TTF3 coupler for XFEL production issues

Michael Pekeler
RI Research Instruments GmbH
Friedrich-Ebert-Str. 1
51429 Bergisch Gladbach
Germany

RI Research Instruments GmbH

Advanced Technology Equipment and Turn-Key System Supplier for Research, Industry and Medical worldwide

- Linear Accelerators
- RF Cavities, Couplers, Auxiliaries
- Superconducting Accelerator Modules
- Electron and Ion Sources
- Beam Diagnostic Elements and Particle Beamlines
- Accelerator Equipment for Particle Therapy
- Specialized Manufacturing Projects

RI Research Instruments today is successfully continuing the business of the former ACCEL Instruments and former Siemens activities in accelerator and specialized manufacturing in Bergisch Gladbach (near Cologne/Köln) Blue colored buildings are the today used space in the above shown technology park.

51% of shares by Bruker EST, Inc. and management holding a significant equity stake of the company

RI Company Organization

research instruments

Managing Directors — Dr. Michael Peiniger, Hanspeter Vogel, Dr. Burkhard Prause

Secretary — Heidi Lohmar

Operational Safety

Stefan Bauer

Quality Management

Michael Kitzig

Business

Superconducting RF,
Cryogenics,
Special Manufacturing,
Projects

Dr. Michael Pekeler

Marketing

Sales

Engineering

Project Management

Business

Normal Conducting RF,
Accelerators,
Systems

Dr. Christian Piel

Marketing

Sales

Engineering

Project Management

Manufacturing

Stefan Bauer

Manufacturing Logistics

Tuning

Milling

Electrical

Surface Treatment

Joining Technology

Assembly, Testing

Engineering Design

Dr. Kai Dunkel,
Dirk Schmitz

Finance

Tassilo Börner

Accounting/
Finance Control

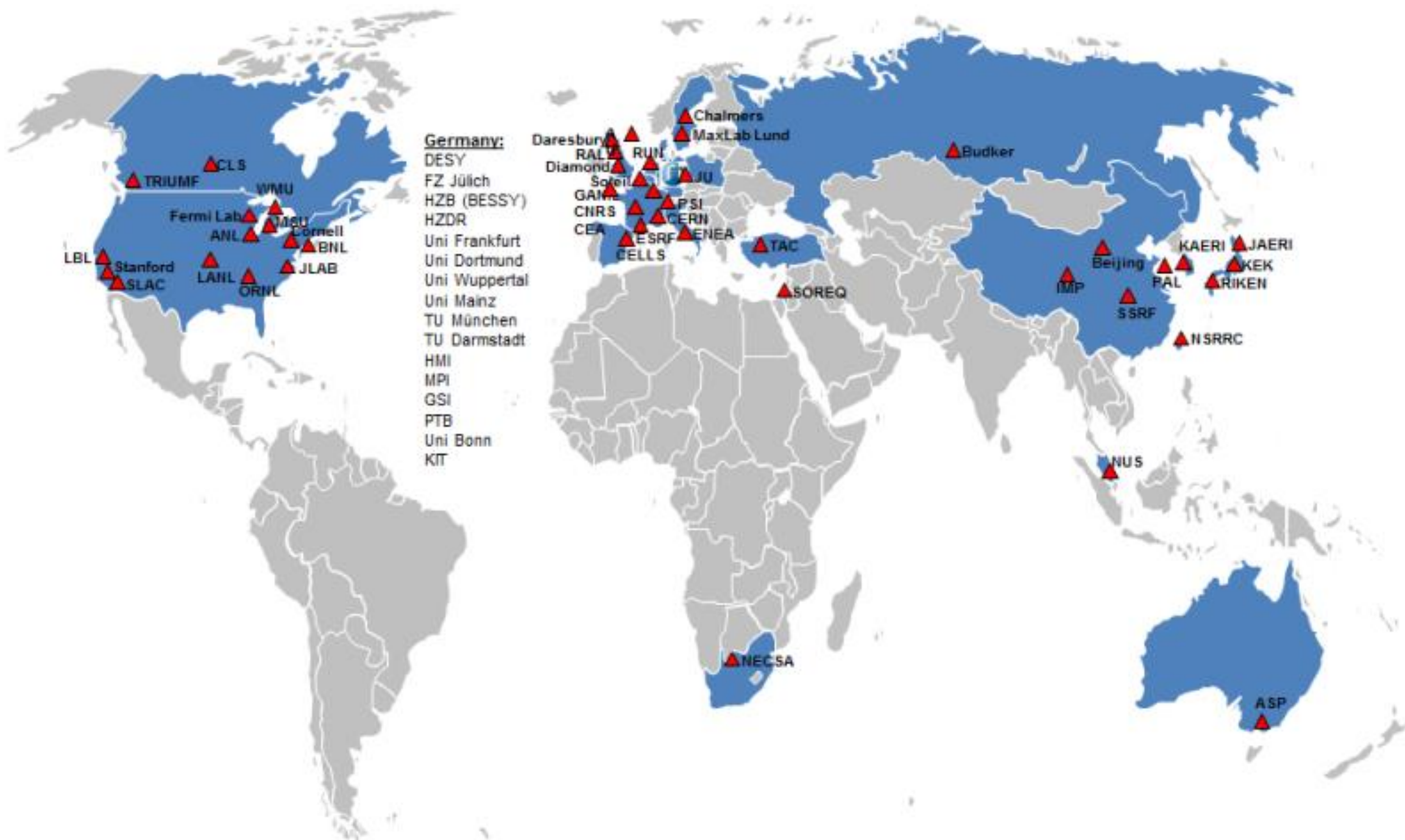
Financial
Project Management

Human Resources

IT-Systems

RI is a **project oriented company**, about 70 projects with contract volumes between < 100 kEUR to > 10 MEUR are running at RI in parallel

World map of customers and partners in "Big Science"



RI's specialized manufacturing

research instruments

Brazing Furnace (1/2)

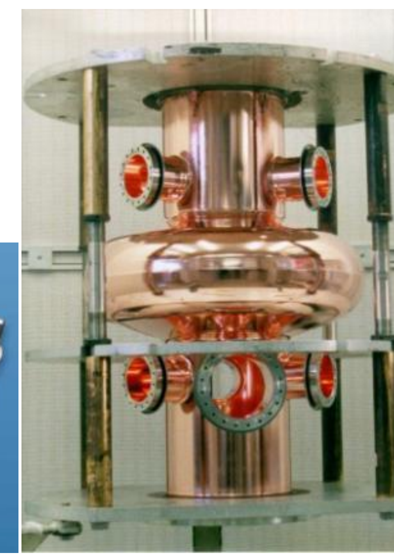
Electron Beam Welder (1/2)

Manufacturing Premises

In house manufacturing technologies:

- Turning (CNC)
- 5 axis milling (CNC)
- Metal working
- Surface technology (cleaning, etching, coating)
- Joining technology (EB, TIG, vacuum brazing)
- Heat treatment
- Assembly (partly in cleanroom ISO 4) and testing
- RF, vacuum, cryogenic
- Quality Control

Superconducting cavity production



1200 SRF cavities produced so far, 40 SRF cavities/year in average over the last 25 years (Siemens, ACCEL, RI). RI is the world leader in SRF cavity manufacturing

XFEL cavity production project

Order for 300 cavities received from DESY in September 2010, order for additional 120 cavities received in March 2013, 420 additional cavities produced at Zanon, Italy

Niobium and
helium vessel supplied by DESY

RI scope:

- Mechanical manufacturing of cavity, respecting the pressure vessel code
- Complete Surface preparation and helium vessel welding
- Shipping to DESY under vacuum and “ready for cold RF test”
- Extensive documentation and QA is crucial and will ensure that cavities are manufactured and treated according to detailed DESY specification. No performance guarantee.

DESY:

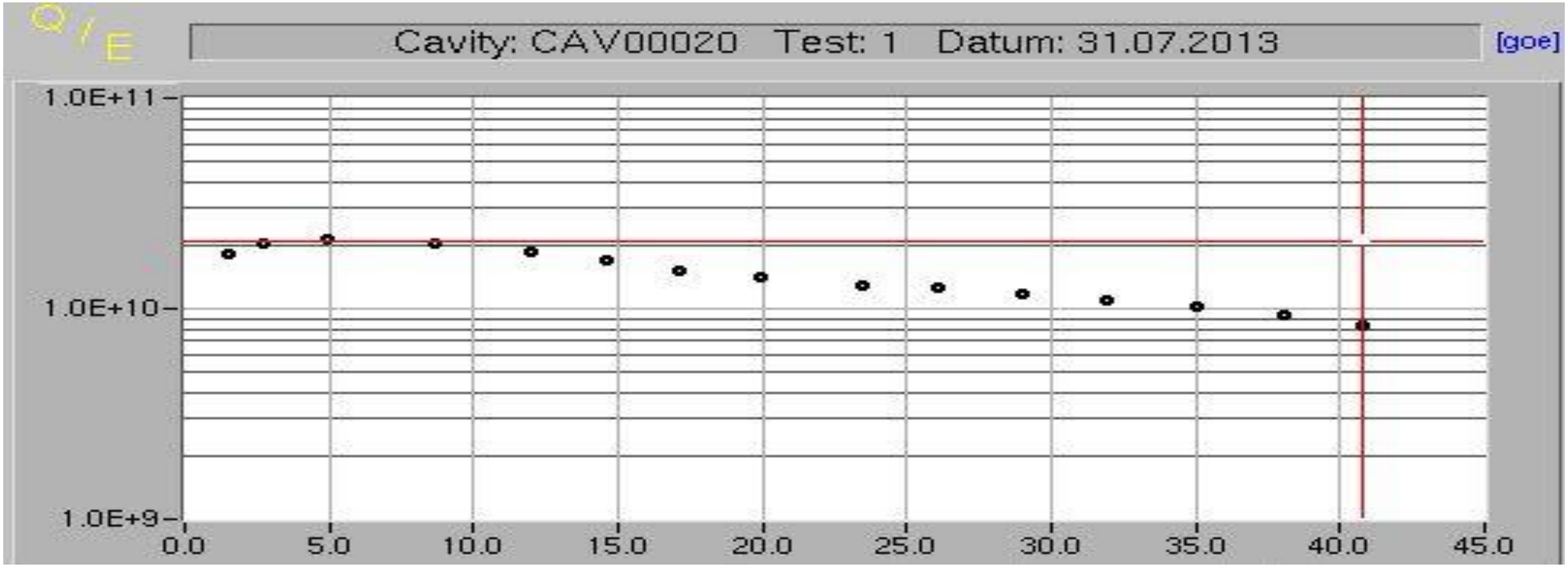
- Cavities will be cold RF tested at DESY (vertical test) with helium vessel already welded
- After successful test, DESY will ship the cavities under vacuum to CEA for module assembly

research instruments

XFEL cavity production project

Status of the project:

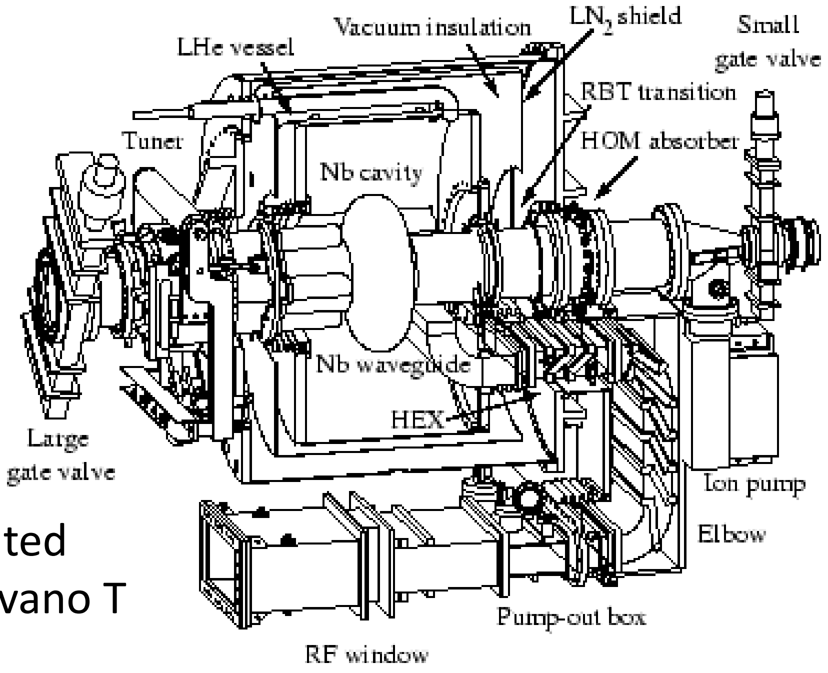
- RI Infrastructure qualified by reference cavities, fields up to 33 MV/m reached with reference cavities
- First series production cavity delivered in May 2013
- Series cavities tested up to 40,8 MV/m. Q_0 above 1^{10} up to 35 MV/m, all well above specification of 23 MV/m with $Q_0 > 1^{10}$
- Ramp up of series production finished, now delivering > 14 cavities per months, 70 cavities in total delivered
- Average gradient is about 32 MV/m
- Project should be finished in May 2015 where the last of the 420 cavities should be delivered



RI experience with coupler production

Coupler projects with copper coating performed by Leybold :

- 2002: 12 TTF3 couplers for DESY and BESSY
- 2005: 4 TTF5 couplers for LAL
- 2005: 4 TW60 couplers for LAL
- 2006: XFEL coupler production study
- 2006: 30 TTF3 couplers for DESY



- Complicated beam pipe components and waveguide parts for 500 MHz SRF modules were copper coated by Leybold until 2009
- Starting from 2009 those components are copper coated now with very good success by German company Galvano T

- 2009: The consortium TED/RI won the production of 670 TTF3 couplers for the XFEL

- 2012: 32 TTF3 couplers for DESY (copper coating missing)

Sample program with Leybold (2002-2008)

research instruments

- Flat samples (sheets)
  – no problem with RRR
  – thickness and adhesion ok

- Samples on stainless steel tubes
  – no problem on RRR (very high > 100, too high?)
  – thickness ok
  – adhesion ok

- Samples on bellows with collars
  – RRR ok
  – uniformity of coating extremely difficult
  – very hard to achieve XFEL spec on a regular basis
  – different problems on adhesion (blisters)

- Verification samples (bellows and tubes)
  – stability on the copper coating thickness on the bellows was difficult
  – production sometimes needed to be stopped until samples showed again stable procedure

Copper coating procedure and QA (Leybold, 2002-2008)

research instruments

- Completely organic free LP1 bath was used, pulsed plating was applied
- Electro-polishing of parts prior nickel strike (1 µm)
- Wet in Wet
- Bellows elongated in order to achieve better uniform coating thickness (went over the elastic limit)
- Glass bead blasting to remove oxides and to test adhesion of copper
- Rinsing with alcohol, drying by N2 blowing, packing in silk paper ("Seidenpapier")
- Visual inspection after copper coating
- 400 ° C heat treatment of parts for two hours under vacuum
- Visual inspection of the parts

Success rate of copper coating (Leybold)

- From 10 pieces, about 6 had to be returned to Leybold for new coating
- Small blisters before heat treatment (400° C) on welds, bellows, pick-up tubes
- Blisters after heat treatment mostly in the bellow section
- Oxidation from rinsing and cleaning procedure
- Maximum 3 times recoating possible, after that, bellows too thin from electro polishing

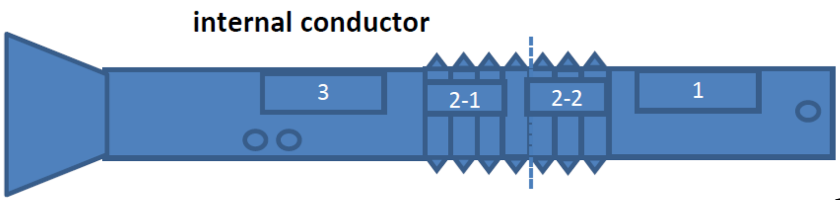
Copper coating at Colini/Switzerland (2013) and Galvano T (2013)

- Samples (tubes and bellows) were sent to Colini to qualify their copper coating
- Collini uses gold plating prior copper coating
- In total it took Collini more than 8 months to develop the copper coating process and successfully do the first coating of coupler parts.
- However the price for the copper coating at Collini was extremely high and the program was stopped.

- Galvano T did samples on bellows and achieved 50% thickness variation on bellows already without pulse plating. They use Nickel strike. RRR was in the right range. They are now producing first coatings of outer and inner conductors. Results expected in December

RI/Collini

	Internal conductor			
Nr.	1	Bellow 2 - 1	Bellow 2 - 2	3
RRR $_{Cu+S.S.}$	8	23.6	25.4	11.2
RRR $_{S.S.}$	1.4	1.6	1.5	1.4
RRR $_{Cu}$	**20.5**	**27.1**	**29.4**	**32.5**



Collini Copper coated warm outer and inner conducter

XFEL coupler production project

- The consortium Thales Electron Devices (TED) and RI Research Instruments won the contract for production of 670 TTF3 couplers in 2010.
- TED and RI agreed on the following work share:

TED:
inner conductor warm (copper coated)
outer conductor warm (copper coated)
outer conductor cold (copper coated)
Antenna
capacitor
motor drive

RI:
TiN coated cold ceramic assembly
TiN coated warm ceramic assembly
EB welding of couplers
hard brazed waveguide box
push rod
cleaning and assembly of couplers ready for RF conditioning in ISO4 clean room

Issues during RF coupler production

The production of a good RF power coupler for use for superconducting RF cavities is challenging as several technologies have to be applied successfully. Several steps of the production have to be made with the parts already copper coated. Extreme care has to be taken to not harm the copper coating during following steps of coupler production.

- TIG welding or brazing of stainless steel
- Brazing of copper to stainless steel
- Brazing of copper to AL2O3 ceramics
- TiN coating of ceramics
- EB welding of copper without metalizing the ceramic
- Cleaning and assembly of couplers in the cleanroom

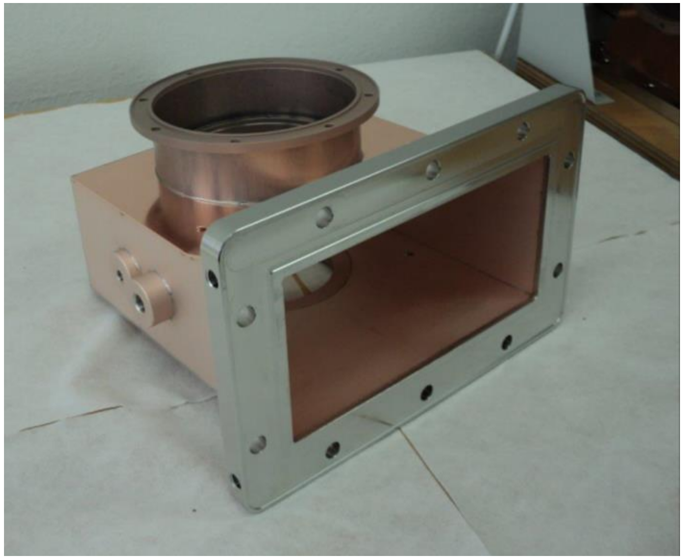
- Copper coating of structures with bellows with tight tolerances on thickness variation and RRR

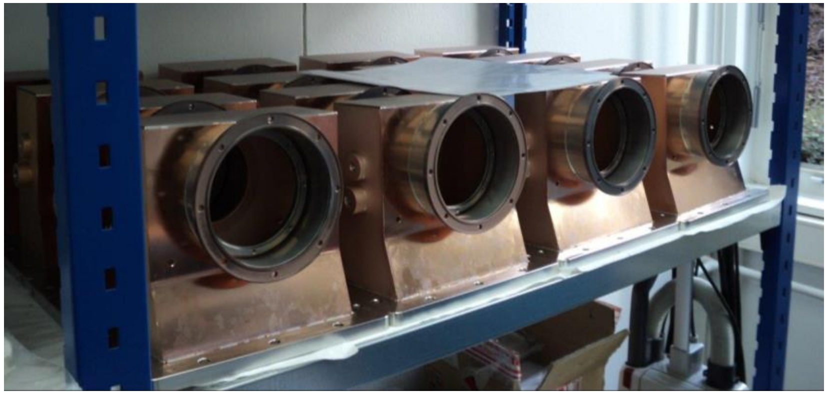
Storge of parts under N2 athmosphere

Push rod and waveguide boxes

- All push rod and about 50% of the waveguide boxes are finished for XFEL. The push rods are TIG welded

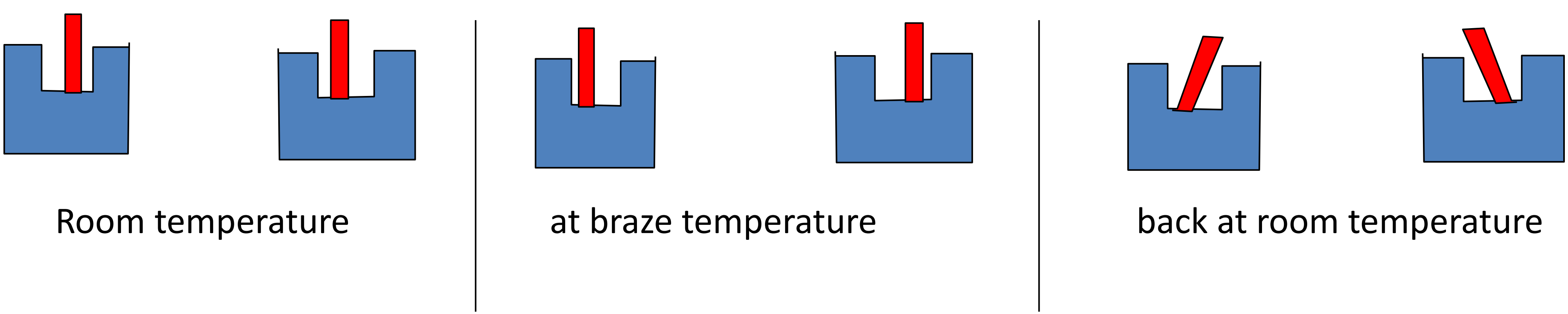
- The waveguide box is a hard brazed structure using copper coated stainless steel walls, copper plate and stainless steel flanges
- The waveguide box single parts are laser tack welded together in order to hold them in position in the furnace.
- 20 waveguide parts are brazed in one brazing cycle





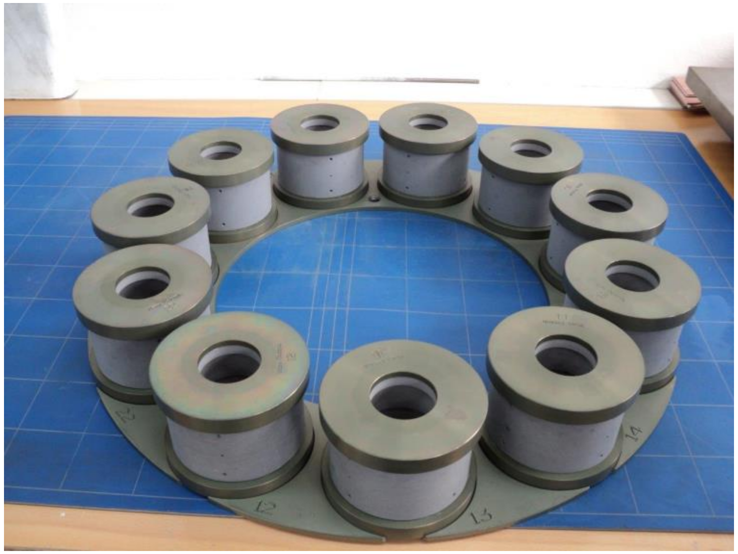
Brazing of copper collars to $Al2O3$ ceramics

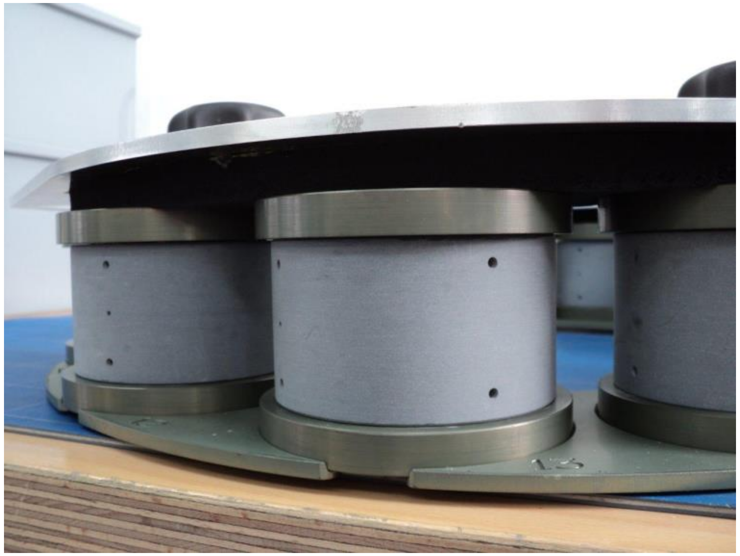
- The ceramics are purchased with metallization from WESGO, Erlangen, Germany
- The ceramics are then annealed in vacuum at 800 °C for one hour
- After the annealing, some ceramics show gray areas, they are blasted away with glass beads
- During brazing it has to be ensured that the copper collars are aligned to the ceramic through the brazing cycle, which is difficult due to different thermal expansion coefficient of copper and ceramic. Sophisticated tools necessary in order to ensure that the copper collar stays straight and does not become conical. Brazing is done using L-Ag 72 at 820 °C
- In addition shielding ceramics are used to protect the ceramics from metallization from vaporized braze material
- Successful brazing needs all metal vacuum brazing furnace
- 100% leak check of the braze joint, success rate of brazing > 99%



Brazing of copper collars to Al2O3 ceramics (2)

research instruments



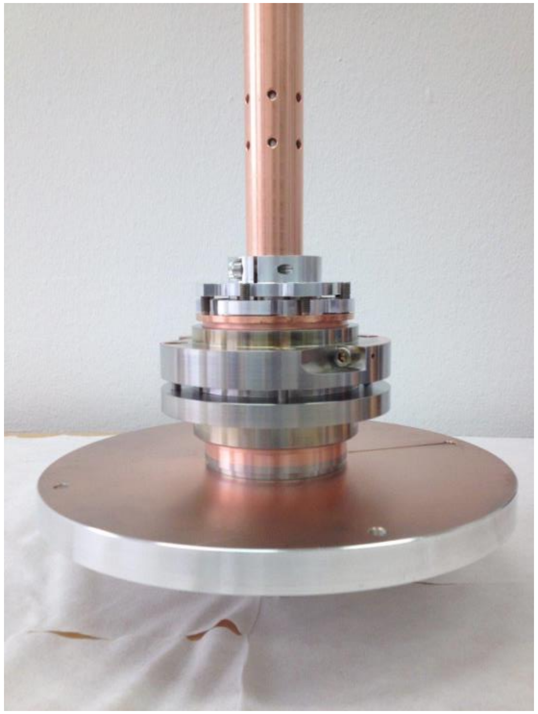


TiN coating of cold and warm windows

- DESY developed a TiN deposition technique using ammonia atmosphere (1E-5 mbar) and Ti wires at 1400 ° C
- RI rebuilt this apparatus for TiN coating
- The ceramics are coated 2 times, 1. side walls, 2. upper and lower face
- There are 40 ceramics in one oven at a time, the coating of the 40 ceramics takes about one week. Therefore ceramics for 20 couplers can be coated in one week
- About 10% of the ceramics show white spots (size several mm or discolorations after coating and need to be re-coated

EB welding of the couplers

- Sophisticated tool necessary that covers the ceramic during EB welding protecting the ceramic being metalized by the welding vapor and that can be removed from the welded coupler easily without harming the copper coating of the coupler
- It has been proven, that the copper coating of the collars will not influence the result of the EB welding
- Smooth EB welds are necessary for a good performance
- No weld beads allowed inside the coupler



Tool for inner conductor to ceramic

Tool for cold part welding

Copper plating and US degreasing

research instruments

- US bath at TED and RI was specified for 10 W/l US power, Ted uses 25 kHz, RI uses 40 kHz

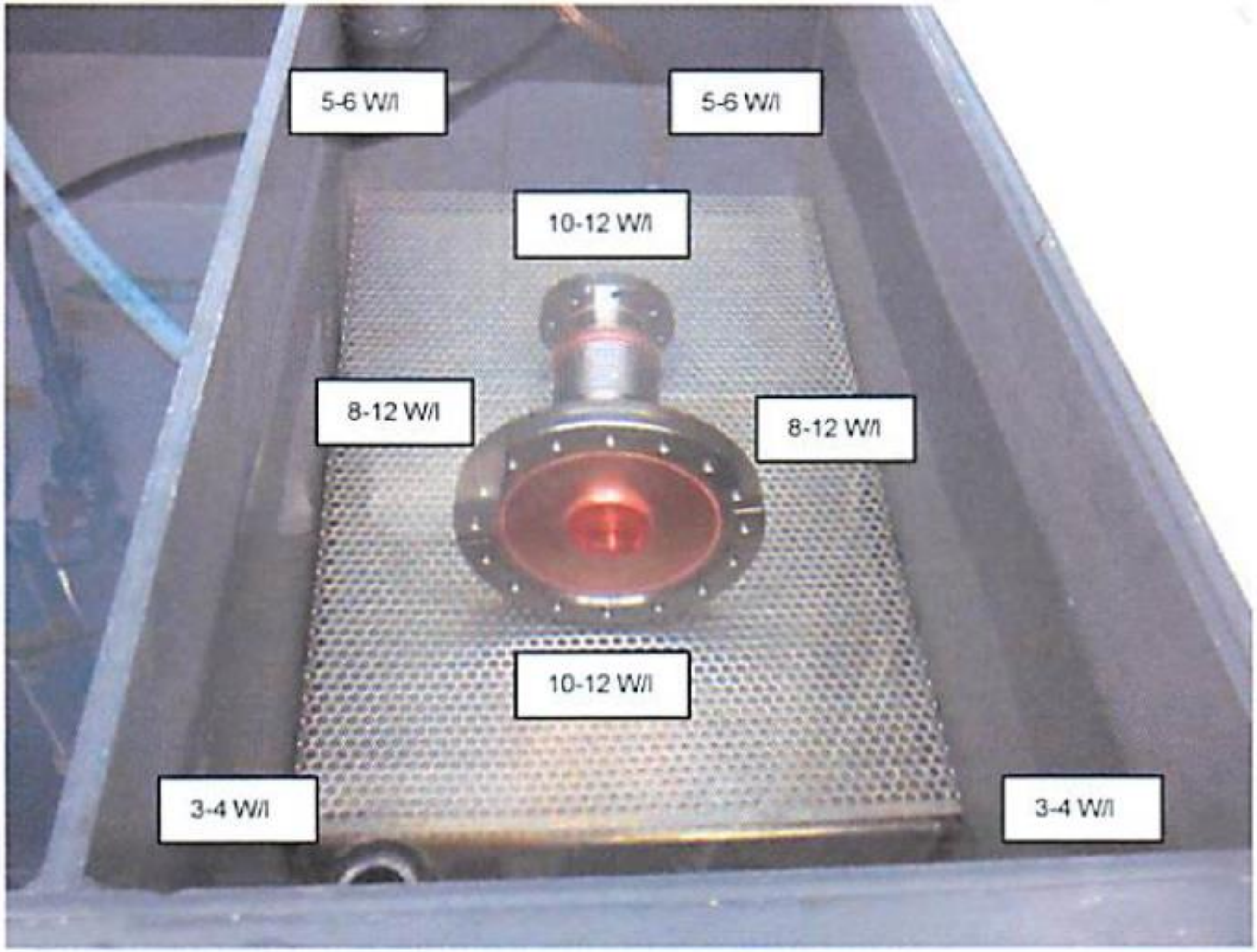
	US bath at TED	US bath at RI
Dimensions	650 x 300 x 300 mm	700 x 500 x 550 mm
US-panel in the bath (at the bottom)	450 x 300 x 80 mm	TSP-P 40/35/460 x 680
Capacity	47l demineralised water	Max 160 l (during degreasing 140 l) with Tickopur R33
Temperature	20 °C	50 °C
US-Generator	Martin Walter Ultraschalltechnologe Typ: MW600TI; 600W; 25kHz Fixed power: 100%	Effective output: 1500 W Peak output: 3000 W Double half-wave operation
US-Process Controller	NGL: UPC3000	NGL: UPC3000

- Measurement of US power was performed recently with some surprising result

	US bath at TED	US bath at RI
Date	23.10.2013	24.10.2013
In the middle of the bath (zero Measurement)	8 - 12 W/l	15 - 23 W/l
In 4 corner of the bath (zero measurement)	3 - 4 W/l	17 - 22 W/l
Average power during treatment	10 W/l	15 - 19 W/l
Peak power	up to 21 W/l	up to 30 W/l

Copper plating and US degreasing

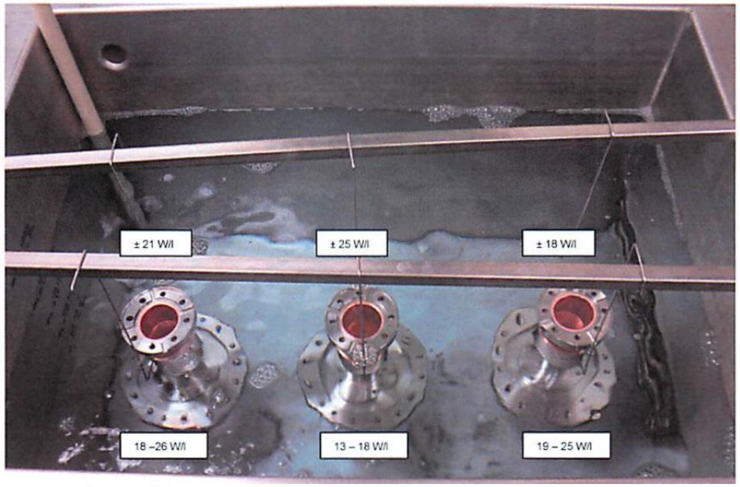
- 6 cold parts were US cleaned at TED first and then at RI. The US power was measured at both companies with the same US power meter.
- All parts treated at TED showed no effect on the copper coating
- US power was measured to be about 10 W/l, parts were positioned horizontally



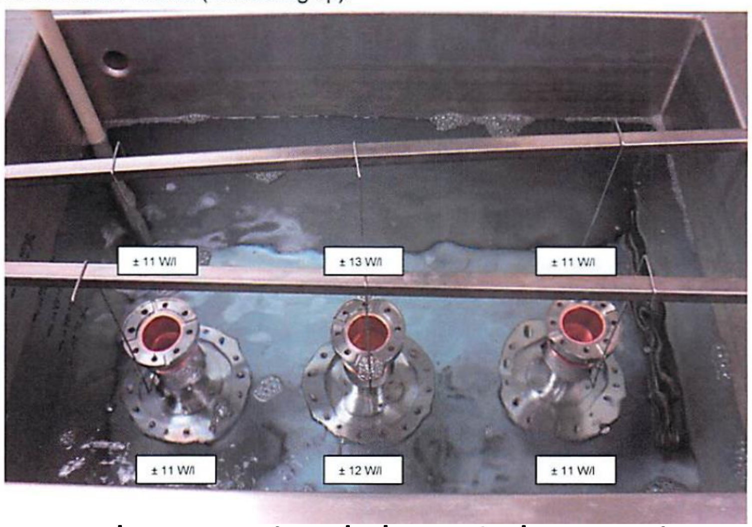
Copper plating and US degreasing

research instruments

Measurement at the level of the CF100 (measuring tip):



Measurement at the middle (measuring tip):

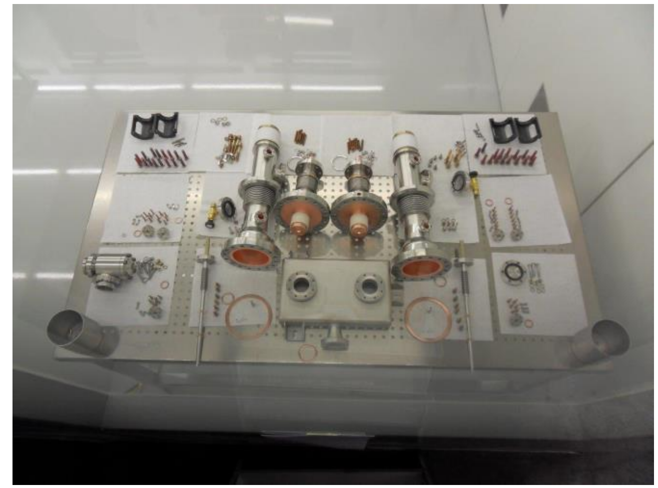


- Parts that survived the US degreasing at TED showed US marks and removal of copper when treated in US bath at RI, parts are hanged vertically, CF 100 flange close to and facing power source
- RI bath for US degreasing is now upgraded to allow regulation of US power, parts will be moved during US degreasing

Cleaning of coupler and clean room assembly for RF test

- US degreasing using Tikopur at 50 ° C for 15 minute at 10 W/l is first step of cleaning followed by DI water rinsing
- Couplers are then dried in ISO4 clean room, difficult to dry the couplers bellows and ceramic area
- Assembly is done using particle counts as QA control step
- After assembly and leak check the motor is driven to show that the couplers can reach the external Q variation
- Delivery to LAL with cold part under vacuum and warm parts under N_2 atmosphere

Cleaning of coupler and clean room assembly for RF test (2)



Status of the coupler production for XFEL

- Standard parts are well advanced like capacitors, push rods, waveguide boxes, pick-ups, thermal collars, etc.
- Remaining issues to be solved are on the cold and warm part
- TED is doing production of copper coated inner and outer conductor in a 3 shift operation now
- TED achieves the specified rate of 8 couplers per week now almost, yield rate of copper coating close to 80%
- RI has proven, to weld 8 cold parts and 8 warm parts within 3 full 8 hours shifts
- The cleaning and the assembly of 4 coupler pairs (8 couplers) is possible at RI with the current installation
- TED and RI expect that the full production rate is achieved at the beginning of 2014 at the latest.

How to make ILC coupler cheap

- Coupler for XFEL is already quite cheap, saving might be only achieved further by higher production numbers
- Robust copper plating procedure/recipe
- Copper thickness variation specified to actual need of the coupler
- Reduce number of parts
- Why two windows?