MULTIPACTOR ELECTRON GUN WITH CVD DIAMOND CATHODES*

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Abstract

A Multipactor Electron Gun (MEG) is developed for the high power microwave generation in the Accelerator Lab of Tsinghua University. This paper presents the recent experimental results of the S-band MEG using hydrogen-terminated and CsI-terminated CVD diamond cathodes. The gun design, cathode preparation and high power experiment are described. An electron beam with 5 μs macro-pulse, 10 Hz repetition rate, greater than 900 mA beam current was obtained.

INTRODUCTION

Multipactor is a resonant secondary electron emission discharge frequently observed in accelerator structures, couplers, RF windows et al. It is usually undesirable and will be suppressed in most cases. However there are a few applications based on this effect, such as the multipactor electron guns (MEG) [1-6], microwave frequency multipliers [7], radar receiver protectors [8], multipactor ion pump [9] and flat thin display [10].

The MEG can be seen as an improvement of the thermionic RF gun. By substituting the thermionic cathode with a secondary electron emission cathode, and the beam exit hole with a secondary electron emission grid, the back bombardment of the thermionic RF gun is used to form the multipactor process. The electron beam is produced, amplified and bunched simultaneously in the cathode-grid gap. When the current in the cavity reaches a steady level by space charge and beam loading effects, the outgoing electron beams will be the saturation emission current.

The advantages of MEG are: 1) short duration, high current electron beams due to self-bunching mechanism of multipactor; 2) fast response, simple structure, long lifetime and tolerance to contamination due to cold cathode. The MEG can form compact and efficient high power microwave generator systems. It can also be used in the small industrial and medical accelerators. By replacing the grid with a two-surface hydrogen-terminated single crystal thin diamond film, the MEG will produce electron beams of even larger current density and good beam quality, which may be used as a high brightness injector. This scheme is similar to the secondary emission enhanced photoinjector [11].

The first MEG was designed in 1969 by Gallagher [1], and then different kinds of such RF guns were developed [2-5]. Among these guns, only the Micro-Pulse Electron Gun (S-band) reached a high macro-pulse current density of 10 A / cm^2, but the cathode material was not mentioned in the literature [3]. In this paper, a multipactor electron gun with CVD diamond cathode is presented, including the gun description, cathode preparation and the high power experiment. The aim of this study is to select and prepare the appropriate cathode material in order to make the MEG beam current as high as possible.

THE MULTIPACTOR ELECTRON GUN

The MEG is composed of a cylindrical RF cavity working in TM_{010} mode, a secondary electron emission cathode and its position adjuster, a secondary electron emission grid with transmittance of 40 %, a waveguide and a RF window (the picture of the MEG is shown in Figure 1).

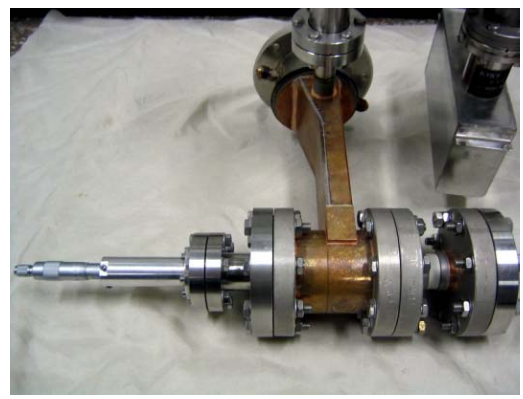

Figure 1: Photograph of the Multipactor Electron Gun.

The gap distance between the cathode and the grid is adjustable; as a result, the natural frequency of the cavity changes rapidly. Since no frequency tuner is designed, the MEG usually works in detuning conditions.

RF parameters are measured before hot tests. At the gap distance of 2.73 mm, the natural frequency is 2806 MHz, the unloaded quality factor is 1972, the unloaded coupling is 3.3, the shunt impedance is 0.175 MΩ.

CAHTODE PREPARATION

The preparation of high performance secondary electron emission material is the key point of making an MEG. According to multipactor dynamics, the MEG has two operation statuses [12]: 1). Small current (~ 100 mA) status corresponding to low impact energy (< 2 keV). 2). large current (~ 1 A – 10 A) status corresponding to high impact energy (>5 keV). The MEGs in references [1] and [2] worked in the first status, while the MPGs in [3] and [4] and the MEG in this study worked in the second one. When MEG works in large current status, it has to use materials having high second cross-over point energy,

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which is corresponding to high escape depth of the material. Diamond is one of the best cathode materials for MEG.

The excellent secondary electron emission property of CVD diamond films is due to the negative electron affinity formed by the hydrogen or CsI termination at the film surface [13]. The secondary electron emission yield is also dependent on the crystal quality which is mainly determined by the thickness of the CVD films [14].

The cathodes used in the MEG are polycrystalline diamond films on Mo substrate grown by microwave plasma assisted chemical vapour deposition (MPCVD). The growth parameters are shown in Table 1.

Table 1: Growth Parameters of CVD Diamond Films

Gas Supply	1 % CH_4 12 hrs.
Substrate Thickness	0.06 mm
Substrate Temperature	870 °C
Microwave Power	1700 W
Boron Doping (B_2H_4)	0.2 %

The Boron doping is to provide conductivity for the diamond films. The hydrogenation procedure involved exposure to H_2 plasma for 30 minutes while the cesiation procedure involved exposure to CsI vapour. Figure 2 shows the SEM image of the film. The thickness of the film is about 5 µm, and the grain size is about 0.5µm.

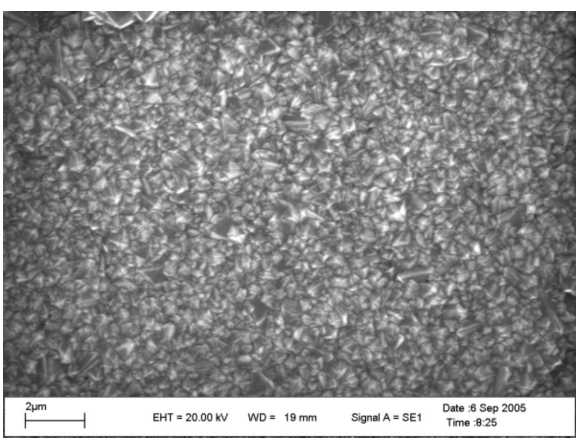

Figure 2: SEM image of the CVD diamond film.

EXPERIMENTAL RESULTS

When the RF power in the cavity (or the corresponding gap voltage) grows to the susceptive region and the transient beam loading is just appropriate, the multipactor discharge will occur [15]. The method of the high power experiment is to adjust the gap distance in order to fit the cathode material requirement and in the same time change the power level of the RF source to initiate the multipactor process.

The high power experiment system is composed of an E2V MG5349 magnetron (frequency range 2993 MHz - 3002 MHz, peak output power 3.1 MW), circulators, directional couplers, vacuum pumps and other necessary parts. The emission electron beam is collected by a faraday cup with a bias voltage of +50 V. The forward RF power from the directional coupler and the macro-pulse current from the faraday cup are measured by a Tektronix 7404B oscilloscope. The repetition rate is 10 Hz. The pressure remained ~ 10^{-4} Pa during the experiment. At the distance of 2.5 mm, the waveforms are shown in Figure 3 and 4.

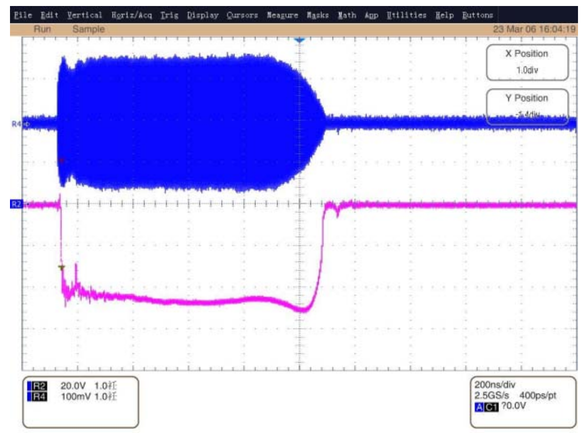

Figure 3: Beam current of MEG with hydrogen terminated CVD diamond cathode (bottom) and RF power delivered to the cavity (top), both on a 1µs / div. time scale.

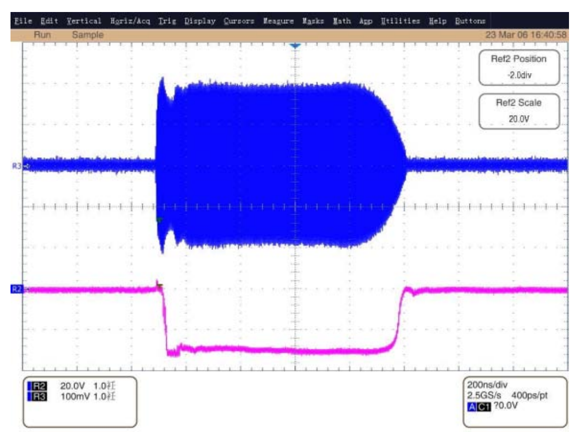

Figure 4: Beam current of MEG with CsI terminated CVD diamond cathode (bottom) and RF power delivered to the cavity (top), both on a 1µs / div. time scale.

The macro-pulse current of the hydrogen terminated and CsI terminated CVD diamond cathode is 920 mA and 600 mA respectively. The emission current density of the hydrogen terminated diamond cathode is 1.2 A / cm^2, and the micro-pulse current density is estimated to be 12 A / cm^2 with the duration of 30 ps.

The emission current decreases rapidly both for hydrogen terminated and CsI terminated CVD diamond films. This is caused by the secondary electron emission yield declination due to continuous high current density electron bombardment. The emission may be restored or enhanced if the surface is exposed to hydrogen or CsI environment [16-18]. This hydrogen gas feed experiment is now in progress in our lab in order to maintain the performance and extend the lifetime of the diamond cathode. But the graphitization of the diamond films by the hydrogen ions may be a new problem [18].

We are also investigating the other robust cathode materials such as OFHC copper, Cu-Al-Mg alloy [19], Pd-Ba alloy and MgO films [20], which may be used in MEG for the small industrial and medical linear accelerators.

CONCLUSIONS

A multipactor electron gun has been designed, built and tested in the Accelerator Lab of Tsinghua University, and a 920 mA pulse current, 5 μs pulse length electron beam has been obtained using the boron doped hydrogen terminated CVD diamond film cathodes. The cathode lifetime is under further investigation.

ACKNOWLEDGMENTS

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REFERENCES

[1] Gallagher W J. The multipactor electron gun. In: Proceeding of IEEE, 57(1), 1969. 94-95.

[2] Liska D J. Multipactoring electron gun for high duty linacs. In: Proceedings of IEEE, 59(8), 1971. 1253-1254.

[3] Mako F M. Electron gun. European Patent Application, EP 0809271 A2, 1997-11-26

[4] Len L K, Mako F M. Self-bunching electron guns. In: Proceedings of the 1999 Particle Accelerator Conference. IEEE, 1999. 70-74.

[5] Guharay S K, Len L K, Mako F M. High-current micro-pulse electron guns and accelerator applications. In: Proceedings of the 2001 Particle Accelerator Conference. IEEE, 2001. 2084-2086.

[6] Galdetskiy A V, Sazonov B V. Theoretical and experimental investigation of cold emitters for alenotron amplifiers. In: Proceedings of the 12th International Conference on Microwave and Telecommunication Technology (CriMiCo 2002). IEEE, 2002: 172-173.

[7] Mako F M. Electron gun having multiple transmitting and emitting sections. US Patent, 6633129, 2003-10-14.

[8] Carlisle T P. X band high power multipactor receiver protector. IEEE Transactions on Microwave Theory and Techniques, 1978, 26(5): 345-347.

[9] Yokoo K, Ono S. High-speed ion pump with a multipactor cathode-the multipactor ion pump. Vacuum, 1981, 32(5): 265-268.

[10] Dijk R, Vissenberg G, Zwart S. A flat thin display with RF electron generation. Journal of the Society for Information Display, 2005, 13 (3): 221-225.

[11] Chang X Y, Ben-Zvi I, Burrill A, et al. Study of secondary emission enhanced photoinjector. In: Proceedings of 2005 Particle Accelerator Conference. IEEE, 2005. 2711-2713.

[12] Zhai J Y. Initial experimental study of the multipactor electron gun. Master's Thesis. Beijing: Tsinghua University, 2006.

[13] Yater J E, Shih A. Secondary electron emission characteristics of single-crystal and polycrystalline diamond. Journal of Applied Physics, 2000, 87(11): 8103-8112.

[14] Dvorkin V V, Dzbanovsky N N, Suetin N V, et al. Secondary electron emission from CVD diamond films. Diamond and Related Materials, 2003, 12: 2208-2218.

[15] Kishek R A. Interaction of multipactor discharge and RF structures: [PhD thesis]. Ann Arbor: University of Michigan, 1997.

[16] Bekker T L, Dayton J A, Gilmour A S, et al. Observation of secondary electron emission from diamond films. IEEE IEDM Tech. Dig, 1992, 92: 949-952.

[17] Mearini G T, Krainsky I L, Dayton Jr J A. Investigation of diamond films for electronic devices. Surface and Interface Analysis, 1994, 21: 138-143.

[18] Mearini G T, Krainsky I L, Wang Y X□et al. Fabrication of an electron multiplier utilizing diamond films. Thin Solid Films, 1994, 253: 151-156

[19] Zhai J Y, Tang C X, Zheng S X, et al. Multipactor experiment on a Micro-Pulse Electron Gun. High Energy Physics and Nuclear Physics, 2006, 30(2): 147-150.

[20] Zhai J Y, Tang C X, Zheng S X. Experimental study on the beam dynamics of Micro-Pulse Electron Gun. High Energy Physics and Nuclear Physics, 2006, 30(Suppl. I): 99-101.