

THE SIMULATION AND ANALYSIS OF SECONDARY EMISSION MICROWAVE ELECTRON GUN

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Abstract

Several new approaches for producing high-current, short-duration pulses of electron beams were reviewed briefly in this paper. The paper presents mainly the simulation and analysis of a secondary emission microwave electron gun. The movement of electron in microwave electric field was simulated and the self-bunching process of the secondary emission electrons in the gun was also proved. Some factors that can affect the secondary electrons multipacting and amplifying have been studied.

KEY WORDS: Microwave electron gun, Micro-Pulses-Gun, Secondary emission, self-bunching

1 INTRODUCTION

The produce of high-current, short-pulses, low-emittance of electron beams has been a challenging problem for many years. High-current pulses and short-duration pulse are widely used in an injector for electron accelerators, such as for industrial linacs, linear colliders and FEL, advanced methods of particle accelerator etc.^{1,2}. Short-duration pulses of electron beams are also used for microwave generation. Recent cathode advances have been driven by the needs for ultra-high-power devices. These devices require higher emission current densities than thermionic cathodes provided and could benefit from modulation of the electron beams at the gun. Direct modulation of the emitted beam can improve the gain and efficiency and reduce the size of the microwave amplifiers.^{3,4,5} At least four different type gun can meet the requirements mentioned above and are being developed. They are field emission, photoemission, ferroelectric emission, and secondary emission and self-bunching. The later is emphasized in the article.

Recently, Field emission and direct modulation of electron using field emission arrays (FFA's) have been developed. Some test results showed that single tip with a radius of curvature about 60 nm to 90 nm have been used to generate current densities of more than 10^8A/cm^2 . Normalized beam brightness from single tips with total current of 10 mA is estimated on the order of $10^{15} \text{A/cm}^2 \cdot \text{steradian}$,⁶ about a factor of hundred times better than thermionic cathodes. Two travelling-wave tubes (TWT's) have been successfully operated.⁷

Field-emitter cathodes are envisioned to be capable of improving the performance of microwave power devices for operating frequency up to 30 GHz.

When photocathode in the microwave cavity is irradiated by a laser beam, then electron emission will occur that this phenomenon is called photoemission. With the advent of high power, short pulse laser, it is now possible to generate electron beams with bunch length less than 0.1ps and charge exceeding tens of nanocoulombs. Until recently, photocathodes have been used mainly as sources of electron beams in RF LINAC. An interest in using the cathodes in high power RF sources is getting growth. Such as, a schematic of two-beam accelerator, the drive beam consist of 24 bunches of electrons, each bunch of about 3 nC charge, about 1.5 mm bunch length and repetition of 3 GHz. The pre-bunched, pre-accelerated beam was accelerated in a slow wave structure to produce 60 MW of RF power at 30GHz.⁸

Electron emission from ferroelectric ceramics, the emission mechanisms have not been fully understood yet, but some experimental results have shown that current densities of about $100 \text{A/cm}^2 \sim 400 \text{A/cm}^2$ were successfully got.^{9,10}

An electron source employed secondary electron emission, in which micro-pulses, high current are formed by resonantly amplifying a current of secondary electrons from the wall in a microwave cavity. The device, the Micro-Pulses-Gun (MPG) is capable of generating short, high peak current bunches with low emittance to meet the requirements for many accelerators

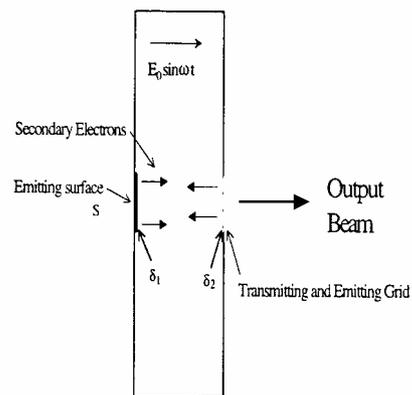


Fig.1 Schematic of micro-pulse-gun

and microwave devices.

We have studied the multipacting process and phase selecting automatically. The studies showed that the gap length of the cavity is of 34mm, peak electric field in the cavity is from 31.5MV/m to 52.4 MV/m, bunched beams will be formed and its phase width will be 3.5ps ~10 ps, peak current is more than 1000A/cm².

2 PRINCIPLES OF SECONDARY EMISSION

Micro-pulses in MPG are formed by resonantly amplifying a current of secondary electrons from a wall in the RF Cavity. Bunching occurs rapidly and is followed by saturation of the current density in about 10 RF periods. The beams bunched are created automatically by a natural phase selection of resonant electrons. Localized secondary emission from the wall of the MPG cavity is dictated by material selection. Fig.1 shows a schematic drawing of micro-pulses-gun concept for producing bunching beams.^{11,12} The MPG cavity is operating a TM₀₁₀ mode. One wall of the cavity is coated with a material with secondary emitting coefficient δ_1 for emitting secondary electrons, and another wall is a grid wall which not only allows transmission of the electron beams, but also provides a certain emitting surface of secondary electrons for electrons multiplication. Of course, the grid wall is opaque to microwave power.

Assume that at the grid wall of the cavity there is a single electron at rest on the axis, which transits the cavity in one-half the RF period and is in proper phase with the microwave electric field. This electron is accelerated across the cavity and strikes the surface S. If δ_1 is the secondary electron emitting coefficient, then number δ_1 secondary electrons will be emitted from the surface S. After that these electrons will be accelerated back to the grid. If δ_2 is its emitting coefficient of secondary electron, T is transmission factor, then $\delta_1 T$ electrons will transmit, $\delta_1(1-T)$ electrons will be yielded. If $\delta_1 \delta_2(1-T) > 1$, after one cycle as mentioned above, the number of electrons will be growth. Then the electrons go and forth between the wall and grid repeatedly so that the number of the electrons were amplified continuously until space charge or cavity loading limits the current. The gain of electrons after N RF periods will be

$$G = [\delta_1 \delta_2 (1-T)]^{N\omega t / 2\pi}, \text{ here } t = NT_{rf}, \omega, T_{rf} \text{ is RF}$$

frequency and period respectively. If there is a "seed" current density J_0 in the MPG cavity initially, then at time t the current density J will be given by

$$J = J_0 [\delta_1 \delta_2 (1-T)]^{N\omega t / 2\pi} \quad (1)$$

For a very low seed current density J_0 , a high current density J can be achieved in a very short time. For

example, $T=0.75$, $J_0=1.0 \times 10^{-10} \text{ A/cm}^2$, $\delta_1=23(M_gO)$, $\delta_2=1.46(A_u)$, then in 14 RF periods $J=863 \text{ A/cm}^2$. If the grid with $\delta_2=4.1$ could be a metallic mesh CVD with M_gF_2 , then in 10 RF periods $J=5302 \text{ A/cm}^2$.

3 SIMULATION STUDY ON MPG

3.1 MPG cavity

Fig.2 shows the schematic of the MPG cavity, which will be operating at 2856 MHz, TM₀₁₀ mode.

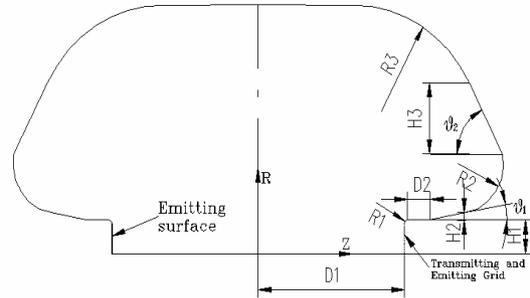


Fig.2 Geometric size of cross section of half-cavity

Calculating the cavity using UMEL-T, its geometric parameters are shown in the table 1 and characteristic parameters of the cavity are listed in table 2.

Table 1 Geometric parameters of the cavity (unit: mm)

| D1 | D2 | H1 | H2 | H3 | R1 | R2 | R3 | θ_1 | θ_2 |
|----|-----|-----|-----|----|-----|-----|----|------------|------------|
| 17 | 3.8 | 5.0 | 1.0 | 10 | 0.5 | 7.0 | 21 | 10° | 61° |

Table 2 Characteristic parameters of the cavity using URMEL-T

| mode | f (MHz) | λ (mm) | Q | R_s (M $\Omega \cdot m^{-1}$) | R_s/Q ($\Omega \cdot m^{-1}$) |
|-------------------|---------|----------------|-------|----------------------------------|-----------------------------------|
| TM ₀₁₀ | 2855.71 | 104.98 | 14194 | 2.364327 | 166.5659 |

3.2 Simulation of the self-bunching process

In order to get optimum parameters to create a micro-pulses and high current density, we developed a program named KDMPG-1, which has been used for simulating the self-bunching process in the cavity. The dynamic equations are given by

$$\frac{d\gamma}{dz} = \frac{eE_z}{m_0 c^2} \cos \varphi \quad (2)$$

$$\frac{d\varphi}{dz} = \frac{2\pi}{\lambda} \left(\frac{1}{\beta_\varphi} - \frac{1}{\beta_e} \right) \quad (3)$$

$$\text{here } \gamma = \frac{1}{\sqrt{1-\beta_e^2}} = \frac{\epsilon_0 + W}{\epsilon_0}, \beta_e = \sqrt{1 - \left(\frac{W}{\epsilon_0 + W} \right)^2}$$

$$\varphi = \frac{2\pi}{\lambda} \left[\int_0^z \frac{dz}{\beta_\varphi} - \int_0^z \frac{dz}{\beta_c} \right] + \varphi_0$$

By means of these equations, KDMPG-1 and UMEL-T, we got some satisfactory results as the following.

3.2.1 Selecting phase width $\Delta\varphi$ as a function of length of the cavity and peak electric field

Fig.3 shows the relation between the bunching phase width $\Delta\varphi$ and the gap length of MPG cavity at different peak RF electric field in the cavity.

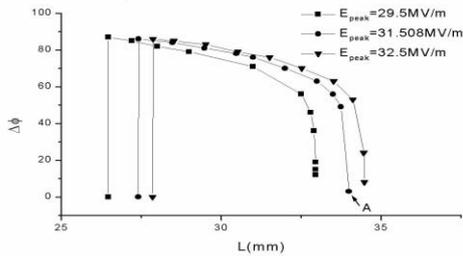


Fig.3 Relation between cavity and $\Delta\varphi$

Bunching phase $\Delta\varphi$ of 3° will be got, if the gap length $L=34\text{mm}$, peak field $E_{\text{peak}}=31.508\text{MV/m}$.

The bunching phase width $\Delta\varphi$ vs peak electric field is shown in the Fig.4. We will find that the electron beams bunched with a $\Delta\varphi$ will only occur at a certain range of peak electric field. Such as, if $L=34\text{mm}$, the peak electric field is from 31.508 MV/m to 52.4 MV/m the electron could be amplified and bunched.

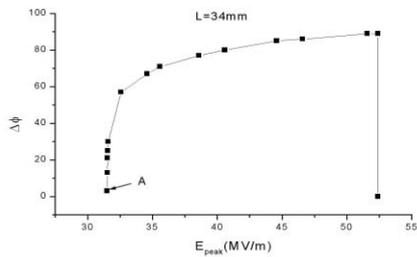


Fig.4 Peak field vs. selected phase

3.2.2 Current density, electron energy as a function of time

According to formula (2), (3) and KDMPG-1 program, we simulated the energy of the electrons bunched, which transmit out the cavity, change with time at the gap length $L=34\text{mm}$, and at different peak electric field. The simulation results are shown in Fig.5. The results showed that the peak electric field E_{peak} must be large than certain value, the energy of electrons will be stable with the time, otherwise, the energy will be on the decrease.

4 CONCLUSION

Based on the MPG cavity, which was simulated using UMEL-T code, we simulated the self-bunching process of secondary emission in the cavity. The simulation results shows the micro-pulse electron beam of 10 ps will be got when $L=34\text{mm}$, $E_{\text{peak}} \geq 32.15\text{MV/m}$. These results also indicated that current density of $1000\text{A/cm}^2 \sim 5000\text{A/cm}^2$ will be achieved by means of the MPG.

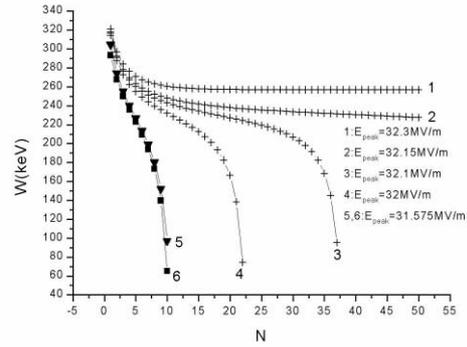


Fig.5 Electron energy vs hitting times

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