A Hybrid Laser-driven E-beam Injector Using Photo-cathode Electron Gun and superconducting Cavity*

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Abstract

A laser-driven photo-cathode electron gun capable of producing pulsed electron beams of 100 KeV with a duration of 35 ps was constructed as a continuing effort towards a high-brightness superconducting RF injector. Various species of photo-cathodes can be obtained either by ion implantation, CVD or ion enhanced deposition in the preparation chamber attached to the injector. A number of photo-cathodes were tested in the light of enhancing the compatibility with the Nb cavity. At the same period, two sets of China made Nb cavities were successfully constructed and tested. As the next step, a hybrid photo-injector, using a DC laser-driven electron gun and one (beta<1) plus three (beta=1) superconducting cavities operating under 2 K is to be constructed. The design of the hybrid injector and possible production of the polarised electron beam from it are also discussed.

1 INTRODUCTION

High brightness electron beam generated by photo-injectors has been used extensively for a number of applications including short wave free electron lasers, other coherent radiation sources as well as wake field acceleration experiments etc.[1]. A scheme of incorporating laser driven DC electron gun with RF cavities is also being developed in some laboratories mainly for enhancing the average power of high brightness e-beams[2]. Due to its low RF loss and large radial aperture, superconducting cavity suits very well for the requirements of accelerating high brightness beam with high average current, and a laser driven superconducting RF gun was considered as an ideal source of such a beam[3].

We have been engaged in the feasibility study of the laser driven superconducting RF electron gun since 1992. Much attention was paid in the first stage to the preparation of photo-cathodes compatible with superconducting cavities. A new technology of applying ion beam implantation in the preparation of the photo-cathode was suggested and developed since then[4]. In the mean time, single cell superconducting cavities are studied and developed in our laboratory. Two sets of China made niobium cavity were successfully constructed and tested[5]. A laser driven high brightness DC electron gun was then designed, constructed and tested as a preliminary step towards the laser driven superconducting RF gun[6]. The first run on beam extraction studies of the gun was completed recently. Cesium telluride photo-cathode was successfully obtained in the preparing chamber of the gun and the characteristics of the cathode are quite satisfactory as far as the quantum efficiency and life time are concerned. Electron pulse of 2.2 A in peak was extracted at a voltage of 45 KV. The beam emittance measured is in the range of 0.5-2 π mm-mrad.

As a follow up, a hybrid photo-injector, using the DC laser driven electron gun and 1(beta<1)+3(beta=1) superconducting cavities operating under 2 K is to be constructed. It is also hopped that this hybrid injector is capable of producing polarised electron beams for the applications in high energy colliders such as Beijing Tau-Charm factory.

2 LASER DRIVEN PHOTO-CATHODE ELECTRON GUN

The laser-driven photo-cathode DC electron gun consists of four main parts, i. e., the photo-cathode preparation chamber, the DC acceleration chamber, the mode-locked laser, and the beam diagnostic system. Fig. 1 is the photograph of the device.

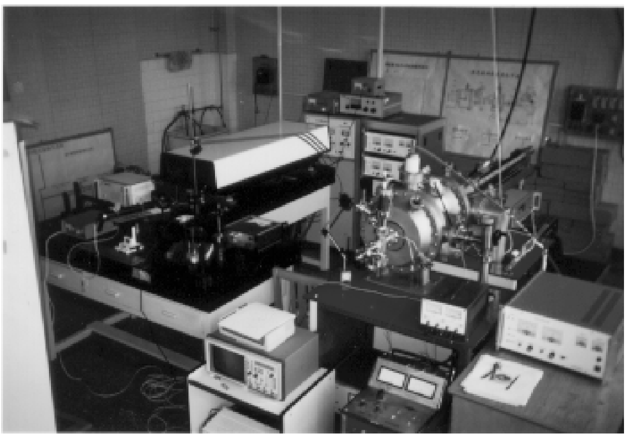

Fig. 1 Photograph of the laser driven DC gun

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The unique feature of the photo-cathode preparation chamber is its capability of fabricating photo-cathodes by three different schemes, including, ion implantation, CVD, and ion beam enhanced deposition. The detailed structure of the preparation chamber is described in [5].

Cesium telluride photo-cathode has been successfully fabricated inside the preparation chamber. A special cesium dispenser source was provided as a key device for the activation of the substrate. Cesium telluride photo-cathode with 2-5% of quantum efficiency can be fabricated inside the preparation chamber routinely at present. The photo-cathode was transferred from the preparation site to the DC acceleration chamber via the photo-cathode load-lock system which turned out to be quit reliable in the experiment.

Beam test was performed with an extraction voltage of 45 KV applied to the cathode. The charge of electron beams was measured by a coaxial Faraday cup located the downstream of the beam line. The typical measured electron pulse is given in Fig. 2 together with laser pulse.

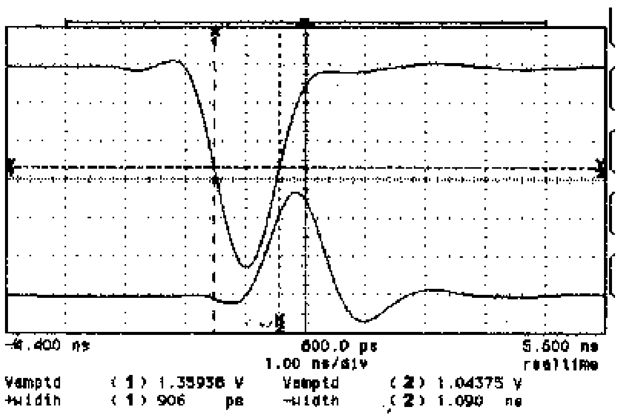

Fig. 2 Typical e^- pulse(upper) and laser pulse(lower)

The multi-pulse response of cesium telluride photo-cathode is also tested by detuning the Pockels cell of the mode-locked laser. Fig. 3 gives the measured results, from which we can see that the cathode has quite desirable multi-pulse response up to 167 MHz repetition rate. This is obviously rather essential for high average current injectors.

The preliminary emittance measurement of the gun was carried out by the pepper-pot technique. It is shown that the emittance of the electron beam was in the range of 0.5-2π mm-mrad, and the brightness was estimated to be 5×10^{10} A/m^{2}rad^2 correspondingly.

3 THE NIOBIUM CAVITY

Two sets of 1.5GHz niobium cavities were constructed using China made niobium sheet. Before the fabrication of the whole cavity, the niobium samples produced in China were investigated in detail, including their mechanical properties, chemical composition, and residual resistivity ratio (RRR). Unfortunately the

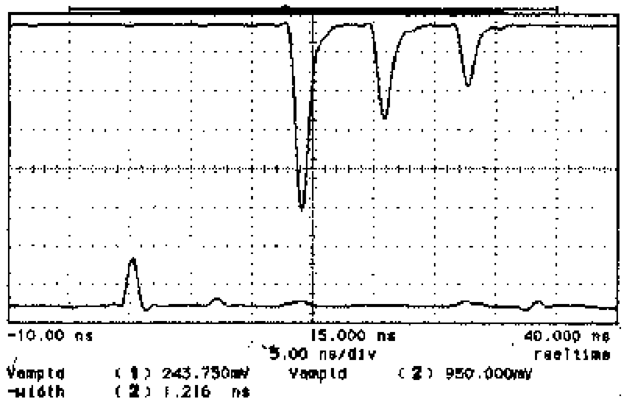

Fig. 3 Multi-pulse response of the DC gun

RRR of the home made niobium was only about 50 as first received from the factory. In order to improve the low temperature thermal conductivity, some pieces of samples were tested and treated at CEBAF laboratory. The RRR of the niobium was improved to 260-470 after vacuum(10^{-6} torr) annealing at temperature of 1400°C for 4-6 hours. The heat treatment of the whole cavity was performed at KEK.

Before the heat treatment, the unloaded quality factor of the cavity was only 3×10^8 and the accelerating gradient was limited to 4.5 MV/m. After the heat treatment, 10^9 of unloaded quality factor and 10MV/m of accelerating gradient were obtained at 2.5°K. Fig. 4 illustrates the curve of the unloaded quality vs. the accelerating gradient.

After the cavity was measured at 2.5°K in our laboratory, it was sent to CEBAF and so as to recheck it at 2°K. With the removal of 2 defects inside the cavity, the unloaded quality factor of the cavity reached to 8×10^9 and the peak electric field reached to 21 MV/m, corresponding to a 15 MV/m of accelerating gradient at 2°K. The curve of the unloaded quality factor vs. the peak electric field is illustrated in Fig. 5

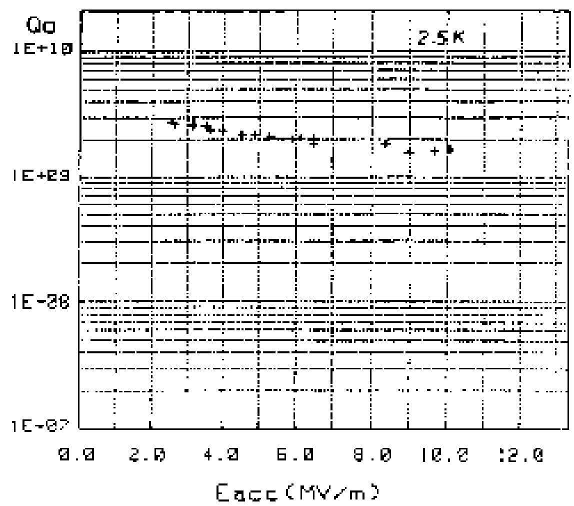

Fig. 4 Q_0 vs. Eacc. of the 1.5 GHz Nb cavity at 2.5°K

4 THE HYBRID PHOTO-INJECTOR AND SUPERCONDUCTING CAVITIES

Based upon the above achievements, a hybrid photo-injector is to be constructed, which consists of a DC laser-driven electron gun and one (beta<1) plus three

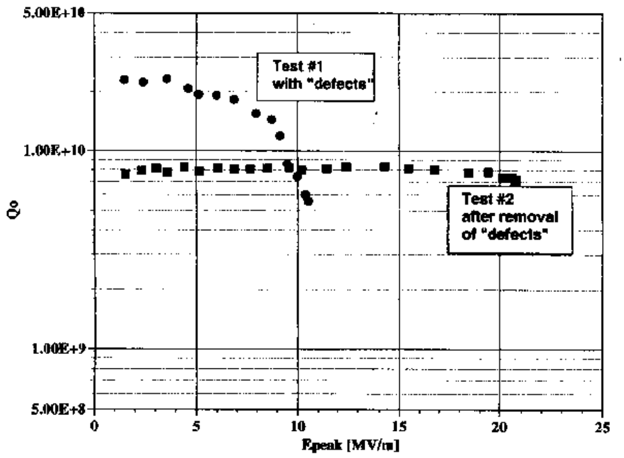

Fig. 5 Q_0 vs. Ep of the 1.5 GHz Nb cavity at 2°K

(beta=1) superconducting cavities.The cryogenic system will be two-stage type, with a working tank and a storage tank. The design of the cryogenic system is being in progress. The designed parameters of the hybrid gun are listed in Table 1.

Longitudinally polarised electron beams for high energy collisions provide a sensitive way to explore the electro-weak process as well as effective means to measure spin dependent properties of particles[7]. The conceptual research of the Beijing Tau-Charm Factory (BTCF) is being discussed in China at this time, and one of the scheduled schemes of the BTCF will require the polarised electron beams. With the construction of the hybrid laser-driven electron injector using photo-cathode electron gun and superconducting cavity,

Table 1. The designed parameters of the hybrid injector

Photo-cathode	Ion implanted/Cs_2Te
Quantum efficiency	10^{-3}-10^{-2}
DC gun	Laser-driven gun
High voltage(KV)	200
Peak current(A)	>1.0
Superconducting Cavity	Niobium cavity
Frequency(MHz)	1500
Unloaded Q	5×10^9
ACC. Gradient(MV/m)	10
Operating Temperature(°K)	2.0
Driving laser	Mode-locked Nd:YAG
Pulse duration(ps)	35
Repetition rate(Hz)	1-10

we hope to produce polarised electron beams on the base of this device for the possible applications in high energy physics.

The polarised electrons are produced in the conduction band of a suitable semiconductor material, such as GaAs, illuminated by circularly polarised light of an appropriate wavelength on the material[8]. The photo-electrons are able to escape from the semiconductor when its surface has been covered with a monolayer of alkali metal and oxidants and the work function of the surface is lowered to the point where the energy of the electron in the vacuum outside the material is less than its energy in the bulk material.

Some modifications have to be done on our existing preparation chamber and driving laser system to enable the production of polarised electron beams. A MBE apparatus should be mounted on the preparation chamber and the vacuum level should be improved to the level of 10^{-11} torr, which is 2 orders lower than our existing level. The laser wavelength should be shifted to a proper value for the selected photo-cathode, and one possible solution is to shift the wavelength of our existing laser by a parameter oscillator.

REFERENCES

[1] C. Travier, Proc. of the European Particle Accelerator Conf., London, 1994, p317.

[2] CEBAF Proposal, A High-Power Infrared Free Electron Laser Using the CEBAF Superconducting Accelerator, 1993.

[3] H. Chaloupka et. al., Proc. of the 10th Int. Free Electron Laser Conf., Israel, 1988, p327.

[4] Zhao Kui et. al., Proc. of the 1994 Linear Accelerator Conf., Tsukuba, Japan, 1994, p413.

[5] Zhao Kui et. al., to be published in the Proc. of the 7th Workshop on RF Superconductivity, Gif Sur Yvette, France, 1995.

[6] K. Zhao et. al., in the Proc. of the 17th Int. Free Electron Laser Conf., New York, 1995, to be published in Nucl. Instr. & Meth., (1996).

[7] J. Clendenin, Nucl. Instr. & Meth., A340(1994)p1.

[8] L. S. Cardman, Nuclear Physics, A546(1992) pp317c.