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HIGH POWER FPC PROGRESS FOR EIC ESR CAVITIES

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HIGH POWER FPC PROGRESS FOR EIC ESR CAVITIES*

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Abstract

Electron-Ion Collider (EIC) is a next generation particle accelerator to be built at Brookhaven National Laboratory, in partnership with Thomas Jefferson National Accelerator Facility. In Electron Storage Ring (ESR), 18 single-cell 591 MHz SRF cavities are required to compensate for up to 10 MW energy loss due to synchronic radiation. Two high power FPCs for each cavity are used to deliver up to 800 kW power to the beam. The high power FPC were designed and reviewed. The FPC prototypes will be ready for high power test around mid-2026.

This paper presents the latest development of FPC prototyping and path forward for FPC conditioning.

INTRODUCTION

The EIC [1] to be built at BNL will be a discovery machine, providing answers to long-elusive mysteries of matter related to our understanding of the origin of mass, structure, and bind of atomic nuclei that make up the entire visible universe. The EIC includes a hadron accelerator that provides hadron beams and an electron accelerator that provide electron beams. The hardon accelerator is based on an upgraded version of the Relativistic Heavy Ion Collider [2] (RHIC) accelerator system. The electron accelerator is a new accelerator system, including electron injector, Rapid Cycling Synchrotron (RCS) and Electron Storage Ring (ESR). Figure 1 shows the schematic layout of EIC.

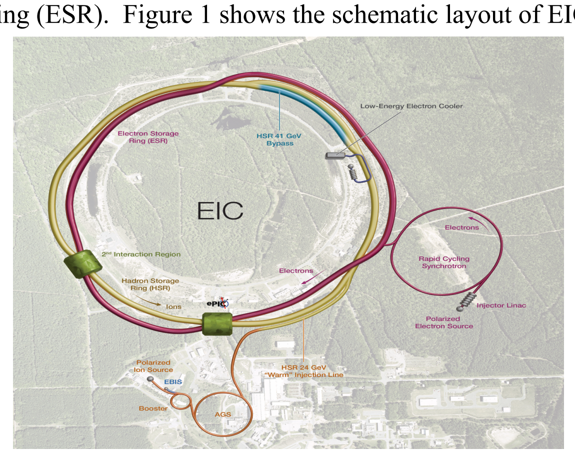

Figure 1: Schematic layout of EIC.

There are 18 single-cell SRF cavities in the ESR for synchronic loss compensation. In each cavity, there are two high power FPCs to deliver up to 800 kW power to the beam. Therefore, a 400 kW CW FPC design is needed for EIC ESR SRF cavity. This paper presents the latest results of FPC prototype and testing plan.

FPC DESIGN OVERVIEW

FPC design features

The EIC FPC is an improved design of KEK/SNS/BNL BeO window FPCs [3,4,5]. Figure 2 shows ESR SRF cryomodule layout and the design of high-power coupler.

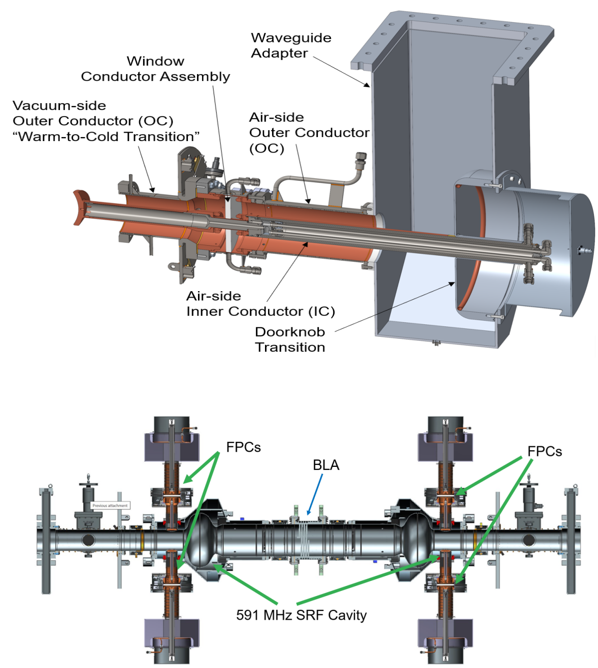

Figure 2: EIC ESR cavity.

There are two FPCs in each cavity, and they are installed horizontally 180 degree apart. With implementing lessons learned from the similar FPC window, there are several features in the EIC FPC[6].

1. RF window material: 99.5% alumina.
2. Broadband window design for multiple frequencies in EIC RF complex.
3. Robust thickness of the RF window: 10.5 mm
4. Large the distance between the window surface to choke tip. This allows visual inspection of the brazing joint and improvement on the uniformity of TiN coating under the choke.

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5. FPC coaxial line was optimized for lower RF field, higher coupling factor, and minimize the multipacting zone in the FPC.
6. Make sure the whole FPC can survive 5 g impact load.
7. Part of vacuum side FPC outer conductor (FPC-cavity connection section) is immersed in liquid helium.
8. Helium gas cooled FPC vacuum side outer conductor.
9. Water cooled inner conductors, air side outer conductor and doorknob.
10. Water cooled window inner and outer surface.
11. 4.5 KV of DC bias will be ready to apply, if needed.
12. Instrumentations: arc detector, vacuum gauge, thermal sensors, water flow switches.

RF-thermal analysis

Table I listed the FPC operation scenarios. FPC-cavity integration study was carried out in the worst power loss case, i.e., the case for FPC conditioning in cryomodule. Figure 3 shows the FPC thermal profile under the worst power loss case, which result is reasonable.

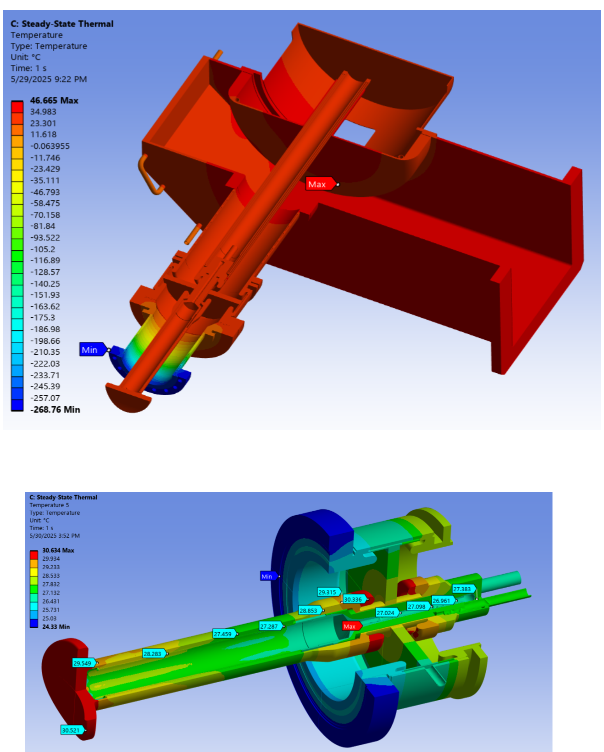


Figure 3: FPC thermal profile

One challenge for ESR cryomodule is the limit available space, which leads to the FPC-cavity flange (2K) to FPC window flange (300 K) as short as 4 inches. This is shown in Figure 4. A comprehensive RF-thermal analysis was carried out and a cooling scheme was designed. The required 5 K helium flow is 200 mg/s and the heat flow to 2 K is minimized to 4.2 W.

Table 1: FPC operation scenarios

Case	18 GeV	10 GeV	CM test to 4.4MV	FPC conditioning in cryomodule
Total Pfwd per cavity (kW)	556	560	223	800
Doorknob OC (W)	362	367	287	950
Doorknob IC (W)	161	166	158	338
WTC (W, warm Cu)	13.6	14.2	14.7	23
Vac side IC (W)	188	198	220	300
Window (W)	28.8	31.9	47.4	2.7

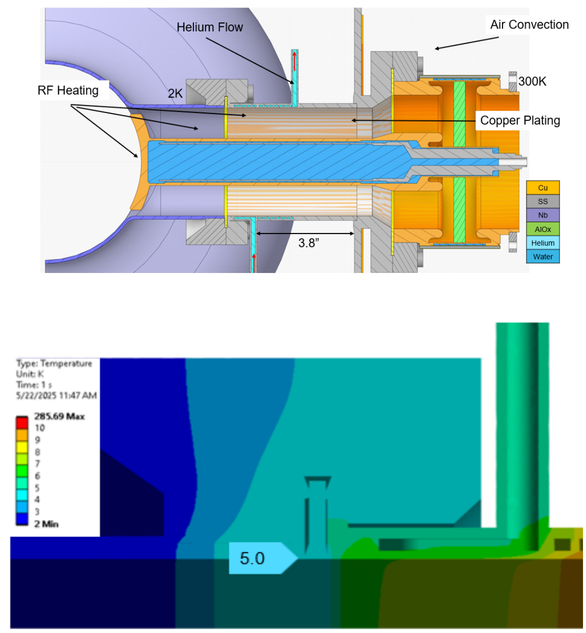
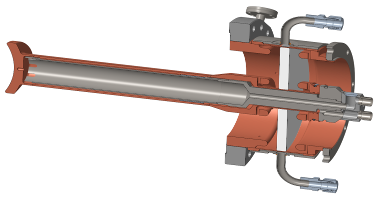


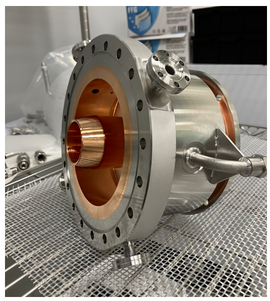
Figure 4 Top: FPC cold-to-warm transition, Bottom: temperature profile around FPC-cavity flange.

FPC PROTOTYPING PROGRESS

A FPC manufacture is broken down into three subcomponents: window assembly, doorknob and coaxial line components. The most challenging part is the FPC window assembly, and the progress is shown in Figure 6. Two whole FPCs will be completed in March 2026.



(a)



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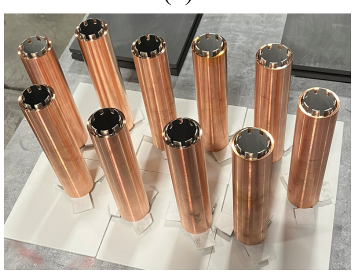

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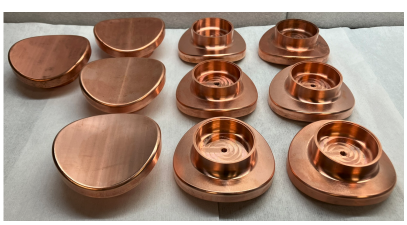

(d)

Figure 5: FPC window assembly and its components.

TiN coating recipe development

To verify the TiN coating uniformity and quality, a window mock up was built with slots to place alumina coupon strips, as shown in Figure 6. The mock-up window was sent to two vendors for TiN coating. TiN coating results were analysed by TEM in CFN at BNL[]. Figure 7 shows the thickness and uniformity along the radius of the window surface. TiN coating covers all over the ceramic, particularly, the area under inner and outer choke. The thickness in most of locations meets the specification (10 +/- 5 nm), except for small area under the inner conductor choke. This is acceptable. SEY measurement results on two TiN coated alumina samples along with an uncoating alumina were shown in Figure 8. It demonstrated the TiN coating dramatically reduced SEY. Therefore, the TiN coating recipe development was completed.

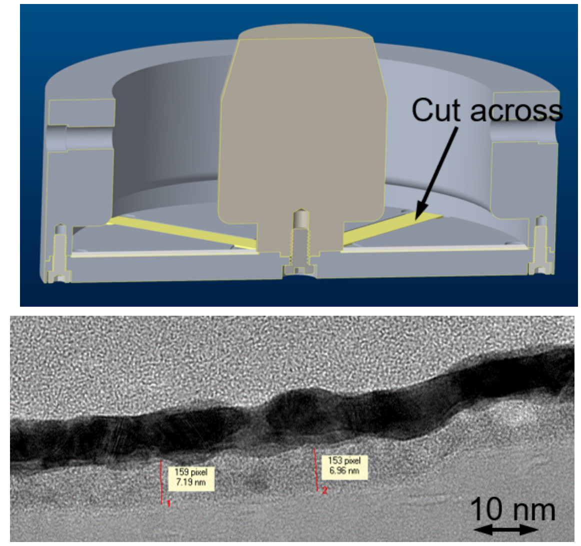

Figure 6: Top: Window mock up; Bottom: TEM measurement.

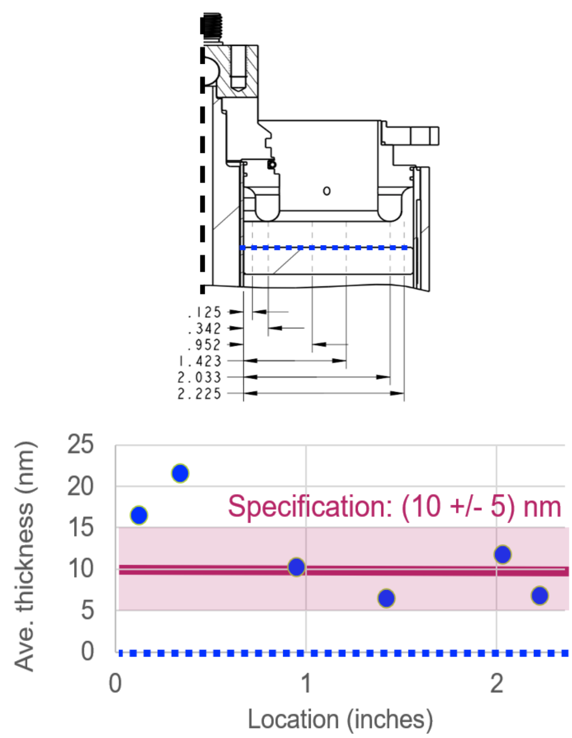

Figure 7: Top: Locations for TEM measurements; Bottom: TiN coating thickness.

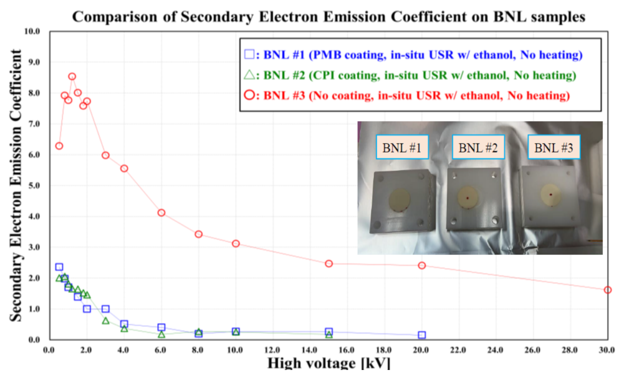

Figure 8: SEY measurement results

FPC TESTING PLAN

FPC conditioning setup

High power RF test is a critical step forward to verify the FPC design. A rectangular conditioning box was designed to adapt two FPCs testing simultaneously. Figure 9 shows the schematic diagram of the FPC conditioning setup. Majority of the instrumentations will be reused from BeO window FPC test.

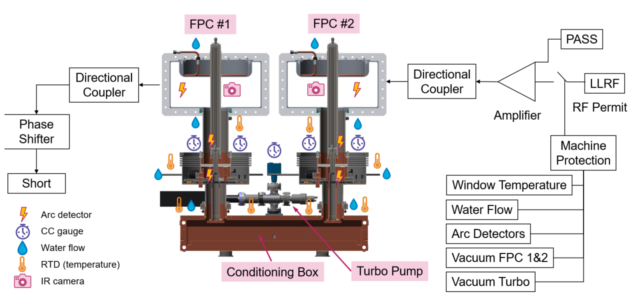

Figure 9: FPC conditioning setup.

FPC conditioning process

Due to the delay of 591 MHz klystron, we plan to condition FPCs with the existing 704 MHz klystron. The 704 MHz FPC conditioning box is a shorten version of 591 MHz conditioning box, which allows minimum resource and time to spend on the one-off test box. Testing FPCs at 704 MHz will verify the power handling capability of the FPCs and provide early reassurance of FPC design and manufacture. The maximum power testing at 704 MHz will be 370 kW, which is equivalent to 400 kW at 591 MHz. Eventually, all FPCs will be conditioned with 591 MHz klystron, prior to installation on the ESR cryomodule.

SUMMARY

A CW 400 kW FPC was designed, and prototyping was in progress. Detailed FPC-cavity integration study has completed. TiN coating recipe has developed. FPC conditioning path forward has laid out. We expect to start high power FPC test in mid-2026.

ACKNOWLEDGE

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The author would also thank Kirk Yamamoto from KEK for measuring the SEY as well.

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