SHINE

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GRAND RAPIDS

Recent progress of fundamental power couplers for the SHINE project

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Introduction

- The Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is a new continuous-wave (CW) hard X-ray free electron laser (FEL) currently under construction in China;
- The SHINE Linac contains 610 1.3 GHz FPCs and 16 3.9 GHz FPCs;
- The SHINE 1.3 GHz FPC, which is used for CW operation, is modified and optimized based on the TTF-III coupler design developed at DESY for high power pulsed operation;
- A SHINE 3.9 GHz FPC to withstand 2 kW CW power and with an adjustment function has been designed.
- Validation of every key manufacturing step has been studied to improve product quality and reliability. Performance criteria and validation techniques have been established for monitoring and controlling of process parameters to ensure that the specified requirements continue to be met.
- To date, 26 SHINE 1.3 GHz and two 3.9 GHz FPC prototypes from three domestic manufacturers have been manufactured and RF power tested.

TABLE I. Main technical parameters of the SHINE 1.3 GHz and 3.9 GHz FPC.

Parameters	**1.3 GHz FPC Specification**	**3.9 GHz FPC Specification**
Operating Frequency (GHz)	1.3	3.9
Type	Coaxial, Double-RF-window	Coaxial, Double-RF-window
Ceramic RF Window type	Cylindrical (cold) + Cylindrical (warm)	Cylindrical（cold）+Planar（warm）
Maximum power (kW)	7	1.8
External quality factor, Q_{ext}	4.12×10^{7}	2.13×10^{7}
Q_{ext} adjustment range	4.0×10^{6} ~ 1.1×10^{8}	1.0×10^{7} ~ 5.0×10^{7}
Antenna adjustment range (mm)	± 7.5	± 3

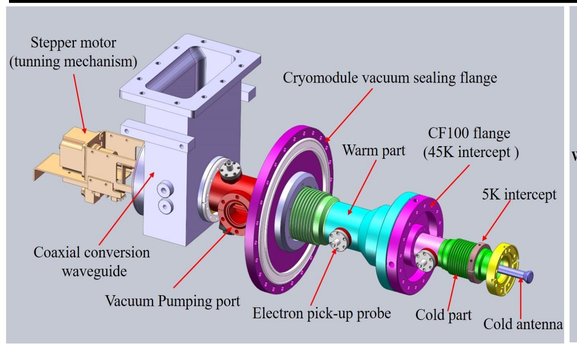


FIG. Mechanical design of the SHINE 1.3 GHz FPC

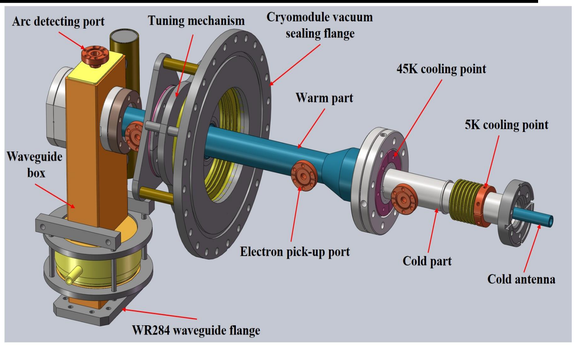


FIG. Mechanical design of the SHINE 3.9 GHz FPC

FPCs MANUFACTURING AND VALIDATION PROCESSES

A. Vacuum Brazing of RF Windows

- Vacuum brazing furnace;
- Leakage rate < 10^{-10} Pa.m^3/s;
- Tensile strength: > 100 MPa;
- Liquid nitrogen shock three times.

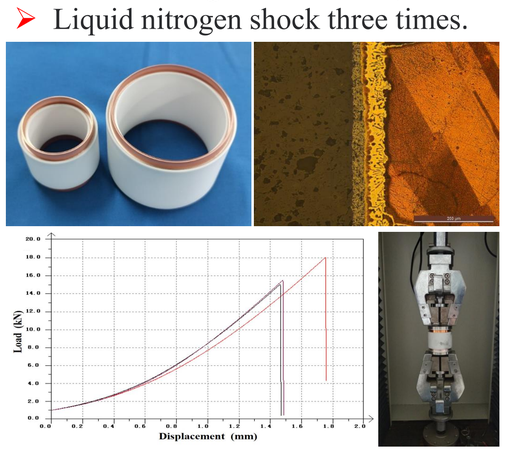


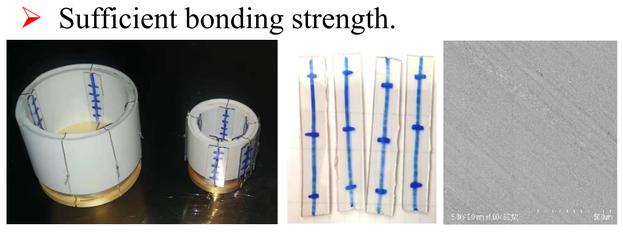
FIG. A standard brazing sample's tensile strength measurement curves , and a pull test of a ceramic RF window

TABLE II. Tensile strength results of ceramic RF windows.

	Sample	Max Load / kN	Tensile strength / MPa
1	Warm ceramic RF window-1	28.5	132.95
2	Warm ceramic RF window-2	27.3	127.33
3	Cold ceramic RF window-1	16.0	125.42
4	Cold ceramic RF window-2	16.5	129.47

B. TiN coating

- Vacuum magnetron sputtering technology is chose;
- TiN film acceptable thickness: 7 ~ 15nm.;
- Sufficient bonding strength.



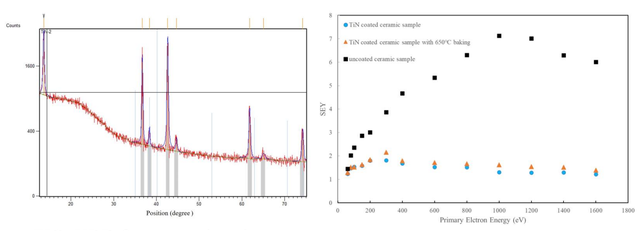


FIG. XRD for comparison between the real TiN film and standard TiN

FIG. SEY vs. primary electron energy

TABLE III. The chemical composition of TiN surface layer.

Etch time	Etch depth	Atomic content %				
		C	O	Ti	N	Ti : N
0s	0nm	18.08	36.24	24.04	21.64	1.11
50s	6nm	1.06	32.8	34.64	31.5	1.09
150s	18nm	0.43	31.21	35.45	32.91	1.07
400s	48nm	0.38	31.01	35.29	33.32	1.05

C. Copper plating

- Sulfate copper plating is our primary choice;
- The copper film thickness: 30μm ± 30 % for the WOC and COC; 150μm ± 30% for the WIC.

FIG. Thickness measurements of the copper films for a (a) warm outer conductor bellow, (b) cold outer conductor bellow and (c) warm inner conductor bellow.

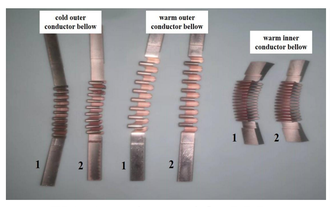


FIG. Samples used for RRR measurements of COC, WOC and WIC

FIG. Copper film of FPC

TABLE VI. RRR measurement results for three sections from 1.3 GHz coupler prototypes.

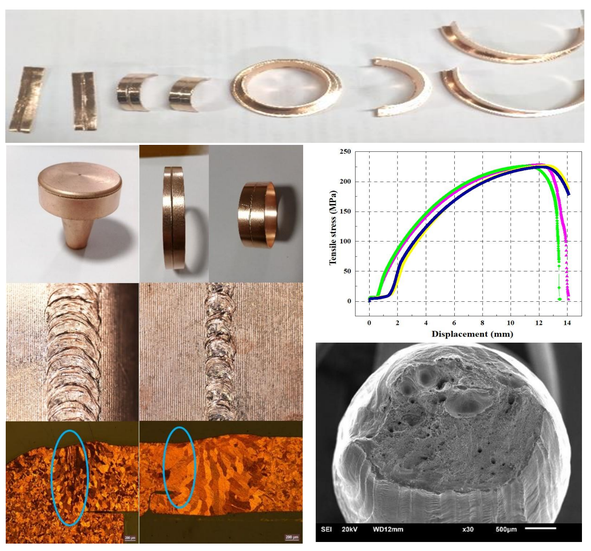
	Cold outer conductor		Warm outer conductor		Warm inner conductor	
No.	1	2	1	2	1	2
RRR	75.1	75.1	59.7	68.4	60.6	56.2

TABLE IX. Fatigue test results for 1.3 GHz coupler bellows.

	Cold outer conductor bellow		Warm outer conductor bellow		Warm inner conductor bellow	
	Cu uncoated	Cu coated	Cu uncoated	Cu coated	Cu uncoated	Cu coated
Cycles to failure	10165	10119	10054	10034	10119	10039

D. Electron beam welding (EBW)

- Sophisticated fixtures were designed to protect the ceramic windows;
- The welding structure of the two copper rings adopts step interlocking, which can be better positioned;
- The average tensile strength of the weld joints was 226 MPa, close to that of the base metal material..



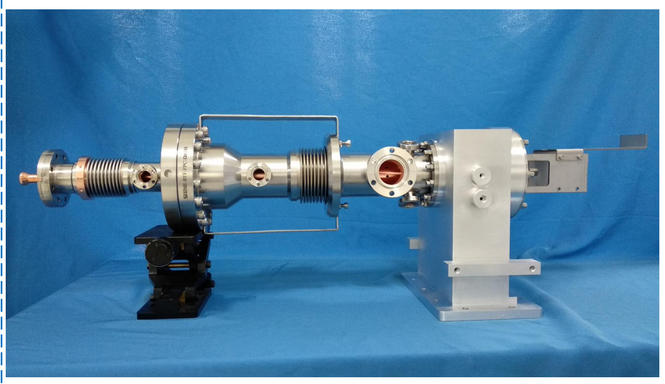


FIG. The SHINE 1.3 GHz FPC

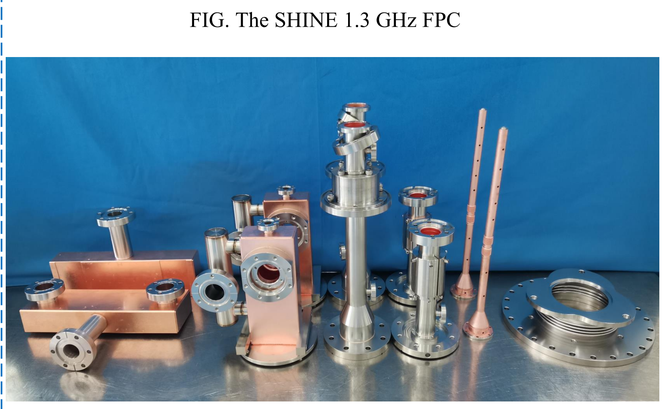


FIG. The SHINE 3.9 GHz FPC

RF HIGH POWER TESTS

1.3 GHz FPCs

- To date, 26 1.3 GHz FPC prototypes have been RF high power conditioned.
- All passed the RF high power tests, including CW operation **at 14 kW for 6 hours in TW mode** and CW operation at **7 kW for 12 hours in SW mode**.
- Even higher power levels were demonstrated at **20 kW CW TW** and **10 kW CW SW** keeping at this level for twelve.

3.9 GHz FPCs

- Two 3.9 GHz FPC prototypes have passed **CW 2 kW in TW mode** maintained for 22 hours and **2.2 kW** for two hours, which was the maximum output power of the SSA.
- They have passed **CW 1kW in SW mode** maintained for 8 hours and **2 kW** for two hours.

FIG. The layout of RF test system for 1.3 GHz FPCs

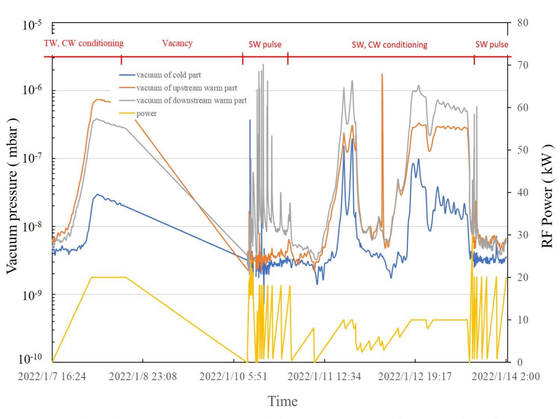


FIG. The RF power test history curves for a pair of 1.3 GHz coupler prototypes.

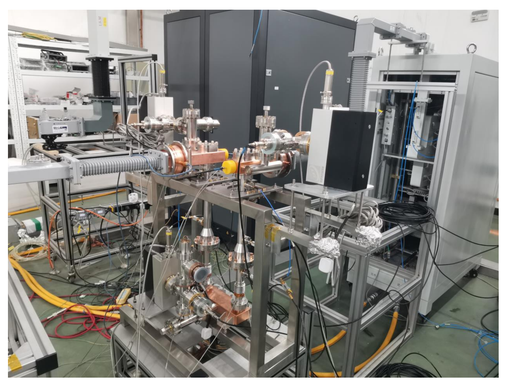


FIG. The layout of RF test system for 3.9 GHz FPCs

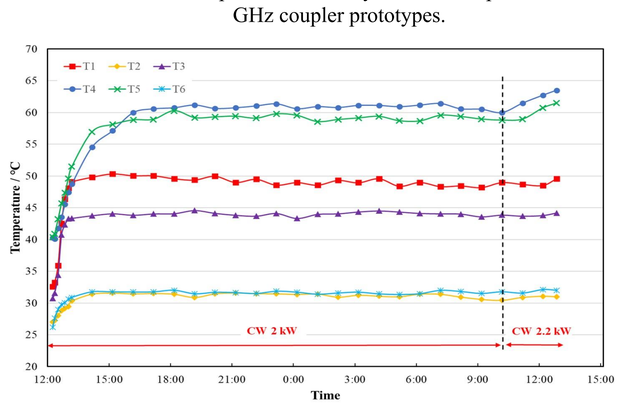


FIG. Temperature distribution for the upstream coupler during the CW conditioning in TW mode for 3.9 GHz FPC prototypes.

ACKNOWLEDGEMENTS

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CONCLUSIONS AND OUTLOOKS

- The 1.3 GHz and 3.9 GHz FPCs that are based on the TTF-III coupler were designed with some modifications for SHINE CW.
- The first batch 26 1.3 GHz and two 3.9 GHz coupler prototypes from three domestic manufacturers were manufactured and RF high power tested at room temperature.
- All the 1.3 GHz coupler prototypes passed the RF high power conditioning requirements at 14 kW CW TW and 7 kW CW SW. Even higher power levels were demonstrated at 20 kW CW TW and 10 kW CW SW, which is a good validation of the manufacturing process.
- Both 3.9 GHz coupler prototypes have successfully passed the RF high power conditioning of CW 2.2 kW in TW mode and CW 1 kW in SW mode. Even higher power levels have been demonstrated with CW 2 kW in SW mode.