Brazing and Vacuum Brazing

Workshop on Pipe Joining Techniques for the ATLAS and CMS Tracker Upgrades

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Soldering/Brazing

Joining of two components with a brazing filler material (BFM), whose liquidus temperature is below the melting point/range of any joined component

→ No melting of the component material

Soldering	Brazing
T_{l_FM} < 450°C	T_{l_FM} > 450°C

Soldering of stainless steel/copper:

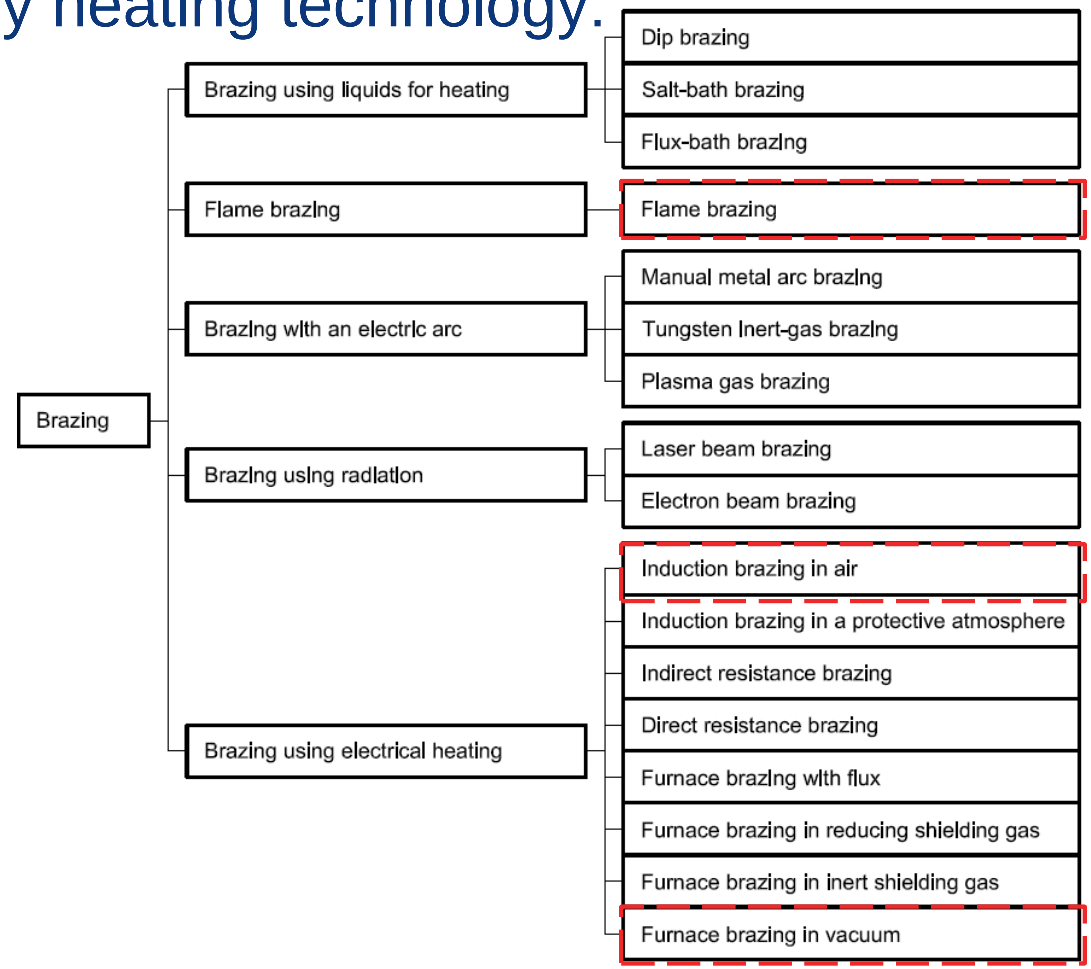
- Typically used SnAg3.5 (ISO 9453 S-Sn96Ag4; T_{liq} = 221°C), R_m ≈ 25 MPa

Brazing at high temperature of stainless steel/copper:

- Typically Ag-based filler metals, i.e. AWS BAg-7 (T_{liq} = 650°C), R_m ≈ 400 MPa

Brazing Technologies

Classified by heating technology:



ISO 857-2

Brazing Technologies

Manual Brazing at Atmosphere

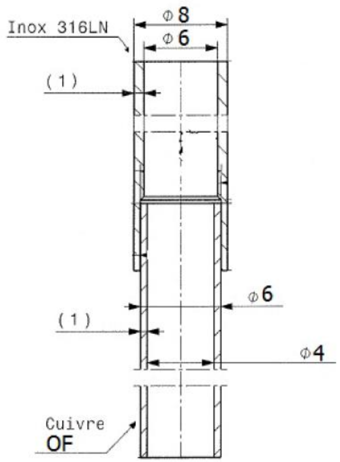
- Heat Sources: Flame Torch (Acetylene), Induction, (Plasma, Arc…)

- Working Temperature of common filler metals: 600-800°C
  - Steel/Stainless Steel, Copper Alloys: I.e. AgCuZnSn (650°C,)
  - Application of flux necessary to remove surface oxides
  - Brazing of tube fittings:

    Lap joints (5-10 mm overlap, rule is min. 3x t_{wall})

    Gap clearance of joint ca. 0.1-0.2 mm on diameter

    Manual process, individal qualification of personell necessary



Brazing Technologies

Manual Brazing at Atmosphere

Preparation of components:

- Cleaning/Etching (Surface treatment)
- Application of flux on brazed surfaces
- Assembly and possible inertisation for tubes (Ar-flush inside) to avoid oxidation on the inner wall
- Brazing material normally applied as rods/wires
- Brazing with avoiding overheating (can change viscosity of filler, incrusting of flux)

Post treatment:

- Cleaning/removal of flux from components. Mechanically and cleaning with detergent/warm water (surface treatment)
  - Flux contains components as KF, Borates etc. -> **corrosive!**
- Visual inspection

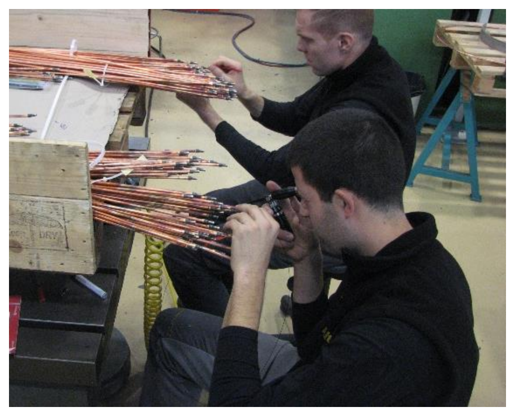
Precausions:

- Ventilation of fumes (flux) which can condense on surrounding surfaces
- Environment of torch flame

Brazing Technologies

Manual Brazing at Atmosphere

Joining of ss-sleeves to 5 m-Cu-OF tubes



Visual inspection (endoscopy)

Qualification samples

Vacuum Brazing

General features of vacuum brazing

Assemblies brazed in vacuum chambers (10^{-2} mbar…10^{-7} mbar)

Parts have to be clean (outgassing, pollution) and principally oxide-free (wetting properties)

Heating performed by radiation, induction, (laser, microwave, EB..)
→ most common technology: vacuum furnaces with resistor heaters

Use of vacuum compatible filler-materials (no volatile components at corresponding brazing temperatures)
→ most common BFM for vacuum brazing:

Silver-Copper alloys (780-950°C)
Gold-Copper alloys (950-1050°C)
Nickel-based alloys (1000-1200°C)

Vacuum Brazing

Advantages of vacuum brazing

No flux used/necessary

no residual fluxing agents have to be removed/cleaned after process, no risk of corrosion induced by remaining flux (mostly acids containing fluorides and/or chlorides)

Particular materials can be de-oxidized under vacuum and high temperature (i.e. copper)

Depending on thermodynamic stability of the specific oxide-scale

Brazed parts stay clean and no oxidation occurs during brazing process

Besides flux has not to be removed, the surfaces stay clean and metallic (applications for UHV and RF-cavities)

Specifically for furnace brazing:

Low distortion of assembled pieces due to homogeneously heated parts

High precision assemblies maintain their geometry and alignment

Vacuum Brazing

Disadvantages of vacuum brazing

General high costs:

- vacuum furnace equipment
- only batch production possible
- preparation of all assembly parts necessary (surface treatm.)
- vacuum grade filler materials more expensive
- long brazing cycles (up to few days from cold to cold)

Specifically for furnace brazing:

Complete assembly has to be heated

Due to high brazing temperatures material properties will be influenced by the heat treatment (annealing, grain growth, diffusion/precipitation)

Complex preparation

Fixed placement of filler material, fixed positioning of assembly parts has to be assured

Vacuum Brazing

Vacuum Furnace Brazing at CERN

- Cooled wall furnaces with ss-vacuum chamber
- HV-pumping groups to reach vacuum range of 10^{-6} mbar (oil-diffusion or turbomolecular pumps)
- All-metal hot zones with molybdenum resistive heaters and Mo/ss-thermal screens
- Horizontal and vertical configurations
- Surveillance of brazing processes with load thermocouples and furnace windows
- Max. temperatures up to 1300°C/1600°C

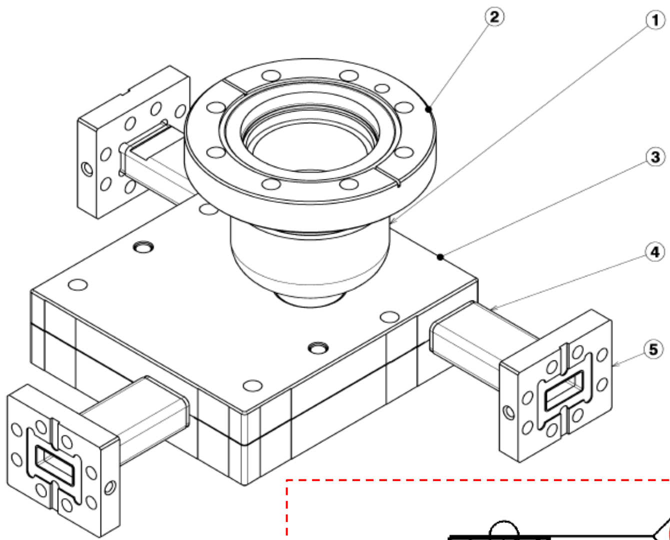
Production cycle of vacuum brazed parts

Design of vacuum brazed joints

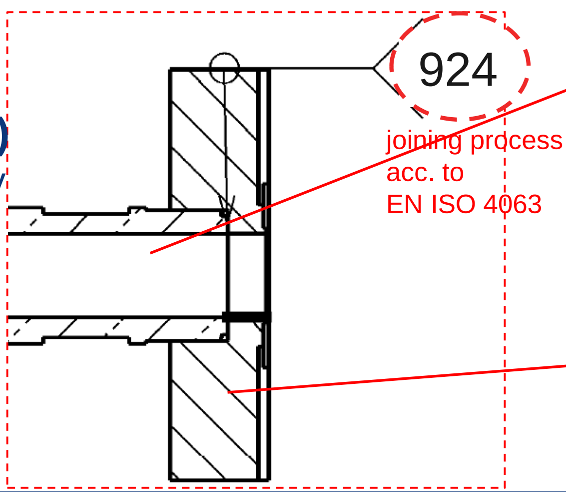
- Materials choice has to be -besides functional requirements- as well in accordance with vacuum brazing needs, i.e.:
  - Copper with low oxygen-content mandatory (OF/OFE copper)
  - Thermal stress release of materials must be considered especially for high-accuracy (if necessary, usage of 3D-forged blanks (OFE-copper, 316LN stainless steel)
  - Materials/alloys must not contain volatile elements (high vacuum at brazing temperature), i.e. Zn, Mn, Cd etc…
- Adequate gap-clearance must be ensured by design and tolerances
  - Depending on the used BFM, certain gap clearances and surface roughness values for the areas to be brazed must be kept
  - For flat joints, planarity has to be tolerated according to max. gap requirements
- Design features for placement of BFM
  - Depending on form of applied BFM, i.e. wires (placed in grooves, chamfers), foils or paste
- Special cases
  - Metallization coatings for Al_2O_3-ceramics
  - Ni-plating etc…

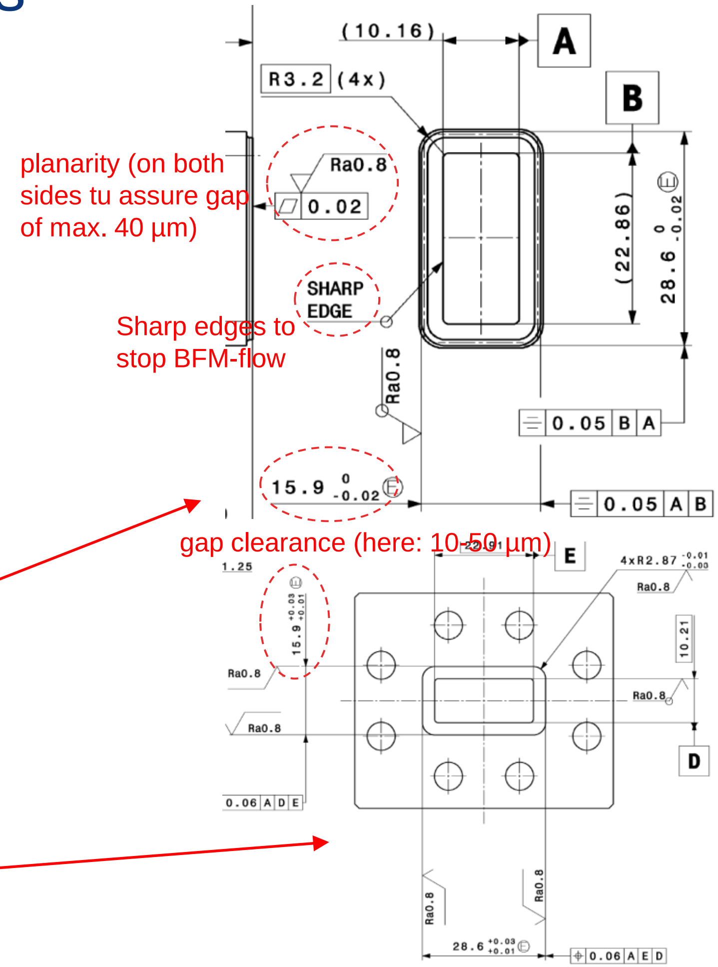
Production cycle of vacuum brazed parts

Design of vacuum brazed joints



RF-switch (CLIC)
Copper (OFE) cavity with ss-flanges for pumping and waveguide-connection





Production cycle of vacuum brazed parts

Machining/tolerance requirements

- Gap tolerances have to be kept during brazing process (heat treatment)
  - Depending on part-geometry and material type, stress releasing heat treatments have to be foreseen before final machining
  - Example: Joint between metal-ceramic: Calculation of gap during brazing necessary. Small diameters may maintain a sufficently small gap at the brazing temperature
- Machining between different brazing steps should be avoided
  - Risk of polluting parts surface makes subsequent cleaning and pickling necessary
  - In some cases, intermediate machining can't be avoided
    - → Use of ethanol as lubricant for machining copper parts brazed with Ag-alloys
    - → Mask brazed joints and sensitive surfaces during machining and surface treatment

Production cycle of vacuum brazed parts

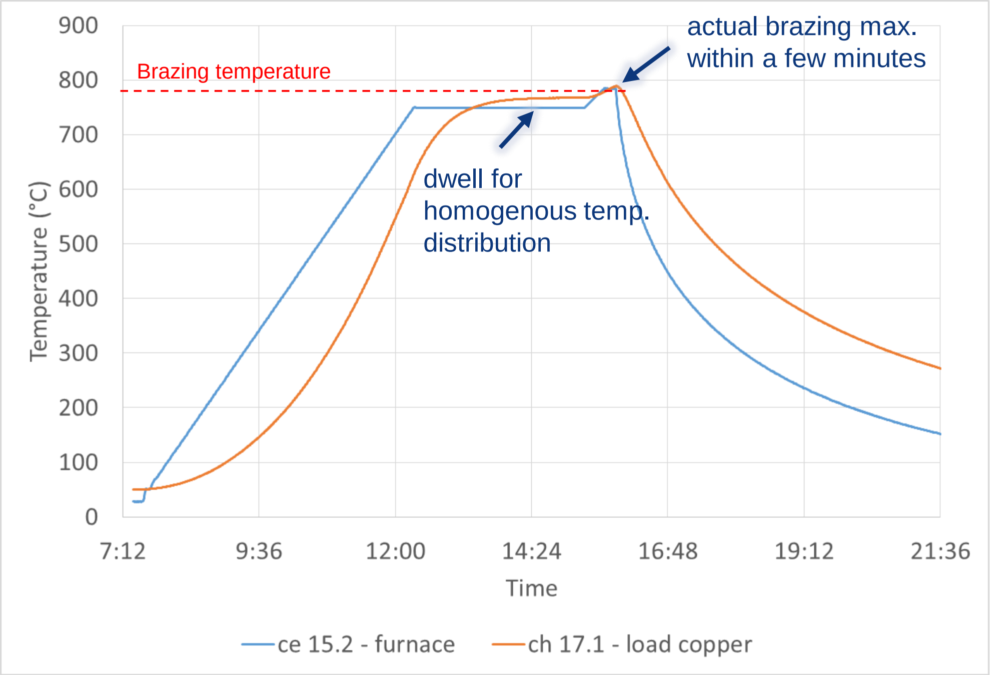
Surface treatment before brazing

- Due to the treatment under vacuum, parts have to be at least entirely degreased before brazing steps
- Oxide scale on metallic components have generally to be removed (i.e. by pickling)
- Special cases for (additional) surface treatments:
  - **Nickel-coating** (wood's-strike) in ss-components for brazing with Ag/Cu-alloys (diffusion boundary, improved wettability)
  - **Silver-coating** (10-15 µm) for diffusion-brazing with copper
  - For some metals (i.e. Nb) special care has to be taken according to fast oxidation at ambient conditions (-> brazing within ca. 24 h after pickling)

Production cycle of vacuum brazed parts

Assembly and brazing procedure

- Vacuum brazing cycle
  - Loading furnace and pumping to high-vacuum at RT
  - Heating-program for brazing



Examples for brazed parts at CERN

Copper/Copper - Stainless Steel/Copper

SS-flanges on copper tubes for LSS-chambers

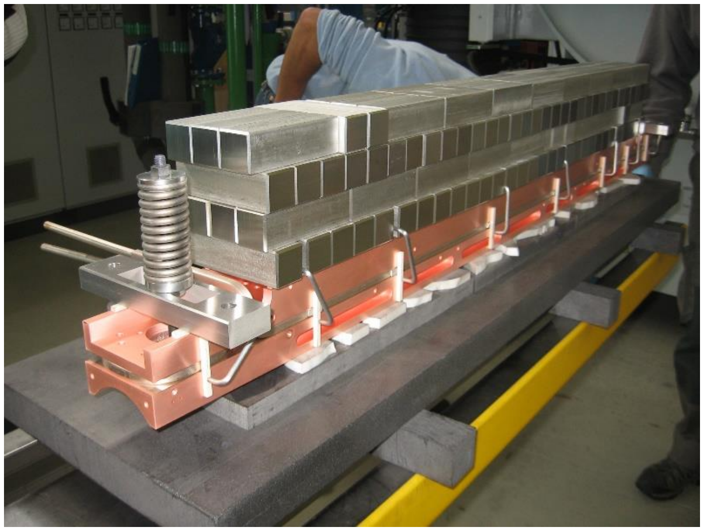
Septum coil – copper coil integrally joined with copper- and ss-tubings

Typical filler materials used:

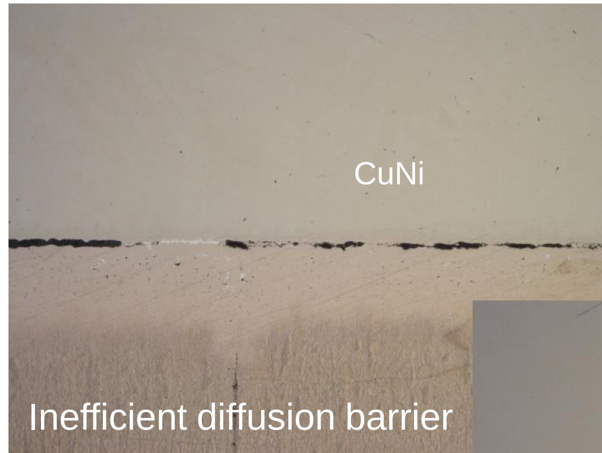
Ag72/Cu28 (eutectic, T_{braze}: 780°C)
Ag68/Cu27/Pd5 (T_{braze}: ca. 815°C)
Ag58/Cu32/Pd10 (T_{braze}: ca. 855°C)…

Examples for brazed parts at CERN

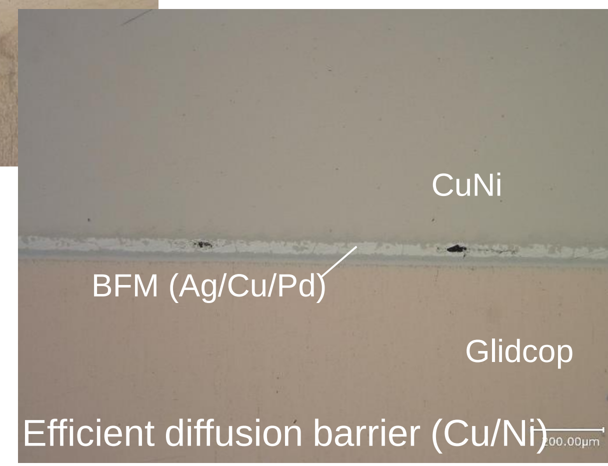
Glidcop®-parts



Collimator Jaw TCTP



(source: EN-MME-MM, M.S. Meyer)

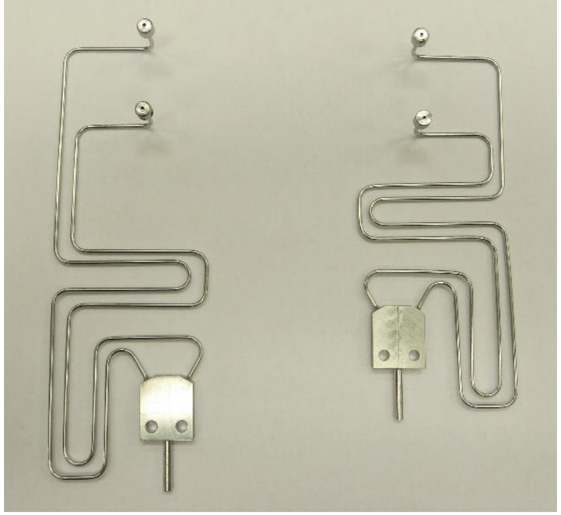


Glidcop demands special attention due to high diffusion coefficient of Ag

For brazing with Ag-based filler materials, a diffusion layer has to be applied. This can be achieved by certain combinations of electroplated copper (H_2-diffusion) and nickel (barrier for Ag).

Examples for brazed parts at CERN

Stainless Steel, other alloys



Ss-tubes for NA62-detector cooling circuit

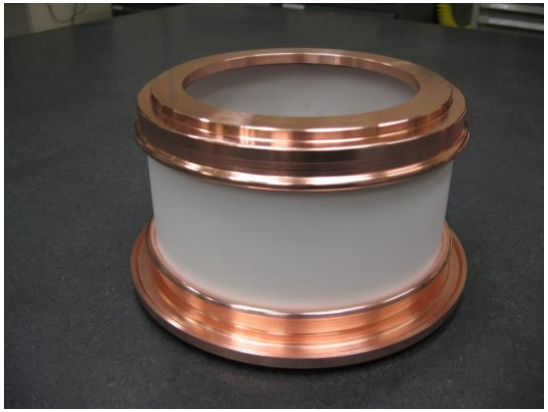
Vacuum chamber (Inconel)

Typical filler materials used:

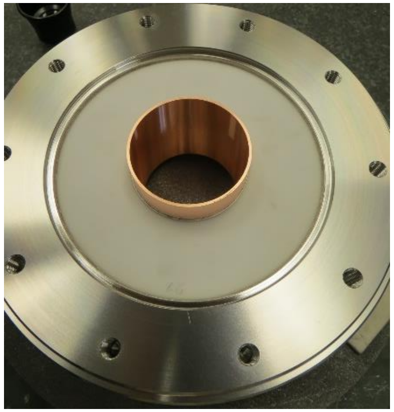
Nicrobraz (Ni-based BFM, T_{braze}: ≥1020°C)
Ag-based BFM as well usable (T_{braze}: 780-950°C)

Examples for brazed parts at CERN

Ceramic Brazing



Copper rings in Al_2O_3 for LHC-couplers



Al_2O_3 RF-window in Ti-flange and Cu-tube for coupler

Kovar/Monel-plugs on ceramic (insulators)

Active brazing of Kovar-rings on AlN-tube (Linac4-source)

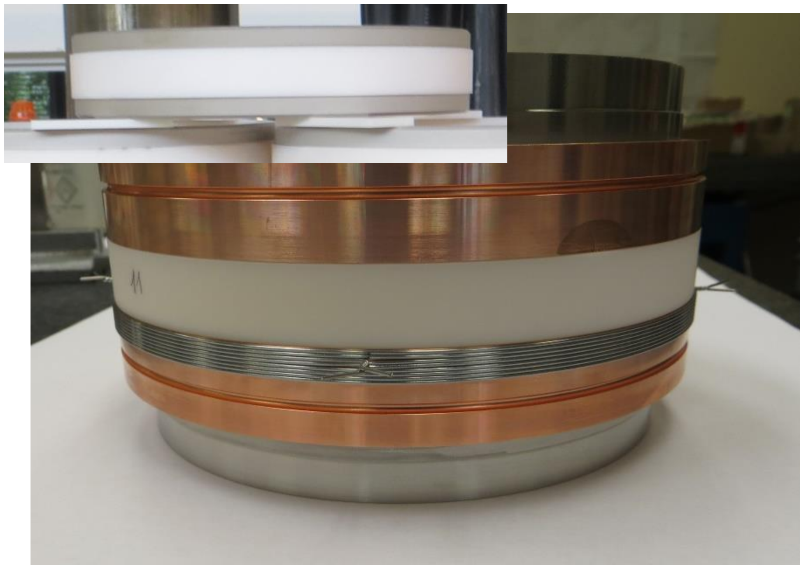
Typical filler materials used:

Ag/Cu-alloys for metallized ceramics

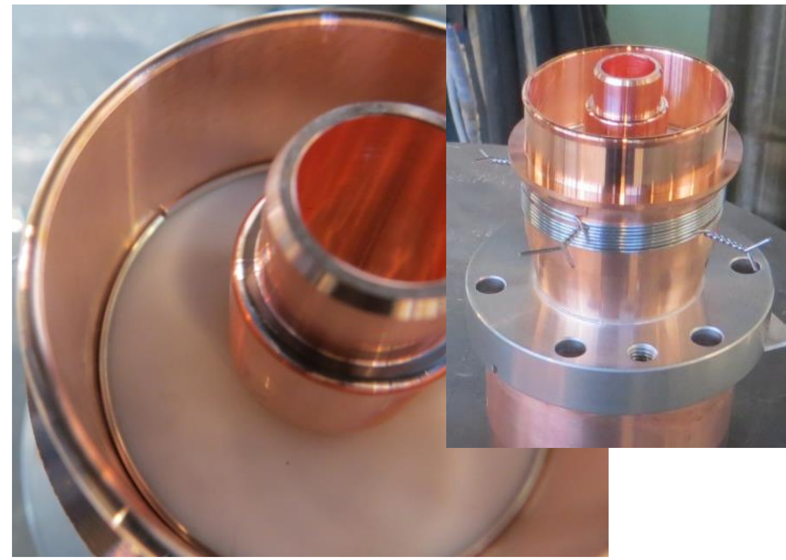
Active brazing filler materials - i.e. Cusil-ABA® (Ag63Cu35Ti2, T_{braze}: ≥850°C)

Examples for brazed parts at CERN

Ceramic Brazing



Amagnetic collars for BCT



HOM feedthrogh

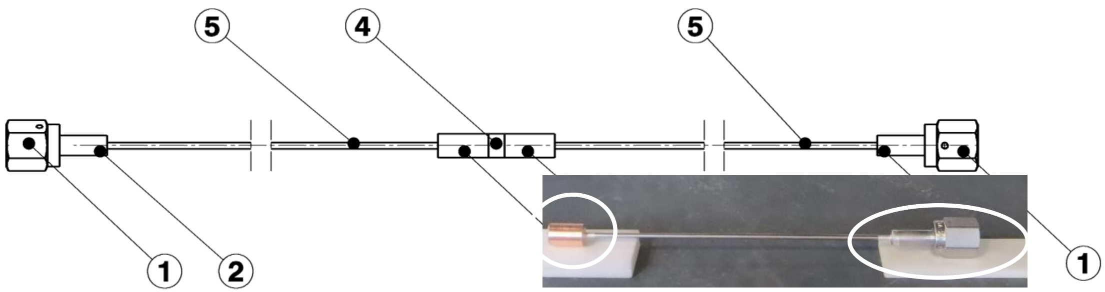
Diffusion brazing of copper/Al_2O_3-joints

Silver deposition on metallized surface of ceramic component (ca. 15 µm)
Copper/Silver creates under contact eutectic liquid phase that joins the interface (external copper parts have to be deformed by i.e. Mo-wires)

Assembly of Capillaries for CMS Pixel Upgrade

Vacuum Brazing Assembly for Lines with Dielectrics

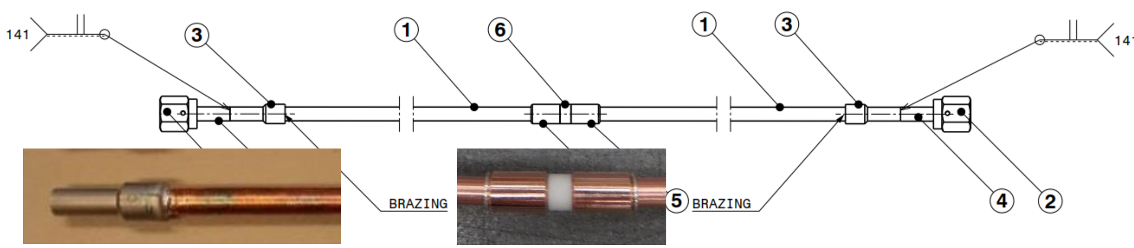
Inlets by ss-capillaries (Ø$_o$1.6 and Ø$_o$2)



ss-copper transition for dielectric

ss-ss direct brazing of VCR-connector to capillary

Return-pipes in copper (Ø$_o$5)



ss-copper transition for subsequent orbital welding

Brazingto ceramic with Cu-sleeves

Assembly sequence:

1. Brazing copper sleeves to capillary/tube
2. Brazing of VCR-connector (with nut) or welding fitting
3. Final assembly with dielectrics

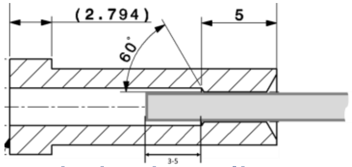
Usage of three different BFM with decreasing metling range

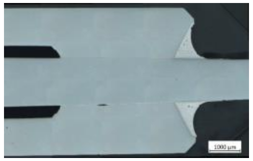
Assembly of Capillaries for CMS Pixel Upgrade

Vacuum Brazing Assembly for Lines with Dielectrics

Capillary to VCR-connector

- Avoiding of BFM close to opening (risk of plugging by filler)

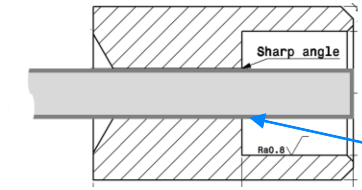




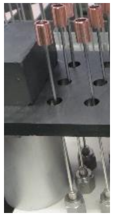
- Limited quality control possible, qualitfication samples with metallographic evaluation

Copper-ss transitions

- Metalluric control and US-inspection on qualification samples

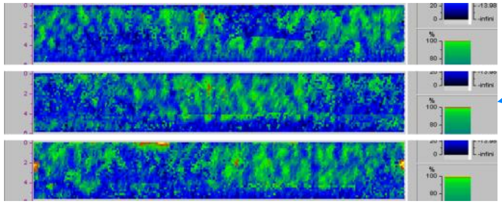


visual control possible during assembly



Real parts due to size not controlable by NDT

- ➢ Visual check
- ➢ Pressure/leak-check (100%)



US-imaging of SS-Cu transition

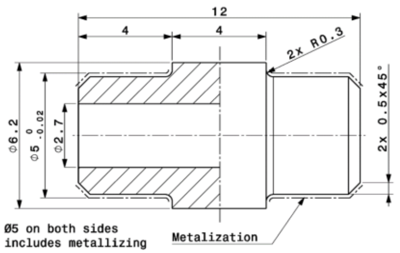
Qualification samples for US-inspection

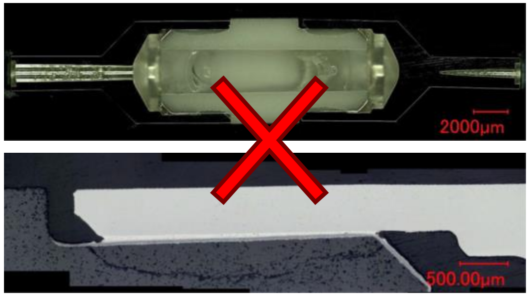
Assembly of Capillaries for CMS Pixel Upgrade

Vacuum Brazing Assembly for Lines with Dielectrics

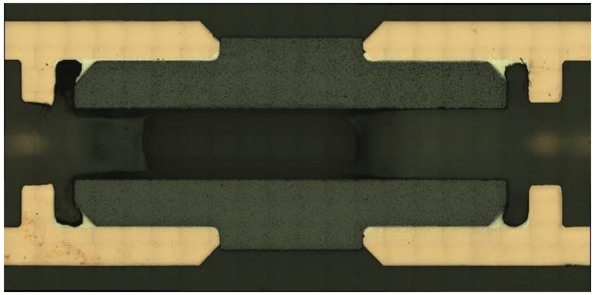
Ceramic to metal-transitions

- Problematic of mismatch in CTE -> Copper/Al_2O_3 up to Ø5 mm feasable with AgCu-alloys
- Thermal stresses on ceramic introduced by metallic part -> soft state of copper compensates stresses by plastic deformation
- Ceramics: Metallization on brazing interface necessary. Mo/Mn+Ni-coating ralized by suppliers





Direct joining on ss-sleeves -> Cracking of ceramic!



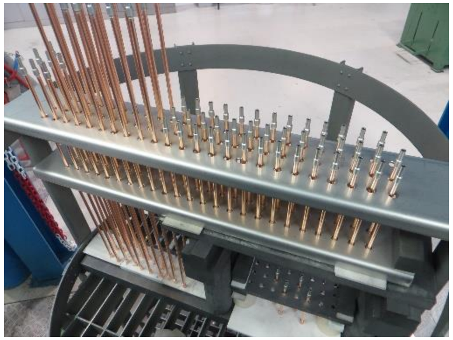
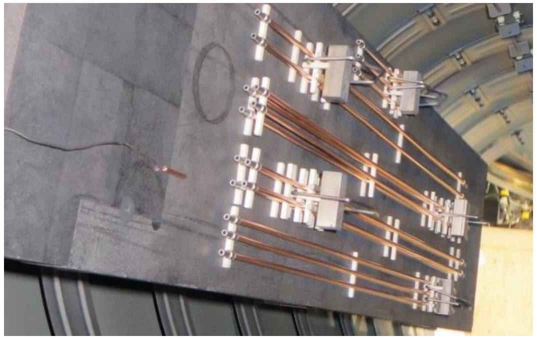
Copper transitions maintain ceramic intact due to plastic deformation/lower youngs modulus

Assembly of Capillaries for CMS Pixel Upgrade

Vacuum Brazing Assembly for Lines with Dielectrics

Some Conclusions/Important points

- Tight tolerances between sleeves and tubes have to respected to allow reliable bonding – max. allowalble ga clearance of ca. 50 µm for most common BFM (siler based)
- Surface treatment for joining surfaces and cleanliness for vacuum heat treatment mandatory
- Components used have to be HV-compatible
- Limited quality control due to small assemblies/bad accessablity -> qualification campain
    - US-Inspection
    - Metallurgical investigation
- Proof tests by leak and pressure tests for 100% of the components strongly advisable

Vacuum Brazing Workshop at CERN

Equipment

XERION2 (all metal)

- working useful space:
  - Diameter (mm): 450
  - Depth (mm): 1600
- Temperature:
  - Max (°C): 1300
  - Normal working temperature range (°C): 200-1300
- Ultimate vacuum (mbar): 10^{-6}
- Charge capacity (kg): 450

TAV (all metal)

- working useful space:
  - Diameter (mm): 650
  - Depth (mm): 2000
- Temperature:
  - Max (°C): 1350
  - Normal working temperature range (°C): 200-1200
- Ultimate vacuum (mbar): 10^{-7}
- Charge capacity (kg): 750

Vacuum Brazing Workshop at CERN

Equipment

PVA (all metal)

- working useful space:
  - Diameter (mm): 650
  - Height (mm): 1750
- Temperature:
  - Max (°C): 1350
  - Normal working temperature range (°C): 200-1200
- Ultimate vacuum (mbar): 10^{-7}
- Charge capacity (kg): 750

DVM (all metal)

- working useful space:
  - Diameter (mm): 400
  - Height (mm): 500
- Temperature:
  - Max (°C): 1600
  - Normal working temperature range (°C): 350-1300
- Ultimate vacuum (mbar): 10^{-7}

Vacuum Brazing Workshop at CERN

Equipment

VAS (all metal)

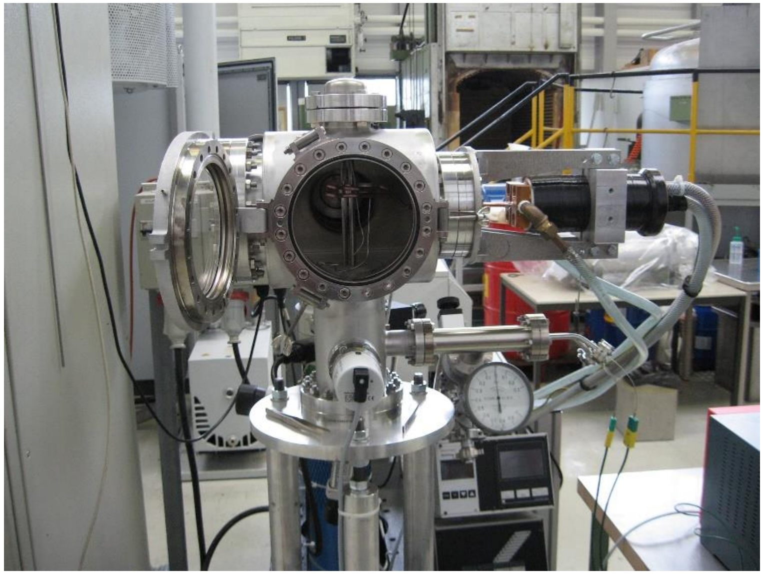
- working useful space:
  - Diameter (mm): 120
  - Height (mm): 200
- Temperature:
  - Max (°C): 1600
  - Normal working temperature range (°C): 200-1200
- Ultimate vacuum (mbar): 10^{-8}

XERION (all metal)

- working useful space:
  - Diameter (mm): 400
  - Height (mm): 500
- Temperature:
  - Max (°C): 1600
  - Normal working temperature range (°C): 200-1600
- Ultimate vacuum (mbar): 10^{-6}
- Atmospheres: Vac., Ar, Ar/H_2, H_2

Vacuum Brazing Workshop at CERN

Equipment



Additional:

- Induction-system (incl. vacuum chamber)
- Air furnaces

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