The experimental effect of encouraging transparent-cathode in relativistic magnetron with "ETIGO-IV"

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The Magnetron is one of the efficiency high-power microwave source, although the energy conversion efficiency decreases with pulsed-power relativistic electron beam. We study the capability to increase energy conversion efficiency of Relativistic Magnetron by using Transparent Cathode. The Transparent-Cathode consists of independent cathode strips. Each cathode strip caused azimuthal magnetic field, and the radial drift velocity of electrons are accelerated more than that of electron emitted from general cathode. It can make abbreviating start-up times. We study the relativistic Magnetron with "ETIGO IV" that is 400kV class repetitive pulsed-power generator. This pulse length is longer considering pulsed-power. In this work, we appear the effect of Transparent cathode compared with traditional cathode. The start-up time of magnetron with Transparent cathode is shorter than that with traditional cathode. The peak power and oscillation efficiency are unconfirmed. We feel strongly that Transparent cathode is encouraging method.

Keywords: high-power Microwaves, relativistic Magnetron, Transparent cathode, combined efficiency, rapid start-up, long pulse

1. Introduction

The Magnetrons are one of the most efficiency microwave source, so these are studied by for many years. Magnetrons come into use for radar, electrical power transmission, microwave oven and etc. The features of magnetron are high oscillation efficiency and comparatively low demand for external magnetic field [1-2]. And this means reduction of the device scale and weight are expected. And these are comparative excellence efficiency in the region of hi-power microwaves, although the operation frequency regions are within the lower microwave region by comparison other high-frequency generator (e.g. gyrotron). In general the efficiency of high-power microwaves is determined by momentary output energy and momentary input energy measured at the time which is fixed the same time at the peak oscillation. In these years, we consider the total efficiency: total input energy and total output energy at least [1]. I.e. enhanced combined efficiency is requested. Some recipes become a candidate to enhance magnetron oscillation efficiency: magnetic priming and cathode priming and anode priming [3-5], among them the Transparent-Cathode is concise and hopeful procedure [6-7]. The Transparent-Cathode consists of independent cathode strips, as against the conventional cathode which consists of a solid columnar cathode. Figure 1 (a) shows the model of Transparent Cathode. Each cathode strip caused azimuthal magnetic field, and the radial drift velocity of electrons are accelerated more than that of electron emitted from general cathode shown in Fig.1 (b). Additionally azimuthal electric field penetrates the cathode strips. The crossed field devices like Magnetron generate from the interaction between azimuthal electric motion and electromagnetic wave. So Transparent Cathode causes electrons rapid spreading, which means rapid start-up, and the penetrating electric field potentiates more efficiency interaction. Additionally the shorter start-up increases the interaction term in pulsed electron beam, and can enhance the combined efficiency.

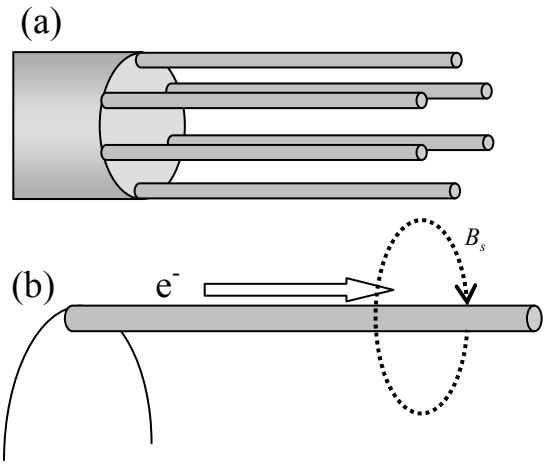

Fig. 1 The models of Transparent cathode
(a)The transparent cathode consists of independent cathode strips. (b)The magnetic effect of transparent cathode near the strip

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It's hope that shorter start-up times and improve operation efficiency.

We aspire for the enhanced combined efficiency by amelioration of Magnetrons structure. We approach the enhanced efficiency through the way abbreviating the start-up time. In this work, we study the effect of Transparent cathode mainly for rapid start-up. The experimental setups are fed by ETIGO IV that is 400kV class repetitive pulsed-power generator.

2. The schematic of Magnetron and Transparent Cathode

The cross section diagram of Magnetron shows in Figure 2. The magnetron comprises the cylindrical anode enclosing coaxial cylindrical cathode. The broken lines within the conventional cylindrical cathode line, show the Transparent cathode. The anode has the spaces as resonator vans. The electrons are emitted by the central cathode are subjected axial magnetic field $\boldsymbol{B}_z$ and drift by Lorentz force. The drifting electrons interact in the space between the two electrodes with the characteristic mode from the structure of resonator vans. In the case of Magnetron with Transparent Cathode, the current flowing each cathode strips cause azimuthal magnetic field $\boldsymbol{B}_s$.

$$B_s = \frac{\mu_0 I}{2\pi r_s}$$

And the radial drift velocity of electrons v_e are shown

$$v_e = \frac{E_0 B_z}{B_z^2 + B_s^2}$$

The electrons are accelerated more than that of electron emitted from traditional cathode. So Transparent Cathode causes electrons rapid spreading, and rapid start-up.

The characteristic dimensions are designed from type A6 Magnetron, which has studied for relativistic magnetrons [3]. The parameter of A6 magnetron is the radius of cathode r_c=15.8 mm, radius of anode r_a=21.1 mm, the gap of resonator vanes on the side of anode $\psi = 20°$, and the depth of resonator vans r_v=41.1 mm. The number of resonator vans is M=6. The external radius of transparent cathode is same to the radius of conventional magnetron cathode r_c. And the number of strips is same to that of resonator vans M. This number is reported developed by numerical simulations [6-8].

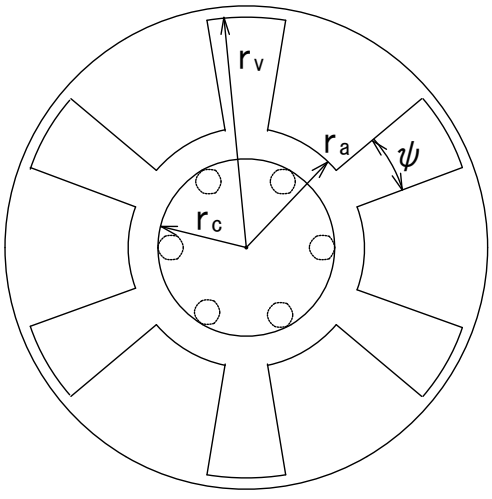

Fig. 2 The schematic of magnetron

3. Experimental Setup

Figure 3 shows the features of Magnetron operations region. These lines show the Hull cutoff and Buneman-Hartree resonance conditions [9] for A6 Magnetron. The power source is repetitive pulsed-power generator called "ETIGO IV" [10], which is capable of delivering, to a matched load, an output pulse of 400 kV in voltage, 13 kA in current, and 130 ns in pulse width, at the repetition rate of 1 Hz. The circle dots and full line are point out Hull criterion. In general, the Hartree voltage is less than the Hall cutoff voltage magnetic insulation. Other dots and lines show Hartree voltage for several oscillation modes. We assume the main operation modes are fundamental π-mode (2.34GHz) or high order 2π-mode (4.6GHz). The Hartree voltage is corresponds to the breakdown voltage of magnetron in the presence of a rotating perturbation field. The Hartree voltage causes the perturbation facilitates the motion of electrons across the cathode-anode gap. The potential energy of the electron efficiently interacts with and provides the electromagnetic wave. On this device, A6 relativistic magnetron requires external magnetic field about 0.5 T to 1.0 T.

The experimental setup consists of stainless steel (SUS304) vacuum chamber encrusted by external magnets. The external magnets architected at Helmholtz coil. These magnets form constant axial magnetic field covering the Magnetron resonator. It can be controlled by outer power source and can form maximal 1.0 T magnetic filed. Anode blocks made from aluminum, and cathode

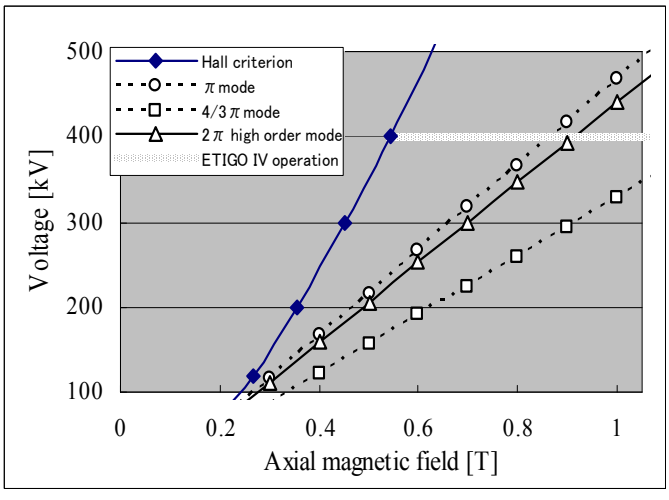

Fig. 3 The features of Magnetron operations region

made from carbon graphite. Graphite as cathode has the advantage of forming good filed emission characteristics and small excitation delays [11] and having resistance to discharge more than aluminum. The axial length of body is 125 mm, which is decided by the wave length of the operation electromagnetic wave 2.34 GHz, and avert discharge from converging electric filed. The stick of Transparent cathode made from graphite shapes like rounded trapezium by manufactural problem. Graphite is breakable.

4. Experimental result

Our magnetrons ware run at constant diode input power, which is maximum voltage not to discharge. Figure 4 shows the voltage and current characteristics of our magnetron as a function of external axial magnetic field $\boldsymbol{B}_z$. Full dots show voltage values as a function of magnetic field, and hollow dots show current values as a function of magnetic field. The diamond dots indicate measured value with traditional cathode, and the triangle dots indicate measured value with transparent cathode. The voltage rises slightly and the current falls fairly monotonically, results which are typical of conventional magnetrons [3]. The transparent cathode shows high resistance than traditional cathode. And in the lower magnetic filed the voltage falls andante, so current not increase rapidly near the Hall cutoff magnetic field. On the other hand, the current with transparent cathode increase by the plasma forming might happen at the high magnetic field. This is caused by pulse time increase as high impedance. Figure 5 shows diode voltage, diode current and microwave pulse from oscilloscope. The waveforms from the magnetron with transparent cathode draw full lines, and the waveforms from the magnetron with traditional cathode draw dashed lines. And heavy lines indicate diode voltage, normal lines indicate diode current. The top lines shows output microwave pulses measured at the point, which distance 2.5 m from output window on central axis. The operation regions are assumed about S-band to C-band: mainly 2 GHz to 5 GHz, we use horn antenna admitting nearly S-band: it assuring calibration coverage 2.45 GHz to 4.6 GHz. The microwave pulse lengths of the magnetron with “ETIGO

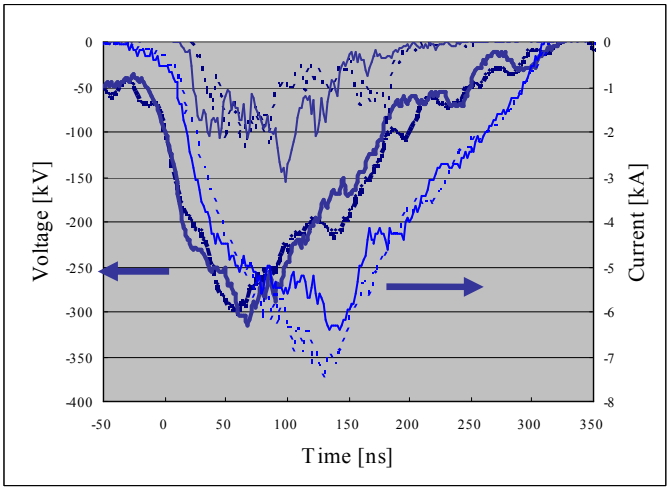

Fig.5 Voltage, current and microwave pulse shapes at 0.76 T. The full lines show the operation with transparent cathode. The dashed lines show the operation with traditional cathode. The heavy lines indicate diode voltage. The normal lines indicate diode current. The top lines indicate microwave pulse shapes.

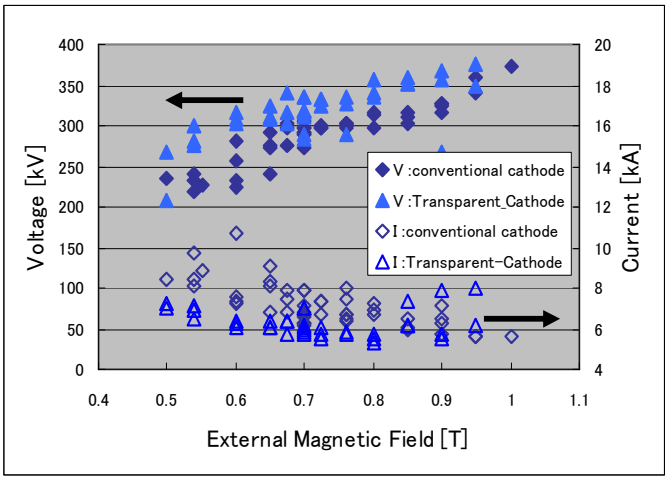

Fig.4 The voltage-current characteristics of the magnetron as a function of magnetic field. The diamond dots denote measured values with traditional cathode. The triangle dots denote measured values with Transparent Cathode.

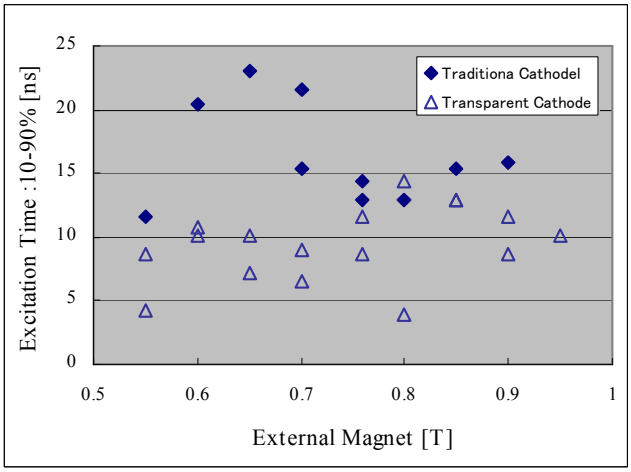

Fig.6 The Excitation time until first peak: 10% to 90% time. The diamond dots denote the time with traditional cathode. The triangle dots denote the time with Transparent Cathode.

IV" are more than 100 ns. And the pulse width (half to half) of voltage and current are respectively about 150 ns and 160 ns. These times go way beyond the time requiring static state magnetron operation. Our experimental setups may research steady oscillation region for relativistic magnetron operation, although the power source is pulsed power device. The peak voltage is less than rated capacity, because the plasma sheath is formed at circumferential cathode, which can not be analyzed at particle in cell simulation. The current with transparent cathode instantaneously increases, as the plasma and electron sheath forming decrease diode impedance. This problem stands out in proportion as increasing external magnetic field, as the electrons are constrained strongly and electron sheath thicken. These problems will come to a settlement by re-designing cathode. It would increase diode voltage and stabilize pulse forms and enhanced pulse width that the cathode is re-designed considering the plasma sheath. The comparing the output microwave form of Transparent cathode to that of traditional cathode, the start-up times are rapidly on an average. The peak value itself is determined by mode stability, which is dependent on situation of electron emission. The oscillation modes are approximate shown in Fig.3, and the diode voltage fluctuates. So the oscillation mode fluctuates too as affairs stand. The excitation time until first peak: 10% to 90% time are shown in Figure 6. The diamond dots denote the time with traditional cathode. The triangle dots denote the time with Transparent Cathode. The oscillation mode turn as external magnetic filed, consequently the start-up time turn as external magnetic field. On the average, the start-up times of oscillation with Transparent cathode are rapidly than that with traditional cathode. Whereas the rapid start-up bind the oscillation mode when the voltage is rising. This mode is not most efficient resonance mode not infrequently. The peak power and enhanced efficiency need high accuracy mode control.

5. Summary and Discussion

The transparent cathode makes high impedance diode at the same external diameter cathode. Especially in the lower magnetic filed nearly Hull cutoff the magnetron with transparent cathode is stabilized. The relativistic magnetron with Transparent cathode may rapid start-up than that with traditional cathode. Our experimental setups may research on over to steady oscillation region for relativistic magnetron operation, using the pulsed power source. By the calibration and assortment of output microwave will discover the occasional oscillation modes, the momentary maximum output powers, total output powers, conventional (momentary) efficiency and total efficiency too.

References

[1] J. Benford and J. Swegle, "*High-Power Microwaves*(Artech House, Norwood, MA, 1992)

[2] S.H. Gold and G.S. Nusinovich, Rev. Sci. Instrum. **68**, 11, pp.3945-3974 (1997)

[3] A. Palevsky and G. Bekefi, Phys. Fluids. **22**, 5, pp.986-996 (1979)

[4] R.W. Lemke, T.C. Genoni and T.A. Spencer, Phys. Plasmas **6**, 2, pp.603-613 (1999)

[5] V. Bogdam, C. Jones, R.M. Gilgenbach, Y.Y. Lau, J.W. Luginsland, B.W. Hoff, M.White, N.M. Jordan, P. Pengvanich, Y. Hidaka and H.L. Bosman, IEEE Trans. plasma **33**, 1, pp.94-102 (2005)

[6] Michael C. Jones, V. Bogdom Neculaes, William M. White, Y.Y. Lau, Ronald M. Gilgenbach, John W. Luginsland, P. Pengvanich, N. M. Jordan, Y. Hidaka and Herman L. Bosman, IEEE transactions on electron devices **52**, pp.858-863 (2005)

[7] M. Fuks, A. Andreev, H. Bosman, S.Prasad, and E.Schamiloglu, Department of Electrical & Computer Engineering, University of New Mexico, USA (2006)

[8] M.C. Jones, V.B.Neculaes, Y.Y. Lau, R..M. Gilgenbach, W.M. White, B.W. Hoff and N.M. Jordan, Appl. Phys. Lett. **87**, 08151 (2005)

[9] R.V. Lovelace, T.F.T. Young, Phys. Fluids **28**, pp.2450-2452 (1985)

[10] A. Tokuchi, N. Ninomiya, W. Jiang and K. Yatsui, IEEE Trans. Plasma sci. **30,** 5, pp.1637-1641 (2002)

[11] R.K. Parker, R.E. Anderson, and C.V. Duncan, J. Appl. Phys. **45**, 2463 (1974)