RECENT PROGRESSES ON DC-SC PHOTOINJECTOR AT PEKING UNIVERSITY*

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Abstract

Progresses have been made on the DC-SC photoinjector at Peking University. A test facility of the DC-SC photoinjector has been completely installed. The performance of 1+1/2 superconducting cavity is improved after special treatment. Electron beam loading tests at 4.4 K have been finished. Upon the present experiments, the gradient of 6 MV/m is achieved. The energy gain of 1.1 MeV is obtained at 4.4 K. The measured rms emittance is about 5 mm-mrad with the beam current of 270 μA. 2 K experiments are in preparation.

INTRODUCTION

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

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

The DC Pierce gun and the 1+1/2 cell superconducting cavity are the two main components of the DC-SC photoinjector. The photocathode is placed at the cathode of the Pierce structure, and bottom of the 1+1/2 cell cavity acts as the anode. By the 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 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 were finished [4]. The simulation results show that 2.6 MeV energy gain, 15 MV/m gradient, <3 mm-mrad rms emittance and 1~5 mA average current can be obtained.

At the end of 2003, the first beam loading test of DC-SC injector was carried out. Then after one year of commissioning and optimizing, the electron beam acceleration was successfully realized. The progresses of DC-SC photoinjector are reported in this paper.

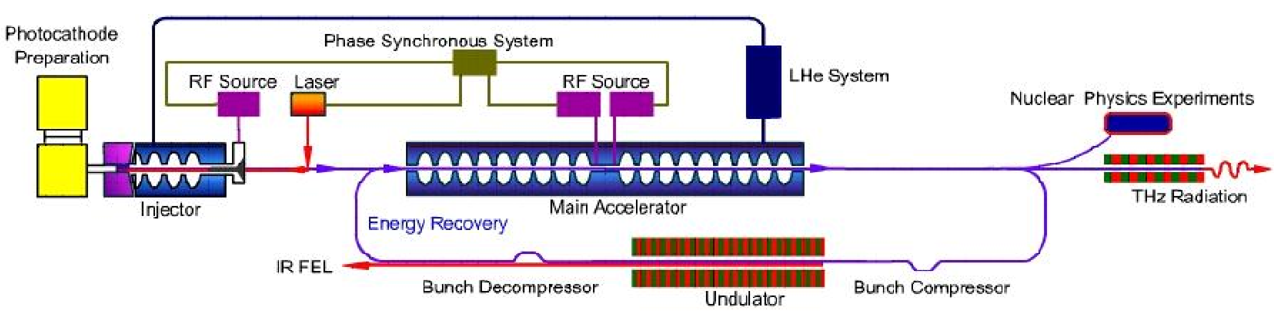

Figure 1. Schematic Layout of PKU-FEL facility

SC CAVITY IMPROVEMENT

The 1+1/2 superconducting cavity is the most important part of the DC-SC photoinjector. The cavity is made of 2.5 mm thick niobium sheet (RRR=250) by spinning, followed by trimming and electron beam welding. Mechanical polishing, electropolishing, buffered chemical polishing (BCP) and high pressure pure water rinsing are done after heat treatment.

Because of some welding problem, the 1+1/2 cell cavity had a relatively low Q_0 value (about 10^7). Furthermore multipacting was encountered from time to time during experiments and could not be easily

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processed. It seemed that the inner surface of the cavity was not good enough. 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).

Figure 2 shows the principle of the dry treatment. The anode is a titanium rod. The cavity is as the cathode. The ultra pure argon gas is selected as working gas. By sputtering processing, small emitters and contaminants on the surface of the cavity can be eliminated and the surface can be polished. Sputtering could take place at different local areas by changing the working pressure.

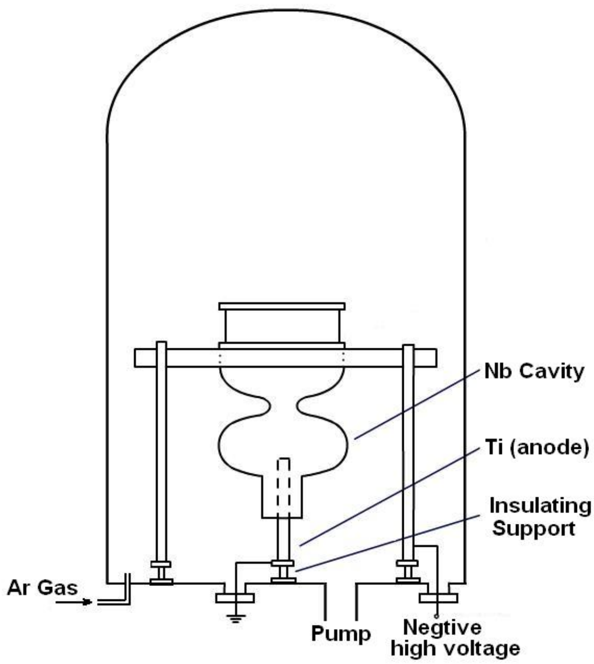


Figure 2. DC sputtering device for post-treatment of 1+1/2 cell cavity

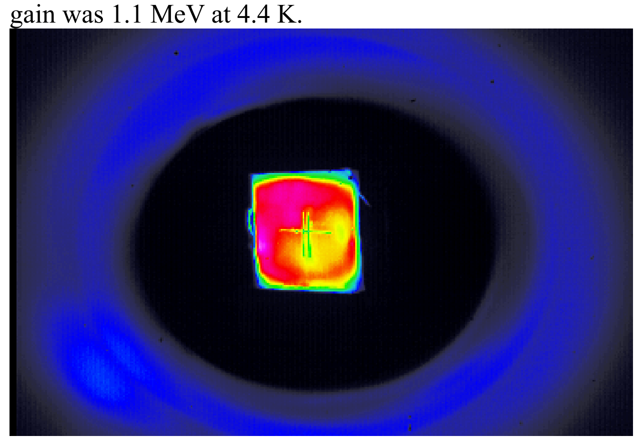
After sputtering treatment, the cavity was annealed under ultra high vacuum for 48 hours. A few μm BCP and 3 hours high pressure water rinsing were performed before the test. Low temperature experiment showed that the Q_0 of the 1+1/2 cell cavity has reached ~10^8 (at 4.4 K). Furthermore, multipacting could be easily processed in a few minutes other than several hours before.

BEAM LOADING EXPERIMENTS

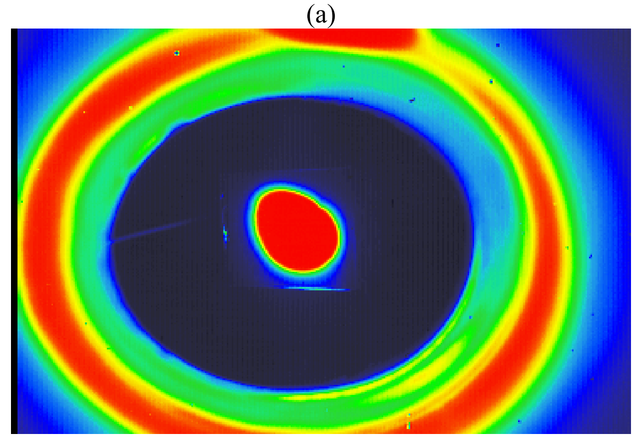
Beam loading tests have been carried out after the improvement of the 1+1/2 superconducting cavity. The beam loading test is at 4.4 K because the 2.0 K system is not ready. Figure 3 is the whole injector beam line. Two faraday cups are used. One is just at the exit of the cryostat to measure the current and 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.

Figure 3. Layout of DC-SC photoinjector beam line

We run the injector at long pulse mode instead of CW mode to avoid thermal quench. 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. Figure 4 gives the beam spot with and without SC acceleration captured at the fluorescence target. From fig. 4 we can see that the electron beam was successfully accelerated by the superconducting cavity. The acceleration and focus effect by the superconducting cavity are obvious. 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.



(a)



(b)

Figure 4. Beam spot before (a) and after (b) SC acceleration.

Energy spread was measured at the 500 keV energy gain. The energy spread is 35 keV which is a little higher than the simulation.

Three-gradient method [5] was used to measure the emittance. The rms emittance of 5.0 mm-mrad was got at the 500 keV energy gain and 270 µA beam current.

The gradient of the cavity and the energy gain is still low because the 2 K low temperature is not ready. 2 K experiments are planned in the next step in order to improve the gradient and energy gain.

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

CONCLUSIONS AND OUTLOOK

DC-SC photoinjector is designed for PKU-FEL, which aims at high average power FEL. The performance of the 1+1/2 superconducting cavity is greatly improved by dry treatment method. 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 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. The upgrade of the injector is underway [6]

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