Selection between Indium and Gallium to make the gasket between silicon flexures and sapphire.

The mating surfaces between silicon flexure (red in figure) and sapphire wire hooks (blue in figure) or mirror shelves hold under purely compressive stress (with zero shear effort).

The mating surfaces are ultra-sound machined with roughness Ra <0.2 µm. The mating surfaces between the two crystals should get in contact as much as possible, with a soft metal to fill the gaps to improve thermal conductivity, and impede lateral shifts. Because the crystals are machined with Ra 0.2 µm, the thickness of the metallic gasket will vary between 0.4 and 0.0 µm. The metal holds by mechanical interlocking between crystal surface imperfections, not by adhesion. Metallic wetting of the metal is welcome to improve thermal conductivity.

Two soft metal candidates have been identified



**Figure 1:** Scheme of the flexure and wire hooks.

**Table 1:** Relevant physical properties of Indium and Gallium.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Property | Unit | **Indium** | **Gallium** | **score** |
| Solid density (near r.t.) | g·cm−3 | 7.31 | 5.91 |  |
| Liquid density @ m.p. | g·cm−3 | 7.02 | 6.095 |  |
| Expansion at melting |  | 1.041 | 0.9696 | G |
| Melting point | °K | 429.7485 | 302.9146 | G |
| Melting point | °C | 156.60 | 29.77 | G |
| Wetting silicates |  | Yes | Yes | X |
| Boiling point | K | 2345 | 2477 | G |
| Vapor pressure | Pa | 1 @ 1196°K | 1 @ 1310°K | G |
| Vapor pressure | Pa | 10@1325°K | 10@1448°K | G |
| Elec. resistivity (20 °C) | nΩ·m | 83.7 | 270 |  |
| Thermal conductivity | W·m−1·K−1 | 81.8 | 40.6 | I |
| Therm. expansion (25 °C) | µm·m−1·K−1 | 23.1 | 18.0 | G |
| Young's modulus | GPa | 11 | 9.8 | X |
| Poisson ratio |  |  | 0.47 |  |
| Brinell hardness | MPa | 8.83 | 60 | G |
| Atomic radius | pm | 167 | 135 |  |
| Magnetic ordering |  | diamagnetic | diamagnetic | X |

Gallium has higher boiling point and lower vapor pressure than Indium, therefore it is a better material for UHV use.

Gallium has half of the thermal conductivity of Indium, therefore it is theoretically worse than Indium as thermal conductor. However, because the ultra-sound machining is capable of surface roughness Ra < 0.2 µm, melting the brazing material would allow negligibly small thicknesses, and thermal resistance from the braze. By melting the braze and letting it flow under compression to allow the two crystals to get in contact with each other, the gap between silicon and sapphire, even in the empty spots, will become smaller than 0.5 µm, sufficiently small to offer insignificant thermal resistance. In addition, with the impedance match provided by the braze material, phonons may even tunnel from a crystal to the other. With so small thickness, the factor of 2 thermal conductivity disadvantage of Gallium becomes fully insignificant.

Both Indium and Gallium wet silica, and will likely wet sapphire.

For gasket forming it is recommended to warm up the parts under compression near the melting point (157°C with Indium, only 30°C with Gallium), to let the excess material flow out of the joint and form the thinnest possible connection. This is obviously easier with Gallium. In addition, because Gallium, like water, expands at crystallization, it automatically liquefies at any point of stress concentration and releases the local stress. Because it expands at crystallization, when cooling below the melting point Gallium will crystallize under hydrostatic pressure thus guaranteeing complete contact between asperities and filling of voids.

Gallium also has smaller thermal expansion coefficient than Indium. The thermal expansion coefficient is such that even at cryogenic temperatures a large fraction of the hydrostatic pressure produced at crystallization would be maintained.

In addition the near room temperature melting point of Gallium makes it much easier to release the contacting surfaces.

The higher Brinnel Hardness of Gallium means that it will likely have larger intrinsic Quality factor than Indium. This is probably an insignificant advantage for Gallium because, with sub µm gasket thicknesses, the gasket material quality factor becomes irrelevant from the point of view of generating Thermal noise (see appendix 2).

In summary, Gallium is more advantageous in all respects to form the gaskets, except maybe for its lower thermal conductivity. The lower thermal conductivity is not a significant factor for gaskets thinner than 10 µm (see appendix 1), and because brazed gasket will be thinner than 1 µm it will be completely insignificant. In addition, because Gallium is easier to flow, and becomes liquid under pressure near room temperature, it will likely generate thinner gaskets with better thermal conductance than Indium.

Therefore, unless a negative reason is identified, Gallium should be used as a gasket material.

**Appendix 1:**

Indium gasket thermal conductivity lower limit back of the envelope evaluation.

Let’s consider an Indium joint with two contact points 5 mm long, 1 mm wide, 10 um thick, considering a thermal conductivity loss by a factor of 0.1 at 20 oK, the thermal conductivity lower limit will be:

0.1 x 81.8 W·m−1·K−1 x 2 x 5 x 10-6 m2 / 10-5 m = 8.18 W·K−1

Comparing it with the conductivity of a sapphire wires 4 mm2 in section, 0.4 m in length,  supposing a sapphire thermal conductivity of 104 W·m−1·K−1 at 20oK,

the fiber thermal conductivity will be:

104 W·m−1·K−1 x 4 x 10-6 m2 / .4 m  = 0.1 W·K−1

Even accounting for the 4 connection points, the gaskets contribute only <5% of the thermal loss along the fiber.

Because the gaskets will be less than a µm, the thermal loss fraction in the gaskets will be lower than 0.5%, perhaps <0.1%.

**Appendix 2:**

Indium gasket contribution to thermal noise, back of the envelope evaluation.

From the point of view of pendulum oscillation in mirror suspensions, the gasket torsional stiffness is in “series” with that of the flexure.  What counts is only the effective Quality-factor of the suspension.

The exact calculation of the effective pendulum Q-factor is complicated, it needs a FEM model. The energy fraction of each FEM cell must be calculated for the pendulum movement of the mirror, then each cell energy must be multiplied by its intrinsic Q-factor, and added up.

A reassuring argument can be obtained considering the lower limit of the elastic constant of the gaskets.

Each side of the hook will be 5 mm2, and 10 µm thickness of Indium is considered for the evaluation; the joint’s elastic constant at room temperature will be:

11 109 N·m−2 x 5 10-6 m2 /10-5 = 5.5 108 N ·m−1

this is an extremely stiff spring, and will be substantially stiffer for the thinner gaskets and at lower temperature. The pendulum action will act in torque across a 3 mm arm. This torque stiffness has to be compared with the torsional stiffness of a 100 µm thick, 5 mm wide silicon flexure. The fraction of energy stored in the 10 µm thick gasket is totally negligible when compared with the energy stored in the flexure section, and that even an Indium Q-factor of 1 (at 20oK it will be at least 100, and the compressional losses in an hydrostatic case will be much lower than that) would not contribute at all to the thermal noise budget.

This is calculated without taking into consideration that, by flowing the metal, the two crystalline surfaces come in contact, the effective thickness of the braze for pendulum motion vanishes (there is only trapped braze in the contact surface porosity), and its losses vanish as well.

The same arguments can be repeated for Gallium.