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# Development of a high current short pulse electron gun*

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Dielectric wall accelerator (DWA), towards high gradient acceleration field (30 MeV/m–100 MeV/m), is under development at Institute of Modern Physics. A prototype was designed and constructed to prove the principle. This needs a short pulse high current electron source to match the acceleration field generated by the Blumlein-type pulse forming lines (PFLs). In this paper, we report the design and test of a new type short pulse high current electron gun based on principle of vacuum arc discharge. Electron beams of 100 mA with pulse width of 10 ns were obtained.

Keywords: Dielectric wall accelerator, Arc discharge, Short pulse high current electron gun, Electric field simulation

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## I. INTRODUCTION

Dielectric wall accelerator (DWA) [1, 2] is a new type of compact induction accelerator, in which the pulse forming lines, switches and vacuum insulated wall are integrated into a single compact geometry. It is a path to high accelerating gradient (30 MeV/m–100 MeV/m) and beam intensity. DWA can be used in many fields, such as flash x-ray, heavy ion inertial fusion, radiography, and proton therapy [3].

Figure 1 shows the sketch map of DWA [4]. It consists of stacks of Blumlein-type pulse forming lines (PFLs), high gradient insulator (HGI), the SiC photoconductive switches, the source and the laser system. The switches are controlled by the laser system. The axial accelerating electric fields are excited by the wall, and the pulse is formed by the Blumlein lines. Particles stemming from the source are continually accelerated by this pulsed electric field to high energy.

At Lawrence Livermore National Laboratory (LLNL), a short-pulse optically switched DWA was developed (insert of Fig. 1), and accelerating voltage with a nominal 3-ns pulse width was obtained [2]. Efforts were made at LLNL in developing DWA components and system architectures for radiography and other applications [5–13].

A prototype DWA is developed at Institute of Modern Physics (IMP), Chinese Academy of Sciences, as shown in Fig. 2. The short pulse proton source is complicated, and it is difficult to realize the source at suitable injection energy. For testing the assembling technology of DWA, an electron source is designed and fabricated.

The DWA consists of two systems: 1) the electron gun, flashboard, and flashboard pulser; and 2) the Blumlein-type PFLs, the pulse-charging system, and the laser triggering system. In normal operation, the system functions as follows. A capacitive discharge unit is used to pulse-charge the

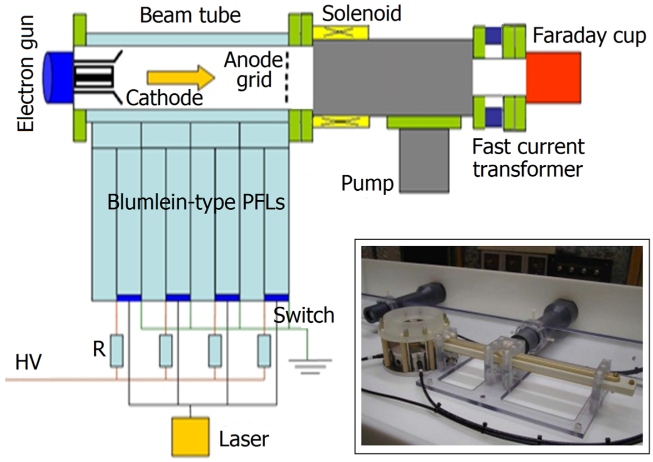


Fig. 1. (Color online) Basic layout of DWA and the short-pulse DWA at LLNL.

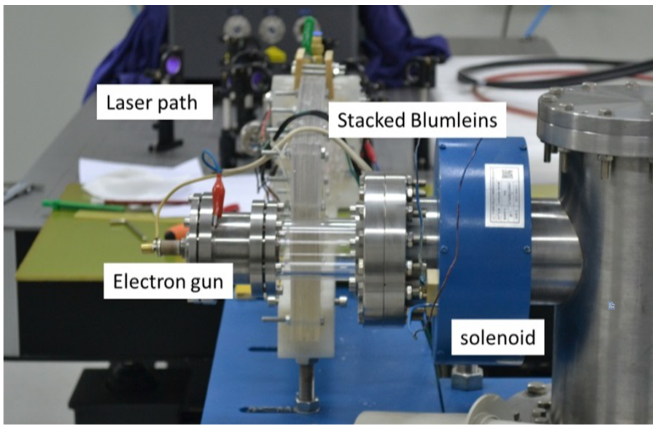


Fig. 2. (Color online) The prototype DWA at IMP.

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PFLs. Next, the flashboard pulser is triggered to apply a high-voltage pulse through resistors across the flashboard gaps. This produces plasma which expands into the diode region. The PFL activation is accomplished by illuminating the photoconductive solid-state switch embedded in each PFL. This is done with an Nd:YAG laser. Once activated, the PFLs produce a transient voltage across the vacuum insulator, extracting electrons from the plasma and accelerating them toward the anode grid. The relative timing of the pulse-charging system, the flash-board pulser, and the laser are fully adjustable.

The DWA works on pulse mode with the duration of 3 ns–10 ns and high peak current of several kiloamperes, so we shall develop a new type of high current pulsed electron gun to match these specifics. The thermionic cathode electron source is problematic because of the space charge limitation and high temperature radiation, which may damage the plastic holder of the gun body. Photocathode would make the present laser system more complicated due to the use of photoconductive switching. The plasma cathode, in which the discharge is excited by a pulse HV power supply and the electrons are extracted by the electric field generated from DWA, is a simple way to avoid the mentioned problems and is capable of producing high current- short pulse electron beam [2].

## II. PRINCIPLE DESIGN AND FLASHBOARD TESTING

The vacuum arc electron gun is capable of generating high current electron beams in pulse mode. The vacuum arc is a discharge between two electrodes in vacuum. At the cathode the current is concentrated to a small number of tiny, discrete sites, called cathode spots. The formation of cathode spots is a fundamental characteristic of the vacuum arc discharge. The spots are where the plasma is produced, and it is this plasma that provides the current path between cathode and anode that keeps the arc alive [14]. In vacuum arc mode, the only source which provides ions or electrons is the cathode itself, so the vacuum arc discharge can be realized by the cathode spots. The arc discharge has the following features: 1) the voltage the arc needs is not very high; 2) the current density near the cathode is very high; 3) the concentration of the charged particles at cathode region is high; 4) a below-threshold current extinguishes the arc; and 5) the arc current itself can break off at any time. The plasma exists in the cathode spots, but the difficulties why we cannot know much about the cathode spots are that they are too small (diameter $\approx 10^{-4}$ cm) and move too quickly ($\nu \approx 10^4$ cm/s).

From Fig. 3, one can see that in vacuum arc mode, it does not require a high voltage to get a high current. So the plasma cathode adopts the vacuum arc discharge technology. The plasma is generated on the dielectric surface by the vacuum arc and the electrons are extracted by PFLs and then high current electron beam of short pulse is delivered into the DWA to test the accelerating mechanism.

The preliminary flashboard test was aimed at determining the cathode geometry and checking the reliability. The first thing is to design the vacuum arc discharge structure.

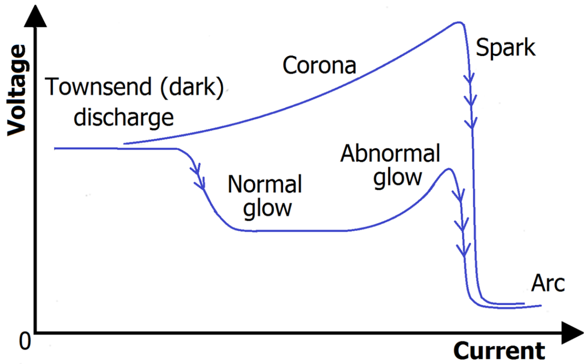


Fig. 3. (Color online) The voltage-current relationship in different discharges.

As shown in Fig. 4, a cathode structure, or flashboard, is designed. The cathode is made of a printed circuit board with very narrow gaps machined into the copper layer. Because discharge occurs more easily at corners, triangular islands with 0.3-mm gap width were adopted as the discharge configuration.

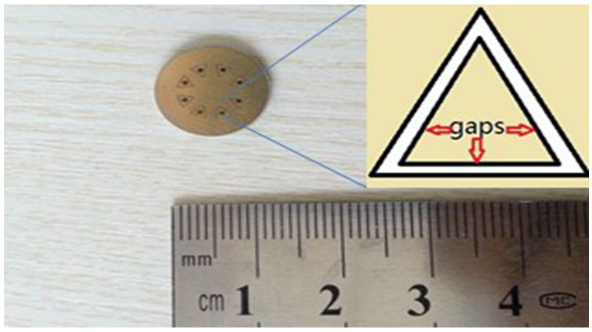


Fig. 4. (Color online) The test flashboard.

The flashboard discharge was tested in atmosphere to check its reliability. Fig. 5 (the x axis is scaled at 4 µs) shows the arc discharge voltage across the gap. Using a high-voltage probe, the arc discharge voltage was measured at 600 V, indicating that the flashboard generates the arc discharge easily at low voltage, hence its use as a plasma cathode.

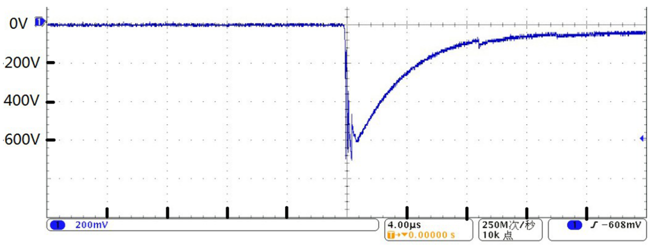


Fig. 5. (Color online) The discharge voltage between the gaps in atmosphere.

The electron beam optics of this gun was simulated by the EGUN code [15], and it was confirmed that the designed structure had a good laminar flow. Fig. 6 shows the simulation result of the electric potential distribution and electron beam transport of the gun. A 45° pierce electrode is adopted to limit the transverse emittance.

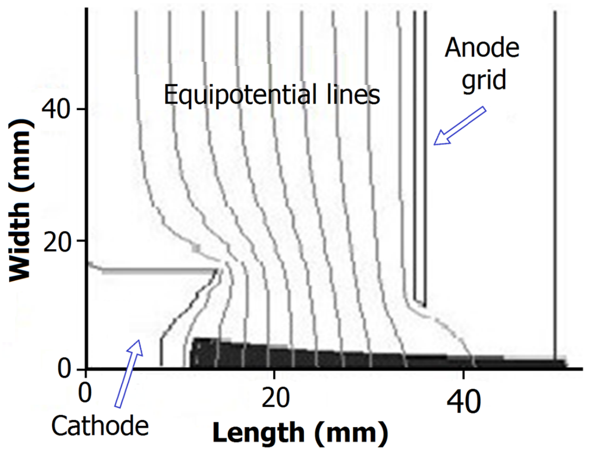


Fig. 6. Simulation results of the electric field and beam transport.

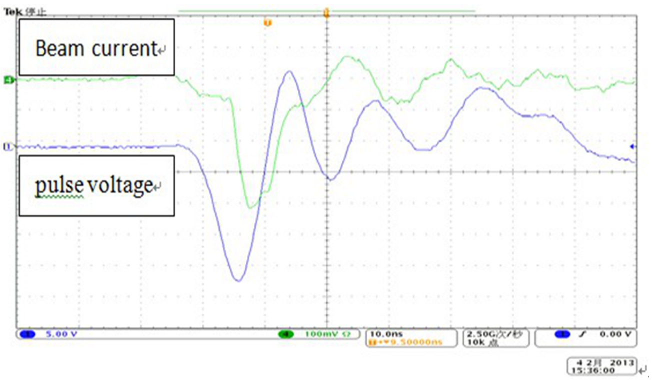


Fig. 7. (Color online) Experiment result of the electron gun in DWA.

## III. EXPERIMENTAL RESULT AND DISCUSSION

Figure 7 shows the experiment result of the electron gun installed in the prototype DWA. At the pulse voltage of 20 kV, and the pulse width of about 10 ns, the beam current was 100 mA, with the vacuum at $1 \times 10^{-4}$ Pa or better. The electron gun basically met the design requirements. In Fig. 7, there is a delay of the current waveform, this is because mainly that a drift time of about 3 ns is needed for the electrons to go from the cathode to the fast current transformer.

Due to the high voltage limit of the DWA power supply with nanosecond pulse output, a substitute of microsecond pulse power supply was used to test the emission ability of cathode with higher pulse voltage. Over 2 A beam current was delivered at 4.5 kV. The relationship between the beam current and the pulse voltage is shown in Fig. 8.

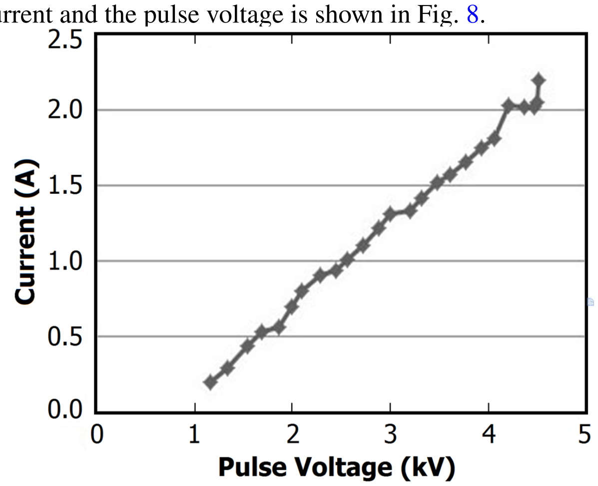


Fig. 8. Current caused by the microsecond pulse power supply.

The peak beam current of the electron gun is lower than that of the vacuum arc high current short pulse electron gun at LLNL, which was 8 A [2]. Due to problem of machining accuracy, the triangular islands do not discharge simultaneously. A solution shall be the etching technology in making the gaps on the flashboards. This shall be able to get 0.1-mm gaps, rather than 0.3-mm we have now. This allows reduced working voltage of the flashboard and increased number of triangular islands, hence the increase of beam current. Also, discharging stability depends on mechanical structure of the flashboard, etching can improve the mechanical stability.

## IV. CONCLUSION

A prototype DWA with a vacuum arc plasma cathode is proved workable. Current of this pulsed electron gun exceeds 100 mA at pulse width of 10 ns. The cathode discharges continuously and stably for over 20 minutes. Peak perveance in excess of $7.2 \times 10^{-6}$ A/V$^{3/2}$ are measured, meeting the definition of a high current pulsed electron gun and requirements of the DWA.

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