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PROGRESS ON HIGH POWER FPC DEVELOPMENT FOR EIC*

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Abstract

The Electron-Ion Collider (EIC) requires 34, 500 kW Continuous-Wave (CW), 591 MHz Fundamental Power Couplers (FPCs) to compensate the Electron Storage Ring's (ESR) 10 MW of synchrotron radiation and other beam driven losses. This paper will describe the FPC design and fabrication status, particularly the technical challenges associated with 500 kW CW operation and the innovative design addressing this. Of important note, the RF window is based on 99.5% purity alumina, and it was designed to be bandwidth, which makes it applicable to FPCs for the EIC's other RF systems, not just for the ESR with frequencies ranging from 197 MHz to 591MHz. This results in significant savings by eliminating the need to design multiple different RF windows for the different RF systems in EIC. This paper will describe the design and prototype progress of the high-power FPCs for EIC.

INTRODUCTION

Brookhaven National Laboratory (BNL) and Thomas Jefferson National Accelerator Facility (TJNAF) are collaborating on the design and construction of the next Electron-Ion Collider (EIC) [1], which is to be built at BNL. The ion beams in EIC will be provided by an upgraded version of the Relativistic Heavy Ion Collider (RHIC) [2] accelerator system at BNL. The electron beams in EIC will be provided by a new electron accelerator, including a pre-injector linac, a Rapid Cycling Synchrotron (RCS) and an ESR.

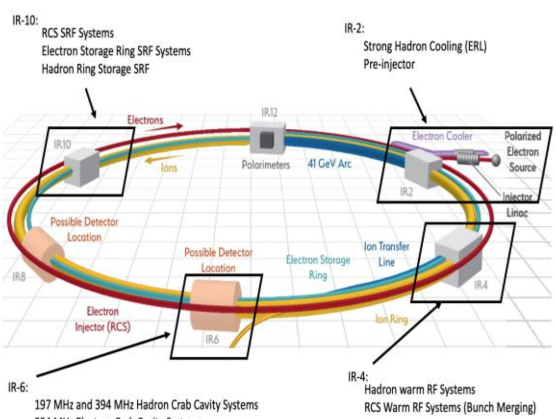

Figure 1: EIC RF systems.

Figure 1 shows the RF systems layout for the EIC. In ESR, there are 17 single-cell 591 MHz SRF cavities, which must compensate synchronic and HOM loss, about 10 MW in total. There are two FPCs in each cavity, and each FPC must deliver up to CW 379 kW to beam. A CW 500 kW high power FPC was designed to fulfil the need for EIC ESR. The paper will present the recent progress on the high power FPC development at BNL.

FPC DESIGN

Figure 2 shows the EIC SRF cavity layout and the design of high power FPC. There are two FPCs for each cavity and they are installed horizontally 180 degrees apart. The FPC is a new generation of choke-structure window FPC, and it is based on design and operation experience of such FPCs at KEK [3], SNS [4] and BNL [5]. The RF window is a broadband design, which covers frequencies below 591 MHz, so this window will be used for other RF/SRF cavities in EIC. Details of the FPC design can be found in the reference [6]. However, here are highlights of EIC FPC design:

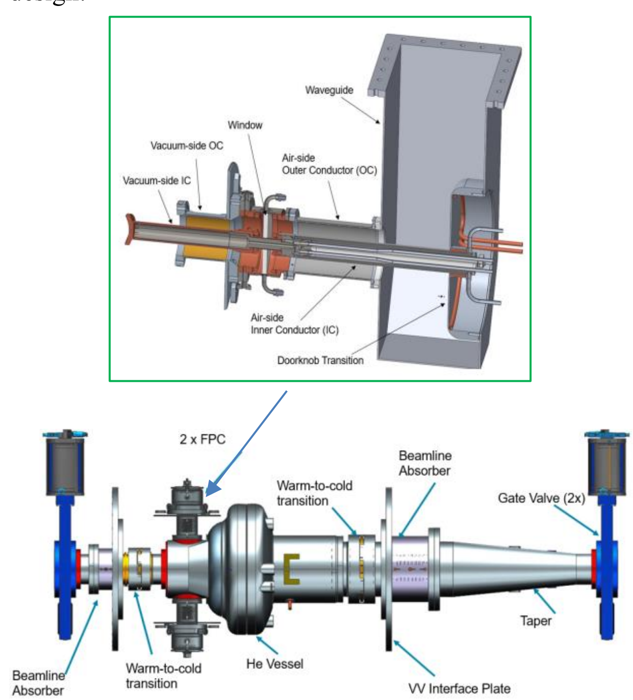

Figure 2: EIC ESR 591 MHz SRF cavity layout (bottom) and EIC high power FPC (top).

- Large the mechanical distance between the window surface to choke tip. This allows visual inspection of the window braze joint and improves the uniformity of TiN coating under the choke.
- The FPC coaxial line inner conductor was increased, optimizing the design for lower RF field amplitude,

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higher coupling factor, and reduced the multipacting zone in the FPC.

- Ensure the FPC can survive 5 g impact loads in all directions.
- Cavity FPC flanges are integral to the helium jacket, extending 2.0 K liquid helium cooling throughout the entire Nb cavity.
- The vacuum side outer conductor provides a thermal separation between 2.0 K and room temperature over a 6 inch length, combining both supercritical gaseous helium trace cooling and an uncooled thermal transition.
- Water cooled inner conductors, air side outer conductor and doorknob.
- Water cooled window inner and outer surface.
- An inner conductor design compatible with applying a DC bias.
- Included instrumentation: arc detector, vacuum gauge, thermal sensors, water flow switches, inline water temperature monitors, and a full suite of RF interlocks on the forward and reflected power.

FPC PROTOTYPE PROGRESS

The FPC prototyping progresses very well and we are on track to deliver two FPCs for EIC ESR 591 MHz single-cell first article cryomodule.

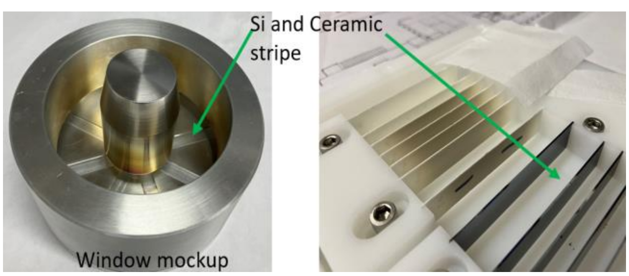

Figure 3: Window mock-up and ceramic strip.

TiN Coating Sample Measurement.

To study the multipacting reduction of TiN coating, two FPC window mock-ups were fabricated and set to two vendors for TiN coating, as shown in Fig. 3. Chemistry components were measured with TEM and SEY curves were measured on the TiN coating. Table 1 shows the chemistry components of the TiN coating sample from two vendors. Both samples have about 50 % of titanium, although one vendor has more percentage of nitrogen, and the other vendor has more percentage of oxygen. So, it is more accurate to call Titanium Oxynitride instead of TiN. Also, both vendors' coating thickness met our spec: 5- 15 nm. Second emission yield (SEY) curved were measured on both samples along with a bare alumina sample. The SEY measurement results are shown in Fig. 4. The SEY measurement results demonstrated that both samples have similar multipacting suppressing effect, which is a factor > 4 lower than the SEY on the bare alumina. Multipacting simulation carried out with bare alumina SEY shows that there will be no multipacting when a 4.5 KV of DC bias is applied on the FPC. However, the TiN coating is still an important step to be implemented during FPC manufacture. The FPCs will be conditioned without DC bias and then a DC bias will be applied only if it is determined to be necessary.

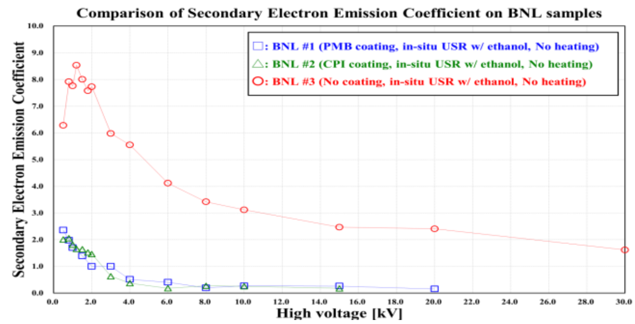

Figure 4: SEY measurement results.

Table 1: TiN Coating TEM Measurement Results

Element	Vender #1	Vendor #2
Nitrogen	34.63	42.94
Oxygen	12.35	8.38
Titanium	53.01	48.68

Brazing Test

Brazing tests were carried out to study the brazing procedure with actual sizes of window and cooper rings (without choke joint), as shown in Fig. 5. After three brazing tests, the brazing procedure was finalized with the brazing results shown in Fig. 6.

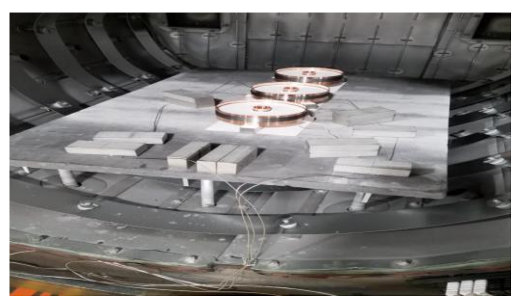

Figure 5: RF window brazing setup.

Figure 6: Brazing results

Other Components

The FPC prototype manufacture is carried out in-house at BNL, with help from partner lab-JLab. Figure 7 shows some of the manufacture progress photos.

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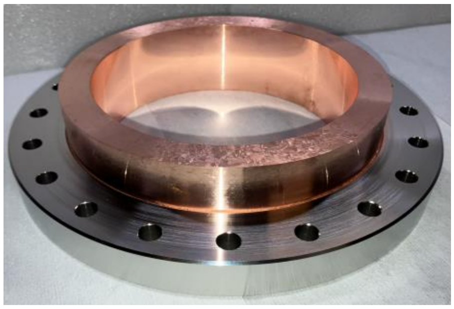

(a) Brazed vacuum side flange

(b) FPC Pringle

(c) Vacuum side inner conductor EB welding test

(d) Inner conductor brazing test

(e) Vacuum side inner conductor cooling water lead
Figure 7: FPC components manufacture.

FPC CONDITONING PLAN

Along with manufacturing FPCs, a FPC conditioning box and related FPC conditioning cart is ongoing development. A 591 MHz 600 kW klystron was ordered and expected to deliver in December 2024. The plan is to start high power conditioning in a FPC conditioning cart, see Fig. 8. The conditioning will be carried out without DC bias first, and then with DC bias applied, if needed. The detail process of FPC conditioning will be followed our experiences high power coupler conditioning, i.e., starting with short pulse, low duty factor, progressing to CW operation as the peak RF voltage and duty cycle are increased.

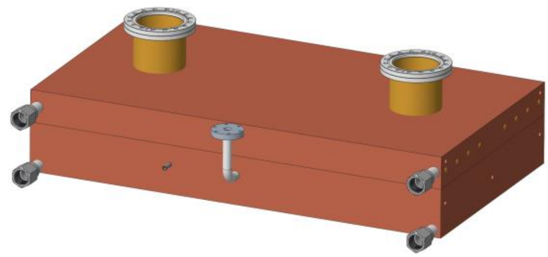

Figure 8: FPC conditioning box

SUMMARY

High power FPC is a challenge for EIC RF/SRF system. Based on design and operation experience of the choke-structure FPC, a new generation of FPC was designed, with improvement on various aspects. A good progress on high power FPC prototype has been made. FPC conditioning setup is ongoing manufacture. The plan is to start high power FPC conditioning in summer 2025.

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