A MICROWAVE THERMIONIC GUN WITH HARMONIC CAVITY

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Abstract:

One of the important subjects of microwave thermionic guns is the back bombardment of electrons. In this paper, a method of suppressing the electron back bombardment is discussed, which accelerates electrons in the microwave gun by harmonic microwave fields of the fundamental mode (TM010) and the high order mode (TM020) whose frequency is exactly two times of the fundamental mode. Some simulated results are given in this paper.

1. INTRODUCTION

One of the important subjects of microwave thermionic guns is the back bombardment of the electrons. Electrons are continuously emitted by the cathode, but can only extracted and accelerated during half an RF cycle. The rule of cathode emission is Schoddky effect:

$$J = J_0 e^{0.4403[E_0 \sin(\phi)]^{1/2}/T_c}$$

(Here J_0 is the zero field current density , ϕ is the phase of the microwave, T_c is the emitting temperature of the cathode).

The electrons, emitted during the accelerating half-cycle, but with a too large phase do not have enough energy to reach the cavity output and accelerated backward to the cathode. That is the mechanism of back bombardment. The back bombardment would reduce the lifetime of the cathode and affect the quality the beam.

To solve the back bombardment we can shorten the length of the first cavity, or add a transverse magnetic field. In this pager we will use the structure of harmonic resonant accelerating field in the first cavity. We add a harmonic field to the fundamental field. So we get a better electronic field in the first cavity.

2. SUPPRESSING THE BACK BOMBARDMENT BY USING HARMONICALLY RESONANT FIELD

In this pager we use harmonically resonant field to suppress the back bombardment. In the first cavity we use the fundamental mode (TM010) and a harmonic mode (TM020) to optimize the accelerating field. In Figure 1 we can see that in the condition of harmonic resonant field the effect of the emission and accelerating are focused obviously contrasting to the condition of only fundamental field. The harmonic resonant field rises faster than the fundamental field in an RF cycle. Between the accelerating half-cycle and the other half cycle there is a section of low gradient field. More electrons can go through the first cavity. But it is necessary that the frequency of the harmonic is exactly twice of the fundamental one.

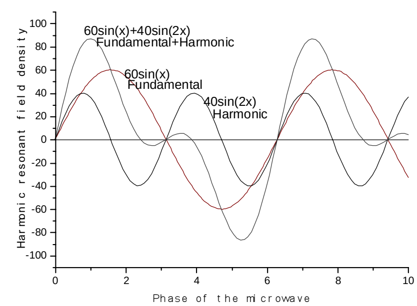

Figure 1: Optimization of accelerating field

We must make some change to the structure of the first cavity. After changing, both the fundamental frequency and twice frequency can be resonant. On the basic of Pill-box cavity, changes make to the structure influence respectively the TM010 and the TM020 mode in the cavity. After some adjust the frequency of the TM020 mode is exactly twice of the TM010 mode. A typical structure is shown in Figure 2.

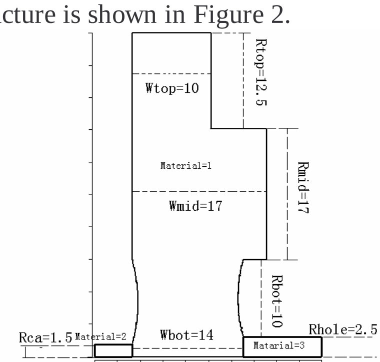

Figure 2: Size of the cavity (unit mm)

The resonant frequencies of the cavity are calculated in E module of MAFIA code. Simulation is proceeded in a 2-dimension model, and results are all of TM modes. With analyzing the shape of the field, we can confirm that the first mode is TM010 and the second mode is TM020, the frequency of which is about twice of the former. The simulating results are shown in Table 1.

Table 1: Frequency computing in E module in MAFIA

Mode Number	Frequency(Hz)
1	2.857730E+09
2	5.724444E+09
3	9.310184E+09
4	1.006525E+10
5	1.284680E+10
6	1.363316E+10
7	1.580874E+10
8	1.648731E+10
9	1.788946E+10
10	1.832828E+10

3. SIMPLE NUMERIC SIMULATION

Firstly we use a simple simulation to find out the filed gradient ratio of the TM010 mode and TM020 mode in which the back bombardment can be well rejected. We neglect the space charge effect of the particles, and consider the emitted electrons are either going straight to the exit through the cavity or coming back to the cathode. Based on the above assumption, we developed a simple simulation code to simulate the whole process. We simulate in the case of the cavity length is 3mm, 6.4mm, 10mm, 14mm, 20mm. We keep the fundamental mode field gradient at 60MV/m and only change the gradient of the high order mode (TM020) to get the ratio of output energy and the back bombardment energy. The results are shown in Figure 3.

We can conclude that the shorter the cavity the more obvious the change of the ratio of output and back bombardment. And when the ratio of the field of fundamental and harmonic is approximately 3:2, the back bombardment can be well restrained. In this pager, the cavity length is 14mm. When the high order mode gradient is 0 MV/m the ratio of output and back bombardment is 10.43 and when the high order mode 40MV/m the ratio 16.03. The back bombardment is not effectively restrained according to the above simulation. But our simulation is only a simply and qualitative one. With a few well-known codes we can get some better results.

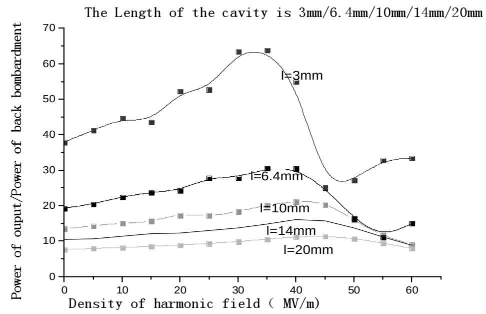

Figure 3: The ratio of output and the back bombardment relative to the field gradient of TM020

4. SIMULATION WITH MAFIA

When simulating with MAFIA, we assume that the cathode temperature is 1700K and the zero field current density of the cathode is 16A/cm^2. The fundamental field gradient is 60MV/m. By changing the gradient of the harmonic field while simulation, we can know whether the back bombardment is well retrained or not under the harmonic field. The total charge of the macro particles is 9.677e-10C. The simulation result is shown on Table 2.

Table 2: the simulation results

Number of macro particle	100000	
Gradient of harmonic field MV/m	0	40
Average power of output (P_o KW)	661	907
Average power of back bombardment (P_b KW)	138	72.7
P_o/P_b	5.96	12.5
Average current of output (I_o A)	1.96	2.57
Average current of back (I_b A)	0.708	0.214
I_o/I_b	2.76	11.9

Under a harmonic field the ratio of output and back bombardment is obviously improved. Fig.4 shows the emission curves assumed in MAFIA code (solid line) or computed according to Schoddky effect (dot line) while the harmonic field gradient is zero. And Fig.5 shows the curves we drawn according to Schoddky effect. One is the curve when the harmonic field gradient is zero (dot line). And another is when the field gradient is 40MV/m (solid line). When the harmonic field gradient is 40MV/m, the cathode will emit twice in an RF-cycle. But most of the electrons are emitted in the first time (0-180 degree).

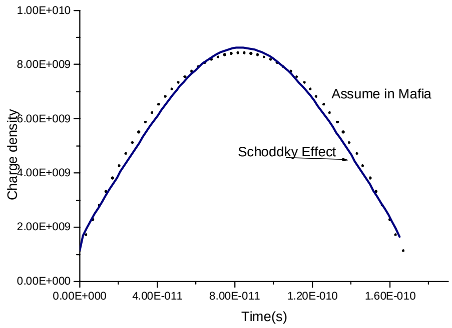

Figure 4: The assumptive emission and the Schoddky effect curve

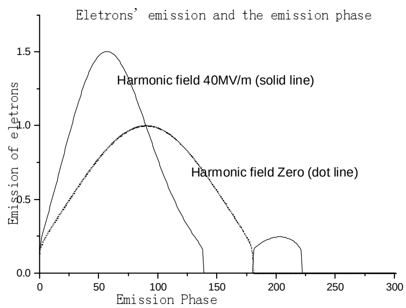

Figure 5: Emission curve from Schoddky effect

5. SUMMARY

The result is shown under:

Table 3: Result compared

The number of macro particles	10000	
Harmonic field gradient (MV/m)	40	0
Output maximal energy (KeV)	470.1	470.1
The output macro particle number	92225	70746.
Back maximal energy(KeV)	418.3	416.7
The backward macro particle number	7752	25618
The energy ratio	12.5.	5.96

Under a harmonic field the average power of the back bombardment suppresses a half of that without harmonic field. So the back bombardment is effectively restrained after adding a harmonic field.

But there are some differences in the simulation results that we calculate in the ideal condition and simulate with MAFIA code. We consider that:

1. In the first simulation the space charge effect of electrons was neglected. Only the electronic longitudinal movement was considered.

2. We took the shape of the paraxial electronic field of the cavity as an ideal cosine function to the longitudinal axis. And the maximal electronic field is at the edge. The emission of cathode is calculated under Schoddky effect. Instead of the idealization, the real paraxial field of the cavity and the maximal electronic field depart from our assumption (Fig.6).

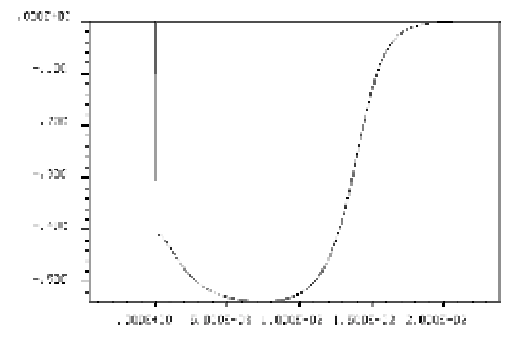

Figure 6: The cavity axial electronic field in Mafia

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