EXPERIMENTAL PROGRESS OF DC-SC PHOTOINJECTOR AT PEKING UNIVERSITY*

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Abstract

Beam loading experiments on DC-SC photoinjector test facility have been finished at 4.4 K. Upon the present experiments, the gradient of 6 MV/m is achieved. The maximum energy gain is 1.1 MeV at 4.4 K. With average beam current of 270 mA, the measured rms emittance is about 5 mm-mrad at the beam energy of 500 keV. Experiments on the test facility has 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.

INTRODUCTION

A FEL facility (PKU-FEL [1]) is under construction at Peking University. It is based on Peking University Superconducting Accelerator Facility (PKU-SCAF)[2]. It 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 and so on. Figure 1 gives a schematic layout of PKU-FEL facility.

As one of the most important components for FEL facilities, a DC-SC photoinjector is being studied, designed, manufactured and tested since 2000[3,4] in Peking University. It is designed to get high quality electron beams with low transverse emittance and high average current (1~5 mA).

In January 2003, the DC-SC photoinjector test facility was constructed. After one year of commissioning and testing, the electron beam acceleration was successfully realized. The DC gun can provide stable electron beams and when the power of output laser went up to 100 mW (266 nm), the average beam current reached 500 μA. However we found that the 1+1/2-cell cavity had a relatively low Q0 value and multipacting was encountered frequently which could not be easily eliminated. To improve the quality of the 1+1/2-cell cavity, sputtering technology was employed. Experiments show that Q0 of the 1+1/2-cell cavity has reached 2×108 (at 4.2 K).

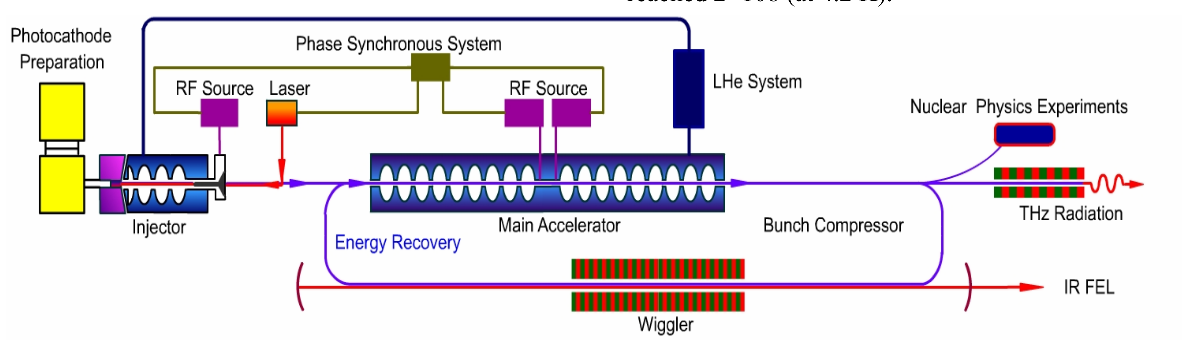

Figure 1: Schematic Layout of PKU-FEL facility

IMPROVEMENT ON SUPERCONDUCTING CAVITY

DC Pierce gun and the 1+1/2 cell superconducting cavity are main components 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 as "dry-treatment" compared to the traditional "wet" treatment (BCP and EP).

* Work supported by National Basic Research Project （No. 2002CB713602
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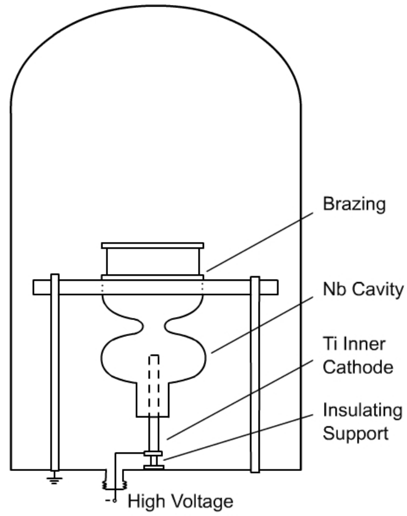

Figure 2: DC sputtering device for post-treatment of 1+1/2-cell cavity.

The principle of the dry treatment is shown in figure 2. The cathode is the cavity. The anode is a rod made of titanium. We select the ultra pure argon gas 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.

After post-treatment, experiments at 4.4K validated that DC sputtering worked remarkably. Q_0 of the 1+1/2-cell cavity reached 2×10^8. Moreover, multipacting could be easily eliminated, and when eliminated at low input power (~ mW), it would not appear at higher input power any more.

BEAM LOADING EXPERIMENT ON DC-SC PHOTOINJECTOR

Beam loading tests have been carried out after the improvement of the 1+1/2 superconducting cavity. Because of the problem on the liquid helium vessel, the platform for 2.0 K is not ready completely. Figure 3 shows the improved injector with beam line for 2.0K test. The vessel for helium is larger. 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.

The following is the result performed at 4.4K. 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_{acc} reached 6 MV/m at the Q_0 ~10^8. The maximum energy gain was 1.1 MeV at 4.4 K.

Figure 3: Layout of DC-SC photoinjector beam line

Three-gradient method [5] was used to measure the emittance. Through changing the current of 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.

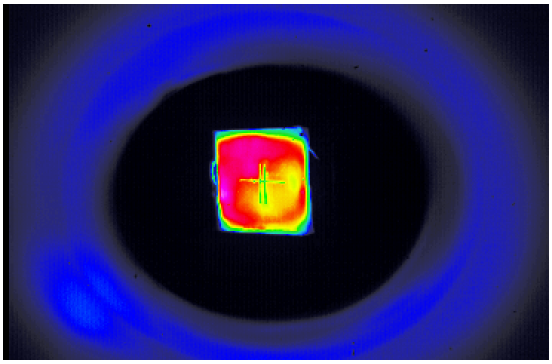

Figure 4: Beam spot at fluorescence target before acceleration by superconducting cavity.

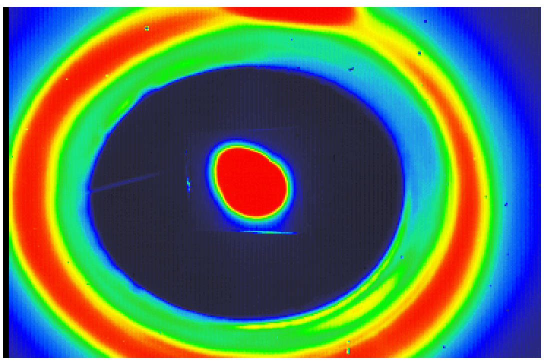

Figure 5: Beam spot at fluorescence target after acceleration by superconducting cavity.

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

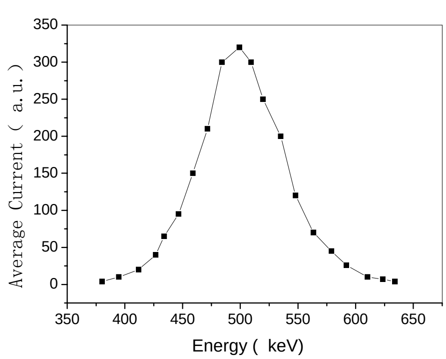

Figure 6: Energy spread at the 500 keV energy gain

UPGRADE OF DC-SC PHOTOINJECTOR

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 requirements of PKU-FEL to the injector, 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 90 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. Its average accelerating electric field is designed as 15 MV/m. The code PARMELA is used to simulate the beam dynamics. Assuming the beam distribution in transverse direction is uniform and in longitudinal direction is Gaussian, we find that in the new DC-SC photoinjector, the energy spread and the emittance can satisfy the requirement of main linac and do not change obviously when the bunch charge is 100pC. Parameters of the new photoinjector are listed in Table 1.

Table 1: Parameters of the new photoinjector

3+1/2 cell cavity	
E_{acc}	15 MV/m
Drive laser	
Pulse length	6ps
RMS spot radius	0.4 mm
Repetition rate	81.25 MHz
Electron bunch (simulated)	
Charge/bunch	100 pC
Energy	5.0 MeV
Energy spread (rms)	0.64%
Emittance (rms)	1.1 mm-mrad
Longitudinal Emittance	16.7 degree-keV

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. The success of the beam loading test of DC-SC injector proved the feasibility of the injector. The 2 K experiments and the upgrade of the injector are underway.

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