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Effect of Voltage on Radiation Characteristics of Triggered Vacuum Diode

Wei Tian*[1,2], Shixiu Chen[1], Jixiong Xiao[1], Kun Chen[1], Fei Gai[1]
[1]School of Electrical Engineering, Wuhan University, Wuhan 430072, China,
Ph./Fax:+86027-67841808/67842781
[2]School of Computer Science, South-Central University for Nationalities, Wuhan 430074, China,
Ph./Fax:+86027-68774460/68774460
*Corresponding author, e-mail: victor-tian888@163.com

Abstract

Based on the conduction mechanism of vacuum trigger diode, an experimental scheme has been designed to research on the effect of voltage parameters on radiation characteristics of vacuum trigger diode. The factors, including charging voltage and anode-cathode voltage, affecting radiation characteristics of vacuum trigger diode are analyzed. Through measure and analysis of trigger current, the reason of voltage effecting radiation is presented. With increase of charging voltage, the trigger current increases, the radiation enhances and radiation band moves up. With increase of anode-cathode voltage, more high density plasma of anode is generated by the electron bombardment anode, the radiation enhances and upper frequency limit is expanded. So it can be concluded that because of trigger electrode, radiation characteristics of vacuum diode can be controlled through voltage parameters. The vacuum diode can be controlled more flexibly and conveniently.

Keywords: *triggered vacuum diode, charging voltage, anode-cathode voltage, radiation characteristics, plasma density*

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1. Introduction

Because of advantages such as simple and compact structure, high power, adjustable frequency, easy realization of repetition frequency and so on, vacuum diode is applied to fields of high intensity accelerator, high power microwave, etc [1-3]. Up to now, the structures of planar diode [4, 5] and coaxial diode [6] have been adopted to research of vacuum diode. In the research of coaxial diode, Kuai Bin et al. have described that in their coaxial vacuum diode, the evolution of electrons is divided into three phases. The radiation is mainly generated in the second phase [7]. On the other hand, in the research of planar diode, three cathode structures have been mainly used. These cathodes are explosive emission cathode of graphite or velvet, some cathode which provides electron by extracting from stationary plasma, and T/F cathode [8-11]. In addition, planar-type cathode with triggered electrode has been presented in 1966 [12]. However, substantial research generally focuses on its switch characteristics [13, 14]. Seldom study reports about effect of control parameters on radiation characteristics of triggered vacuum diode. So vacuum planar diode of triggered electrode is designed in this paper in order to achieve effects of voltage parameters on radiation characteristics of triggered vacuum diode (TVD).

2. Design of Experiment Scheme

Radiation equipment of pulsed plasma is composed of power supply, rectifying device (T1 is voltage regulator, T2 is booster transformer, and D is high-voltage rectifying silicon stack), high-voltage pulsed capacitor C_p of energy storage, trigger device and diode. Figure 1 shows circuit diagram of experiment. Figure 2 shows structure diagram of triggered vacuum diode. The diode has three electrodes: anode, cathode and triggered electrode. Method of field-breakdown is adopted into breakdown between cathode and triggered electrode. In main circuit, two ends of C_p connect anode and cathode of diode respectively. Two ends of trigger device connect triggered electrode and cathode respectively.

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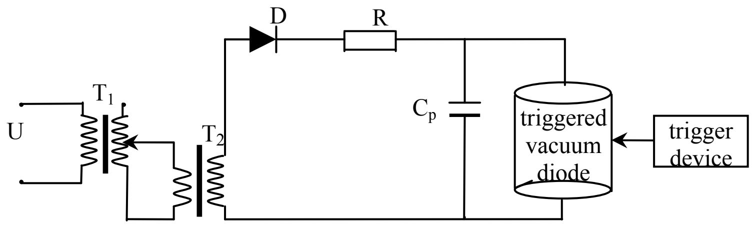

Figure 1. Circuit Diagram of Experiment

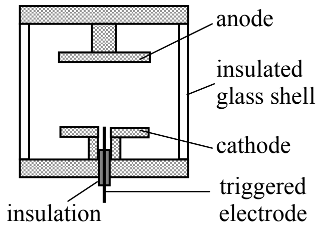

Figure 2. Structure Diagram of Diode

Tektronix TDS2022B oscillograph is adopted to measure triggered pulse waveform. Radiation signal is collected through ETS-Lindgren Model 3117(double-ridged horn antenna), then is transmitted to oscillograph(Tektronix DPO/DSA73304D) by cable (Semflex HPI-160).

In the experiment process, atmospheric pressure of diode is 3~5×10^{-3}Pa. Distance between anode and cathode is 6cm. Temperature and humidity in lab are 31^{o}C and 62% respectively.

3. Experiment Process

The experiment process is: (1) Freewheeling capacitor of trigger device is charged to 200V~300V. Then trigger device generates triggered pulsed high voltage (20kV~30kV), which brings into breakdown between cathode and triggered electrode. After that, initial plasma is formed near cathode and triggered electrode, as Figure 3(a) shows. (2) Electrons from surface of initial plasma move towards anode under electric field effect. Then they bombard anode to form plasma near anode. Subsequent electrons towards anode interact with plasma near anode to radiate microwave. Formation of plasma near anode is shown in Figure 3(b). (3) Simultaneously, ions, which are formed by electrons bombarding anode, move towards cathode under electric field effect. Then they bombard cathode to form arc plasma. Subsequently, plasma near cathode and anode rapidly diffuse in inter-electrode gap. The diffusion is called ambipolar diffusion. Finally, it causes conduction of inter-electrode gap, and radiation terminates [15-17]. Formation of discharge channel is shown in Figure 3(c). Development of plasma in Figure 3 is taken photos through high-speed camera.

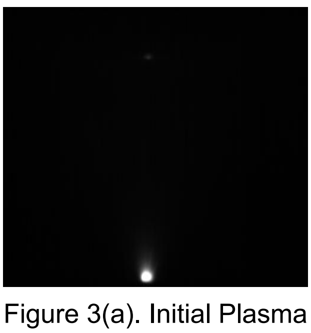

Figure 3(a). Initial Plasma Formed

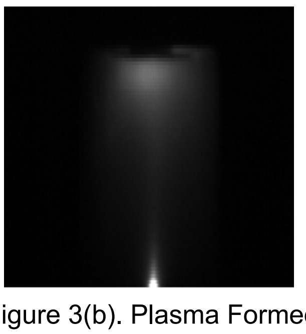

Figure 3(b). Plasma Formed Near anode

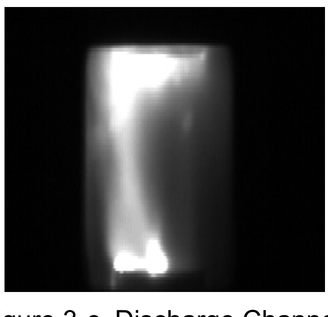

Figure 3-c. Discharge Channel

4. Results of Experiment

In order to analyze effect of voltage parameters on radiation characteristics of TVD, three different kinds of charge voltage (300V, 250V and 200V) are applied to capacitor of trigger device, and three different kinds of anode-cathode voltage (20kV, 30kV and 40kV) are adopted. The freewheeling capacitor of trigger device is 470μF. Antenna and cable attenuation aren't considered in following experiment.

In following experiment, charge voltage and anode-cathode voltage are abbreviated to V_c and $V_{a\text{-}c}$ respectively.

Field intensity amplitudes of radiation with different charging voltage and anode-cathode voltage are shown in Figure 4. The field intensity amplitude refers to larger value but not maximum value. Time domain waveforms and amplitude-frequency characteristic curves of radiation for charging voltage 300V and anode-cathode voltage 20kV, 30kV and 40kV are shown in Figure 5. Radiation waveforms for charging voltage 250V and 200V are respectively shown in Figure 6 and 7. These time domain waveforms are measured through oscillograph. These amplitude-frequency characteristic curves are received by Fourier transformation of time domain waveforms.

The following can be received through above experimental data: (1) Under the condition of same charging voltage of trigger device, the higher anode-cathode voltage is, the greater field intensity amplitude of radiation from diode discharge is. (2) Under the condition of same anode-cathode voltage, the higher charging voltage is, the greater field intensity amplitude of radiation from diode discharge is.

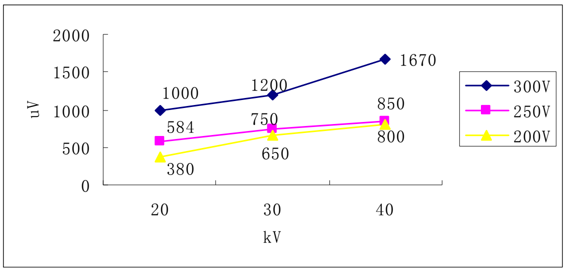

Figure 4. Field Intensity Amplitude of Radiation with Different Charging Voltage and Anode-Cathode Voltage

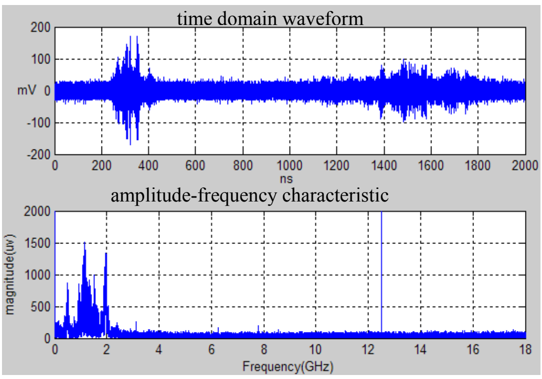

Figure 5(a). Radiation Waveform for V_c=300V and $V_{a\text{-}c}$=20kV

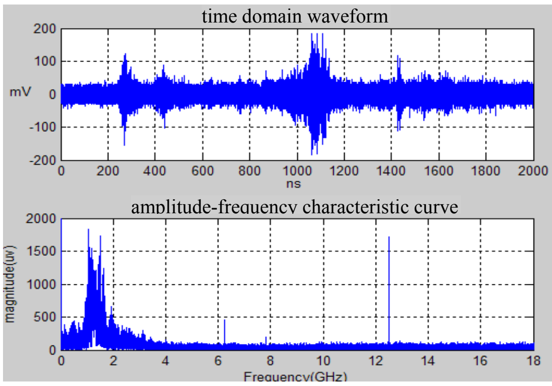

Figure 5(b). Radiation Waveform for V_c=300V and $V_{a\text{-}c}$=30kV

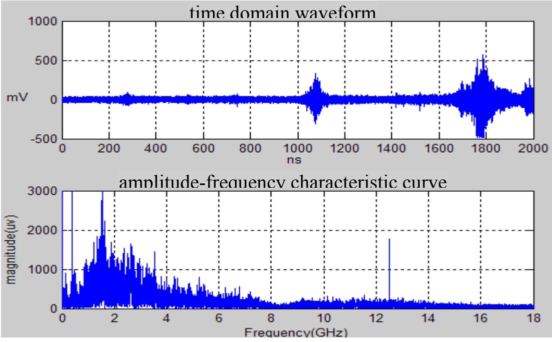

Figure 5(c). Radiation Waveform for V_c=300V and $V_{a\text{-}c}$=40kV

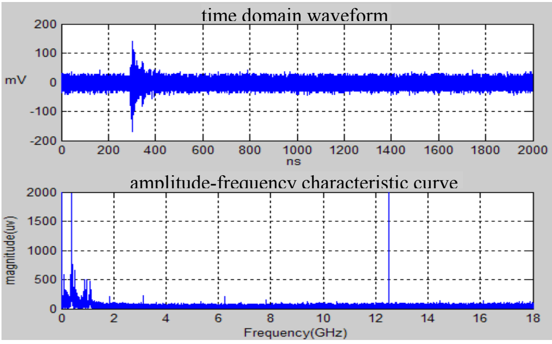

Figure 6(a). Radiation Waveform for V_c=250V and $V_{a\text{-}c}$=20kV

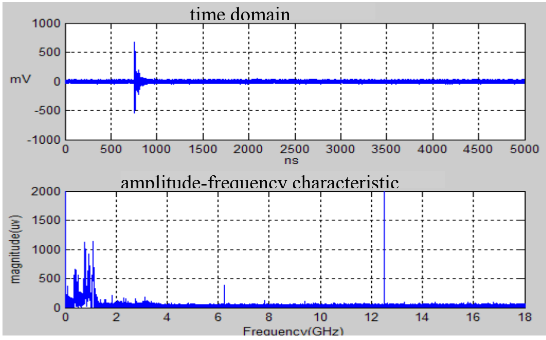

Figure 6(b). Radiation Waveform for V_c=250V and $V_{a\text{-}c}$=30kV

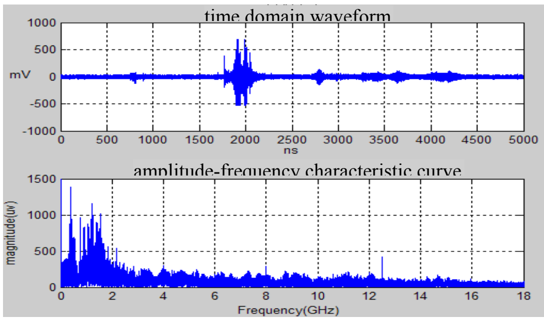

Figure 6(c). Radiation Waveform for V_c=250V and $V_{a\text{-}c}$=40kV

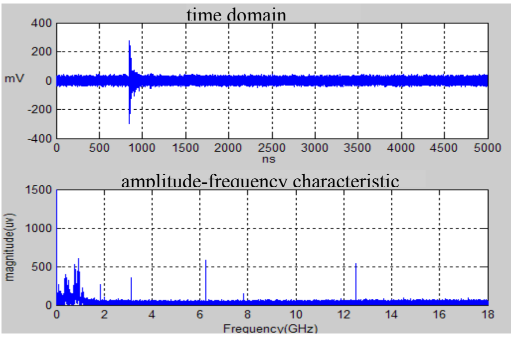

Figure 7(a). Radiation Waveform for V_c=200V and $V_{a\text{-}c}$=20kV

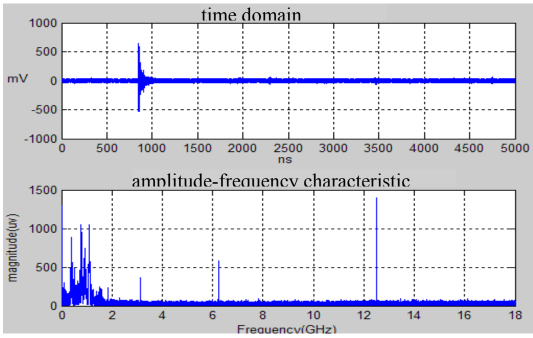

Figure 7(b). Radiation Waveform for V_c=200V and $V_{a\text{-}c}$=30kV

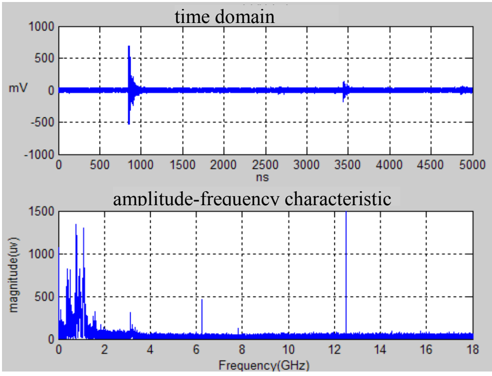

Figure 7(c). Radiation Waveform for V_c=200V and V_{a-}

5. Analysis of Results

From above experimental data, we can see that control parameters (anode-cathode voltage, charging voltage) would affect radiation. This is because the parameters could adjust density or quantity of plasma.

5.1. Effect of Charging Voltage on Radiation

Through monitoring trigger current, the reason that charging voltage affects radiation can be found out.

Trigger current waveforms for different charging voltage (300V, 250V and 200V) are shown in Figure 12. Parameters of trigger current are presented in Table 1. Here, resistance of shunt meter is 4.5mΩ.

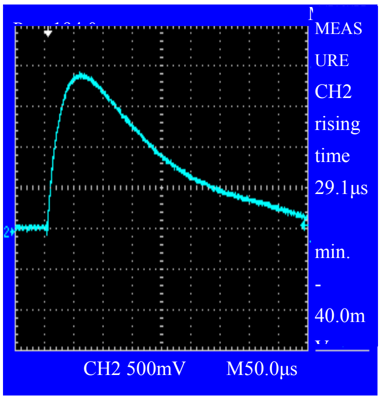

Figure 12(a). Trigger Current Waveform for V_c=300V

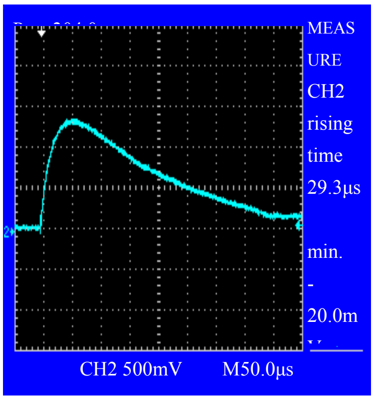

Figure 12(b). Trigger Current Waveform for V_c=250V

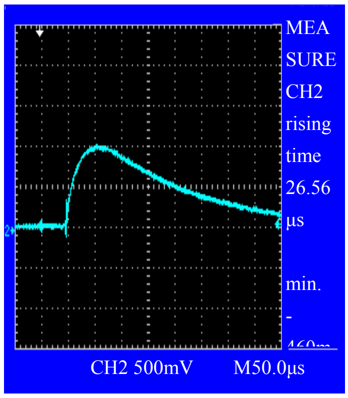

Figure 12(c). Trigger Current Waveform for V_c=200V

Table 1. Trigger Current Parameters

p.c. / V_c	max trigger current (A)	max voltage of oscillograph(V)	rising time (μs)
300V	400~444	1.9~2.0	25~30
250V	289~311	1.3~1.4	25~30
200V	222~244	1.0~1.1	25~30

In Table 1, p.c. represents parameters of trigger current.

According as reference [18], the following can be received by analysis of above experimental data. Because of increase of charging voltage, trigger current increases.

Meanwhile, the rising time of trigger current is almost invariant. Under the above condition, quantity of trigger plasma(initial plasma) increases. More electrons are extracted from the plasma to bombard anode. Then more plasma of anode is formed to interact with electrons. So radiation would be enhanced. The field intensity amplitude of radiation from diode is great accordingly.

Table 2. Radiation Frequency Band of Convergent Energy

$V_{a\text{-}c}$ / V_c	20kV	30kV	40kV
300V	0.91~2.00GHz	0.86~1.72GHz	0.85~3.50GHz
250V	0.36~1.14GHz	0.36~1.18GHz	0.36~1.79GHz
200V	0.36~1.14GHz	0.36~1.16GHz	0.36~1.17GHz

In addition, frequency bands, which radiation energy concentrates in, with different charging voltage and anode-cathode voltage are shown in Table 2. Combined with references [19], the following can be received by analysis of data in Table 2 and effect of plasma density on dispersion characteristics. Under the condition of same anode-cathode voltage, with increase of charging voltage, trigger current increases. Density plasma also increases. So radiation band moves up.

From Table 2 and Figure 4, the following could be seen, too. Radiation bands for charging voltage 200V and 250V have no significant difference. Their field intensity amplitudes of radiation have a little change. Only when charging voltage is higher than 250V, bands and amplitudes of radiation have significant difference.

5.2. Effect of Anode-Cathode Voltage on Radiation

With increase of anode-cathode voltage, electrons bombard anode with larger momentum. So, higher density plasma of anode is formed.

Plasma electron frequency can be expressed as:

$$\omega_{pe} = \sqrt{n_e q_e^2 / \varepsilon_0 m_e} \tag{1}$$

So, Frequency of plasma is higher with increase of density plasma of anode. These are beneficial to interaction between electrons and plasma. So radiation would be enhanced. The field intensity amplitude of radiation from diode is greater. In the same way, because of higher anode-cathode voltage, frequency band of radiation is wider, and upper frequency limit is expanded.

Through above analysis, it can be seen that TVD can radiate more widely than vacuum diode without triggered electrode. TVD is ultra-wide-band microwave radiator. Moreover, because of triggered electrode, radiation of TVD can be controlled better through modulation of voltage parameters.

6. Conclusion

The following is proved by experiment. In TVD, field intensity amplitude and frequency of radiation could be more flexibly controlled by not only anode-cathode voltage but also charging voltage.

(1) With increase of anode-cathode voltage, electrons bombard anode with larger momentum. Higher density plasma near anode is generated. So the radiation enhances and upper frequency limit is expanded.

(2) With increase of charging voltage, the trigger current increases. Then more plasma of anode is formed to interact with electrons. So the radiation enhances and radiation band moves up.

Through above work, mechanism of this equipment could be comprehended more, but also best operation parameters, which will provide a basis for further study, could be selected. Moreover, the work fills the gaps in the field of radiation characterristics of triggered vacuum diode.

Acknowledgement

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