Fabrication Challenges and Process Optimization of HOM Absorber for the S^{3}FEL

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Outline

Introduction

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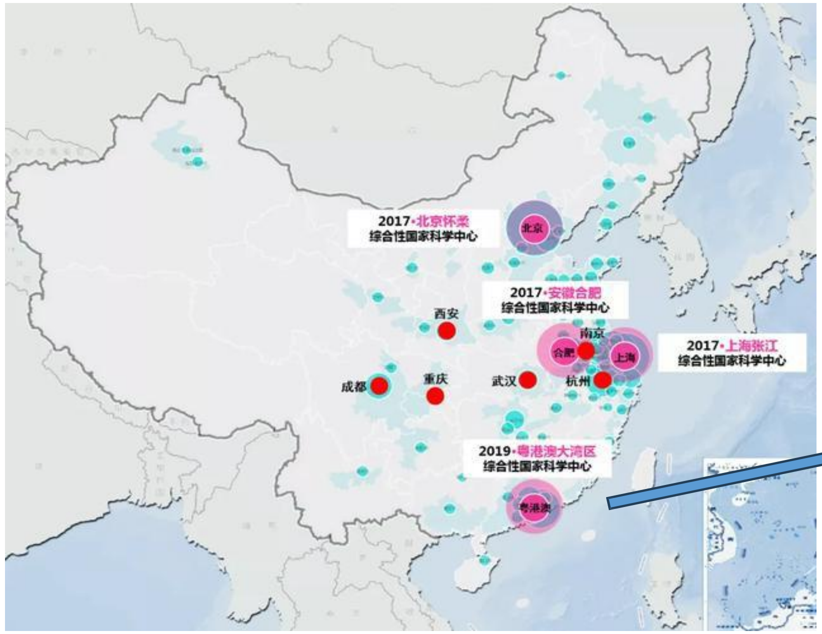
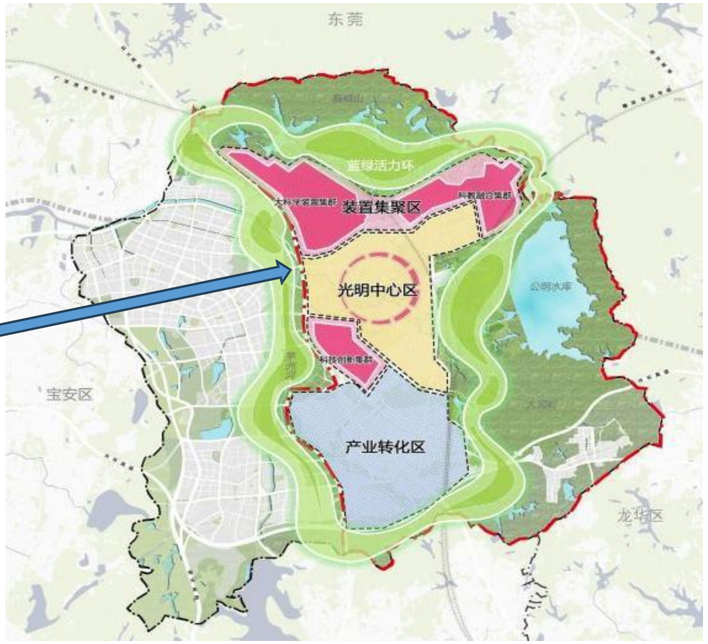
S³FEL: Shenzhen Superconducting Soft x-ray Free Electron Laser

Construction unit: Institute of Advanced Light Source Facilities, Shenzhen (IASF)

Construction site: Guangming District, Shenzhen (Guangming science city, cluster of facilities)





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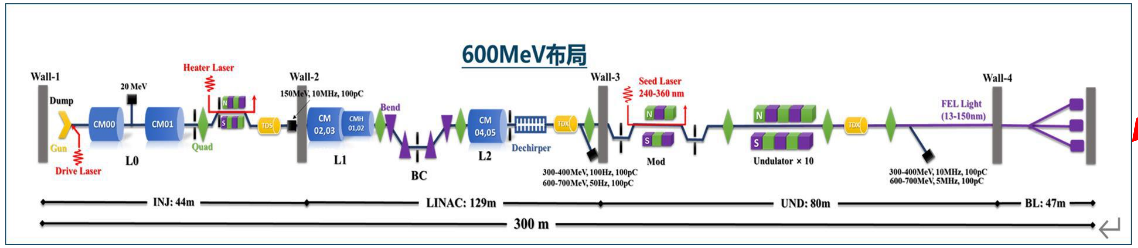
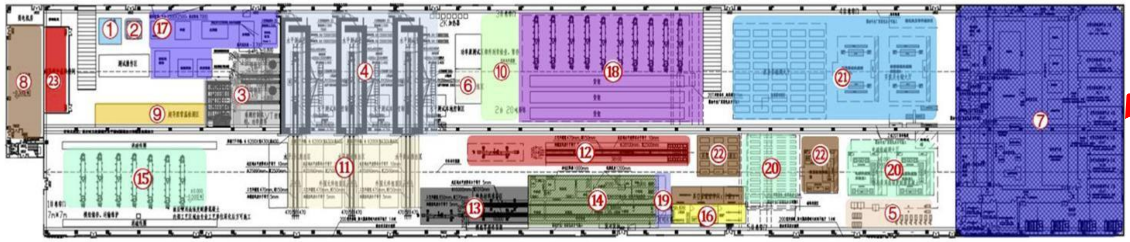
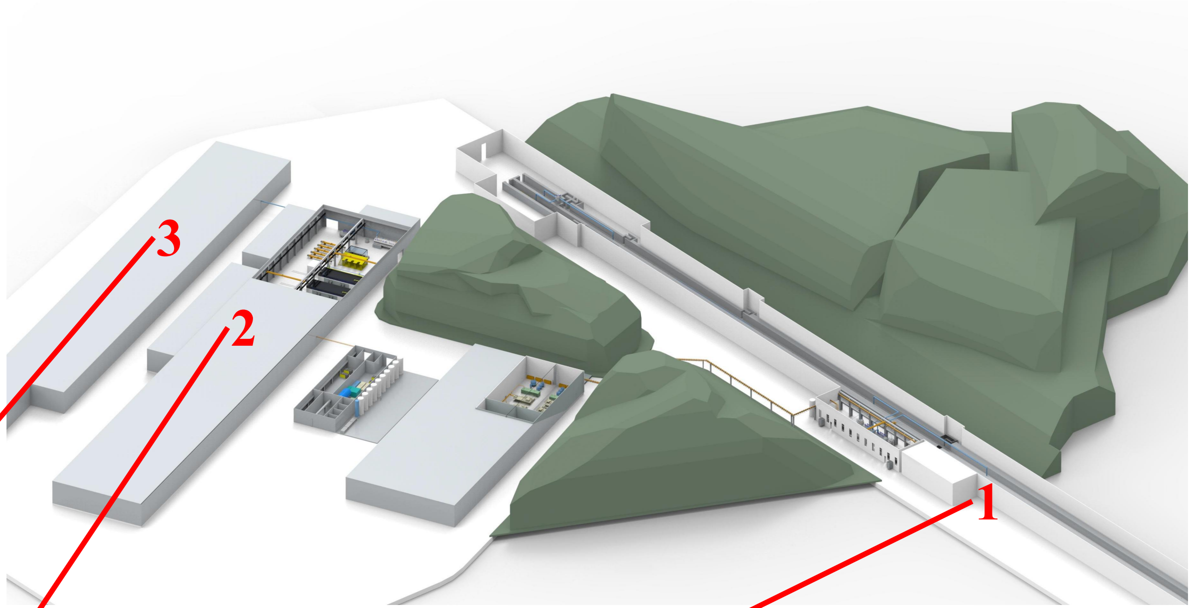
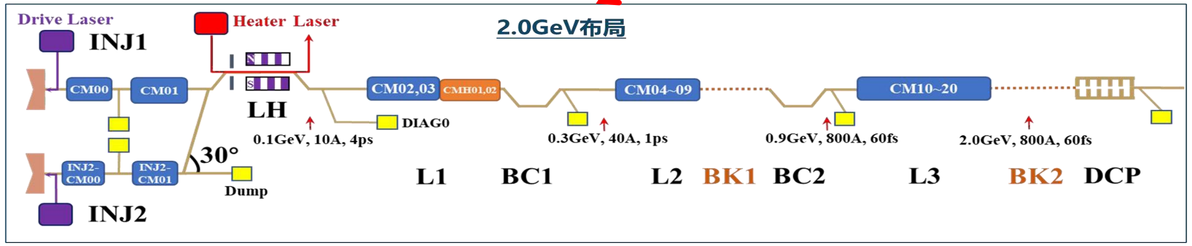
Layout of S³FEL Accelerator

No.	Naming
1	S³FEL
2	Superconducting Module Test Facility (SMTF)
3	Linac Test Facility (LTF)









HOM Absorber Requirements for S^3FEL

	SMTF	LTF	S^3FEL	Total
1.3 GHz CM	1	5	18	24
1.3 GHz HOM Absorber	1	5	18	24
3.9 GHz CM	1	2	2	5
3.9 GHz HOM Absorber	1	2	2	5
Injector CM	/	1	2	3
Injector HOM Absorber	/	1	2	3

S^3FEL requires 24 1.3GHz HOM absorbers, 5 3.9GHz HOM absorbers and 3 injector HOM absorbers in total.

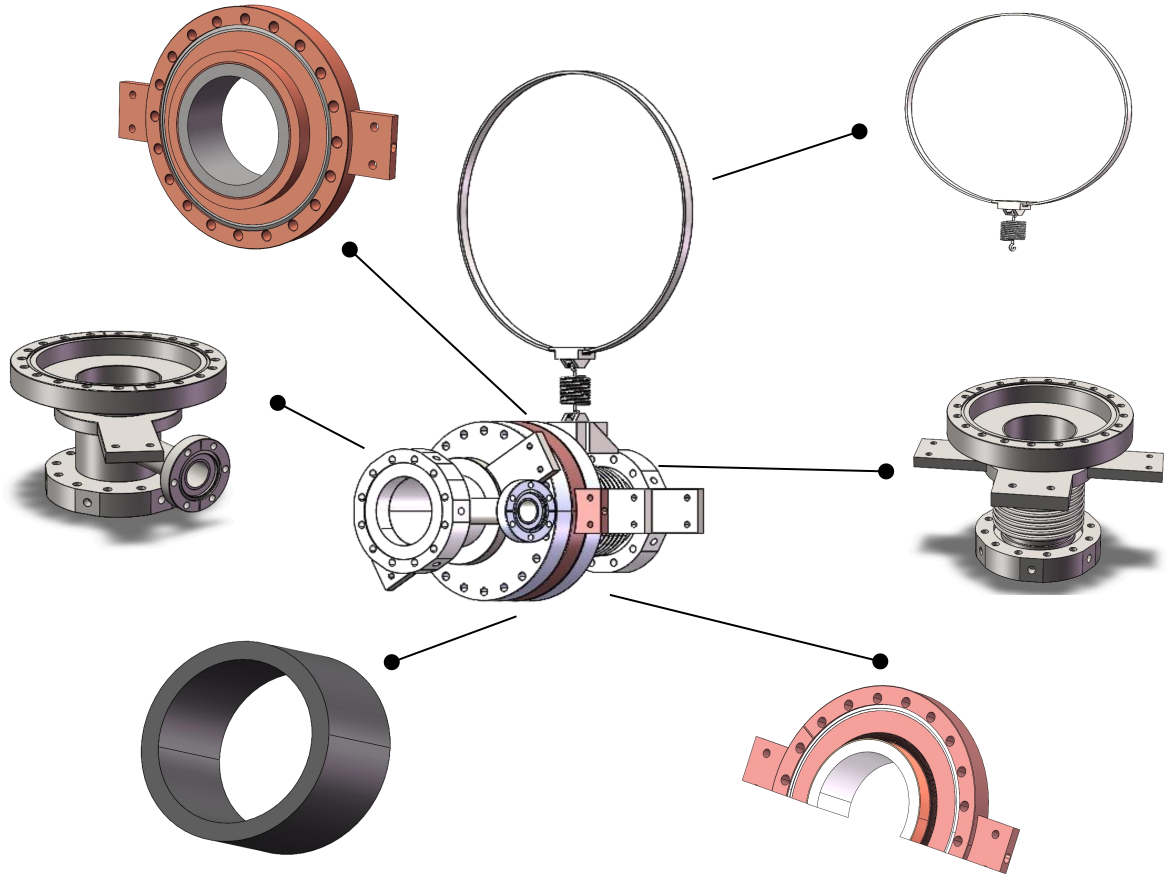
AlN is used for the 1.3 GHz and 3.9 GHz HOM absorbers, while SiC is used for the injector HOM absorbers.

Development of HOM Absorber

Design of the HOM Absorber

S^3FEL 1.3GHz HOM Absorber structure

- Beamline HOM absorber
- Support structure
- Upstream and downstream components
- Ceramic (AlN)
- OFHC copper flange
- Vacuum port
- bellows



Function and Key Parameters of the HOM Absorber

Main Functions: ★ HOM power absorption ★ Beam instability suppression ★ Heat extraction

Key Parameters for 1.3GHz HOM Absorber

Parameter	1.3GHz HOM Absorber
Design absorption capacity	100W
Permeability	< 1.05
Vacuum leak rate	≤ 1.0E-11 Pa·m^3/s
Remanence	< 1.0 Gs
Thermal conductivity	≥ 50W/(m·K)

HOM Power Calculation (1.3GHz)

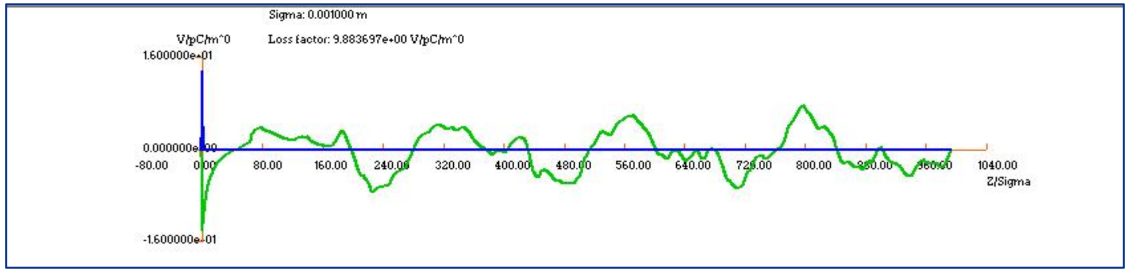
HOM Power： $P_{Hom} = k*Qb_2*f_{rep}$ $k_{HOM} = k_{Total} - k_{Fundamental\ mode}$

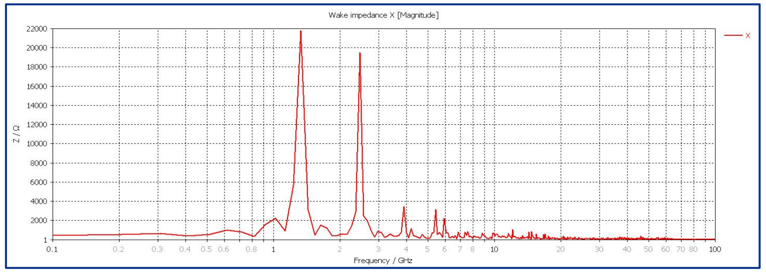
single-cavity loss factor for a 1.3GHz 9-cell TESLA cavity: $k_{Total} = 9.884V/pC$

$k_{Fundamental\ mode} = \omega/4 \cdot R/Q \cdot \exp[-(\omega\sigma_z/c)^2]$ $R/Q = 977\Omega$, $f = 1.3GHz$, $\sigma_z = 1mm$, $k_{Fundamental\ mode} \approx 1.99V/pC$

$k_{HOM} = 7.89V/pC$ **S3FEL Design Parameters: Charge: 300pC; Repetition Frequency: 1MHz**

$P_{HOM} = 5.68W/CM$ **(preliminary cavity-only estimate, including only eight cavities and excluding bellows, gate valves and other interconnection components).**





The 100 W design capacity provides a large margin for this preliminary cavity-only HOM power estimate.

Fabrication Challenges & Process Optimization

Fabrication Route

Fabrication Route of HOM Absorber:

AlN ceramic metallization → OFHC copper flange machining → AlN ceramic–OFHC copper vacuum brazing

↓

Tests (thermal shock test, helium leak test, etc) ← Assembly of upstream and downstream with copper flange

Key technologies

★ AlN ceramic metallization

Impact:

Subsequent brazing process and brazing strength

★ AlN ceramic - OFHC copper brazing

Impact:

Vacuum performance and heat conduction capability

★ Thermal stress concentration

Impact:

Excessive local stress and ceramic cracking

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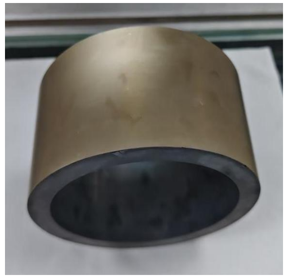
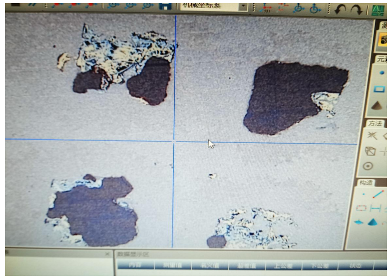
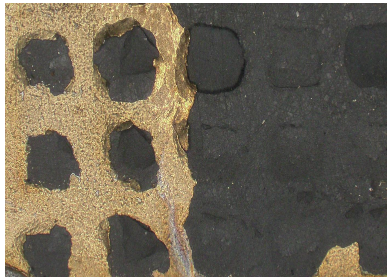
Challenge and Optimization 1: Metallization

Challenge:

1. Aluminum Nitride metallization formula.
2. Uniformity control of the metallization coating.
3. Ceramic treatment before metallization.

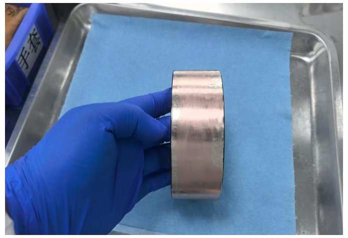


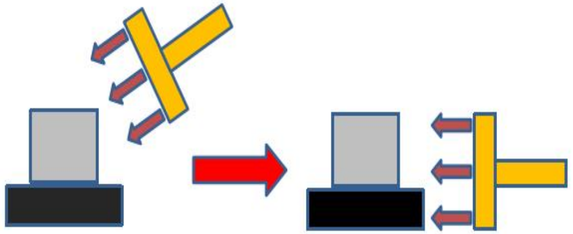




Optimization:

1. Multiple rounds of formulation verification.
2. Uniformity control of the metallization coating.
3. Pre-baking of AlN ceramic at 400 °C for 1 hour before metallization.





A stable metallization process was established for reliable AlN–copper brazing.

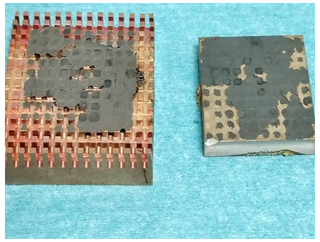
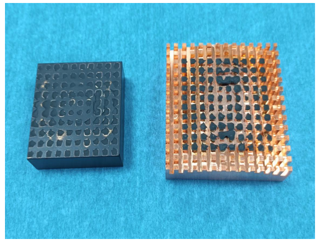
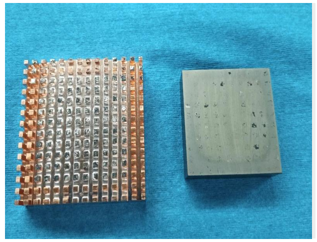
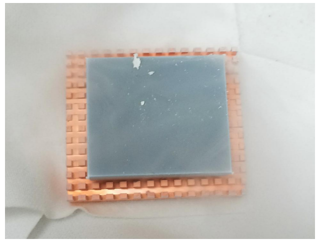
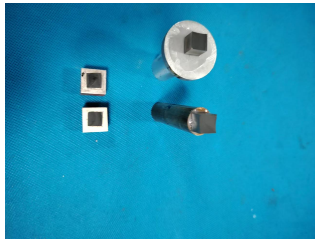
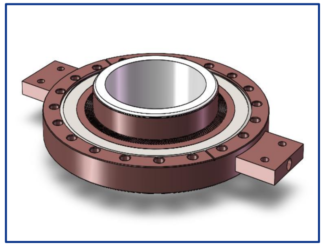
Challenge and Optimization 2: Brazing

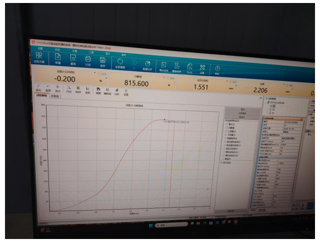
Challenge:

1. Low bonding strength after brazing.
2. Risk of voids and incomplete bonding at the brazed interface.

Optimization:

1. Tensile strength tests were performed on AlN–copper brazed samples with different brazing formulations.
2. The copper structure was modified to form a fully enclosed brazing interface.



The optimized brazing route achieved a tensile strength above 90 MPa.

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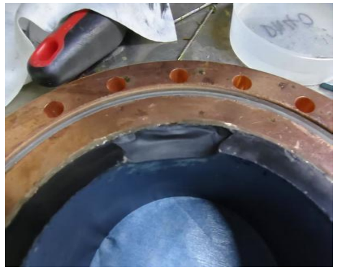
Challenge and Optimization 3: Thermal Stress

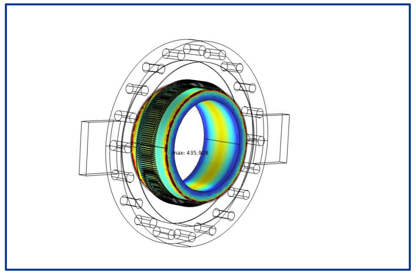
Challenge:

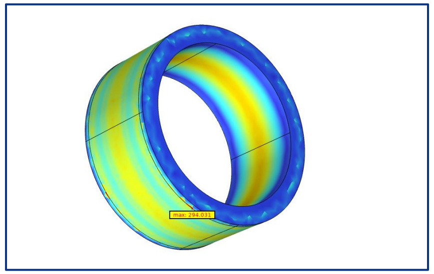
1. Excessive local thermal stress caused ceramic cracking during thermal shock tests.
2. The thermal expansion mismatch between AlN ceramic and OFHC copper increased residual stress.

Optimization:

1. The stress release groove structure of the copper flange was optimized.
2. Rounded corners were introduced to the ceramic edges to reduce stress concentration.

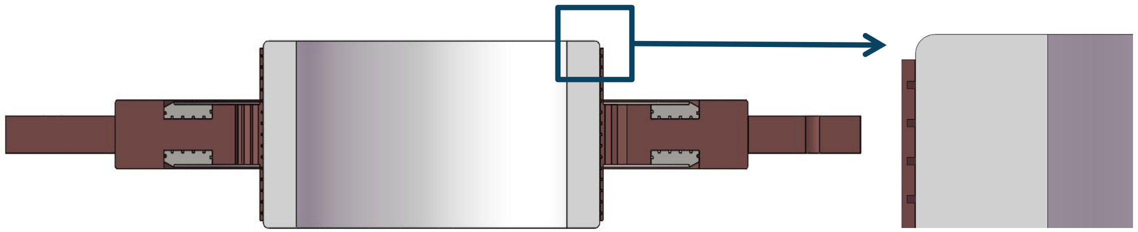




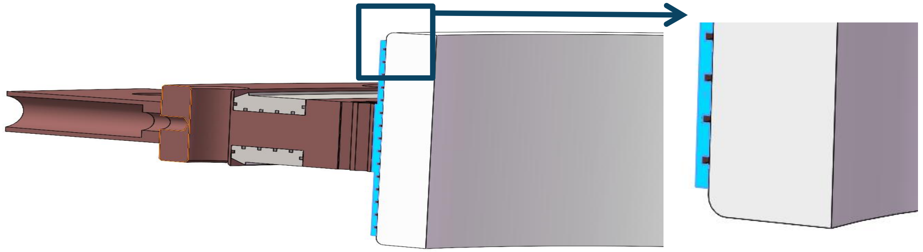


No ceramic cracking was observed after structural optimization.

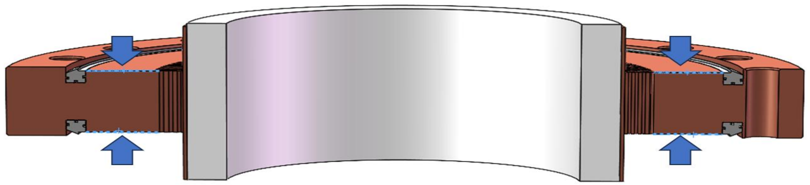
Additional Structural Optimizations



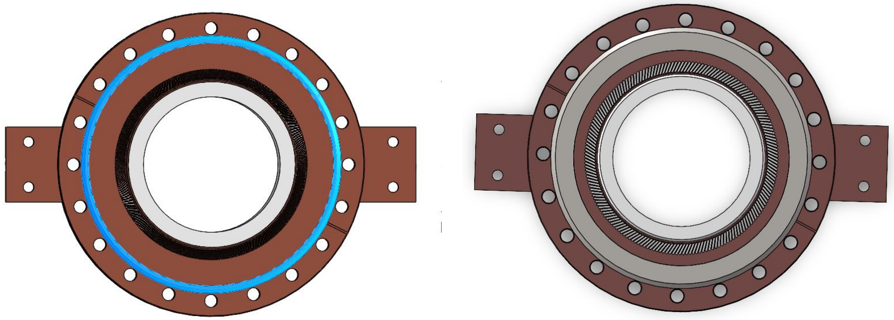
Adjusted the height of the OFHC copper thin-walled ring



Added brazing filler grooves

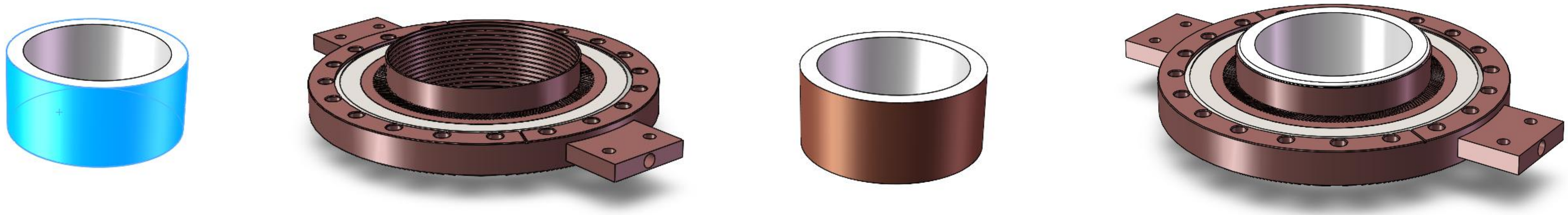


Optimized the thickness of the OFHC copper flange

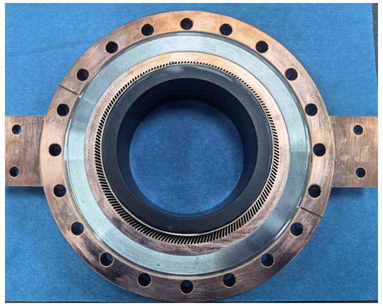


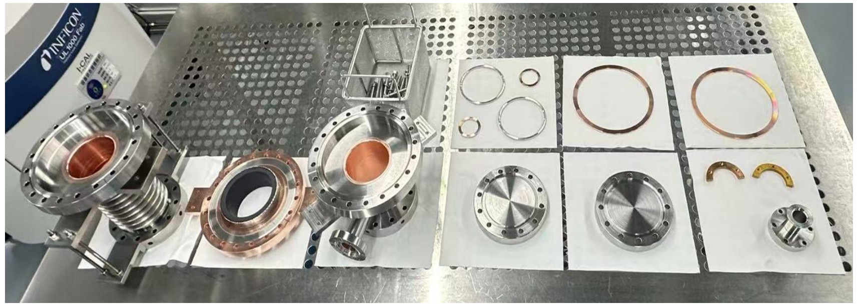
Enlarged the knife-edge sealing structure in the flange

Process Flow of AlN-Copper Vacuum Brazing



Ceramic metallization → OFHC copper flange machining → Copper foil pre-brazing → Final vacuum brazing

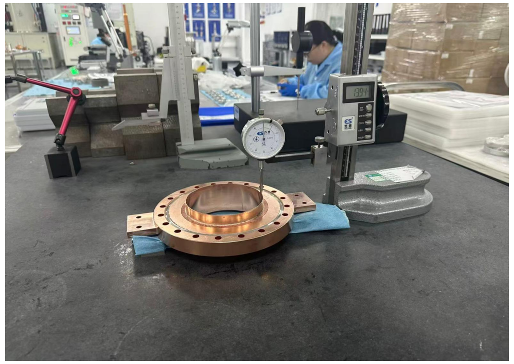




Absorber ceramic material: AlN, consistent with the material used in the SHINE HOM absorber.

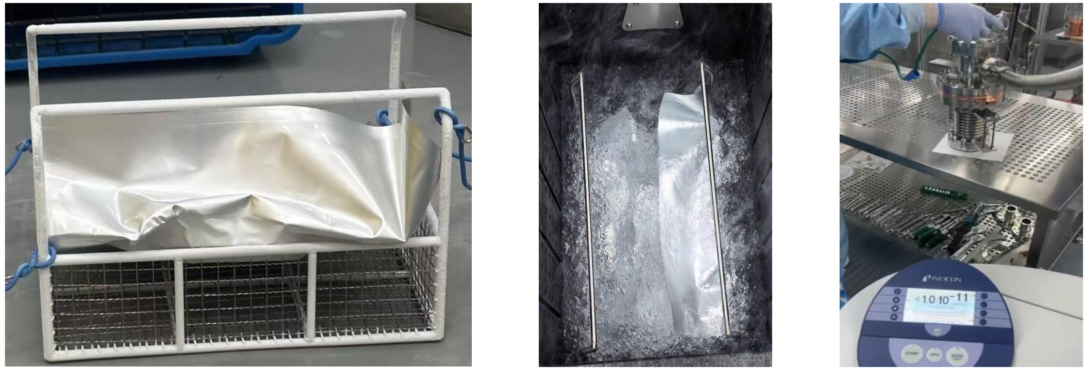
Fabrication partner: MorTek Electronic Technology (Suzhou) Co. Ltd.

Tests

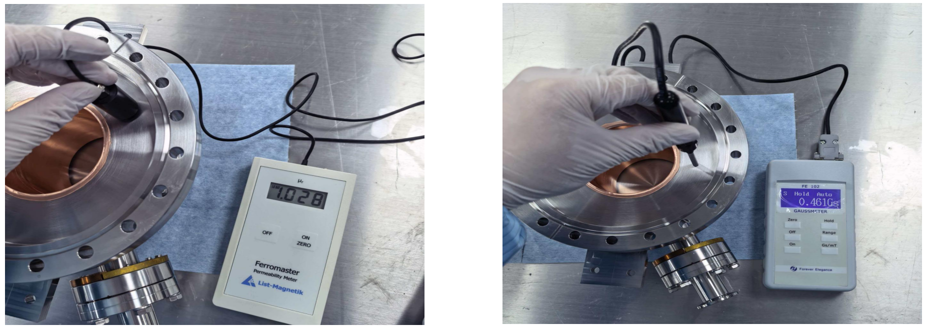


Dimension measurement

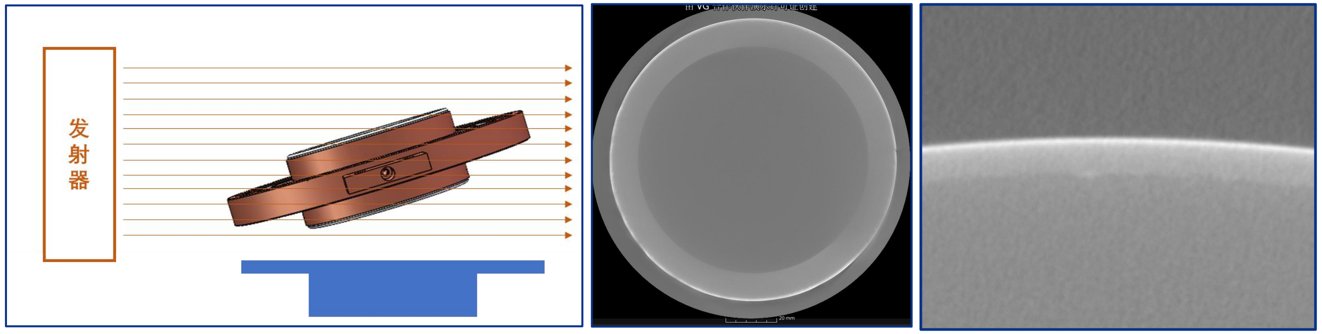
Endoscopic inspection



Thermal shock and helium leak tests



Magnetic permeability and remanence tests



CT inspection of brazed joints

Summary

Summary

A 1.3 GHz HOM absorber prototype for the S^{3}FEL has completed factory acceptance testing.

Key fabrication challenges, including AlN metallization, AlN–copper brazing and thermal-stress control, were optimized during the development process.

No ceramic cracking was observed after structural optimization and subsequent thermal shock tests.

The optimized fabrication route will be used for subsequent series production.