About treading the path from a high temperature brazed beryllium-copper component to an electro-formed copper-component for AGIPD @ European XFEL.

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DESY

1) Introduction

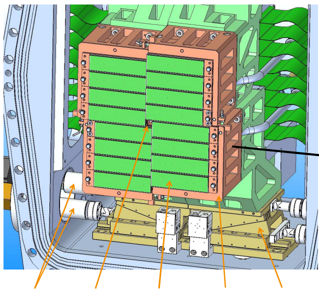
more about ***AGIPD***
and see poster #108

This poster presents the development from a high temperature brazed copper-beryllium cooling block to an electro-formed one considering material, cooling efficiency and manufacturing technology. The requirements are:

- 4 AGIPD sensors per cooling block
- total heat load = 200 W
- - 20°C sensor temperature
- non-uniformity of surface temperature less than 5 K
- coolant = silicone oil
- cooling of electronic components with return flow
- operation in high vacuum

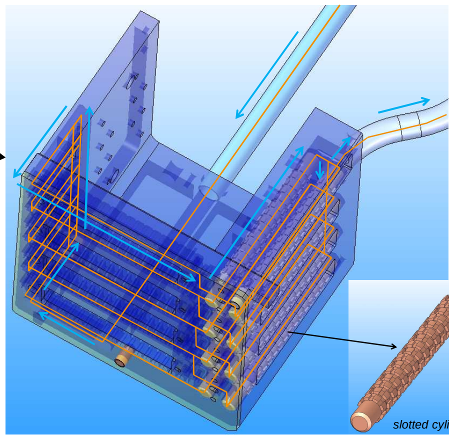
First design was for a cooling block made out of beryllium-copper, with highly complex milled cooling channel structure. However, vacuum tight high temperature brazing of the single pieces turned out not to be processible.
Second design substitutes most of the sophisticated cooling channels for inserted pins. The cooling capacity was verified by FE-simulations, and Cu-PHCE will be used instead of beryllium-copper, the knowledge of high temperature brazing of Cu-PHCE being available at DESY.
The apprehension that high temperature brazed copper could become too soft lead to a **third design** utilizing electro-forming, which is presently in production.

2) What‘s it all about?



The detector is divided in four quadrants. Each quadrant is mounted on a motion stage. With help of actuators the quadrants can be moved horizontally and vertically. This allows centered hole sizes of nearly 0 mm up to 27 mm and a number of other arrays.
Since the quadrants are independently moveable, all cooling blocks need an independent cooling circuit.

3) How does the coolant flow?



Inlet and outlet are on the back side of the cooling block. The silicone oil flows to the front and is then distributed to all cooling channels beneath the surface of the cooling block by a system of jointing deep bores.

After cooling the sensor‘s rear sides, the return flow is split to eight deep bores with slotted cylinders in. Those end up in one deep bore that leads to the outlet.

What are the slotted ones for?
With the return flow of the silicone oil, electronic components on the PCB are cooled. This happens via a copper adapter between cooling block and the PCB (PCB and adapter not shown in picture). Therefore it‘s important to keep the flow turbulent to achieve low temperatures as best as possible.

4) Original plan

Material: beryllium-copper
- Material with good thermal conductivity (min. 300 W/mK) is needed.

Geometry: elaborate thin cooling channels in jacket, 3 mm thick cover plate
- Mazy cooling channel geometry with sharp edges to get the silicone oil flow turbulent

Joining process: high temperature (HT) brazing in vacuum furnace
- Device must be operated in high vacuum. Oil pressure will be around 4 bars.

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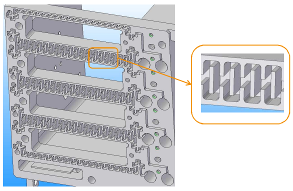


5) First tests (at DESY)

Tests with following brazing materials / temperatures:

- L-Ag 72 (Ag, Cu) at 780°C
- SCP1 (Ag, Pd, Cu) at 815°C
- CB4 (Ag, Cu, Ti) at 850°C

After brazing the pieces were connected, but in case of stainless steel ←→ BeCu even not liquid tight.

In the course of cause study it turns out, that:

- the drawing demanded for „beryllium-copper“
- the order was for CuBe2 (160 W/mK; melting range of 870 – 970°C)
- but foreseen was CuNi2Be (300 W/mK and melting range of 1000 – 1030°C)

6) Research, new ideas, other materials, decision

HT brazing of beryllium-copper
Research didn‘t reveal a possibility for successful, vacuum tight brazing of beryllium-copper. The reason for the difficulties appears to be rooted in the high reactivity of beryllium with other metals already at low temperatures. Brittle intermetallic phases are formed, that prevent to form vacuum tight brazing joints. [1] Probed techniques to avoid this effect seemed to be too time-consuming.

Laser welding of beryllium-copper
It‘s possible, but was dismissed because of the complicated geometry of the weld seam.

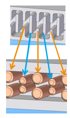
Alternative materials, HV compatible, HT brazable

Glidcop Al-15	310-340 W/mK	1075-1085°C MR [2]
CuCrZr	365 W/mK	1083°C MP [2]
Cu-PHCE	400 W/mK	1085°C MP [3]

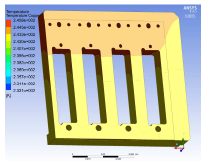
Decision
Decision for 3D-forged Cu-PHCE, because

- it is specified by DESY for use in vacuum [3]
- know-how for HT brazing of Glidcop or CuCrZr is not in-house, as well as wrought material is not.
- know-how for HT brazing of Cu-PHCE is available in-house, but also outside
- 3D-forged wrought material is in stock

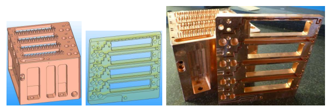
7) Simplified geometry



Milled cooling channels replaced by similar layout of cylindrical pins to achieve similar turbulent flow. Milling time reduced to one-third by this measure.
Extended wall thickness from 1.2 mm to 2.5 mm to gain brazing surface.



New simulations done to check effectivity of new geometry.
ΔT on surface = 2,5 K;
[ΔT of cooling liquid = 12,7 K (not shown)]



Cooling channels moved from jacket to the cover in order to have a 10 mm thick copper piece instead of only 3 mm. Bores for pins in jacket.

8) High temperature brazed cooling block

First brazing step:

- 2 tubes stainless steel, 2 small covers Cu-PHCE
- CuSn12 1020°C 25 minutes

Second brazing step:

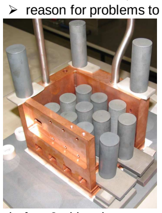
- 1 cover Cu-PHCE
- L-Ag 72 850°C 15 minutes
- seriously leaky, pieces heavily deformed

First repair:

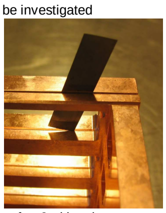
- L-Ag 72 840°C
- much better, but still 3 leaks

Repair steps #2, #3, #4:

- with L-Ag 72, without brazing material, at 840°C, at 835°C, for 20 minutes, for 15 minutes …
- still 2 small leaks, 10^{-6} mbar can be achieved
- reason for problems to be investigated

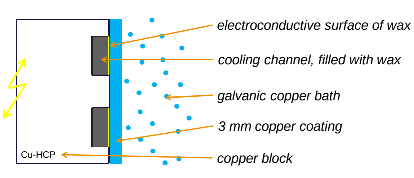


before 2nd brazing



after 2nd brazing

9) A more than 100 year old, new technique: electro-forming [4]



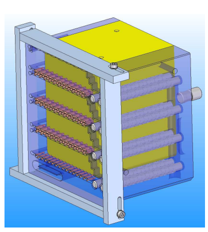
Electro-forming for the AGIPD cooling block
Instead of closing the cooling channels and deep bores by HT brazing, the copper will be deposited by a galvanic process. To do so:

1. All cavities will be filled with a wax.
2. The surface of the wax must be made electroconductive.
3. Then the cooling block will be put in the galvanic bath for ~3 days.
4. After the process the cooling block will be warmed up to 180°C to melt the wax out.
5. Now the electro-formed surfaces can be facemilled, additional geometry can be manufactured (bores, threads, cutouts).

What’s the advantage compared with high temperature brazing?
The copper is only heated to 180°C, not to 1020°C. At 180°C copper doesn’t change structure and doesn’t get soft.

More than 100 years old, but new?
At the end of the 19th century this technique was the only possibility to manufacture seamless copper tubes: take a tree trunk, turn it for plane surface, paint it with tar pitch, wrap lead foil around it and put the whole thing in a copper bath for a long time (months).

Generally speaking the knowledge of this technique is not popular, even though certain components can't be produced alternatively. [4]



10) Conclusion

Since chipping of ambitious copper geometry is very challenging, the cooling block out of Glidcop or CuCrZr might have been the better choice in terms of manufacturing.
Unexpectedly brazing of the copper block turned out to be a problem. Investigation just started.
Discussions about the copper brazing are very welcome.
If knowledge of high temperature brazing of copper-beryllium alloys would be available in the community, it would be highly appreciated to learn about that.

11) References

[1] Armor and heat sink materials joining technologies development for ITER plasma facing components, Journal of Nuclear Materials 283-287 (2000)
[2] Proposal company Reuter Technologie, Alzenau, Germany
[3] Technische Spezifikation: Halbzeug für die Fertigung von Absorbern, Blenden, Koppelzellen und Kollimatoren aus Kupfer; Nr. Vakuum 009/2013
[4] Company Galvano-T, Windeck, Germany, www.galvano-t.de

12) Acknowledgements

U. Naujoks, Co. Körber & Körber (Germany), Co. Galvano-T (Germany), FS-DS group members

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Material encyclopedia

CuBe2	= CW101	= C17200
CuNi2Be	= CW110	= C17510
Glidcop Al-15		= C15715
CuCrZr	= CW106	= C18150
Cu-PHCE	= CW022	= C10300
Cu-HCP	= CW021	= C10300