MEDSI Design Guidelines

Section 1 – Cooling

Sub section 1.1 – Thermal contact between Silicon and Copper

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Design Issue

A common need is to cool a Silicon Mirror or Crystal by clamping to a water cooled or liquid Nitrogen cooled copper heat sink. This note gives some best practice guidelines on how this should be done, the uncertainties and sources of data on this issue.

Indium Thermal Interface Material

The thermal interface material performs two functions.

- It provides improved thermal conductance between the silicon and copper.
- It allows differential thermal expansion between the silicon and copper.

Indium foil is the most common material used, with thicknesses of 100µm, 250µm and 500µm commonly used.

To ensure good conductance the Indium should have the oxide layer removed. This can be done as follows

Clean for 3 min in Hydrochloric Acid followed by washes in Water, Acetone, Water and Water. The indium should then be placed into a nitrogen filled bag with paper used to prevent the indium from touching each other. Do not use Aluminium foil.

The indium should be good quality with no surface dents or scratches.

Indium is available in a variety of grades such as 99.9%, 99.99% and 99.999%. There is no indication that purities of better than 99.9% give any improvement on thermal conductance.

Copper and Silicon surface

The copper and silicon surface should be flat and smooth.

Some tests have been conducted with very low levels of roughness, but Ref 1 suggests that polishing below an Ra0.8 µm has no effect on improving conductance.

The degree of flatness required is debatable but it is accepted that flatness is critical.

Copper and copper alloys diffuse into indium which forms a copper-indium intermetallic. There is no evidence that this effect has any detrimental effect on the thermal conductance and there does not seem to be any need to coat the copper with nickel.

Clamping Pressure

High clamping pressures can produce distortion of the silicon optics so there is a desire to clamp with the minimum pressure to give the best compromise in minimising distortion and maximising thermal conductance.

The yield strength test, under tension, were measured (Ref 4) at 295 K with results of 1.19, 0.78,0.72 and 1.01 MPa. The Indium Corporation quote a flow stress of 280psi (1.93 MPa, 19.3 Bar)

One approach is to load the interface to a level where the indium will yield and flow to give better thermal contact. The pressure at which such changes take place could be reduced at a higher temperature and so one option is to bake the assembly at 35-40C with a high load and then after cooling reduce the clamping load to a much lower level.

However tests between coper and copper with 100µm Indium reported in Ref 3 show no improvement in conductance from 5 Bar to 20 Bar.

Data shown in Ref 5, shows a small continuation in reduction in thermal resistance for 0.003in(76µm) indium foil from 60pis to 200psi.

This would indicate that a design pressure of 0.5MPa (5 Bar, 72psi) is a good target clamping pressure.

Indium Heat Spring ®

The Indium Corporation offer an Indium foil that has modified surface that is claimed offers a substantial improvement in thermal conductance.

Indium Gallium Eutectic

Another alternative thermal interface material is Indium Gallium Eutectic. Ref 1 shows substantially improved thermal conductance over Indium.

The eutectic does have to be worked into the copper and silicon surface to ensure good wetting, this can be done using short stainless steel brushes.

The presence of small bubbles is however a problem and when the system is under vacuum these bubbles can cause very large voids which reduce the thermal contact area substantially.

If a eutectic is used the copper does need to be Nickel plated.

Silver loaded grease

Thermally conductive greases have been used for the semiconductor industry and offer good wetting characteristics and low modulus of elasticity. They are however messing, difficult to apply a defined thickness and have problems of pump out during thermal cycling. There are low outgassing

grease suitable for UHV applications which could offer high conductance especially if loaded with conductive silver particles. However there does not seem to be much work done on this solution.

Carbon Nano Tubes

Carbon Nano tubes are predicted to have an extremely high thermal conductivity along the axis and may offer alternatives to indium in the future.

Heat transfer coefficient

Ref 1 suggests 15,000 W/m^2K at 100psi (0.69 MPa)and 20,000 W/m^2K at 170psi (1.2 MPa)

Ref 2 suggests 10,000 to 20,000 W/m^2K over the range 0.1 to 0.9 MPa

Ref 5 suggests the following values

Fair contact = 3,000 W/m^2K

Good contact = 5,000 W/m^2K

Excellent contact = 8,000 W/m^2K

Enhanced area equivalent to direct cooling = 18,000 W/m^2K

References

Ref 1 - Thermal contact resistance across a copper-silicon interface

A.M.Khousary, D.Chojnowski, and L.Assoufid

(Note Fig 5 has the Silver Foil and Indium Foil labels the wrong way around)

Ref 2- Measurement of thermal contact conductance of Spring-8 beamline components

T Mochizuki, H Ohashi, M Sano, S Takahashi, S Goto

Proc. of SPIE Vol.6705 (2007)

Ref 3 – Thermal Contact Resistance Study

P Marion, L Zhang, L Vallet, M Lesourd

MEDSI-PROC-2004

Ref 4 – Tensile strength and ductility of Indium

R Reed, C McCowan, R Walsh, A Delgado, J McColskey

Materials Science and Engineering A, 102 (1988) 227-236

Ref 4 – Indium Corporation data sheet TIM 98142 R1

Ref 5 – Cryogenic cooling of monochromator crystals: Indirect or direct cooling?

P Marion, L Zhang, L Goiurand, M Rossat, K Martel