freedom and only non-magnetic materials sets a complete set of challenging requirements on the design.

There are several components in the thermal path from the cooler to the sample: an electrical insulator, a thermal interface, a braid, and the stage with sample on it. Furthermore, some of the parts are shielded against radiation with a cryogenic cooled shield around it.

2. Thermal modelling

The initial estimate of the heat load and temperature gradient over the thermal path has been investigated with a thermal FEM model. In the model, inleak via conduction and radiation has been included. Also, the thermal contact resistances based on the equations of Mikić [2] have been included. After some iterations and improvements, this did result in a design with the temperature gradient of the various parts as indicated with the FEM model line in Figure 1. From this it is expected that the main thermal gradients occur over the braid and stage. The thermal gradients over the contacts and other components seem to be neglectable based on the model.

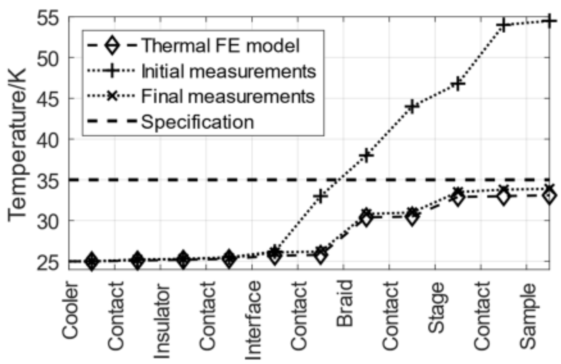

Figure 1. Thermal gradient over the main parts and contacts

3. Verification measurements

To verify the design, the components have been tested in a cryostat. A cryostat is a device in which cryogenic temperature below 10 Kelvin can be reached. One of the test setups is shown in Figure 2. In this test setup, the thermal conductivity of the test material was validated for the temperature range between 25 and 300 Kelvin.

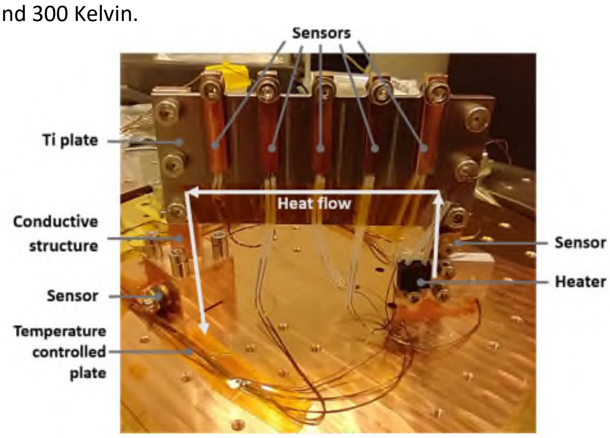

Figure 2. Cryostat test setup

The results of these initial measurements are shown in Figure 1. Based on these measurements it is concluded that there is a large deviation between the modelled and measured temperature gradients. The main reason for this is the much higher measured thermal contact resistances.

3. Design iterations and improvements

To reduce the thermal gradient, many design iterations and tests have been performed to come to a solution which meets the specifications. Investigated solutions are the use of exotic materials, low and high emissivity coatings, interface layers and coatings in between the contacts surfaces, increased contact forces, improved contact surfaces and soldering of contacts (which is challenging in a UHV environment).

4. Final results

Based on the modelling and findings during the design iterations, multiple improvements have been implemented into the design. This led to optimized performance as indicated with the final measurements line in Figure 1. Which does result in almost the same temperature gradient as has been calculated with the thermal FEM model. With this performance the required sample temperature has been achieved.

In the presentation the design will be explained in more detail. But the focus will be on the thermal problems which have been encountered and which improvements have been tested and implemented in the design.

References

[1] https://www.mi-partners.nl/
[1] Mikić B B 1974 Thermal contact conductance; theoretical considerations *Int J heat mass tran* **17** 205-217