

# A STEP CLOSER TO THE CW HIGH BRILLIANT BEAM WITH THE ELBE SRF GUN-II

R. Xiang<sup>#</sup>, A. Arnold, P. Michel, P. Murcek, J. Teichert, HZDR, 01328 Dresden, Germany  
P. Lu, H. Vennekate, TU Dresden & HZDR, 01328 Dresden, Germany

## Abstract

In order to achieve the CW electron beam with a high average current up to 1 mA and a very low emittance of 1  $\mu\text{m}$ , an improved superconducting photo-injector (SRF Gun-II) has been installed and commissioned at HZDR since 2014. This new gun replaces the first 3.5-cell SRF gun (SRF Gun-I) at the SC Linac ELBE. The RF performance of the niobium cavity has been evaluated, the beam parameters for low charge bunches have been measured, and the first beam has been guided into the ELBE beam line. The results agree with the simulation very well. The photocathode transfer system has been installed for the first high current beam test planned in 2015. However, the unexpected strong degradation on the cavity and also on the photocathode was found soon after the first photocathode exchange. In this contribution the results of the SRF Gun-II commissioning and the latest experiment will be presented in detail.

## MOTIVATION

The development of top quality photocathode electron guns has become one of the key technologies for modern light sources and large collide facilities based on electron accelerators. There are several successful photo-gun types for various facility requirements [1], like DC guns, rf guns, SRF guns [2] and so on. The Rossendorf SRF Gun-I successfully operated for the radiation source ELBE at HZDR from 2007 to 2014. To achieve higher current and lower beam emittance, a new 3+1/2-cell niobium cavity with a superconducting solenoid and a new 13 MHz laser have been recently developed.

## SRF GUN-I

The SRF Gun-I developed within a collaboration of the institutes HZB, DESY, MBI and HZDR has been operated for the superconducting linac ELBE since 2007 [3] (Fig.1). With the Cs<sub>2</sub>Te photocathode driven by a 13 MHz UV laser, the SRF gun produced beams up to 400  $\mu\text{A}$ . The maximum energy of the electron beam reached 3.3 MeV, bunch charge 400 pC and transverse emittance was 3 $\pm$ 1 mm mrad with 80 pC bunch charge. In April 2013 the first IR-FEL succeeded in ELBE driven by SRF Gun-I [4].

SRF Gun-I was at the same time a test bench for the SRF gun techniques, CW beam diagnostics and normal conducting photocathode materials:

- The principle concept of SRF cavity with normal conducting photocathode works practically well.
- There is no obvious degradation found in the cavity

quality (Fig.2).  $E_{\text{acc}}$  reached 6.5 MV/m in CW mode, and 8 MV/m in pulsed mode, corresponding to peak field on axis  $E_{\text{peak}}$  17.5 MV/m and 22 MV/m, respectively.

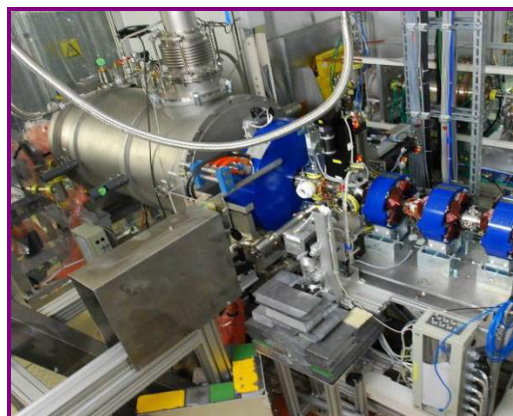


Figure 1: SRF gun-I with the diagnostic beam line.

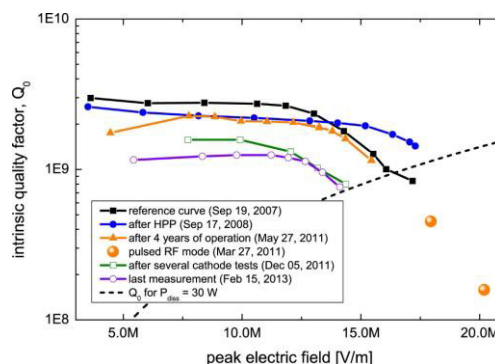


Figure 2: RF measurement result for SRF Gun-I shows that the cavity with cathode inside has the quality factor  $Q_0$  as same as the virgin cavity

- Performance of Gun-I cavity is limited by strong field emission; half-cell is the weak point for the mechanical stability and Lorenz force detuning.
- Multipacting appears mostly in the photocathode area; bias voltage is able to suppress the multipacting.
- LN<sub>2</sub>-cooled photocathode works in gun for a long life time; photocathode exchange can be performed in short time without cavity warming up; However, photocathode itself and the exchange process must be particle free.
- RF-focusing, solenoid compensation and proper laser shaping are helpful methods for the emittance compression, but a high acceleration gradient at

<sup>#</sup> r.xiang@hzdr.de

cathode and high energy gain are most important for beam quality

## SRF GUN-II

In order to improve the beam quality, in May 2014 the new SRF gun with improved parameters (ELBE SRF Gun-II) was installed at HZDR.

A new cavity with fine gain niobium and a superconducting solenoid are the key points of the new SRF gun [5]. Some modifications for the cavity itself and for the cryomodule have been made. One of the interesting changes is the new field distribution: in Gun-I the field in half cell is 60% of that in Tesla cell, and this rate has been increased to 80% in order to reach higher acceleration gradient on cathode surface. From the beam dynamic simulation, the emittance and the bunch length benefits from this change.

The SC solenoid is immigrated into the gun cryomodule, which reduces the distance between the solenoid field and the low energy electron bunch. Additional  $\mu$ -metal shields promise the solenoid field and the stepper motors fields near the cavity down to sub- $\mu$ T level. Details of the SC solenoid design and testing are published in [6].

### SRF Cavity Characterization

The measurement of the intrinsic factor  $Q_0$  shows a better cavity quality than the Gun-I. The horizontal measurement (green dots) is some lower than the vertical test in JLab (blue ones) in Fig. 3, but the new cavity is still better than that in SRF Gun-I in Fig.2 [7].

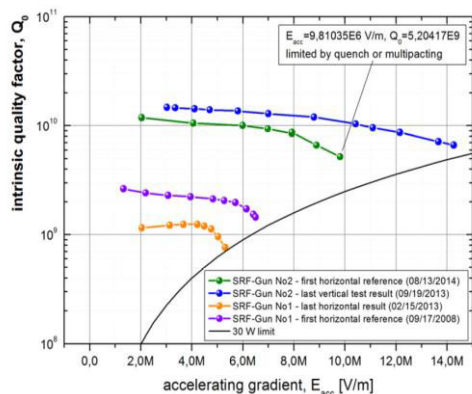


Figure 3: Intrinsic quality factor  $Q_0$  vs. accelerating gradient  $E_{acc}$  in the cavity Gun-II [7]

### Beam with Low Bunch Charge

During the cavity installation, a copper cathode was mounted into the Gun-II. And all of the cavity commissioning activities were performed with this copper cathode, which had very low quantum efficient (QE) but provided with 100 kHz repetition rate about 0.2 pC/bunch for the first beam detective purpose

With the beam line shown in Fig.1, the first low bunch photo beam and dark current have been measured (in Fig. 4). Compared with the Gun-I, the dark current from the virgin cavity Gun-II was quite low. The photo beam was with much higher brilliance and very little divergence through the beam line. The same as the simulation predicts, the best launch laser phase is about  $60^\circ$  to reach the best energy spread and the smallest beam size, depending on the gradient. The beam parameters match very well to the Astra simulation (Fig. 5).

The kinetic energy of electrons is 4 MV/m with  $E_{acc}$  of 8 MV/m, and the emittance is about  $0.3 \mu\text{m}$  measured with both slit scan and quadrupole scan.

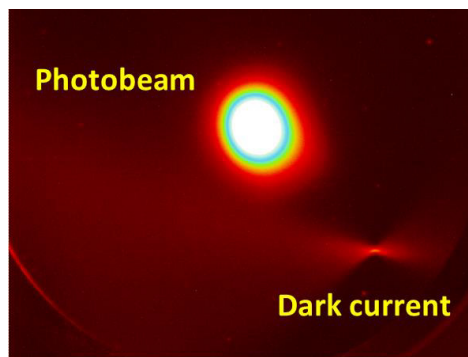


Figure 4: The photo beam and dark current on the YAG screen with copper cathode in SRF Gun-II. At  $E_{acc}$  of 8 MV/m the dark current collected by faraday cup downstream is about 17 nA.

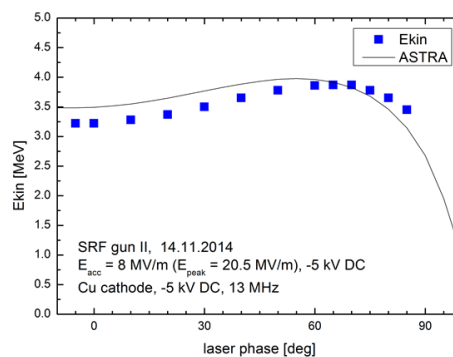


Figure 5: The beam energy at gun exit vs. laser phase

The electron beam from SRF Gun-II was guided into the ELBE accelerator in Feb. 2015. The gun was operated at 9 MV/m CW mode, and the beam energy was measured as 19 MV/m after the first SC linac module. The longitudinal distribution after the acceleration seemed to show sub-bunched structure. The theoretical analysis is under going to understand the transfer process through the dogleg and the accelerating process through the first linac.

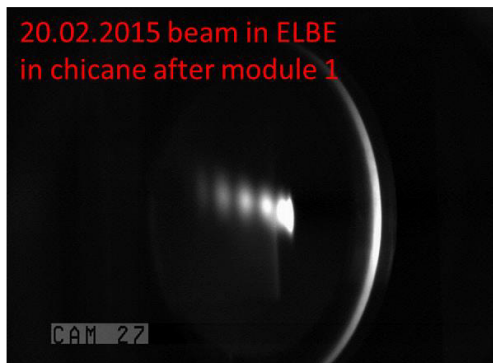


Figure 6: Electron beam longitudinal distribution after the first accelerator module.

## LATEST EXPERIMENT

Soon after the success of the commissioning with copper cathode, the operation with a  $\text{Cs}_2\text{Te}$  photocathode has been executed in February 2015.

### Photocathode

To realize the two modes operation task, eg., high average current (1mA) mode and high bunch charge (1nC) one, photocathodes with stably high QE are urgently in demand.

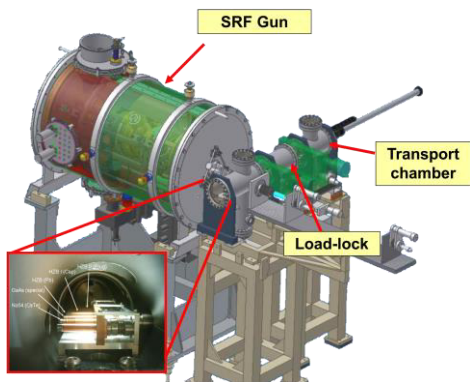


Figure 7: SRF gun with the photocathode transfer system.

A series of  $\text{Cs}_2\text{Te}$  photocathodes were prepared separately in the photocathode lab at HZDR [8]. The QE of photocathode was 1 % to 3 % after the coating on optical polished Molybdenum plugs. The fabrication process is the standard technique, 10 nm tellurium film activated by cesium atoms. Then the cathodes were transported to the SRF gun through UHV transfer system. The typical vacuum in the transfer system during the transport and cathode exchange was  $1 \times 10^{-9}$  mbar.

### SRF Gun-II with $\text{Cs}_2\text{Te}$ Photocathode

After the first  $\text{Cs}_2\text{Te}$  photocathode was inserted into SRF gun, the first RF test has been done. At the beginning a little multipacting was conquered, but then several small electron flashes appeared on the screen at the gun exit. Finally because of the strong field emission and the increased helium consumption the gradient in CW mode

could not be over 7 MV/m. At the same time, the unexpected low photocurrent was detected from the photocathode, which however didn't show obviously optical change in the inspection later back in the transfer system.

After the  $\text{Cs}_2\text{Te}$  was removed from the cavity the cavity quality doesn't recover. The dark current was then analysed. When a gradient  $E_{\text{acc}}$  of 6.85 MV/m was loaded, dark current collected by the faraday cup was about 50 nA, which was only few nA before  $\text{Cs}_2\text{Te}$  photocathode was inserted. The high peak power training for the cavity is still going on.

## CONCLUSION

The SRF Gun-II has been commissioned with a copper cathode and the beam parameters have been measured with the old beam line. The low bunch charge beam has been guided into the ELBE accelerator. However, the first operation with  $\text{Cs}_2\text{Te}$  photocathode failed, which leads cavity pollution. The reason of degradation both for the cavity and for the photocathode is under study. A technique, to apply a surface field emission measurement before insertion, may be helpful to detect the potential particle pollution.

## ACKNOWLEDGMENT

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