Design and manufacturing of the ITER ECRH Upper Launcher mirrors

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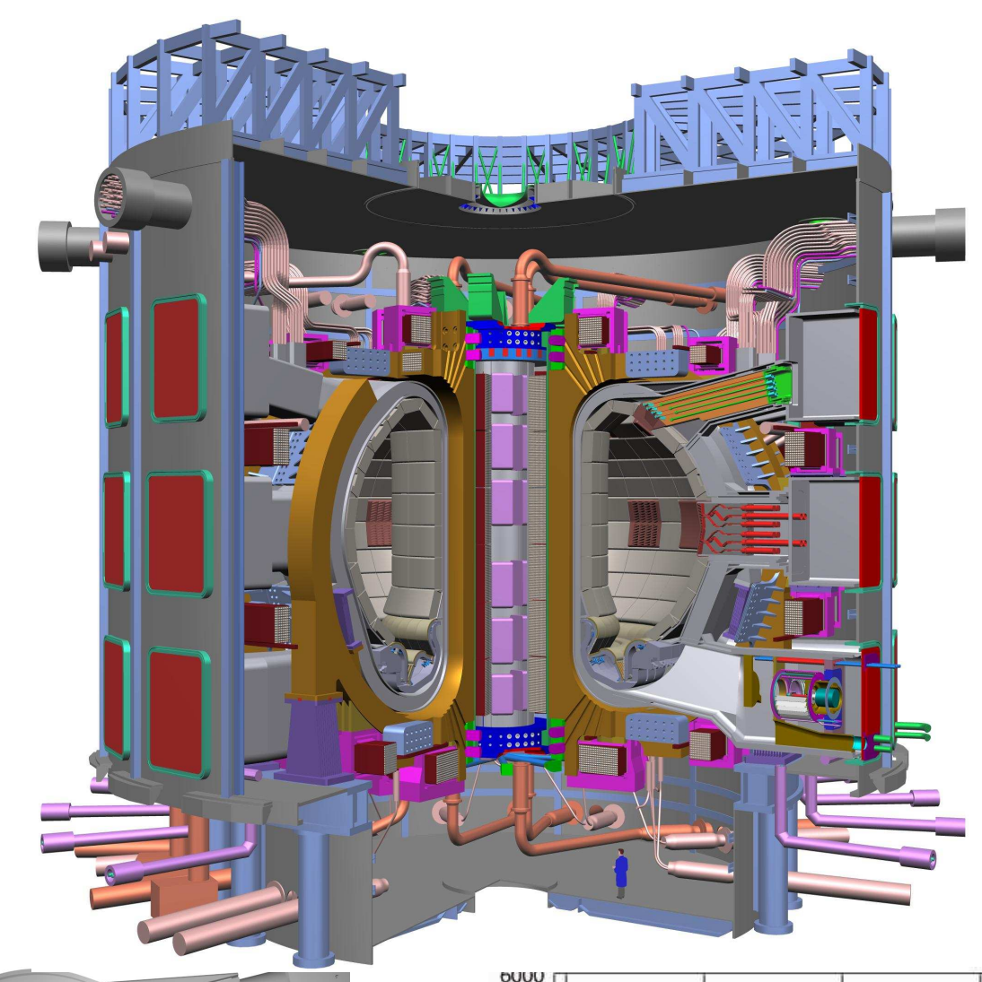
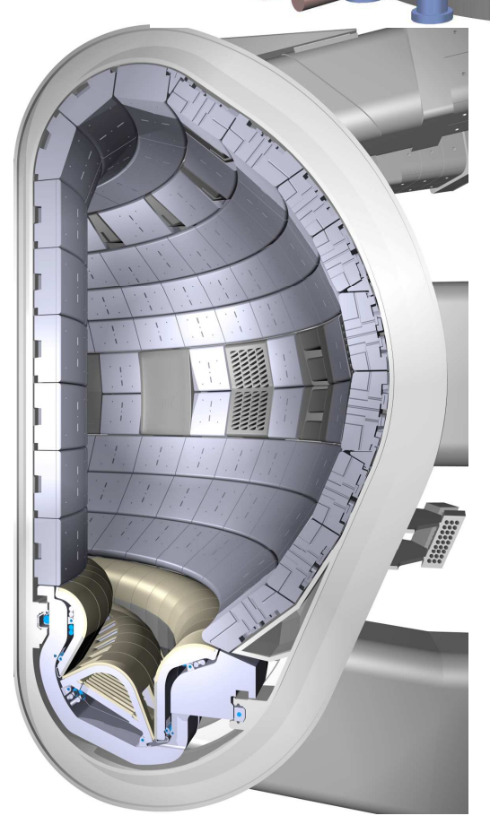
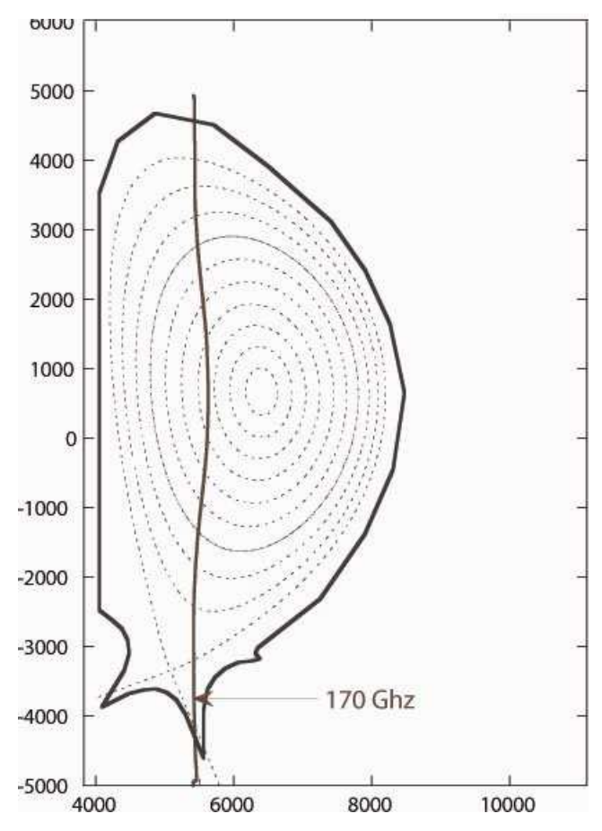
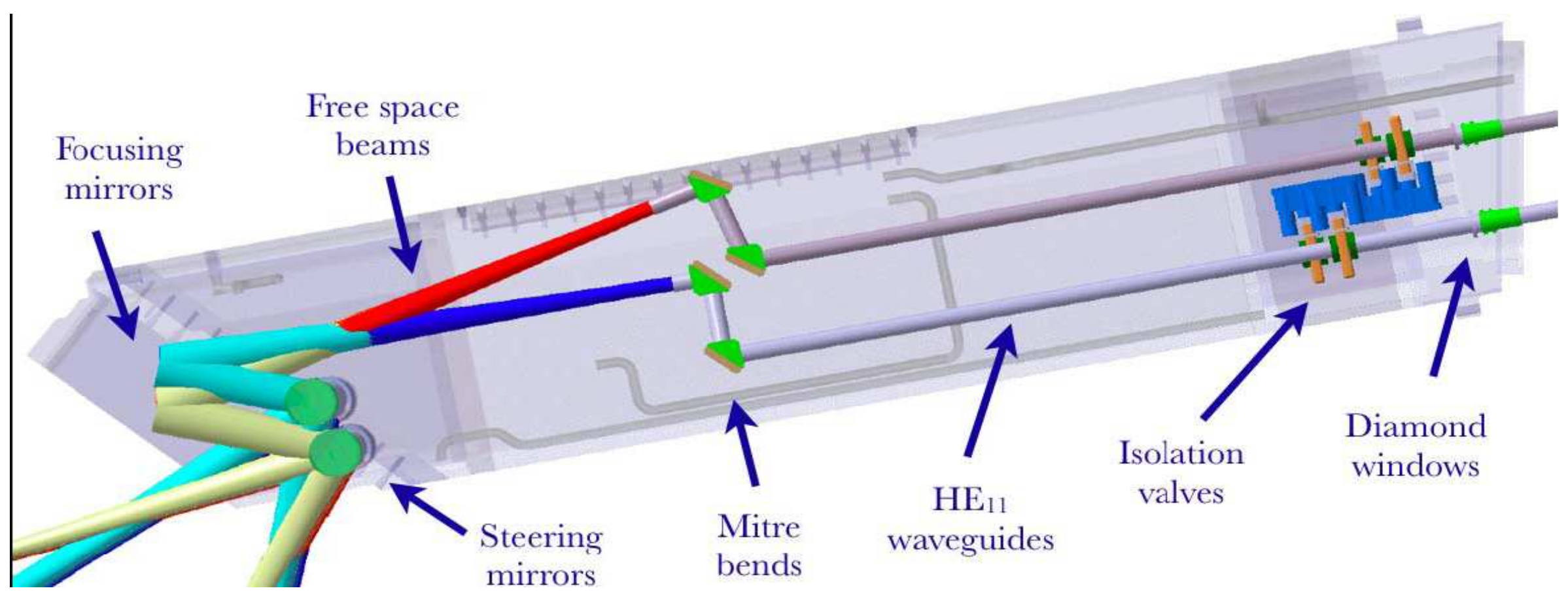






Classical lay-out

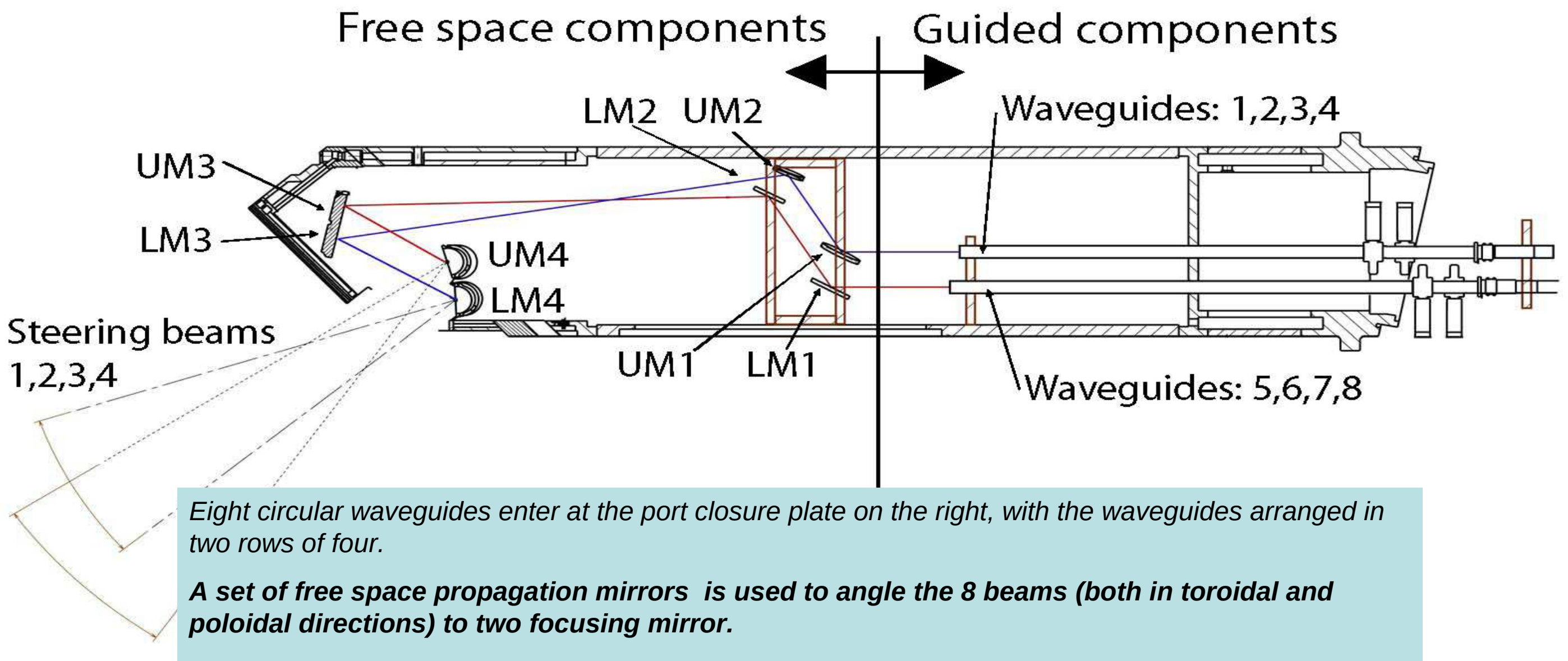


Eight circular waveguides enter at the port closure plate on the right, with the waveguides arranged in two rows of four.

A miter bend `dog-leg' assembly is used to angle the 8 beams (both in toroidal and poloidal directions) to one single focusing mirror, the incident beams partially overlap in both toroidal and poloidal directions.

The reflected beams are then directed downward to two separate flat steering mirrors, which redirect the beams into the plasma with a toroidal injection angle.

Quasi-optical lay-out



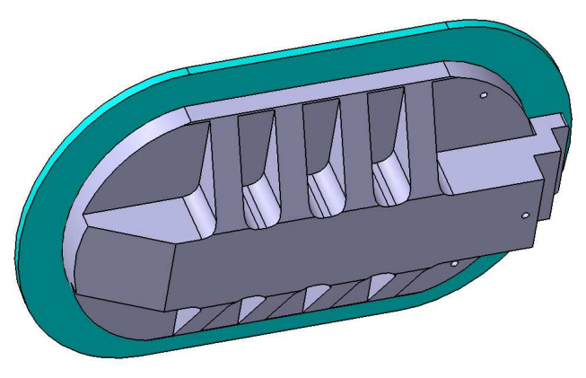
Eight circular waveguides enter at the port closure plate on the right, with the waveguides arranged in two rows of four.

A set of free space propagation mirrors is used to angle the 8 beams (both in toroidal and poloidal directions) to two focusing mirror.

The reflected beams are then directed downward to two separate flat steering mirrors, which redirect the beams into the plasma with a toroidal injection angle.

The steering mirrors (M4) are subject to electromagnetic loads from a disruption scenario and thermal loads coming from the plasma and the input mm-wave. The design is optimized for low induced currents together with high heat evacuation capacity and has been chosen as representative for prototype manufacturing (see paper presented at SOFT 2006).

Manufacturing routes

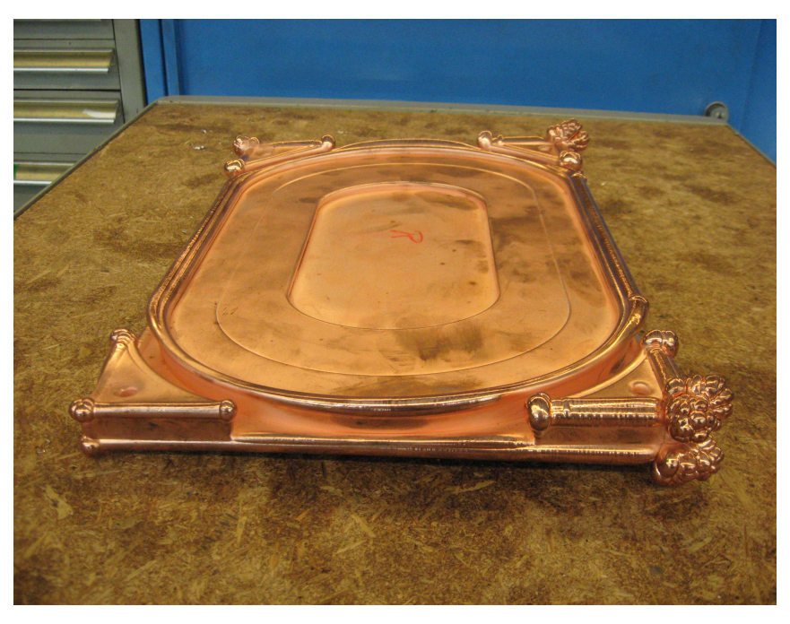


The steering mirrow view from the bottom. The thin edge not actively cooled reduces the emg forces induced during plasma disruptions

Heat load estimations for the Steering mirrors (UM4 & LM4)
Heat flux from plasma: 10 kW/m2 x (0.29 m x 0.2 m) =600 W
Volumetric heating: 1 MW/m3 x (0.29m x 0.2m x 0.03m)= ~700 W
Ohmic loss: 4 x 2 MWx 0.2%= 26.8 kW (peak 3 MW/m2)
Total heat to be removed ~ 28.1 kW

Electrodeposition

Cu Electrodeposition is the preferred option, but the size of the mirror plate (290x 200 mm) and the need of a thick Cu deposition at the center (4 mm thick) imposes a long bath time (> 250 hrs in a pyrophosphate bath) . Due to the low current density inthe center respect to the edges, first tests only reached 1.85 of 4 mm of deposition thickness at the mirror center after 100 h deposition.



The current density profile makes the deposition rather in the edges than in the center, which is the opposite of the desired Cu profile

Hot Isostatic Pressing (HIP)

Previous HIPof equivalent structures of copper - SS structures with cooling tubes have shown significant deformation of the cooling tube structure. In some cases the deformation can increase the cooling efficiency of the mirror, but in the same time change the flow properties of the cooling channel.

The pre-HIPped prototype mirror assembly consisting of the SS box, cooling tubes and copper mirror as viewed from the a) side and b) top

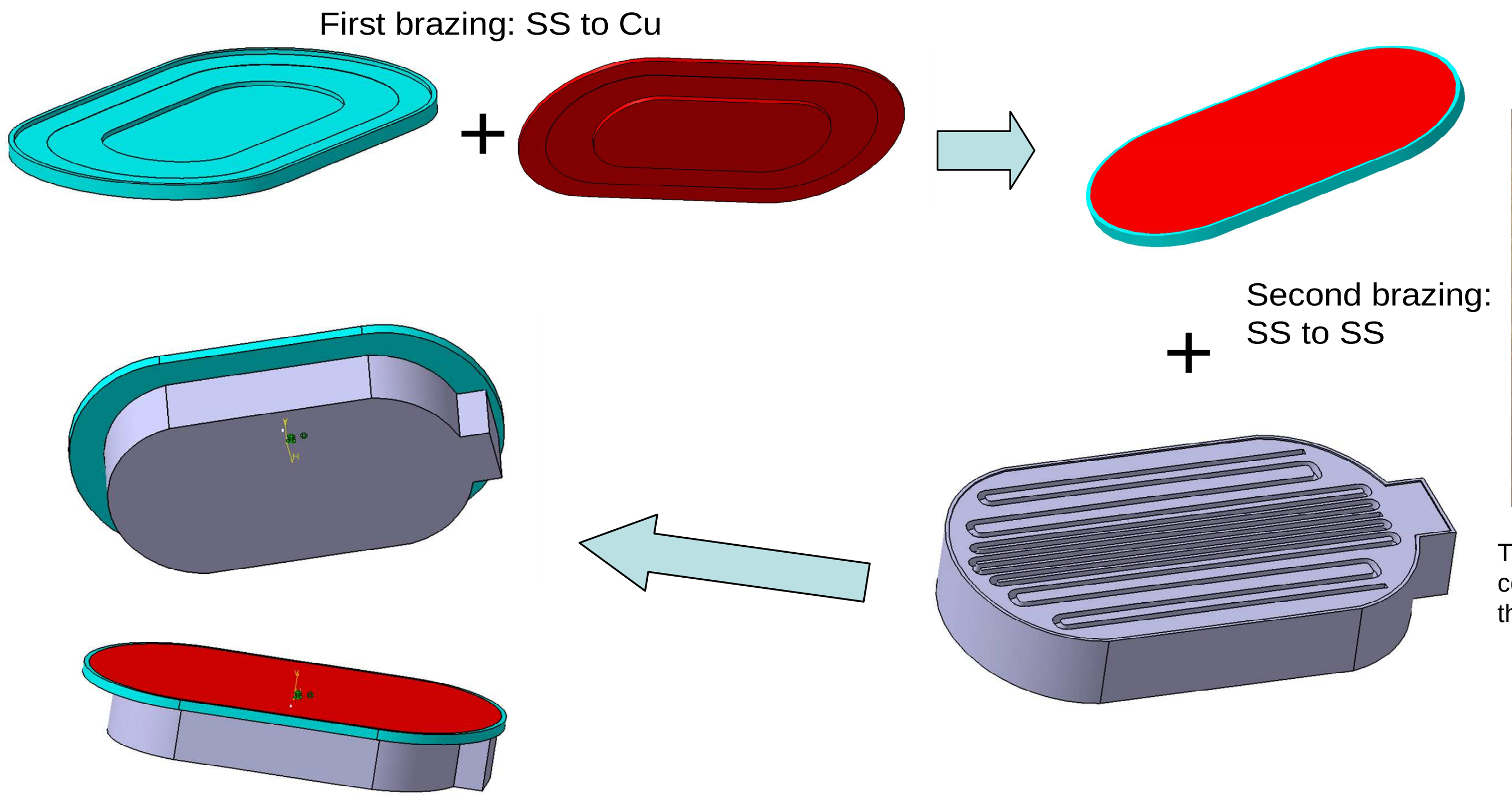
Vacuum brazing

The main steps for the fabrication of the front steering mirrors are:

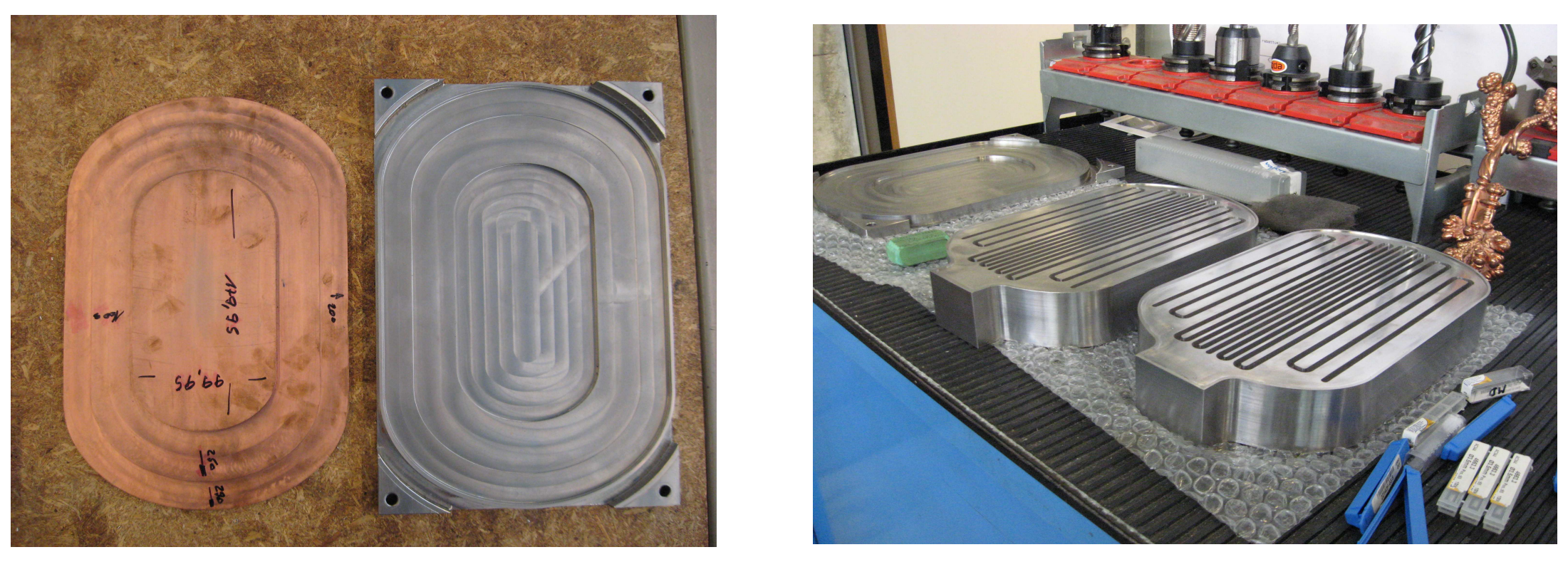
Step 1: Cutting the SS plates in the same laminar sense In order to guarantee a continuous brazing, the SS pieces to be brazed have to be cut in the same sense and follow an annealing heat treatment comprising high heating, followed by quick cooling in order to keep the homogeneous austenitic structure after return to ambient temperature.

Step 2: Starting from rough block: elliptical contour and elliptical pockets at bottom face (male of the previous piece): Important parameters of this operation are the planity (0,02 mm), parallelism and perpendicularity <0,01 mm

Also to be taken into account, the last step of machining shall be done without heavy lubricating or with non-silicone based oils, as they are difficult to remove during the previous to brazing cleaning process. In our case, in order to obtain the required planarity (and avoiding an annealing treatment of the Cu, which would make machining more difficult), an extra-thickness at the top-flat side was added.



In general, brazing defects (pockets) have two effects:
· discontinuity in the exchange of the thermal stream between the absorber and the heat exchanger body
· eventual leaks or future hot spots/crack roots.
This problem has been solved performing a solid HIPafter brazing.

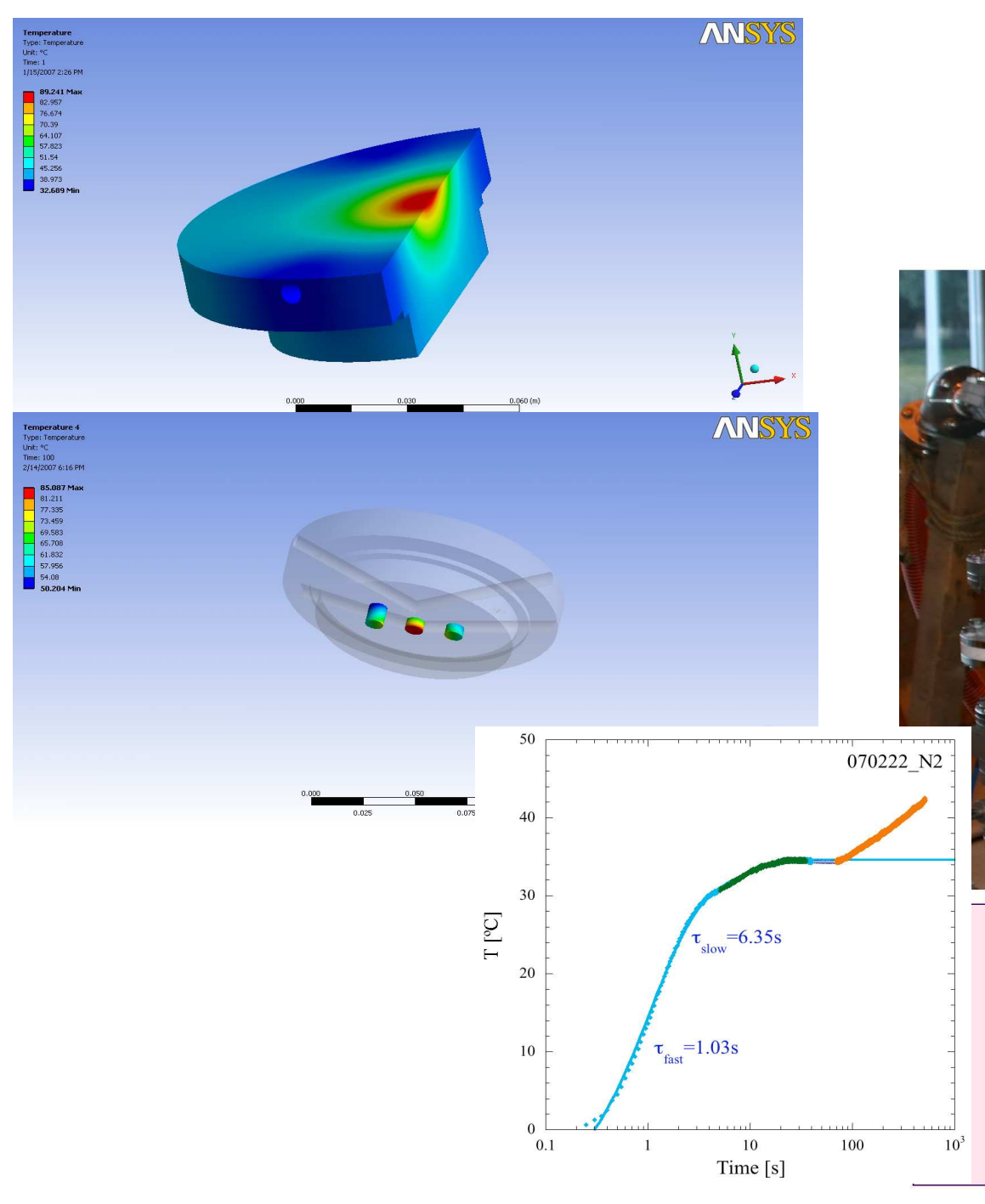


The ultrasonic tests showed that a large area (> 50% of the total surface) was poorly brazed, which could produce thermal discontinuities and hot spots due to the peaked heat deposition. Due to this the mirror was subject to solid HIP after brazing.

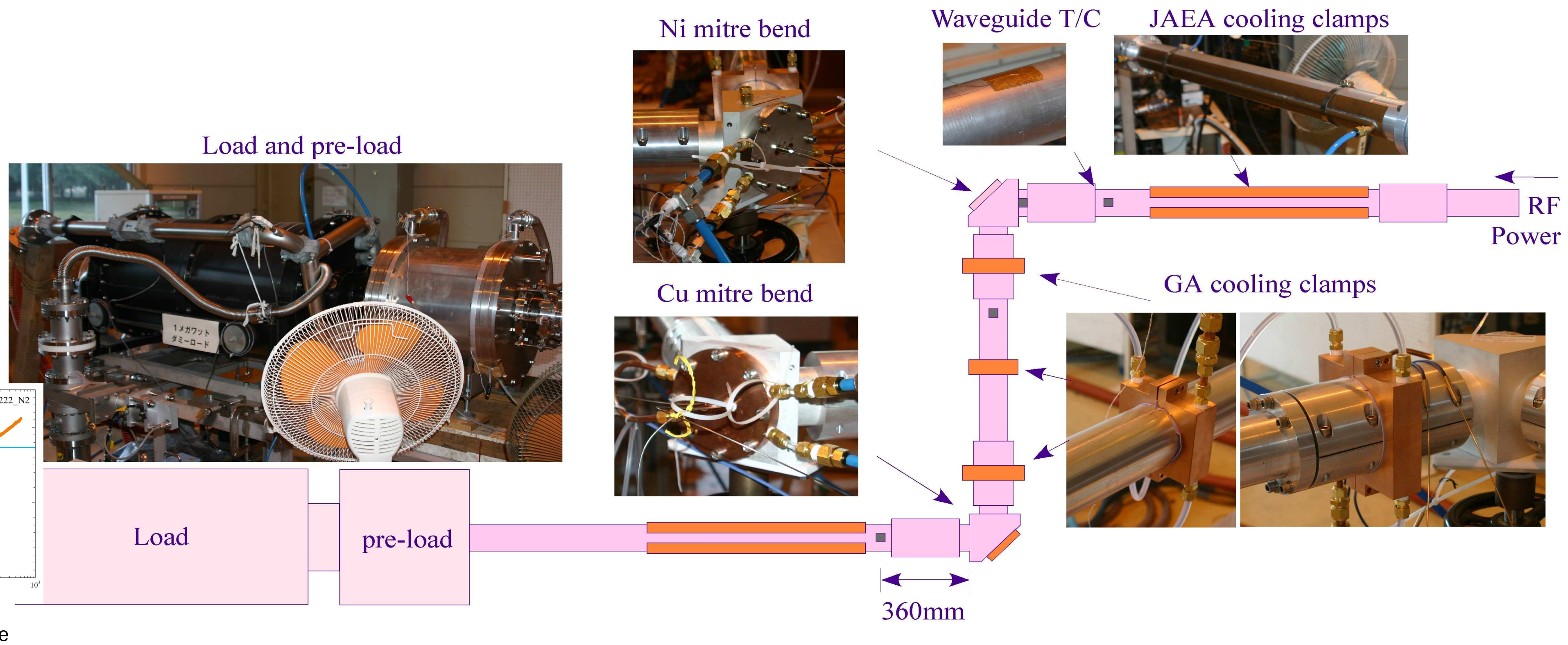
Due to the small SS thickness required below the Cu, the control of deformations during thermal & machining proccesses remains as the weak point of this manufacturing route.

Testing a high power mitrebend mirror with a low power beam

At the classical launcher lay-out, miterbend mirrors are subject to the higest peak load (3.6 MW/m2)
ANSYS simulations were carried out and the results compared to measurements performed in collaboration with GA and JAEA. Incident powers of up to 0.7MW and pulse lengths between 400 and 1'000 s. were achieved.
The percentage of absorbed power was 0.22% for the copper and 0.42% for the nickel, which is approximately a 30% increase over the theoretical and low power absorption coefficients.



Temperature distribution from ANSYS and time constant (ANSYS/tests)



Conclusions

- Brazing + Solid HIP shows to be a powerful method to join large & flat surfaces, as required for the steering mirror, but the control of the geometry remains as the key aspect.
- Electroplating would be the preferred solution if thick large & deposition issues are solved
- Tests performed for the mitrebend mirror showed that a 2MW input beam can be simulated at low power depostion increasing absorption artificially with the use of a thin Ni coating sprayed on the mirror surface.

Acknowledgements

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