DEVELOPMENT OF A MICRO-PULSE ELECTRON GUN BASED UPON PI-MODE DUAL-CAVITY*

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Abstract

The concept of a novel micro-pulse electron gun (MPG) based upon π-mode dual-cavity is proposed and analyzed in this paper, and we termed it as dual-cavity micro-pulse electron gun (D-MPG) as compared to single-cavity standard MPG. From simulations, it is clear that the D-MPG is capable of yielding dozens of ampere peak currents and a few ps bunch length. Thought the mechanism for dual cavity is not fully understand, the D-MPG has demonstrate the potential to be the injectors for FEL and THz radiation facilities. Also it is a good candidate to replace the thermal cathode for industrial and medical accelerator system because of the cost-effective of the D-MPG.

INTRODUCTION

The highest brightness mainly relies on the injectors and in particular by the electron gun performance, hence the conceive of the electron gun is of paramount importance. Up to now, the injectors aimed at high quality electron beams are characterized by the following conditions: high gradient cathode field and high cost laser system. However, the high cost of injectors make it a obstacle for wide use around the world. The need for cost-effective gun system has driven the development of the micro-pulse electron gun (MPG) [1-3]. Since the multipacting effect is typically one of major cause of power consumption in the RF devices or failure of ceramic windows, there are many works studied to suppress its adverse effect [4-8]. Also the multipacting effect was found to have amplification function in the cavity [9], the micro-pulse electron gun demonstrate the potentialities of this function by resonant electrons to saturation [1-3]. The concept of micro-pulse electron gun describe a new kind of RF gun as a positive application of multipacting in the cavity.

In this paper, a novel dual-cavity micro-pulse electron gun (D-MPG) as compared to standard MPG is proposed. The standard MPG is widely studied for its simply structure, but it is imperative to note that because of the phase focusing mechanism as will discussed later, the width of micro-pulse is limited by this mechanism. In this point, the standard MPG is hard for further development, so the conceive of dual cavity is necessity. Combined with GaP as the cathode and anode material, the π-mode dual-cavity allows much longer gap distance as well as the cavity voltage, which help to boost the energy high enough to reduce the effect of space charge force. As a result of dual-cavity, it can be shown that the D-MPG give rise to electron beams with a few ps width, which is much better than the standard MPG.

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DUAL-CAVITY DESIGN

D-MPG Simulations

The working principle of MPG can be illustrated as below: The initial electrons in the cavity traverse from cathode to 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 secondary electrons travel in the opposite direction from anode to cathode. Triggered by the initial electrons, the secondary electrons traverse back and forth between the electrodes until saturation so a series of micro-pulses are expected to export through the grid electrodes.

According to standard MPG, the quality of micro-pulse is confined by the phase focusing mechanism:

$$0 \le \theta_0 \le \arctan(2/N\pi) \quad (1)$$

It can be shown from Eq. (1) that only the electrons which belongs to a small range would survive in the cavity after a few periods, which can be termed as the self-bunching process. As the characteristic of MPG, the pulse is bunched in the cavity and steady output at saturation, that is the reason for the name "micro-pulse gun" . The Eq. (1) predict the width of pulse, which is about 9% of the period of RF field, and in the 2.856 GHz case, the value is found to be about 31.5 ps at the base of the pulse. It is important to note that the full width at half maximum (FWHM) of the pulse is about 15 ps, which results in good agreement with the results from reference [2]. Unfortunately, This width is limited to a constant value and hard to low further. The scale of width is preferable for the industrial accelerator systems, but not for the FEL or some kind of units which need sub-ps width beam quality.

So how to decrease the pulse width is the purpose of this paper, in what follows we will represent the dual-cavity structure in the MPG, namely D-MPG. The working principle of D-MPG is a little different from that of standard MPG, while the time for electrons to fly from one electrode to another electrode is even multiple of half period. For the reasons as will discussed below, this structure will provide a possibility to increase the quality of beams.

The D-MPG simulations were carried out by introducing a PIC code, i.e. VORPAL [10], which allows inclusion of the electromagnetic field and electron distribution minutia. Figure 1 shows the comparison of the micro-pulse of two cavities, and it is evident that the beam quality of D-MPG is better than MPG. Also, we have at the maximum accelerating field of 20 MV/m at the presence of space charge effect as shown in Fig. 2. The pulse width (FWMH) in Fig. 2 is about 2-3 ps, but it has a long tail. In what follows, the details analysis of the dual-cavity structure is presented.

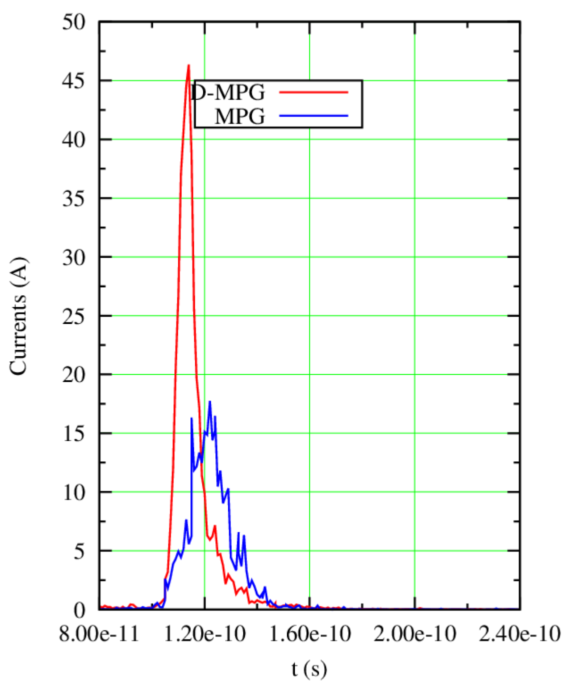

Figure 1: Comparison of micro-pulse of the single-cavity (corresponding to standard MPG) and the dual-cavity (corresponding to D-MPG). The frequency is 2.856 GHz, and the total gap distance D=6 cm, and the maximum accelerating field Ez=15 MV/m with the absence of space charge force in this case.

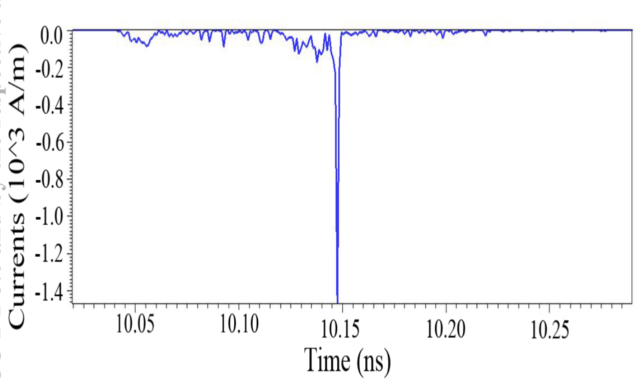

Figure 2: The micro-pulse at the exit of grid-anode. The abscissa in the figure is the time by seconds, and the vertical axis represents the current monitored at the exit of anode.

Dual-Cavity Structure

The layout of dual-cavity structure is shown in Fig. 3.

The new structure of producing acceleration in the cavity is to excite a π-mode TM010 standing wave in the dual cell. The main advantages of this structure two points: (a) the electrons born in the first half-cycle will directly accelerate to the other side, a half-cycle later, when the sign of electric field changes, these emitted electrons which born in the later will traverse back to the same electrode (that is the one-surface multipacting) and generate secondary electrons. It is easy to know that by splitting the initial emitted electrons into two parts, the emitted electrons are bunched into a small sheet. Ignoring the emission time, the high quality sheet of electrons correspond to high quality of secondary electrons, thereby result in high quality micro-pulse at the exit of anode. (b) Because r/Q measures the efficiency of acceleration, r/Q in the dual-cavity is much higher than that in the single cavity. At this point, increasing the r/Q would benefit for the efficiency of the accelerating system and the cost.

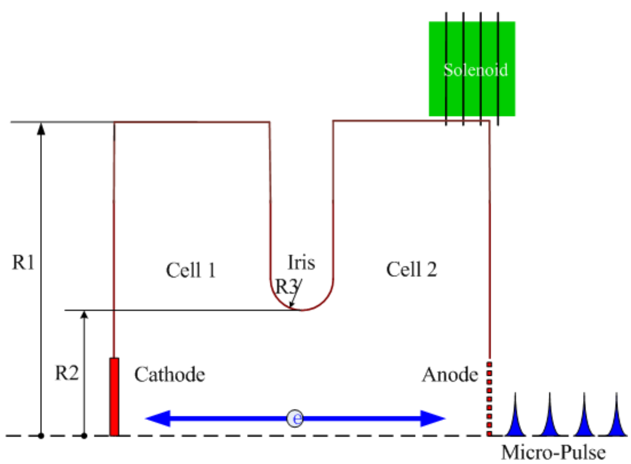

Figure 3: Layout of the dual-cavity structure of D-MPG.

Figure 4 shows the electric field map for TM010 mode in the cavity. Space charge is always included in the gun, and degrade the beam quality. In order to cancel the effect of space charge forces, the maximum accelerating field at the axis is set to about 20 MV/m. The surface electric field near the iris is much higher than accelerating field, this situation would enhance the probability of break down in the cavity. Fortunately, the maximum surface electric field around the iris is lower than Kilpatrick criterion [11], hence the breakdown is not realized in this case.

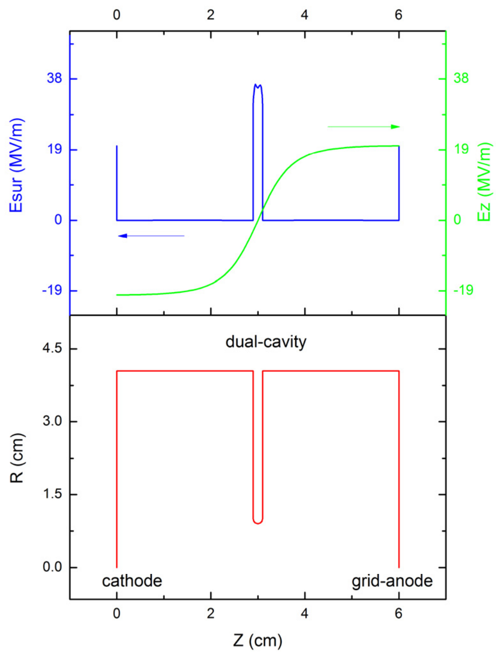

Figure 4: Bottom: The dual-cavity shape of D-MPG. Top: the green solid line represents the acceleration field E_z along the z axis, while the blue solid line represents the surface field E_{sur}. The peak-to-average ratio E_{max}/E_0 calculated by SUPERFISH [12] is 2.2167.

Previous investigations into cathode/anode of MPG are based on the MgO surface material, from which the susceptibility area corresponding to impact energy is extensive. But the maximum impact energy is limited to about 80 KeV, therefore limited the increasing of the gap distance and the cavity voltage. In order to match the capability of the dual-cavity structure, it is necessary to use GaP material to realize the saturation. The secondary emission curve for Cu, MgO and GaP is given in Fig. 5.

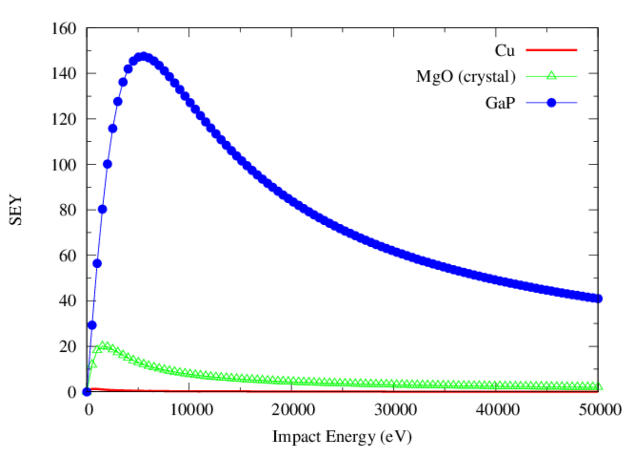

Figure 5: Secondary emission curve (SEY) for Cu, MgO and GaP (Data comes from reference [13]).

CONCLUSION

In this particle, the analysis and simulations of D-MPG that based upon π-mode dual-cavity are carried out, and the simulation results show the potential to yield much more short pulse width in this kind of structure. The details of beam dynamics theory still remains to be study in the near future. But it is clear that the involution of cavity structure is a direction to the further development of micro-pulse electron gun.

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