14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPL138

UPDATE ON THE STATUS OF C-BAND HIGH GRADIENT PROGRAM AT LANL*

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Abstract

This paper describes the status of C-band high gradient research program at Los Alamos National Laboratory (LANL). The program is being built around two test facilities: C-band Engineering Research Facility in New Mexico (CERF-NM), and Cathodes And Radio-frequency Interactions in Extremes (CARIE). Modern applications such as X-ray sources require accelerators with optimized cost of construction and operation, naturally calling for high-gradient acceleration. In 2021, we commissioned CERF-NM, a high gradient test stand powered by a 50 MW, 5.712 GHz Canon klystron. The test stand is capable of conditioning accelerating cavities for operation at surface electric fields in excess of 300 MV/m. CERF-NM is the first high gradient C-band test facility in the United States. In the last several years, multiple C-band high gradient cavities and components were tested at CERF-NM. The construction of CARIE began in October of 2022. CARIE will house a cryo-cooled 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 status of the facility, the designs of the photoinjector and the beamline, and plans for components fabrication, installation, and conditioning are described below.

INTRODUCTION

High gradient C-band (5.712 GHz) accelerator development and research facility construction is ongoing at Los Alamos National Laboratory (LANL) 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 multi-GeV 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 Los Alamos Neutron Science Center (LANSCE) [2]. These future facilities will be built with accelerator structures operating at a high gradient to fit in a limited footprint within available space of the existing LANSCE facility. Operation of the future ICS source is also highly dependent on the quality (low emittance and high brightness) of the accelerated electron beam. This may be achieved through a ground-up redesign of the radio-frequency (RF) photoinjector to allow operation of the photoinjector and the photocathode at high gradients. This paper delivers a summary of the latest LANL efforts in high gradient C-band research and testing at LANL and updates on the status of the two C-band test facilities in operation and under construction: C-band Engineering Research Facility in New Mexico (CERF-NM), and Cathodes And Radio-frequency Interactions in Extremes (CARIE).

C-BAND ENGINEERING RESEARCH FACILITY IN NEW MEXICO, CERF-NM

CERF-NM [3, 4] is the first and currently only high gradient C-band test facility in the United States. CERF-NM is built around a 5.712 GHz Canon klystron that supplies 50 MW RF pulses with the pulse length that can be varied between 300 ns and 1 microsecond, repetition rate up to 200 Hz, and is tunable within the frequency band of 5.707 GHz to 5.717 GHz. The RF power from the klystron is coupled into a WR187 rectangular waveguide that brings power into a 3 foot by 4 foot lead box built to provide radiation protection to equipment and operators during high gradient testing. The lead box is radiologically certified for dark currents with electron energy up to 5 MeV and average current up to 10 μA.

Several accelerating cavities have been tested at high gradients at CERF-NM in the last two years (Fig. 1). The first two cavities were 5.712 GHz single-cell proton accelerating cavities fabricated by SLAC National Accelerator Laboratory [5]. The first cavity was made of copper and the second cavity was made of copper-silver with 0.085% of silver. The surface electric fields measured in the copper cavity at the end of high gradient conditioning were higher than 300 MV/m with breakdown probabilities below 10^{-4} 1/pulse/m. The surface electric fields measured in the copper-silver cavity at the end of high gradient conditioning were higher than 400 MV/m with breakdown probabilities below 10^{-4} 1/pulse/m [5].

Next, we fabricated two three-cell test cavities with the ratio of the iris radius, a, to the wavelength, λ, of $a/\lambda=0.105$. The cavities were built and tested to establish a benchmark for the high gradient structure performance at C-band. The structure was a direct scale of the similar test structures fabricated and tested by other institutions at the frequencies of X-band and S-band [6, 7]. Both cavities were conditioned up to the input power of 13 MW at the pulse length of 1 microsecond that corresponded to the peak surface electric field of 255 MV/m in the first cavity and 308 MV/m in the second cavity [8]. Maximum achieved fields were limited by the test stand and breakdown maps could not be produced for these cavities.

*This work was supported by Los Alamos National Laboratory's Laboratory Directed Research and Development (LDRD) Program.
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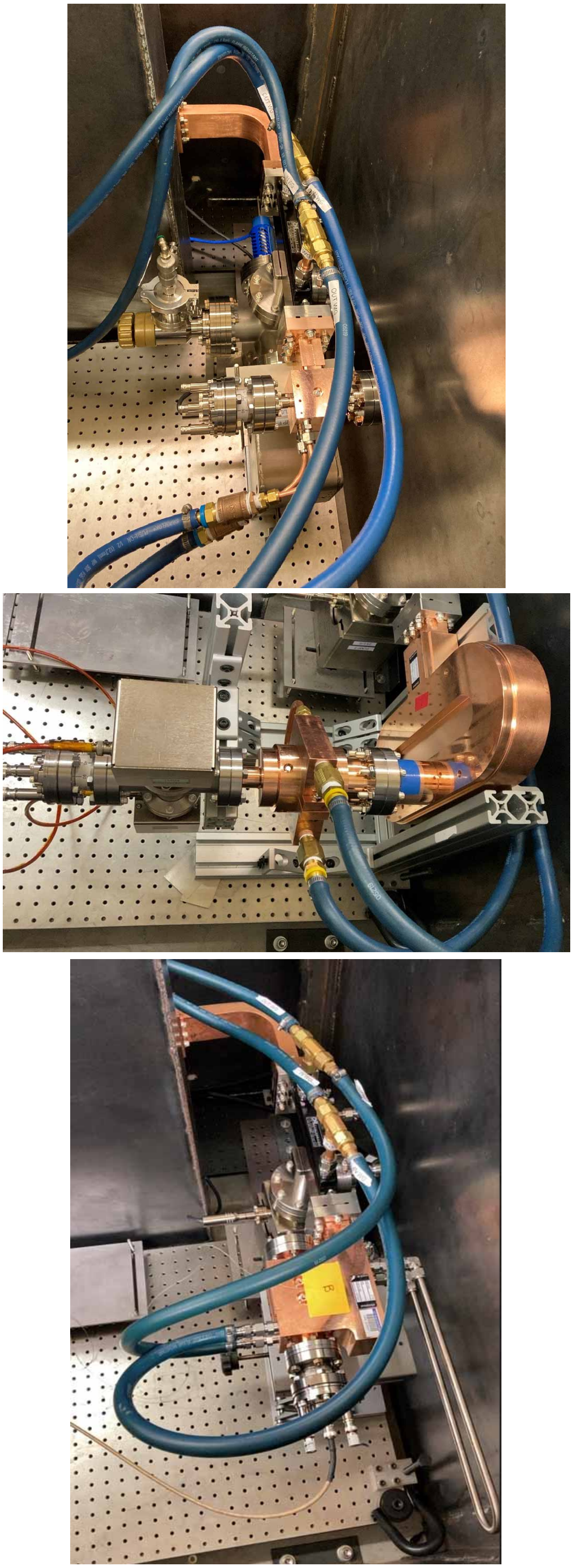

Figure 1: Photographs of various cavities and components tested at CERF-NM: SLAC's proton cavity (top); the three-cell benchmark cavity (middle); LANL's pRad upgrade proton cavity (bottom).

A two-cell proton accelerator cavity with distributed coupling and optimized cell shape was the next cavity tested at CERF-NM [1]. The cavity was designed as a prototype accelerating cavity for the multi-GeV LANSCE upgrade which will include a C-band accelerating section operating at a gradient of 40 MV/m. The cavity was conditioned up to the accelerating gradient of 100 MV/m and the breakdown map was recorded.

LANL has plans to offer CERF-NM test facility to collaborators interested in high gradient testing of other C-band cavities and components. Some potential collaborators expressed the need to perform high gradient testing of their RF structures at cryogenic temperatures. Thus, a possibility of adding a cryo-cooler to CERF-NM is being investigated.

CATHODES AND RADIO-FREQUENCY INTERACTIONS IN EXTREMES, CARIE, HIGH GRADIENT PHOTOINJECTOR TEST FACILITY

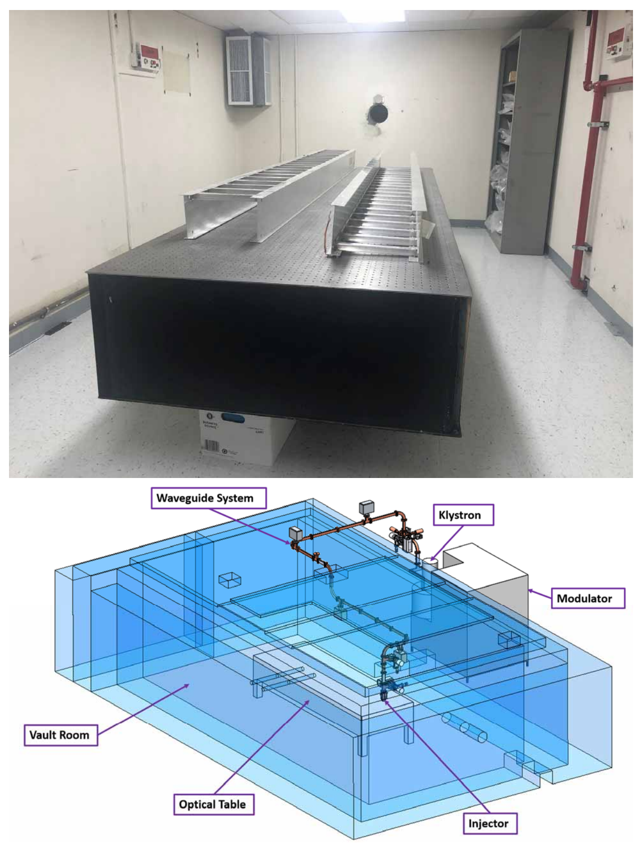

Figure 2: Current photograph of CARIE vault (top); Schematic of the waveguide line to be constructed in CARIE vault in 2023 (bottom).

In October, 2022, LANL started construction of a new C-band accelerator test facility for cathode, accelerator, and material science studies called CARIE. A radiation protection vault was identified on LANSCE mesa capable of accommodating an electron beam with the beam power

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up to 20 kW (see the photograph in Fig. 2). The new location will house a cryo-cooled copper RF photoinjector with a high QE cathode that will produce a 7 MeV, 250 pC electron beam. The new 50 MW C-band klystron for CARIE facility is on order to be delivered to LANL in summer of 2023. The waveguide line has been designed to deliver the power from the klystron to the RF injector installed in the vault (Fig. 2). All components for the waveguide line are currently on order. For details on the status of CARIE vault and the waveguide line design and construction see [9].

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 [10]. The chosen form of the cavity also permits for lower input power and mitigates dissipation at cryogenic temperatures with only 8 MW of peak power required to operate this photoinjector at 240 MV/m cathode field at room temperature, and less than 2 MW of peak power required for operation at the temperature of liquid nitrogen. 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 coupling two cells with a 180^0 phase advance. The distribution of fields and the CAD model for the injector is shown in Fig. 3. The photoinjector is currently in fabrication with the estimated delivery in June, 2023. For further details on the photoinjector see [11, 12].

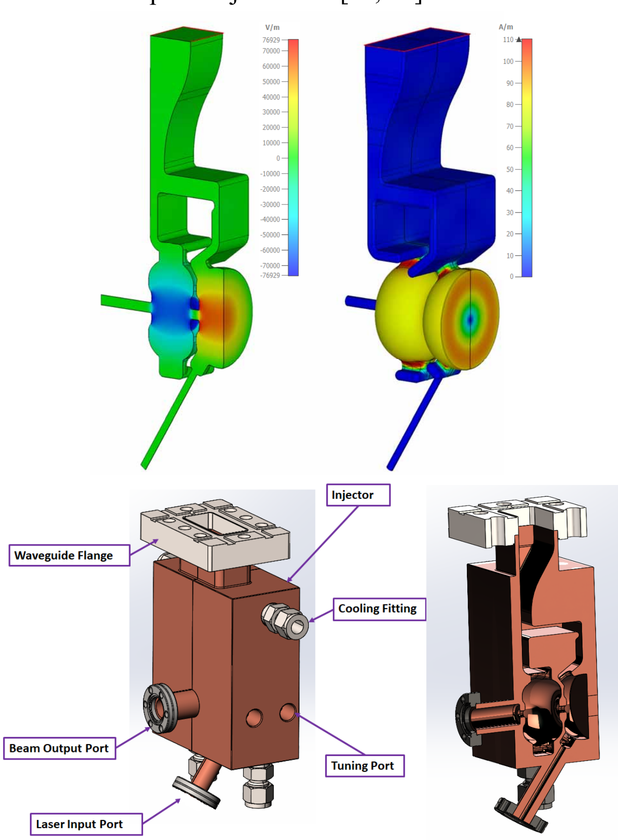

Figure 3: Electric and magnetic fields distributions in CARIE photoinjector cavity (top); CAD model of the CARIE photoinjector (bottom).

The unexplored challenge related to operating photocathodes at high gradients is the behavior and stability of high-quantum efficiency (QE) photocathode materials when exposed to the very high electric fields. One of the innovations of the new project is to employ heterostructured semiconductors to improve performance and increase lifetime of high-QE photocathode materials at high electric fields and increase the brightness of the beam [13]. Heterostructured photocathodes will be deposited on specially designed cathode plugs (Fig. 4) that are compatible with LANL's ACERT test stand. Traditional INFN-style cathode plugs are difficult to use in the ACERT system and would require major modifications to fit into growth or characterization chambers. The new cathode plug design is much shorter and will connect to a second specially designed piece in the vacuum suitcase for compatibility of the CARIE system with INFN plugs.

Figure 4: Photograph of the INFN cathode plug (left); CAD model of the ACERT cathode plug (middle); photograph of the ACERT cathode plug (right).

CONCLUSION AND PLANS

In summary, this paper reported the status of C-band high gradient accelerator program at Los Alamos National Laboratory. We constructed and commissioned the C-band high gradient test facility CERF-NM, and high gradient testing of accelerator cavities is on-going. The following cavities have already been tested at CERF-NM: the two side-coupled proton accelerator cavities, the two copper three-cell a/λ=0.105 cavities, and a two-cell proton accelerator cavity with distributed power coupling for LANSCE upgrade. The CERF-NM test stand is open to collaborators.

Beyond operating CERF-NM, LANL further develops its C-band accelerator capabilities. In October of 2022 we started constructing a high gradient photoinjector and accelerator test facility CARIE. CARIE will house a cryo-cooled copper 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 photoinjector cavity, and multiple waveguides, vacuum pumps, and diagnostics are all in various stages of procurement to be delivered in summer of 2023. We plan to assemble the klystron and the waveguide line in the fall of 2023 and condition the first photoinjector cavity before the end of the year.

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REFERENCES

[1] S.S. Kurennoy *et al.*, "High Gradient Accelerating Structures for Proton Radiography Booster Linac", presented at IPAC'23, Venice, Italy, May 2023, paper TUPM007, this conference.

[2] B.E. Carlsten *et al.*, "Future Los Alamos Neutron Science Center (LANSCE) Directions and Enabling R&D Studies", presented at IPAC'23, Venice, Italy, May 2023, paper TUPM014, this conference.

[3] E. I. Simakov *et al.*, "High Gradient High Efficiency C-Band Accelerator Structure Research at LANL", in *Proc. NAPAC'19*, Lansing, MI, USA, Sep. 2019, pp. 882-884. doi:10.18429/JACoW-NAPAC2019-WEPLO20

[4] D. Gorelov *et al.*, "Status of the C-Band Engineering Research Facility (CERF-NM) Test Stand Development at LANL", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 509-512. doi:10.18429/JACoW-IPAC2021-MOPAB146

[5] M. Schneider *et al.*, "High gradient off-axis coupled C-band Cu and CuAg accelerating structures", *Appl. Phys. Lett.*, vol. 121, p. 254101, 2022. doi:10.1063/5.0132706

[6] E. I. Simakov, V. A. Dolgashev, and S. G. Tantawi, "Advances in High Gradient Normal Conducting Accelerator Structures", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 907, p. 221, Nov. 2018. doi:10.1016/j.nima.2018.02.085

[7] V. Dolgashev, S. Tantawi, Y. Higashi, and B. Spataro, "Geometric dependence of radio-frequency breakdown in normal conducting accelerating structures", *Appl. Phys. Lett.*, vol. 97, p. 171501, Oct. 2010. doi:10.1063/1.3505339

[8] M. R. A. Zuboraj *et al.*, "High Gradient Testing Results of the Benchmark a/λ=0.105 Cavity at CERF-NM", in *Proc. NAPAC'22*, Albuquerque, NM, U.S.A., Aug. 2022, pp. 505-507. doi:10.18429/JACoW-NAPAC2022-TUPA75

[9] W. Barkley *et al.*, "Status of CARIE Facility Design and Construction", presented at IPAC'23, Venice, Italy, May 2023, paper MOPA008, this conference.

[10] J.B. Rosenzweig *et al.*, "An ultra-compact X-ray free-electron laser", *New J. Phys.*, vol. 22, p. 093067, 2020. doi:10.1088/1367-2630/abb16c

[11] P. Anisimov *et al.*, "Emittance Compensation in a High Charge TOPGUN Photoinjector", presented at IPAC'23, Venice, Italy, May 2023, paper WEPA042, this conference.

[12] H. Xu *et al.*, "C-band Photoinjector Radiofrequency Cavity Design for Enhanced Beam Generation", presented at IPAC'23, Venice, Italy, May 2023, paper TUPL139, this conference.

[13] E.I. Simakov *et al.*, "Update on the Status of C-Band Research and Facilities at LANL", in *Proc. NAPAC'22*, Albuquerque, NM, U.S.A., Aug. 2022, pp. 855-858. doi:10.18429/JACoW-NAPAC2022-THYD3