DEVELOPING OF SUPERCONDUCTING RF GUNS AT BNL*

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Abstract

BNL is developing several superconducting RF guns for different applications. The first gun is based on a half-cell 1.3-GHz elliptical cavity. This gun is used to study generation of polarized electrons from GaAs photocathodes. The second gun, also of a half-cell elliptical cavity design, operates at 704 MHz and is designed to produce a high average current electron beam for the R&D ERL from multi-alkali photocathodes. The third gun is of a quarter-wave resonator type, operating at 112 MHz. This gun will be used for photocathode studies, including a diamond-amplified cathode, and to generate a high charge, low repetition rate beam for the coherent electron cooling experiment. In this paper we describe the gun designs, present recent test results, and discuss future plans.

INTRODUCTION

Developing superconducting RF (SRF) photoinjectors is a part of the SRF program that is important for several projects in progress or under consideration at the Collider-Accelerator Department of BNL. The SRF photocathode guns promise to generate high-bunch-charge, high-average-current, low-emittance electron beams. The three SRF guns described in this paper address different issues, from generating polarized electrons, to experimenting with different photocathodes, to producing high-intensity beams for energy recovery linacs and electron coolers.

1.3 GHz SRF PLUG GUN FOR GaAs PHOTOCATHODES

SRF guns, which combine excellent vacuum conditions of DC guns and high accelerating gradients of RF guns, potentially can generate very low emittance polarized electron beams from GaAs photocathodes with long lifetime. Our simulations show that a SRF gun can exceed the ILC's requirement for vertical beam emittance by a factor of two, if an ellipsoid charge distribution is used. There will be no need for a damping ring.

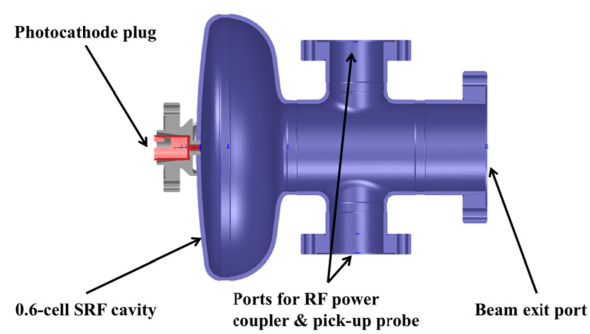

Figure 1: BNL 1.3-GHz plug SRF gun cavity.

Table 1: Parameters of the 1.3 GHz SRF gun

RF frequency	1300 MHz
Cavity active length	0.6 cell
Energy gain	0.6 MeV
Maximum field at the cathode	15 MV/m
e^- emission RF phase at 2.5 MV	20°
Cavity Q_0 at 2 K	7×10^9
Cavity operating temperature	2 K
Bunch repetition frequency	81.25 MHz
Bunch charge	0.12 pC
Bunch length	10 ps
Cathode spot size	2 mm dia.

We are using a 0.6-cell 1.3-GHz SRF plug gun to test the quantum efficiency (QE) and lifetime of a GaAs photocathode. It has got its name from a removable niobium plug holding a cathode and located at the back of the gun. The gun and cathode transfer system were

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designed and fabricated by AES, Inc. [1]. Figure 1 illustrates the cross section of the gun and Table 1 lists its main parameters. The Q_0 of 3×10^8 was obtained in a vertical test of the gun with a GaAs photocathode at JLab [2]. With our improved photocathode holder design, the Q_0 of the gun is estimated to be higher than 5×10^8.

A beam line for the beam test has been assembled and leak checked. A high temperature vacuum bake of the gun is necessary to achieve 10^{-11} Torr vacuum. Nb-Ti flanges began leaking during the bake. We plan to replace Nb-Ti flanges with two Conflat flanges, which can hold the high temperature easily. The refurbishment of the gun will be finished soon, and the final photoemission measurements are expected to take place in a few months.

The VTA test of the gun with the new holder and cathode is scheduled for mid-October of 2012. The goal of this is to test heat generating mechanism of the heavily doped GaAs in RF field. We successfully activated the bulk GaAs in a preparation chamber. The highest QE was 10% at 532 nm, which dropped to 0.8% after passing the photocathode through a transfer section to the gun [3].

704 MHz SRF GUN FOR R&D ERL

The R&D ERL at BNL is a facility dedicated to develop accelerator technologies for future energy recovery linac applications [4]. The project will be commissioned in several stages with an eventual goal to demonstrate operation with beam currents as high as 500 mA. A 704 MHz elliptical half-cell SRF gun was designed by BNL [5, 6] and fabricated by AES, Inc. Its main parameters are listed in Table 2.

Table 2: Parameters of the 704 MHz SRF gun

RF frequency	703.5 MHz
Cavity active length	8.5 cm (0.4 cell)
Maximum energy gain	2.5 MeV
Maximum field at the cathode	33.4 MV/m
E_{acc} at 2.5 MV	29.4 MV/m
e^- emission RF phase at 2.5 MV	33.4°
Energy gain at 500 mA	2.0 MeV
e^- emission RF phase at 2.0 MV	29.9°
Beam power at 500 mA	1 MW
R/Q	96.2 Ohm
Cavity geometry factor	112.7 Ohm
Cavity Q_0 at 2 K	3×10^{10}
Cavity operating temperature	2 K
Cavity RF losses (2 K) at 2.0 MV	1.4 W
Cathode operating temperature	80 K
Copper cathode RF losses (80 K) at 2.0 MV	226 W

The actual length of the nominally half-cell cavity is 0.4 cells. A copper cathode stalk is connected to the cavity via a specially designed quarter-wave choke joint. All surfaces of the choke joint are grooved to prevent multipacting [7]. The gun has two fundamental RF power couplers allowing delivery of 1 MW to a 500 mA electron beam. HOM damping is provided by a beamline ferrite load with a ceramic break [8]. A high temperature superconducting (HTS) solenoid is located inside the cryomodule near the beam exit.

The gun cryomodule was designed and fabricated by AES. Fundamental power couplers were manufactured by CPI/Beverly and were conditioned with maximum RF power of 250 kW pulsed and 125 kW CW in a full standing-wave mode [9]. The gun cavity was chemically etched, cleaned and vertically tested at Jefferson Lab. It reached accelerating gradient of 35 MV/m when tested without a cathode stalk.

The cryomodule was assembled at BNL, including its hermetic string (Figure 2) preparation in the clean room. It is installed in the ERL blockhouse for cold testing in Fall 2012 and subsequent beam operation. This gun will use a CsK_2Sb photocathode and is expected to operate with a gap voltage up to 2.5 MV and eventually generate a beam current of 500 mA at 2 MV.

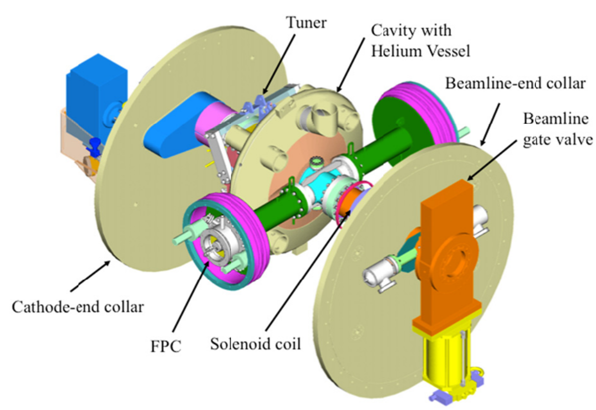

Figure 2: Hermetic string assembly of the 704-MHz SRF gun for R&D ERL.

112 MHz SRF GUN FOR COHERENT ELECTRON COOLING EXPERIMENT

A superconducting 112 MHz quarter-wave resonator (QWR) was developed for photocathode studies and electron gun experiments by collaborative efforts of BNL and Niowave, Inc. [10]. The low frequency was chosen to take full advantage of QWR benefits. The long wavelength allows generating long bunches and thus reducing space charge effects. A short, w.r.t. the wavelength, accelerating gap makes transit time factor close to unity and the gap field practically constant.

The gun will operate at 4.5 K with liquid helium provided from a quiet helium source via the cryomodule

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cryogenic tower. Assuming a residual surface resistivity of 10 nOhm and a residual magnetic field of 60 mG, we expect to achieve the cavity quality factor of 1.8×10^9.

The QWR's center conductor geometry naturally accommodates a half-wavelength choke joint and allows mechanical decoupling of the cathode assembly from the niobium cavity [11]. A low RF loss photocathode stalk operates at room temperature. It is hollow, allowing inserting a small photocathode pack via a load lock system. Experiments are planned with multi-alkali and diamond-amplified photocathodes. The gun cryomodule is shown in Figure 3 and the gun parameters are listed in Table 3.

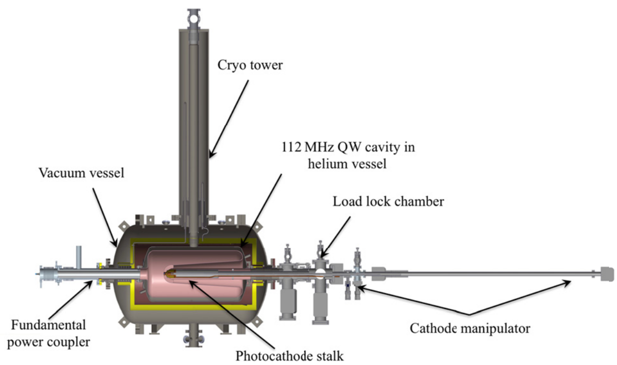

Figure 3: 112 MHz SRF gun cryomodule.

Table 3: Parameters of the 112 MHz QWR SRF gun

RF frequency	112 MHz
Maximum energy gain	2.0 MeV
Bunch charge	1 to 5 nC
Bunch repetition frequency	78 kHz
R/Q	127.3 Ohm
Geometry factor	38.5 Ohm
Cavity Q_0 at 4.5 K	1.8×10^9
Cavity RF losses at 2.0 MV	17 W
RF losses in the cathode stalk at 2.0 MV	38 W
Frequency tuning range	78 kHz
Frequency tuning with FPC	3 kHz
Q_{ext} of FPC, min.	1.25×10^7
Available RF power	2 kW

The 112 MHz gun will be equipped with a double-purpose fundamental RF power coupler/fine frequency tuning assembly [11]. The fine frequency tuning with a range of 3 kHz will be used for remote frequency adjustment. It will complement a larger range (78 kHz) tuner, which will be used only for an initial frequency set up. A focusing solenoid is placed on top of the FPC close to the cryomodule flange.

The cavity was chemically etched, high-pressure rinsed at Niowave, and first cold test of the gun was successfully performed there in December of 2010. The cavity *Q* of greater than 10^9 was measured and maintained up to ~0.5 MV accelerating voltage, and the pressure sensitivity of the fundamental mode was measured at 10 Hz/mbar [9]. At present, the gun cryomodule is undergoing modifications for compatibility with installation in RHIC tunnel, where it will become a part of the Coherent electron Cooling Proof-of-Principle (CeC PoP) experiment [12]. The first cool down of the modified gun at BNL is scheduled for 2013. The gun is expected to operate at an accelerating voltage up to 2 MV and generate electron beams with a charge per bunch from 1 to 5 nC.

SUMMARY

The superconducting RF photoemission sources of electron beams promise to provide high-quality electron beams for a variety of accelerator applications. At BNL, we are pursuing several design options. The 704 MHz gun for R&D ERL is assembled and its commissioning will begin soon. The other two guns are at different stages of modification with the goal to begin experiments in 2013.

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