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STATUS OF THE CARIE HIGH GRADIENT PHOTOCATHODE TEST FACILITY AT LANL*

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Abstract

This paper describes the status of assembling and commissioning of the Cathodes And Radio-frequency Interactions in Extremes (CARIE) C-band high gradient photoinjector test facility at Los Alamos National Laboratory (LANL). The construction of CARIE began in October of 2022. CARIE will house a high gradient copper RF photoinjector with a high quantum-efficiency cathode and produce an ultra-bright 250 pC electron beam accelerated to the energy of 7 MeV. The 50 MW 5.712 GHz Canon klystron will power the facility. The klystron was received and installed in fall of 2023. It was commissioned to the maximum operating power and repetition rate in early 2024. The WR187 waveguide line will bring the power from the klystron into a concrete vault that is rated to provide radiation protection for an electron beam powers up to 20 kW. The first RF injector was fabricated and is made of copper and does not have cathode plugs. This injector will be commissioned to validate operation of the CARIE facility. The second injector is designed for use with cathode plugs and novel photocathodes and will be fabricated. The status of the facility, the photoinjector and the beamline are summarized in this paper.

INTRODUCTION

At Los Alamos National Laboratory (LANL), we conduct high gradient C-band accelerator studies motivated by multiple LANL project and future mission needs. LANL has proposed a high gradient C-band upgrade to Los Alamos Neutron Science Center (LANSCE) proton linac to enable higher energy proton radiography [1, 2]. There is an identified need for a powerful directional high-repetition-rate narrow-bandwidth complementary X-ray Inverse Compton Scattering (ICS) light source at LANSCE [3]. The accelerator structures delivering beams for these proposed facilities must operate at a high gradient because of the existing space limitations. The number of photons produced by the proposed ICS source is also highly dependent on the quality (low emittance and high brightness) of the electron beam, which can be improved by an order of magnitude by redesigning the radio-frequency (RF) photoinjector for operation at high gradients.

In October of 2022, LANL started construction of a new C-band accelerator test facility for cathode, accelerator, and material science studies called Cathodes And Radio-frequency Interactions in Extremes (CARIE) [4-6]. This paper describes the current status of this facility.

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Figure 1: Photograph of the CARIE klystron (top); photograph of the chiller that supplies cooling water to the klystron and the facility (bottom).

INSTALLATION AND COMISSIONING OF THE KLYSTRON AND THE WAVEGUIDE LINE

The new 50 MW C-band klystron for CARIE facility was ordered from Scandinova and delivered to LANL in fall of 2023. A photograph of the klystron with a short waveguide line ending with a water-cooled load is shown in Fig. 1 (top). The chilled water for cooling the klystron and the load is supplied by an Advantage Engineering

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MGD-series chiller rated for 9.1 kW of cooling duty [Fig. 1 (bottom)].

The waveguide line has been designed to deliver the power from the klystron to the RF injector installed in the vault rated for 20 kW of electron beam power [Fig. 2 (top)]. However, only a short section of a beamline was assembled first to conduct testing and conditioning of the klystron. The klystron was fully conditioned in early 2024. The maximum achieved peak powers and repetition rates are summarized in Table 1. The peak power and repetition rates were eventually limited by the cooling capacity of the chiller.

Table 1: Maximum Power and Repetition Rates Achieved During Conditioning of the C-Band Klystron

Rep. rate	**Pulse Width 1 μs**	**Pulse Width 1.25 μs**	**Pulse Width 1.5 μs**
1 Hz	36 MW	36 MW	36 MW
20 Hz	N/A	36 MW	36 MW
40 Hz	N/A	25 MW	20 MW

It was decided to assemble the second section of the waveguide line up to the high-power RF circulator as shown in Fig. 2 (middle). The assembly of this section was started in April of 2024. The circulator was designed and fabricated by Microwave Techniques LLC [Fig. 2 (bottom)] and is rated to operate at 50 MW of peak power, 5 kW of average power, when filled with SF6 and pressurized to 50 psig. However, the waveguide windows manufactured by Microwave Techniques are only rated to 36 psig. Thus, a decision was made to only pressurize the circulator to 30 psig and condition to no more than 15 MW of peak power. It must also be noted that this particular design of the circulator has never been previously tested at high power. The high-power testing of the circulator is scheduled to start in June of 2024.

FABRICATION AND TESTING OF THE RF INJECTOR

The 1.6-cell C-band photoinjector cavity was designed for the CARIE test stand. The cell profile was optimized to reduce peak surface fields for the high gradient and to keep the injector operating below the threshold of notable dark current emission even at 240 MV/m electric fields at the cathode [7]. Approximately 8 MW of peak RF power is required to operate this photoinjector at 240 MV/m cathode field at room temperature. Due to the minimized crosstalk between the two cells of the injector cavity, the injector was designed with distributed side coupling with two waveguides individually powering two cells with a 180^0 phase advance [8]. The CAD model for the injector is shown in Fig. 3.

The RF injector was fabricated by Dymenso, LLC and delivered to LANL in fall of 2023. The injector was then cold-tested and tuned to achieve the correct coupling frequency and the uniform field profile. Photographs of the injector during the cold-testing are shown in Fig. 4. Tuning of the injector was performed with pushing and pulling on the stainless-steel tuning studs in both 0.6 cell and the full cell. The bead pull test was performed after each round of tuning until a balanced field profile was measured in the two cells. The coupling characteristics of the injector cavity before and after the tuning are shown in Fig. 5 (top). The final electric field profile on axis of the injector measured with the bead pull is shown in Fig. 5 (bottom). Final measured characteristics were in good agreement with the design and CST simulations.

The second version of the RF photoinjector was designed to include the removable stainless steel cathode plug. It was decided to use the INFN-like design of the

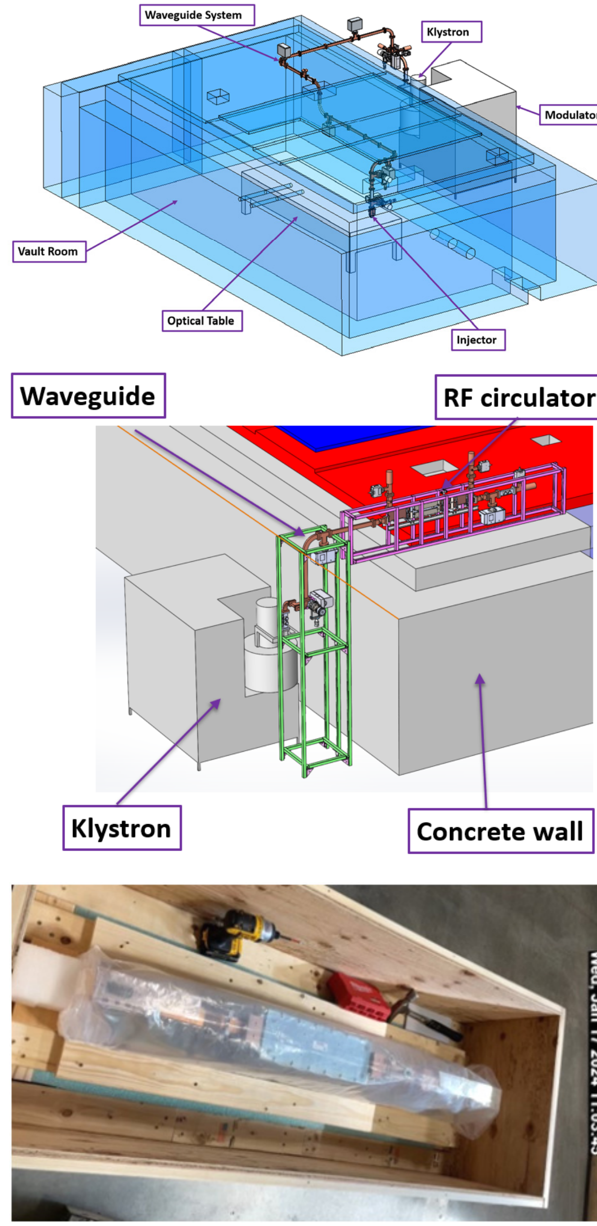

Figure 2: A schematic of the waveguide line for the CARIE test facility (top); a schematic of the waveguide line up to the RF power circulator currently under construction (middle); a photograph of the high-power circulator in the crate delivered from Microwave Techniques (bottom).

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cathode plug for CARIE with a modified cathode end. The purpose of the modification was to mitigate multipacting around the plug at high RF fields. The plug that will be used in CARIE will also separate into two parts for compatibility with LANL's ACERT cathode deposition facility [5]. For more details on the design of the RF photoinjector see Ref. [9]. We are finalizing the CAD drawings of the photoinjector with the plug. Fabrication will follow.

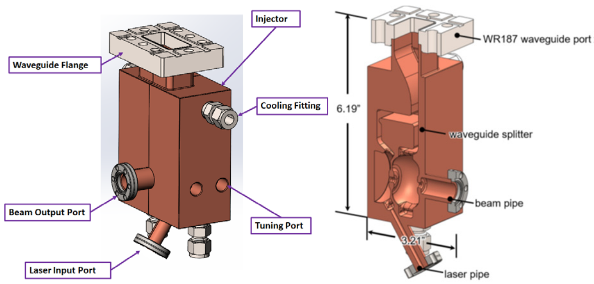

Figure 3: The CAD model of the 1.6 cell all-copper RF photoinjector for CARIE (left); a longitudinal cross-section of the CAD model showing details of the design (right).

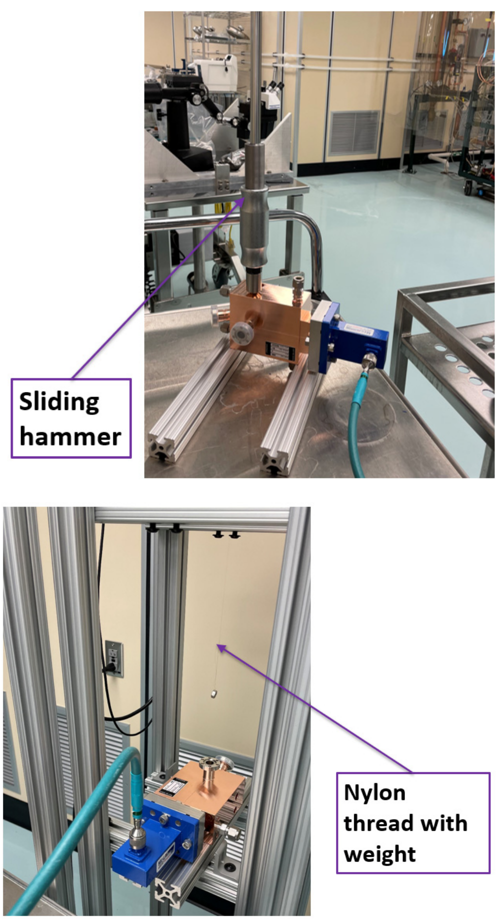

Figure 4: Photograph of the 1.6 cell RF injector during tuning (top); photograph of the 1.6 cell RF injector on the bead pull test stand (bottom).

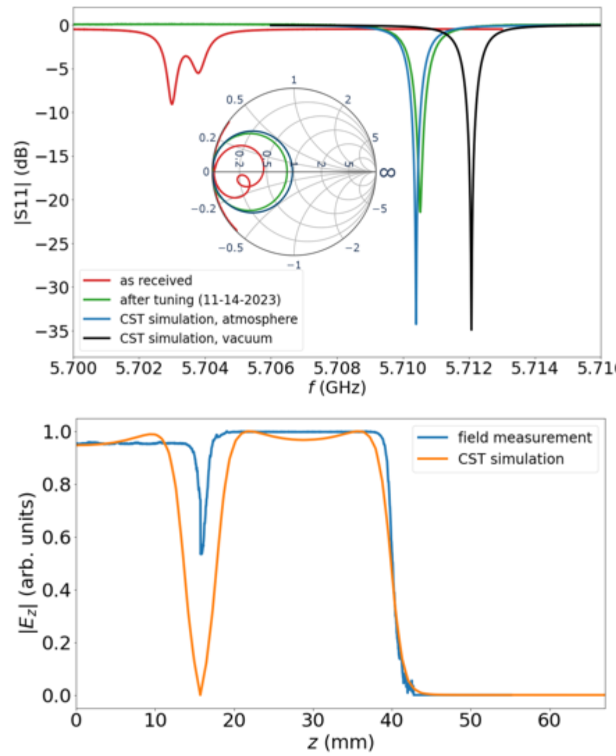

Figure 5: Coupling characteristics of the 1.6 cell injector as computed with CST and as measured before and after the tuning (top); the electric field profile on axis of the 1.6 cell injector as computed with CST and measured with bead pull showing balanced fields in the two cells (bottom).

CONCLUSION AND PLANS

In summary, this paper reported the status of construction and commissioning of the high gradient photoinjector and accelerator test facility CARIE. CARIE will house an RF photoinjector with insertable high quantum-efficiency cathodes that will operate at a high accelerating gradient up to 240 MV/m on the cathode. The components for CARIE including the 50 MW Canon klystron, the RF circulator, the first all-copper photoinjector cavity, and multiple waveguides and vacuum pumps are now delivered at LANL. The assembly and commissioning are in progress. The second version of the photoinjector that includes the cathode plug insert has been designed and will be procured in the near future. We plan to condition the all-copper photoinjector in fall of 2024 and proceed with assembling the beamline and diagnostics. For details on simulations of the beam dynamics see Refs. [10, 11]. For details on diagnostics see Ref. [12]. The photocathode team at LANL is working on improving their cathode deposition methods and the vacuum suitcase for cathode transfer. For details on cathode fabrication see Ref. [13] and for details on the vacuum suitcase design see Ref. [14].

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