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DESIGN AND RESEARCH OF A MICRO-PULSE ELECTRON GUN

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Abstract

Micro-pulse electron guns (MPG) are a novel electron source which can produce narrow-pulse, high-repetition rate electron current. Theoretical and experiment work have been done to study physical properties and steady operating conditions of MPG. Proof-of-principle work has been finished and the next work is to research the parameters of the MPG electron beam and understand the MPG properties. Thus, a high-voltage accelerating platform which can supply 100 kV direct voltage was designed. Furthermore, electromagnetic and mechanism designs were operated to adapt the high voltage platform and measure beam parameters.

INTRODUCTION

The multipactor, based on a secondary electron emission (SEE) [1], is often destructive to the microwave device such as waveguide, coupler, RF resonant cavity [2-3], and its avoidance has been a major task for sic-tech workers.

The underlying mechanism behind the multipactor has been studied deeply [4-7]. But before the publications of this theoretical work, the first electron gun based on multipacting was made by Gallagher in 1969 [8]. Among those publications, the beam self-bunching effect attracted the attention of Mako, who gave the concept of the micro-pulse electron gun (MPG) and obtained important conclusions about MPG [9-11]. After the initial work of Mako, many other research institutions have made their contributions to the development of MPG [12-14].

MPG could produce a narrow-pulse electron beam due to the self-bunching effect. In addition, simple structure and high tolerance to contamination make it a potential electron source for accelerators and microwave systems [15]. However, no records on the applications of MPG have been reported until now. One of the reasons to explain the limitation of the MPG applications may be the bad stability of MPG operation.

In our previous work, a prototype electron gun has been designed, tested and the steady operation of MPG has been obtained [15]. Yet several problems remained. For instance, the steady operation time cannot meet the demands of MPG applications as a novel electron source, the beam parameters such as energy spread, intrinsic emittance need to be detected and the former system doesn't have the ability to do this job. Our goal is to design and build a new MPG test system at the basis of previous work in addition to detect the beam parameters and study the principle of MPG steady operation.

This paper presents the electromagnetic design and test of a MPG which works for high voltage accelerator platform. In the second section, basic concepts of MPG are introduced and several types of gun shape are compared. The third section gives the fabrication of the new gun, and brief introduction of HV platform. Finally, primary experiment results are presented.

THE MPG MODEL

Working Principle of MPG

The MPG shown in Figure 1 consists of three parts in general: RF cavity which works at TM010 mode, cathode with the secondary electron yield (S.E.Y) of $\delta_1$grid anode with the S.E.Y of δ_2.

The initial electrons in the RF cavity which are caused by field emission move from cathode to grid anode by means of their interaction with electromagnetic fields, and they impact the anode after odd multiple of half period and generate secondary electrons. The triggered secondary electrons traverse back and forth between the electrons until saturation.

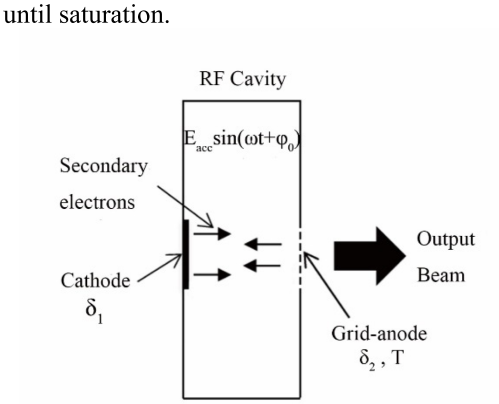

Figure 1: The schematic diagram of the MPG model.

The Choice of Cavity Shape

The general cavity type for TM0101 mode is pill-box cavity. Figure 2 shows the comparison of three pill-box like cavities. (a) is the general pill-box cavity, (b) is the concave cavity that equivalent to pill-box with a part cut inside, (c) is the convex cavity that shapes like a pill-box added two parts. Figure 3 demonstrates the electric field distribution of three different cavities. a1/a2 are three-dimensional diagrams and pseudo-color maps of general pill-box cavity. b1/b2, c1/c2 are have the same meaning for concave cavity and convex cavity separately. Concave cavity has the sharpest peak among these three cavities. What's more, there is a 'flat roof' in the centre electric field of concave cavity and it helps decrease the electron transverse energy difference.

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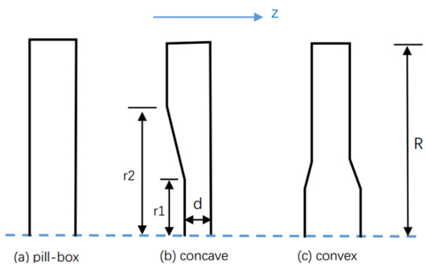

Figure 2: The schematic diagram of three types cavity.

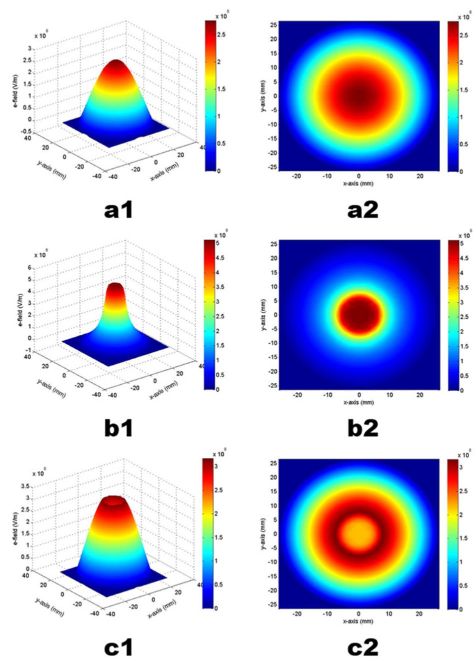

Figure 3: Electric field distribution of different cavities.

After the cavity shape was chosen, we optimised the dimensions of the concave cavity, and Figure 4 shows the final electromagnetic field distribution. The maximum electric field is located in the centre ‘flat roof’ and the maximum magnetic field is at x=13mm.

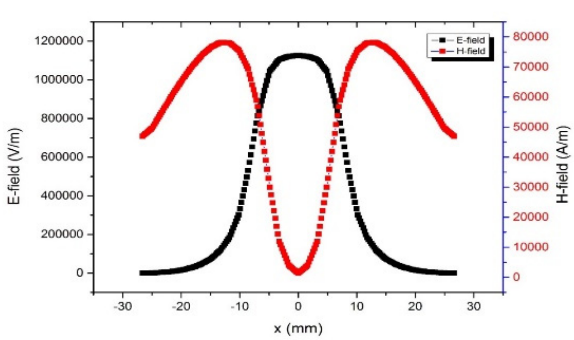

Figure 4: Electromagnetic field distribution of the optimized concave cavity. Maximum of electric field is in the centre of the cavity (x=0, black dash), and a centre ‘flat roof’ is clearly demonstrated. Magnetic field is at a maximum at x~13mm.

HIGH VOLTAGE PLATFORM

The high-voltage accelerating platform consists of two distinct parts:

- MPG-II which could produce high repetition rate, narrow pulse electron beam;
- 100KV high voltage system.

MPG-II

The RF cavity is made of stainless steel. The cathode is made of Cu-Al-Mg alloy and the grid anode is made of oxygen-free copper. Figure 5 shows the details of MPG-II. Magnetic coupling was chosen and the external Q changes from 140 to 244 with the coupling loop angle changes from 0° to 90°. Table 1 shows the test RF parameters of MPG-II.

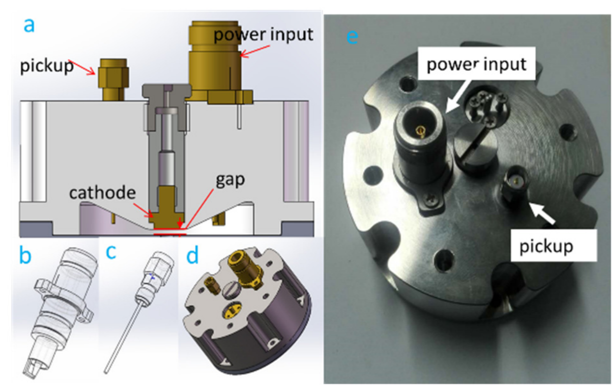

Figure 5: Details of MPG-II. The cutaway of MPG-II (a), coupling loop (b), pick-up antenna (c), MPG-II pictures of design (d) and physical (e).

Table 1: RF Parameters of MPG-II

RF parameters	Test value
f_0	2856MHz
d	1.75mm
Q_0	157
r_{shunt}	0.036MΩ

High Voltage Platform

The key components include the ceramics, MPG-II, pump and all those components have been fabricated tested. These are exhibited in Fig 6.

The Glassman high voltage source could supply 100KV. The ceramic (pink part) has the length of 200mm, inside radius of 190mm. The white part of ceramic’s length is 400mm and inside radius is 120mm.

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EXPERIMENTAL RESULTS

The information of output current which is obtained by faraday cup is showed in the oscilloscope. Figure 7 shows the output signal of electron beam. The yellow line is the current signal and blue line is the pickup signal. Table 2 demonstrates the details of output current.

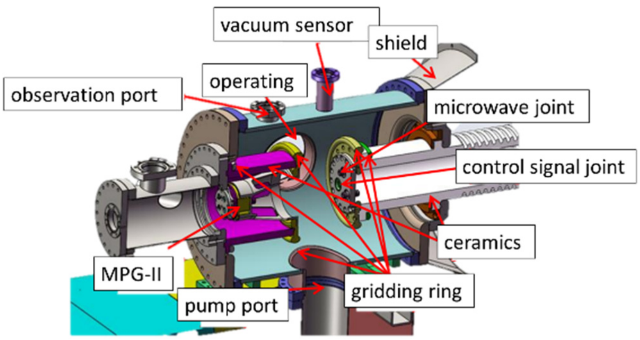

Figure 6: Components of high-voltage accelerating platform, shown in cutaway view.

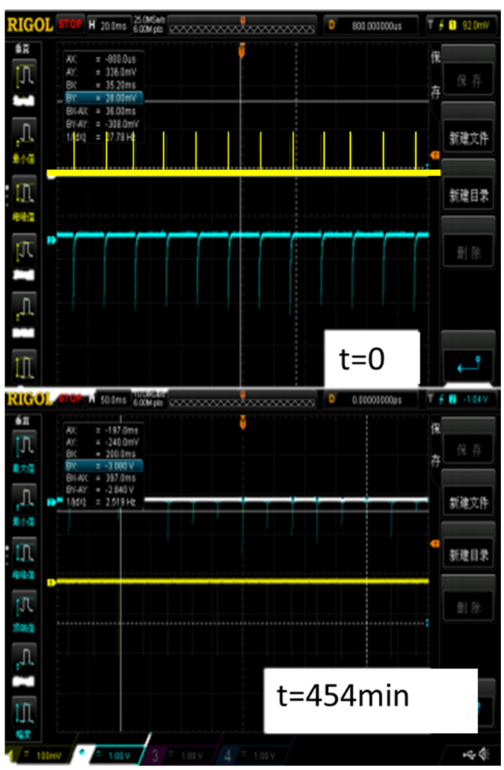

Figure 7: Schematic of current signal. The output current at t=0 (up), at t=454min (down).

Table 2: Current Parameters

Parameters	Value
Current	~10mA
Life time	~454min
Pulse length	10us

In the study of MPG, lifetime limitations are the biggest challenge. In our experiment, the pulse length jitter was observed not only the current decrease. The time evolution of beam current and pulse-length is shown in Figure 8. Current at this experiment is 1.08mA and the life time is about 600min. But the pulse length jitter occurred in t=150min before the decrease of amplitude. With the input power increases, the jitter amplitude decreases.

Figure 9 shows the comparison of surface morphology between initial and after bombardment. Dose effect was observed in Henrist's work [16], which is related to the electron bombardment influence to the material surface. The color of grid anode changed after the electron bombardment.

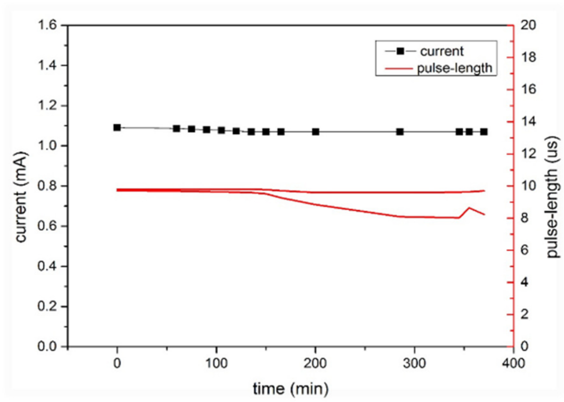

Figure 8: Time evolution of beam current and pulse-length over 360 minutes.

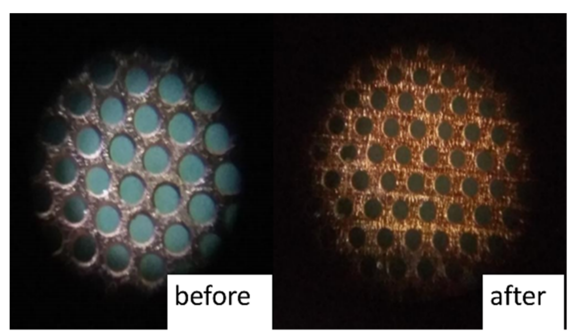

Figure 9: Comparison of surface morphology between initial and after bombardment.

CONCLUSION

At the high voltage platform, the MPG-II beam output experiment has been operated. The key point of MPG-II application, lifetime, is 454mins. In addition, the pulse length jitter and dose effect were also observed. In our next work, the S.E.Y. of material in different conditions will be tested and the relationship between pulse length jitter and power input will be studied.

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