EXTRACTION OF PULSED ION BEAMS FROM AN ANODE
COVERED WITH LIQUID MATERIAL

Akira KITAMURA and Syukuro YANO

Department of Nuclear Engineering,
Kobe University of Marcantile Marine,
Higashinada-ku, Kobe 658, Japan

ABSTRACT

In order to extend the life of anodes of pulsed ion diodes, a trial was made to extract ions from a plasma created by surface flashover on the oil-covered anode. The diode with this anode worked well as a so-called pinched electron beam diode. Production of proton beams of 10 kA with energies of about 400 keV was confirmed by measurements with biased ion collectors and those of prompt γ-rays from the reaction $^{19}F(p,\gamma\alpha)^{16}O$. Substantial reduction of damage and substantial extension of the life of the anode disc were realized.

1. Introduction

Intense pulsed light ion beams (LIB) are considered to be one of the most promising energy driver for inertial confinement fusion (ICF). One of the shortcomings of the ion beam diodes developed so far is their short lives. This is mainly due to damage of the anode. The foil anode used in reflex triodes and pinch-reflex diodes cannot survive after one shot operation. The thick anode plate used in pinched electron beam diodes (PED) is exposed to strong flux of electrons, and severe damage is produced in one shot operation. On the other hand, The anode of magnetically insulated diodes with externally applied field (MID) suffers less damage, and can be used for several or several tens of shots, because the flux of electrons flowing into the anode is relatively low. It is doubtful, however, whether these anodes remain sound after an operation at the output beam power level of 10^{13} W required for drivers in future LIB ICF reactors. Moreover, for drivers in ICF reactors the anode life of more than 10^7 shots under 1-10 Hz operation is thought to be necessary. Therefore, development of a long life anode with high repetition rate is one of the most important subjects for future LIB ICF reactors.

Recently, extraction of ion beams from an MID with a cryogenic anode has been reported[1]. The gases injected onto the diode region are adsorbed as the source of the anode plasma on the refrigerated anode base. This method may be one of the solutions to the repetative use of the anode.

In this paper, another possibility is presented; an ion beam is extracted from a plasma created from liquid material on the anode disc by a surface flashover. For simplicity, we call this combination of the liquid layer and the anode disc as an anode. The liquid layer can be easily reformed before every shot, and the anode disc suffers less damage when it is coated with the liquid layer. This means that the anode has the longer life. This method has potential ability to be applied to the ultra-high power diodes with a high repetition rate.

2. Experimental apparatus

The experimental arrangement is shown in Fig.1. A high voltage pulse is formed by an 800 kV-5 kJ Marx generator with a 3 Ω pulse forming line, and propagates into a diode through a transmission line. The diode consists of an 8 mm-thick polyethylene disc anode of radius 70 mm and an annular stainless steel cathode of inner radius 45 mm and outer radius 50 mm. The surface of the anode disc is covered with a thin layer of liquid material before every operation of the diode. As the first trial, we used a layer of diffusion pump oil. The layer is formed by a puff of the pressurized oil through oil spray nozzles at 5 sec before the high voltage is applied to the anode. The thickness of the layer is about 0.5 mm. The oil is stored in the oil reservoir, which is evacuated beforehand and pressurized just before the momentary opening of a magnetic valve between the reservoir and the nozzles. The pressure of the residual air in the diode chamber was maintained below 0.03 Pa during this procedure.

The diode voltage is measured with an electrostatic probe. Subtraction

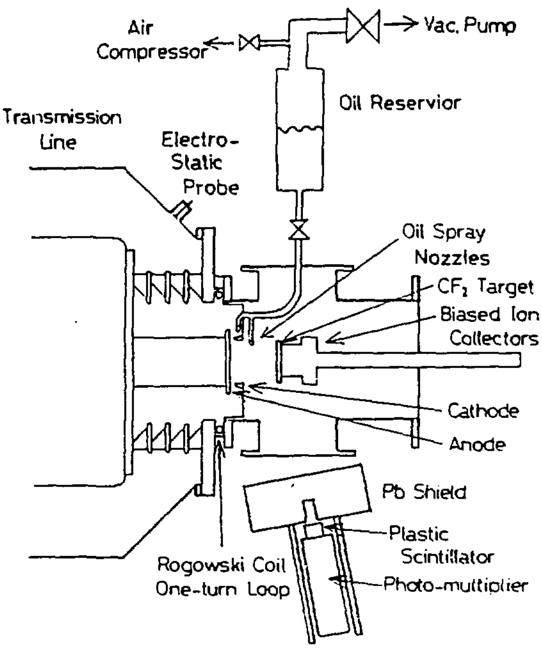
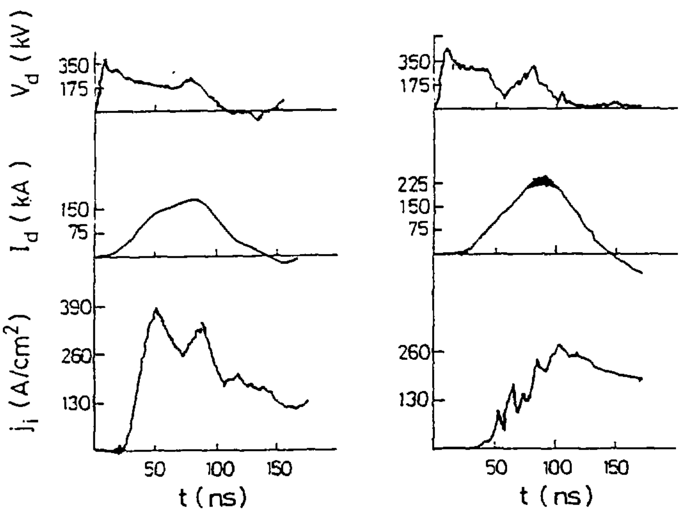


Fig.1. Experimental arrangement.

of the inductive voltage component from the measured voltage, the so-called $L\dot{I}$ correction, is made with use of a one-turn loop. The total diode current is measured with a Rogowski coil, and the emerging ion current is measured with 5-channel biased ion collectors (BIC) located in the downstream side of the diode. The current of protons having energies greater than 340 keV is also measured by utilizing the nuclear resonance reaction $^{19}F(p,\gamma\alpha)^{16}O$[2]. Gamma rays emitted from a thick teflon (CF_2) target are detected with a plastic scintillator-photomultiplier system (SPM). The output pulse height and detection efficiency of the SPM were calibrated with use of proton beams from a 1.6 MV tandem pelletron accelerator. The rise time and the FWHM of the output pulse of the SPM were 4 ns and 5 ns, respectively. This SPM is almost completely shielded from X-rays originating in the diode by a suitably designed collimator.

3. Experimental results and discussion

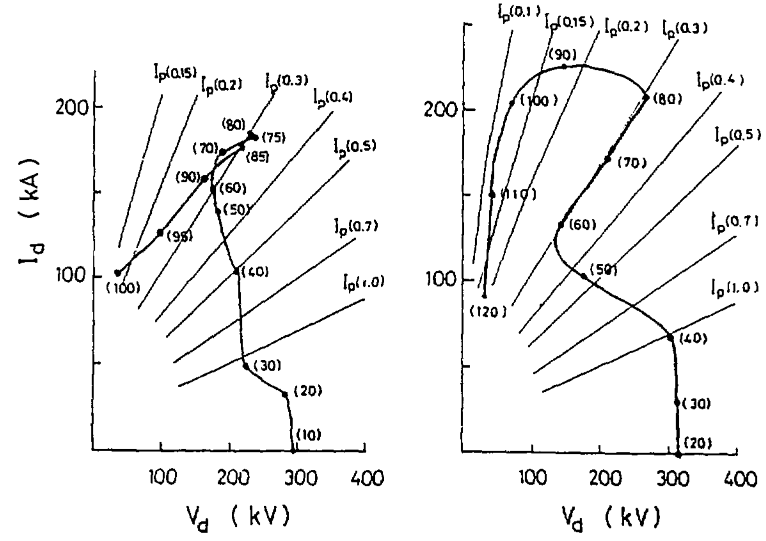
First, we describe characteristics of the diode without the oil layer on the anode. Typical oscilloscope traces of the diode voltage V_d, the diode current I_d and the ion current j_i are shown in Fig.2-(a). This ion current was measured at a distance of 40 mm from the anode on the axis of symmetry. The anode-cathode gap d_{ak} was 6.5 mm.



(a) the oil-uncovered anode

(b) the oil-covered anode

Fig.2. Typical oscilloscope traces of the diode voltage V_d, the diode current I_d and the ion current j_i.



(a) the oil-uncovered anode

(b) the oil-covered anode

Fig.3. V_d-I_d diagrams. (t) is time in ns, and $I_p(d)$ is the parapotential current for the effective gap d in cm.

The V_d-I_d diagram of this shot is shown in Fig.3-(a). The diode current I_p predicted by the parapotential flow theory[3] is also shown in the figure, and is expressed as follows;

$$I_p = \frac{2\pi m_e c}{e \mu_0} \cdot \frac{R}{d} \cdot \gamma \cdot \ln(\gamma + \sqrt{\gamma^2 - 1}), \qquad (1)$$

where R is the radius of the cathode, d is the effective gap of the diode, m_e is the electron rest mass and γ is the relativistic mass factor of electrons. It is found that during the time interval from 50 ns to 90 ns after the voltage rise the measured diode current I_d agrees well with the parapotential current I_p for the effective gap d equal to 0.3 cm.

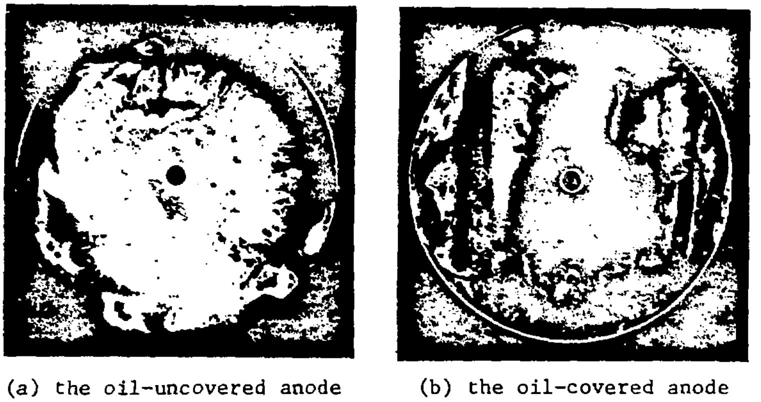
A pinhole X-ray photograph showed that electrons strike not only the part of the anode surface opposite to the annular cathode but also the whole anode area inside the cathode. In every shot severe damage on the anode surface was produced especially near its center. Ten-shot-operation made a hole of radius 15 mm near the center of the anode polyethylene disc of thickness 8 mm. Therefore it is apparent that this diode operates as a PED.

The ion beam efficiency of a PED is expressed as follows[4];

$$\frac{I_i}{I_e} \geq \frac{1}{2} \cdot \frac{R}{d} \cdot \sqrt{\frac{2 e V_d}{m_i c^2}}, \tag{2}$$

where I_i and I_e are the ion current and the electron current flowing in the diode, respectively, and m_i is the ion mass. From eqs. (1) and (2) the ion current is predicted to be greater than 20 kA for the effective gap of 0.3 cm. The measured ion current on the axis rises up at 25 ns after the voltage rise, and reaches the maximum of 380 A/cm^2 at 50 ns. The distribution of the ion current along the radial direction was also measured and found to be almost uniform within the error of ±20 % over the area inside the annular cathode. The maximum total ion current is then estimated to be 30 kA. This value agrees well with the theoretical value predicted above.

Next, we describe the diode characteristics with the oil-covered anode. When the anode is covered with an oil layer, substantial reduction of damage of the anode disc is realized. Photographs of the anodes both after two shots operation, (a) without the oil layer and (b) with the oil layer, are shown in Fig.4. In contrast to damage spreading over the oil-uncovered anode surface, damage on the oil-covered anode is localized and slight. The latter damage is extending in the vertical direction. This is due to inhomogeneity of the oil layer. The thickness of the oil layer of about 0.5 mm is slightly less than the practical range of electrons with energies of 280 keV which corresponds to the maximum diode voltage.



(a) the oil-uncovered anode (b) the oil-covered anode

Fig.4. Damage on the anode disc.

Then, slight decrease in the oil thickness results in damage of the anode disc. The oil-covered polyethylene anode disc could be used for twenty shots without substantial changes in V_d, I_d and j_i. Depth of the damage of the anode disc after twenty shots was less than 2 mm, in contrast to the erosion of 8 mm after ten shots operation without the oil layer.

This diode worked well as a PED with almost the same characteristics as those of the diode with the oil-uncovered anode. It was confirmed from a pinhole X-ray photograph that electrons were pinching and striking almost the whole anode area inside the cathode. Typical oscilloscope traces of V_d, I_d and j_i are shown in Fig.2-(b). The ion current was measured at the same position as in the case of the oil-uncovered anode. The anode-cathode gap distance d_{ak} was 9.5 mm. The increase in d_{ak} by 3 mm for the oil-covered anode was necessary to make the diode impedance nearly equal to that of the diode with the oil-uncovered anode. The diode current and the ion current rise up later by about 10 ns than those in the oil-uncovered diode with 6.5 mm gap. In the oil-uncovered diode with 9.5 mm gap, they rose up at almost the same time as those in the oil-uncovered diode with 6.5 mm gap. Therefore it seems that the flashover is harder to develop on the oil film than on the conventional anode material.

The V_d-I_d diagram is shown in Fig.3-(b). The measured diode current agrees well with the parapotential current for the effective gap of 0.3 mm during the time interval from 60 ns to 80 ns. The effective gap, however, seems to be rather unstable compared with that in the oil-uncovered diode.

There may be a possibility that ions are extracted from a plasma produced from oil vapor filled in the space between the anode and the cathode. If that is the case, energies of ions do not agree with eV_d. To make sure of the origin of the ions, and to confirm that the majority of the ions are protons, measurements of γ-rays produced by the nuclear reaction $^{19}F(p,\gamma\alpha)^{16}O$ at the CF_2 target were performed under the condition d_{ak}= 12.5 mm. This gap distance was necessary to make the diode voltage rise up above the reaction threshold of 340 kV. The diode also worked as a PED with the effective gap of 0.7 cm. Typical traces of j_i measured with the BIC placed at 60 mm from the anode, γ-rays from the CF_2 target mounted on the face of the BIC, and V_d are shown in Fig.5. There is a marked coincidence between j_i and γ-ray countings until 96 ns. If we take into account the time of flight of 340 keV protons, the discrepancy between j_i and γ-ray countings begins at 90 ns. This agrees well with the time when V_d begins to fall down below 340 kV. The maximum proton current onto the 30 cm^2 CF_2 target is calculated to be 4.8 kA. This agrees well with that of 5.6 kA calculated from the measured ion current distribution with the BIC. Therefore, it is apparent from the above discussions that protons originating in the anode plasma formed on the oil layer are the major constituent of the ion beam, and that the potential voltage of this plasma is equal to V_d.

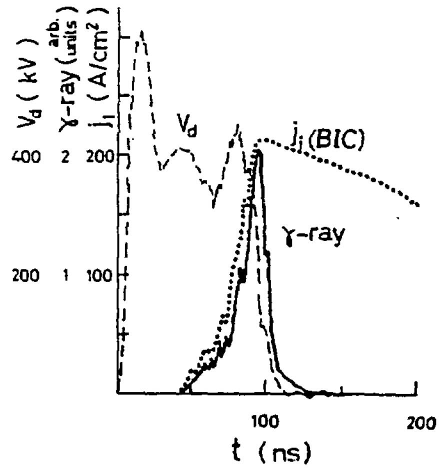


Fig.5. Comparison of signals from the γ-ray detector (the solid line) and from the BIC (the dotted line). The diode voltage V_d is shown as the broken line.

4. Conclusion

Proton beams of about 10 kA with energies of 400 keV were extracted from the oil-covered anode of a PED. Substantial reduction of damage and substantial extension of the life of the anode disc were realized.

The future effort will be directed toward 1) making the liquid layer thicker and more uniform, and 2) making the flashover on the liquid surface easier to develop.

The present method will be more effective to reduce damage for the anode of the MID, scince the electron current into the anode of the MID is less than that in the PED.

REFERENCES

1) Kasuya, K., Horioka, K., Takahashi, T., Urai, A. and Hijikawa, M.: Appl. Phys. Lett. 39 887 (1981).
2) Golden, J., Mahaffey, R. A., Pasour, J. A., Young, F. C. and Kapetanakos, C. A.: Rev. Sci. Instrum. 49 1384 (1978).
3) Creedon, J. M.: J. Appl. Phys. 46 2946 (1975).
4) Goldstein, S. A. and Lee, R.: Phys. Rev. Lett. 35 1079 (1975).