ABSTRACT

The DC-SC photoinjector is a compact electron gun integrating a DC Pierce gun with a 1.3 GHz 1+1/2 cell superconducting cavity. A test facility of the DC-SC photoinjector has been completely installed in Peking University and beam loading tests at 4.4 K have been finished. To date the gradient of 6 MV/m has been achieved. The maximum energy gain is 1.1 MeV at 4.4 K. With average beam current of 270 μA, the measured rms emittance is about 5 mm-
mrad at the beam energy of 500 keV. In this paper some of the experimental results are summarized.

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**Keywords:** Photoinjector, Free Electron Lasers, Superconducting Cavity
1. INTRODUCTION

A FEL facility (PKU-FEL [1]) is under construction at Peking University. PKU-FEL is based on Peking University Superconducting Accelerator Facility (PKU-SCAF)[2]. PKU-FEL has the characteristics of high stability and high average power. PKU-FEL will run in IR (5~10 μm) and THz (100~3000 μm) region. The facility can also provide high-quality electron beams for experimental studies in some relative fields such as nuclear physics, high energy physics, etc. Figure 1 gives a schematic layout of PKU-FEL facility.

It is well known that the injector is one of the most important components for FEL facilities. A new type of superconducting electron gun, named DC-SC photoinjector, is being studied, designed, manufactured and tested since 2000[3,4]. The DC-SC photoinjector is designed to get high quality electron beams with low transverse emittance and high average current (1~5 mA).

DC-SC photoinjector test facility was constructed in January 2003. At the end of 2003, the first beam loading was tested. Then after one year of commissioning and optimizing, the electron beam acceleration was successfully realized. In this paper, progresses of DC-SC photoinjector are reported.

2. DC-SC PHOTINOJECTOR

The two main components of the DC-SC photoinjector are the DC Pierce gun and the 1+1/2 cell superconducting cavity. The photocathode is placed at the cathode of the Pierce structure, and at the bottom of the 1+1/2 cell cavity is the anode. The 1+1/2 superconducting cavity is based on the TESLA type cavity [5]. By this design, the influence of the photocathode on the superconducting cavity can be avoided because the photocathode is placed outside the superconducting cavity. The good vacuum conditions should increase the
lifetime of the very sensitive photocathode. Additionally, the back wall of the half-cell has a conical geometry, which leads to an RF focusing of the electron bunch. Simulations of the DC-SC photoinjector are complete [4]. The simulation results show that 2.6 MeV energy gain can be obtained at the gradient of 15 MV/m. The rms emittance can be below 3 mm-mrad. The average current can reach 1~5 mA.

3. QUALITY IMPROVEMENT OF THE 1+1/2 SUPERCONDUCTING CAVITY

The 1+1/2 superconducting cavity is the most important part of the DC-SC photoinjector. The whole procedure of the preparation of 1+1/2 cell cavity was done at Peking University. The cells are made of 2.5 mm thick niobium sheet (RRR=250) by spinning, followed by trimming and electron beam welding. After heat treatment, the cavity undergoes mechanical polishing, electropolishing, buffered chemical polishing (BCP) and high pressure pure water rinsing.

Because of some welding problem, the 1+1/2 cell cavity had a relatively low $Q_0$ value. Experiments indicated that the $Q_0$ of the 1+1/2 cell cavity was about $10^7$. Furthermore multipacting was encountered from time to time during experiments and could not be easily eliminated. It seemed that the inner surface of the cavity was not good enough and earlier mechanical polishing and BCP did not work well.

To improve the quality of the 1+1/2 cell cavity, sputtering technology was employed. We call this method “dry-treatment” compared to the traditional “wet” treatment (BCP and EP).

Figure 2 is the principle of the dry treatment. The cavity is as the cathode. The anode is a rod made of titanium. The ultra pure argon gas is selected as working gas. By sputtering, the surface of the cavity can be cleaned by eliminating small emitters and contaminants.
Through controlling the working pressure, sputtering could take place at different local areas. In addition, the surface can be polished by sputtering.

After sputtering, the cavity was annealed from high temperature to room temperature under ultra high vacuum for 48 hours. A few μm BCP was performed when the cavity was taken out of the sputtering chamber. The cavity was installed to the cryostat after 3 hours high pressure water rinsing and one day drying.

Low temperature experiment showed that the $Q_0$ of the 1+1/2 cell cavity has reached $\sim 10^8$ (at 4.4 K). Moreover, multipacting could be easily processed in a few minutes compared to several hours before.

4. BEAM LOADING TESTS

Beam loading tests have been carried out after the improvement of the 1+1/2 superconducting cavity. Because the 2.0 K system is not ready, the beam loading test was done at 4.4 K. The whole injector with beam line is shown in figure 3. Two faraday cups are installed to the beam line. One is just at the exit of the cryostat to measure the current. The other is at the end of the bending magnet to measure the energy. A CCD camera is installed before the bending magnet to measure the beam shape. A quadruple magnet is used to measure the emittance.

To avoid thermal quench, we run the injector at long pulse mode. The width of the macro pulse is 3.5 ms. The repetition rate of the laser is 81.25 MHz. The DC voltage is 40 kV. The electron beam was successfully accelerated by the superconducting cavity. Figure 4 is the beam spot with and without SC acceleration captured at the fluorescence target. From this we can see the acceleration and focus effect by the superconducting cavity. The $E_{\text{acc}}$ reached 6 MV/m at the $Q_0 \sim 10^8$. The maximum energy gain was 1.1 MeV at 4.4 K.
Energy spread was measured at the 500 keV energy gain. The energy spread is 35 keV which is a little higher than the simulation. Figure 5 is the result of energy spread at 500 keV.

The three-gradient method [6] was used to measure the emittance. By changing the quadruple magnet, different beam spots were measured. By square fitting, the rms emittance was obtained. At the 500 keV energy gain and 270 μA beam current, the rms emittance was 5.0 mm-mrad.

The gradient of the cavity and the energy gain is still low because the test is only at 4.4 K. In order to improve the gradient and energy gain, 2 K experiments are planned in the next step. The expected $E_{\text{acc}}$ and energy gain are 15 MV/m and 2~3 MeV respectively.

The success of the beam loading test of DC-SC injector proved the feasibility of the injector. The DC-SC photoinjector can be used as the injector for high average power FEL facility.

5. UPGRADE OF DC-SC PHOTINOJECTOR

DC-SC photoinjector is designed for PKU-FEL, which aims at high average power FEL. Through experiments on the DC-SC photoinjector test facility, we have validated that the DC-SC photoinjector is a good choice to provide moderate average current electron beams with low bunch charge and very high repetition rate.

Experiments on the test facility also indicate that to fulfill the injector requirements of the PKU-FEL, it is necessary to upgrade the core elements of the photoinjector — the DC gun and the superconducting cavity. The voltage of the DC gun will rise to 150 kV, and accordingly, the structure of high voltage terminal will be improved, which will lead to some changes in the structure of the cryostat. A 3+1/2 cell cavity will be employed for the new
injector. Design and optimization have been accomplished. Parameters of the new photoinjector are listed in Table 1.

6. CONCLUSION

The DC-SC photoinjector is designed for high average power FEL facility. The performance of the 1+1/2 superconducting cavity is greatly improved by dry treatment method. Electron beam loading tests are successfully carried out. 1.1 MeV energy gain is obtained at 4.4 K. The 2 K experiments and the upgrade of the injector are underway.
TABLE CAPTIONS

Table 1. Simulation results of the 3+1/2 cell DC-SC photoinjector
FIGURE CAPTIONS

Figure 1. Schematic Layout of PKU-FEL facility

Figure 2. DC sputtering device for post-treatment of 1+1/2 cell cavity

Figure 3. Layout of DC-SC photoinjector beam line

Figure 4. Beam spot at fluorescence target before (left figure) and after (right figure) SC acceleration.

Figure 5. Energy spread at the 500 keV energy gain
REFERENCES

Table 1

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Figure 1
Figure 3
Figure 5