

PLASMA COMPRESSION EFFECT IN AN ION DIODE WITH PASSIVE ANODE

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Outline

1. Introduction
2. Experimental setup
3. Basic calculations
4. The modes of the diode operation
5. Plasma compression effect
6. Conclusion

1. Introduction

Principal problems of High-Power Pulsed Ion Beam formation:

1. Suppression of the electronic component of the total diode current
2. Formation of dense, uniform plasma at the anode ($n_i > 10^{14} \text{ cm}^{-3}$)

1. The problem of suppression of the electron component of the diode current

- **R.N. Sudan and R.V. Lovelace** Generation of Intense Ion Beams in Pulsed Diodes // Physical Review Letters, **1973**, vol. 31, # 19, pp. 1174- 1177

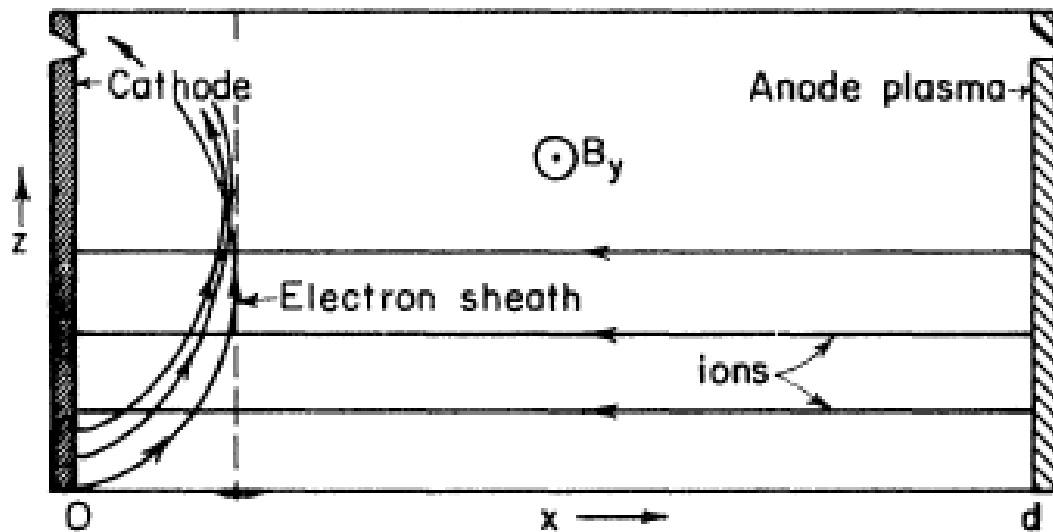
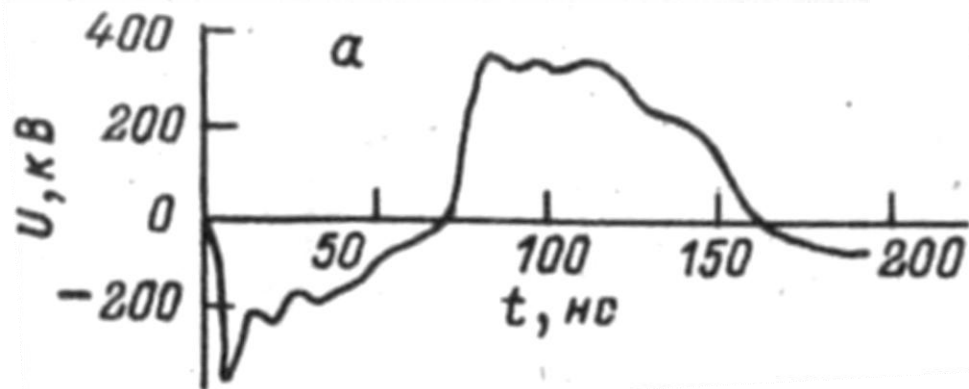
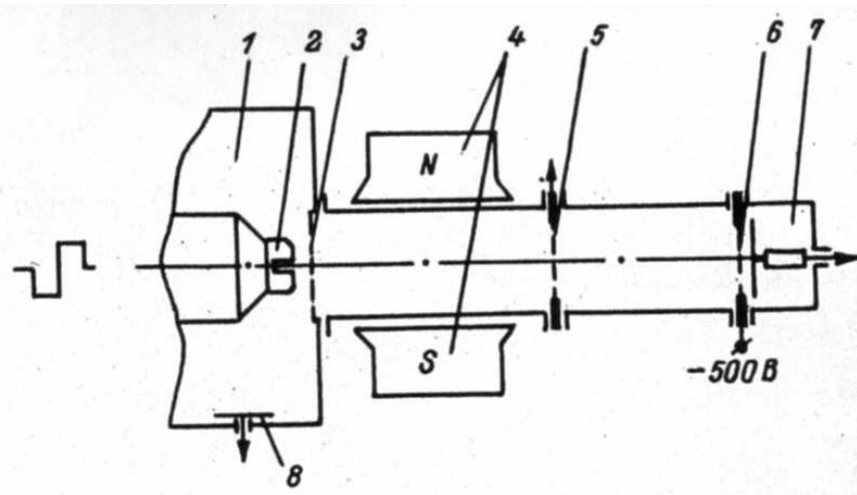


Fig.1 Geometry of ion diode suggested by R.N. Sudan and R.V. Lovelace

2. Formation of dense, uniform plasma at the anode ($n_i > 10^{14} \text{ cm}^{-3}$)

- E. I. Logachev, G. E. Remnev and Y. P. Usov. *Techn. Phys. Lett.*, vol. 6, no. 22, pp. 1404–1406, **Nov. 1980**.

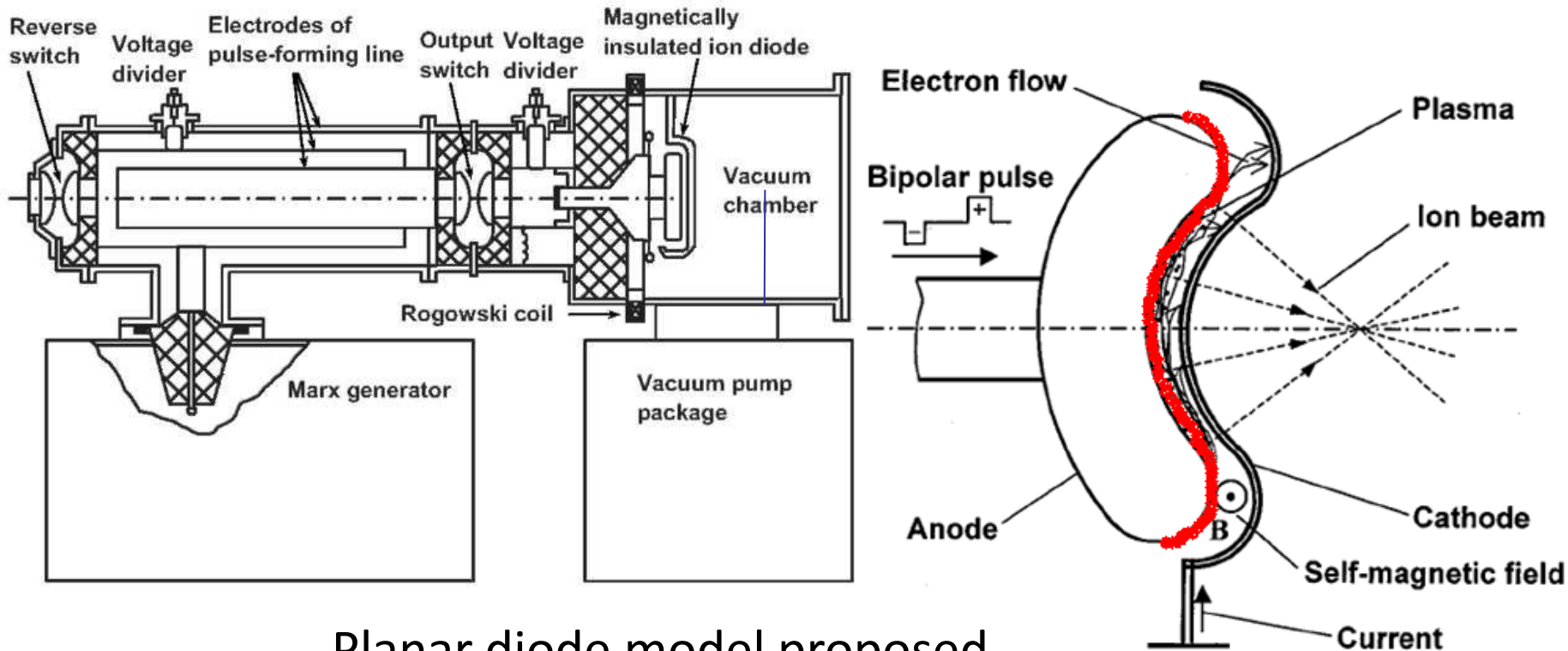


Basic diagram of the setup:

- 1 - Gun,
- 2 - Potential electrode,
- 3 - Tungsten mesh, transparency 80%,
- 4 - Deflecting magnet,
- 5 - 1st probe,
- 6 - 2nd probe,
- 7 - Faraday cup.

• J. P. Xin, X. P. Zhu, and M. K. Lei PHYSICS OF PLASMAS 15, 123108 (2008)

Schematic of TEMP-6-type HIPIB apparatus in bipolar-pulse mode



Planar diode model proposed for the initial plasma formation process

- In spite of much progress in powerful ion beam generation, many processes in an ion diode with magnetic self insulation have not been researched enough.

The purpose of the work is to investigate with high temporal resolution a magnetically insulated ion diode in bipolar-pulse mode.

2. Experimental installation TEMP-4M



Accelerating voltage 250-300 kV,

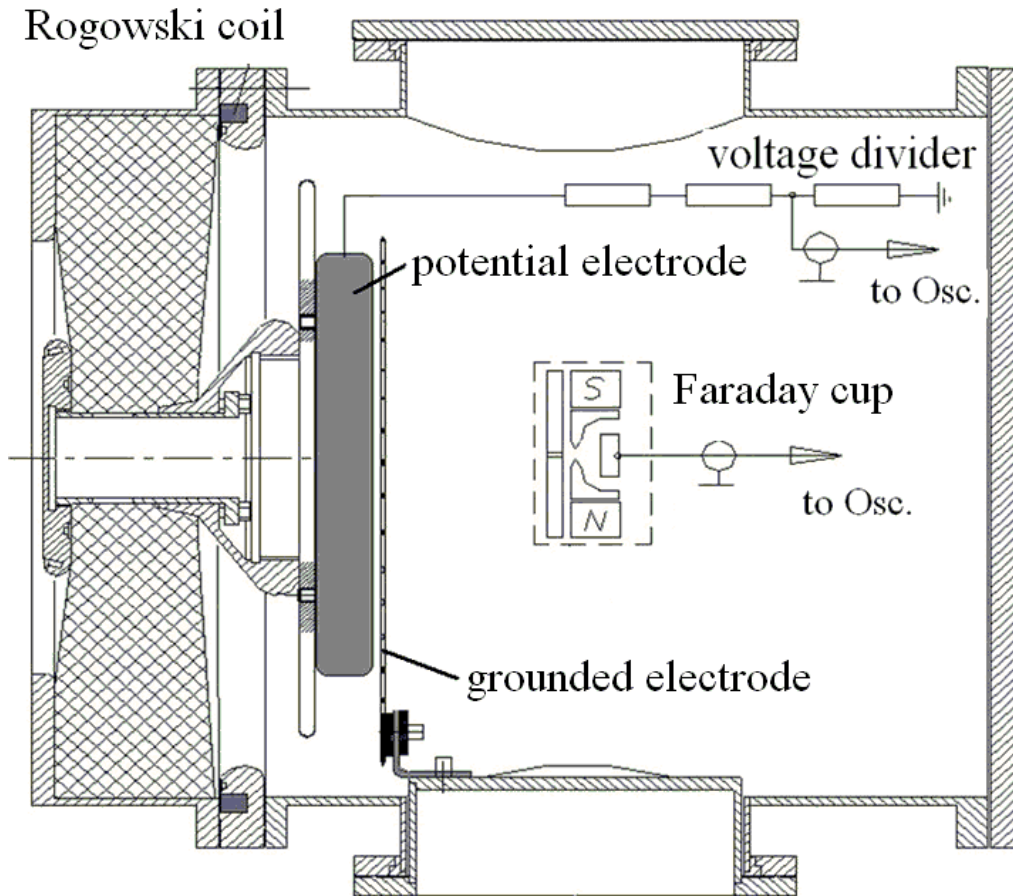
Full pulse duration 100 ns,

Total ion energy in pulse is up to 90 J;

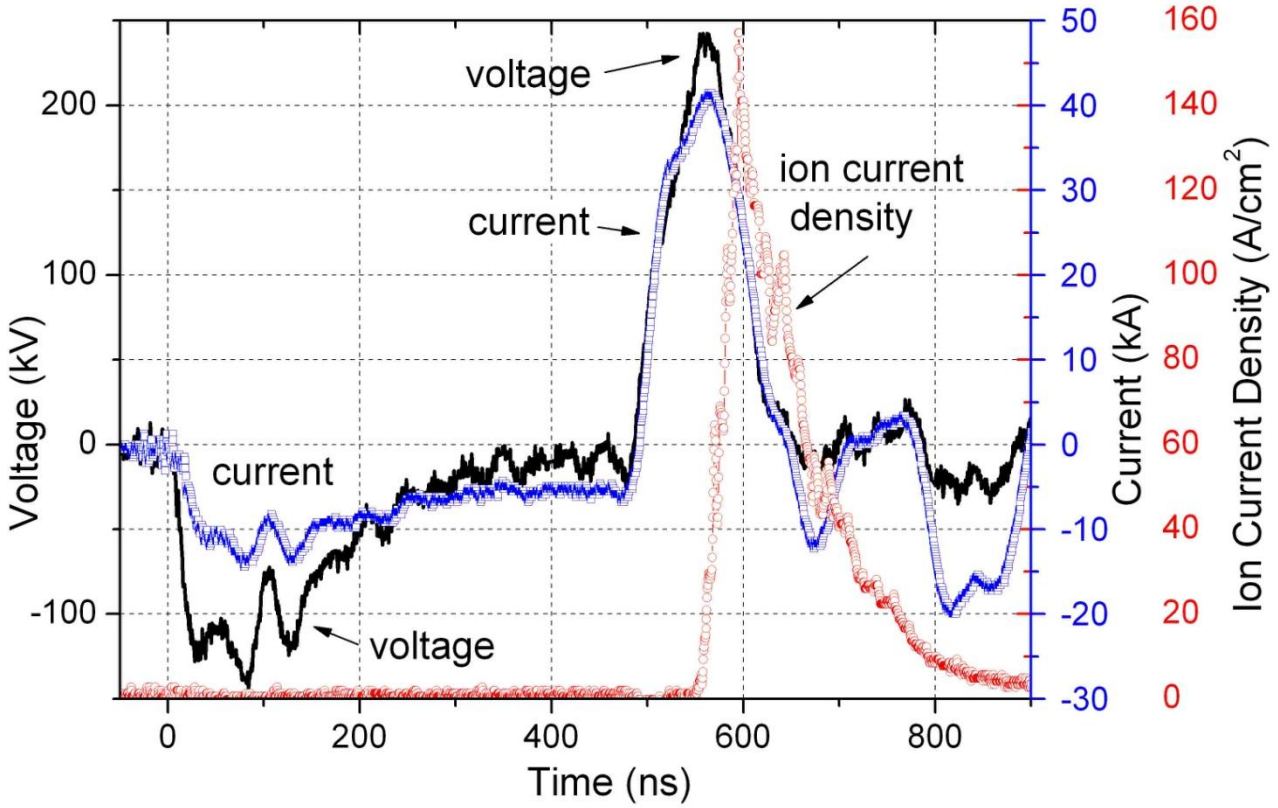
Beam composition: ions of carbon (C^+ , C^{2+}) and protons

PLASMA COMPRESSION EFFECT IN AN ION DIODE WITH PASSIVE ANODE

Diode system



Diode joint of the accelerator TEMP-4M



Oscilloscope traces of voltage, total current and ion current density.



A.I. Pushkarev *et al.* Patent RU 86374 U1 (2009).

Calibration of the diagnostic equipment

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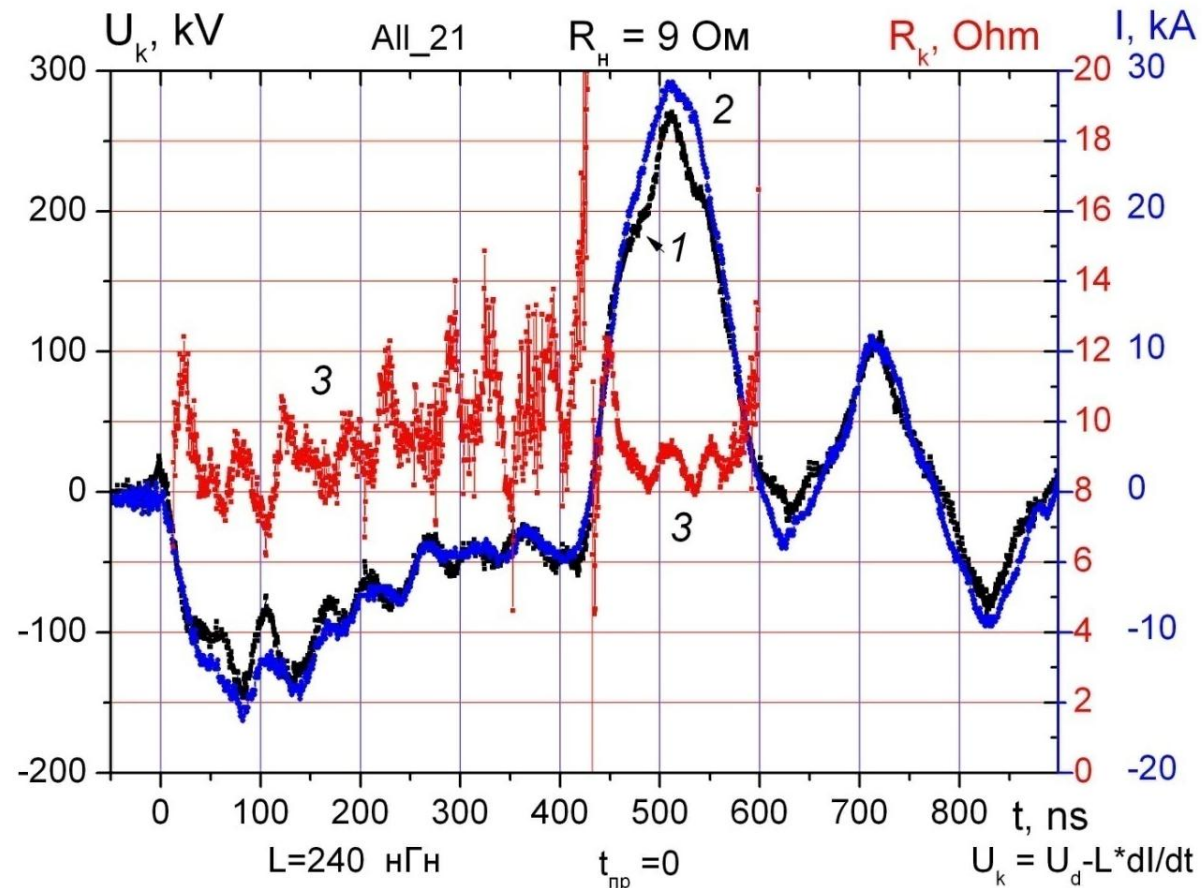
DIAGNOSTIC EQUIPMENT OF A TEMP-4M GENERATOR OF
HIGH CURRENT PULSED ION BEAMS

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Oscilloscope traces of
voltage, current and
impedance of load



3. Basic calculations

Electron current density

$$J_e = \frac{\alpha \cdot 4 \varepsilon_0 \sqrt{2e}}{9 \sqrt{m_e}} \cdot \frac{U^{3/2}}{d_0^2}$$

Ion current density

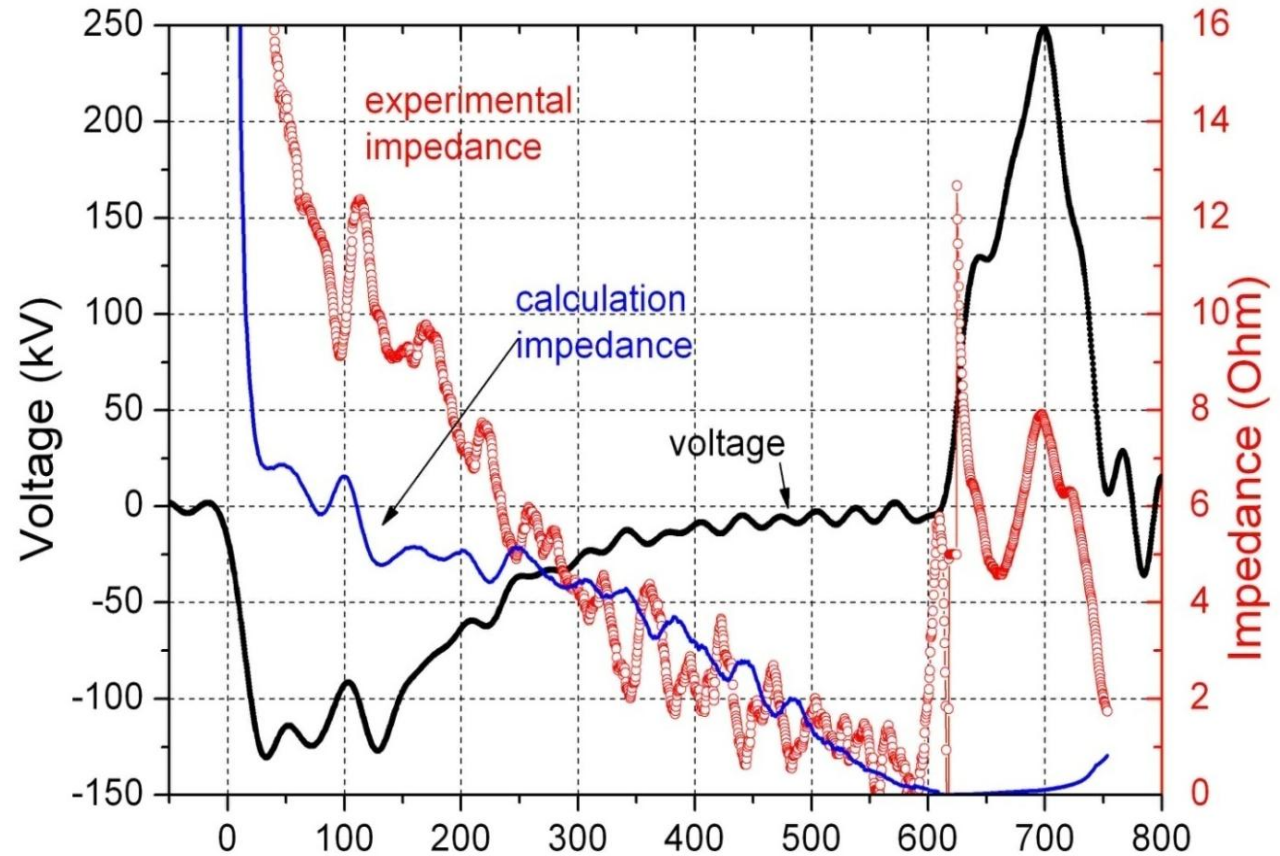
$$J_{ion} = \frac{\alpha \cdot 4 \varepsilon_0 \sqrt{2z_i}}{9 \sqrt{m_i}} \cdot \frac{U^{3/2}}{(d_0)^2}$$

$$R_{calc} = \frac{U}{S_0 \cdot J_e} = \frac{(d_0 - v \cdot t)^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot U^{1/2}}$$

Accelerator Operating Modes

$$R_{\text{exp}} = \frac{U}{I}$$

$$R_{\text{calc}} = \frac{U}{S_0 \cdot J_e} = \frac{(d_0 - v \cdot t)^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot U^{1/2}}$$



Discrete emissive surface mode
 $R_{\text{exp}} > R_{\text{calc}}$

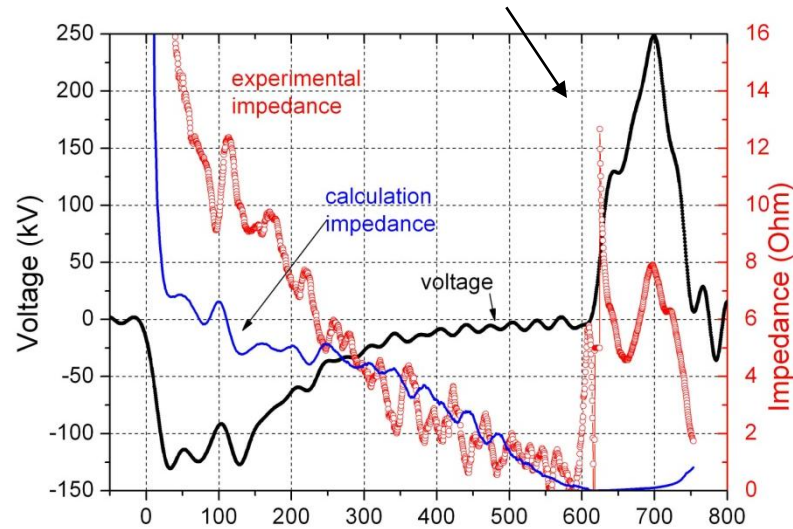
Space charge limitation mode
 $R_{\text{exp}} = R_{\text{calc}}$

Magnetic self-isolation mode
 $R_{\text{exp}} > R_{\text{calc}}$

Space charge limitation mode

$$v(t) = \frac{1}{t} \left[d_0 - \sqrt{\frac{2.33 \cdot 10^{-6} \cdot S_0 \cdot U^{3/2}}{I}} \right],$$

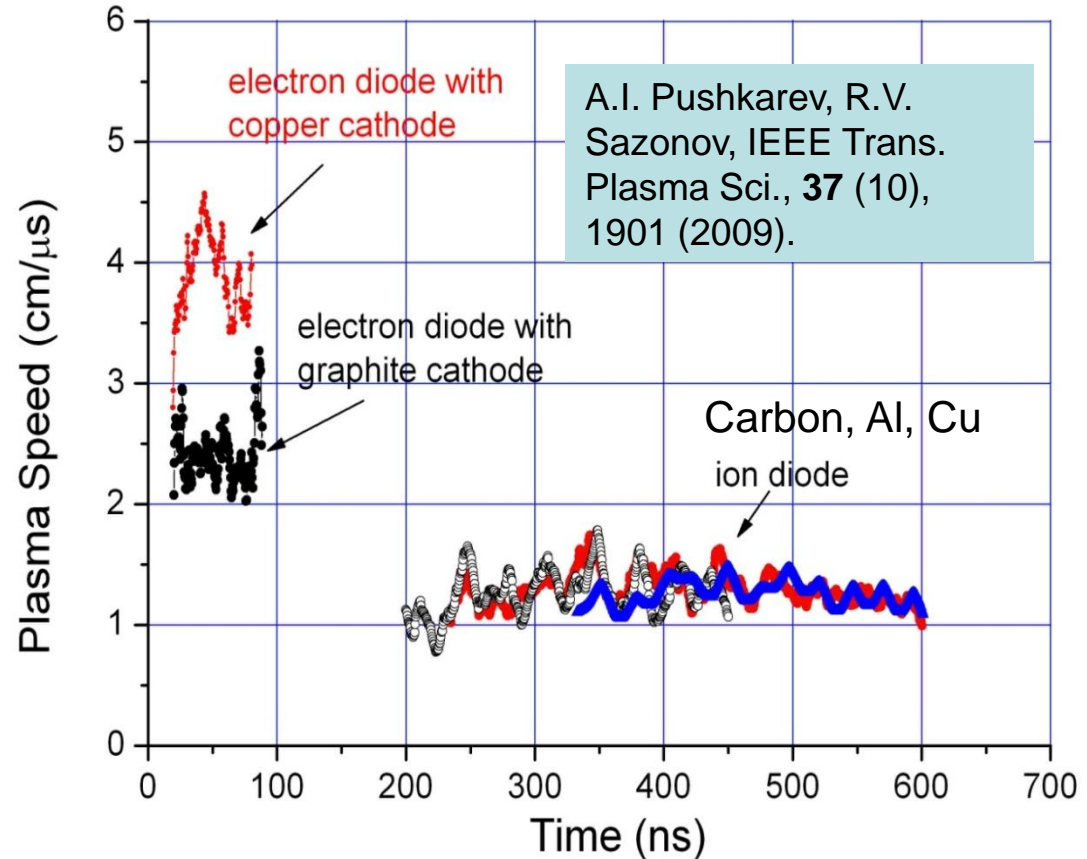
Pushkarev A.I. *et al* Phys. of Plasmas **17**, 013104 (2010).



$$R_{\text{calc}} = R_{\text{exp}}$$

$$V = 1.3 \pm 0.2 \text{ cm}/\mu\text{s} = \text{constant}$$

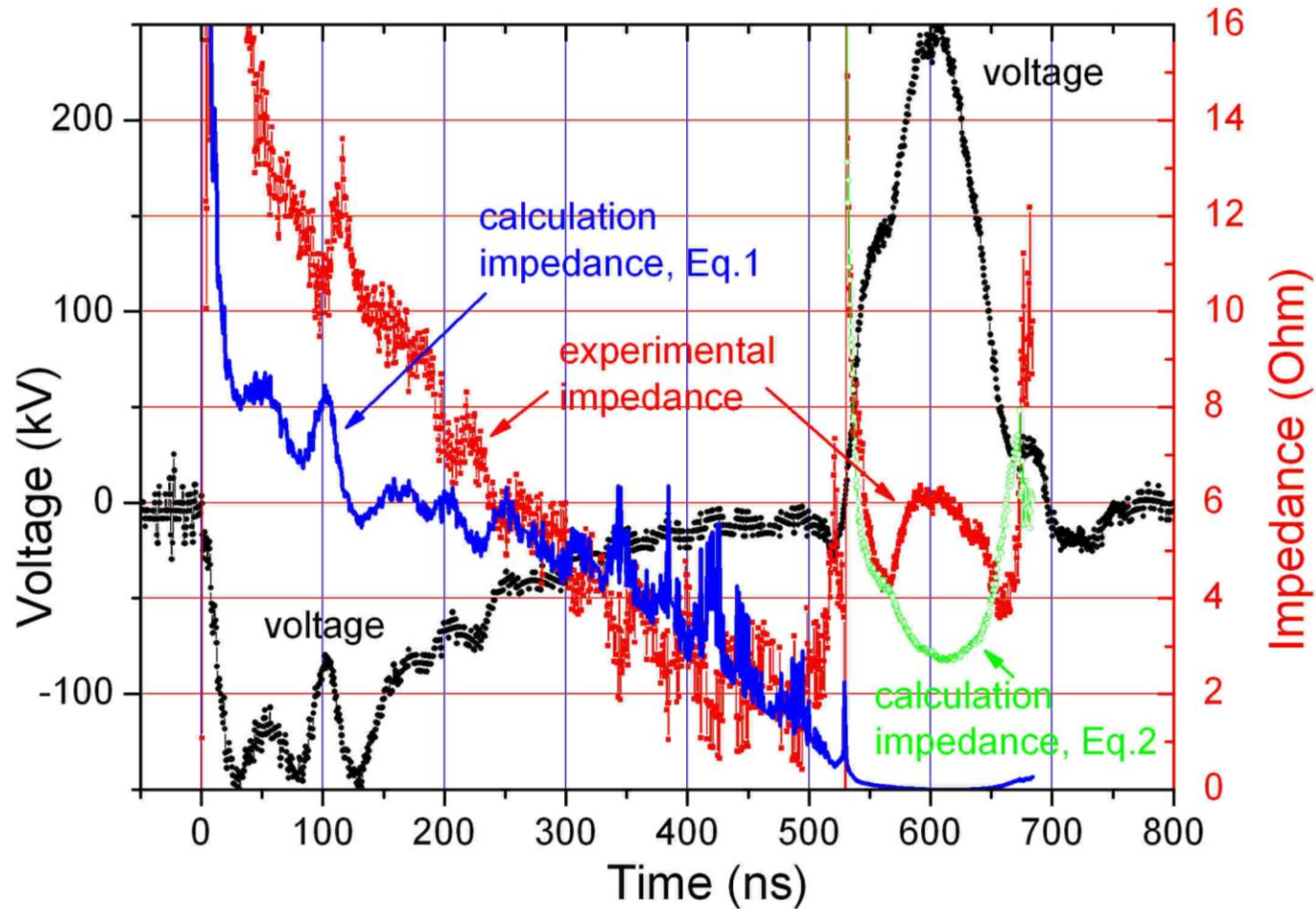
PLASMA COMPRESSION EF



A.I. Pushkarev, R.V. Sazonov, IEEE Trans. Plasma Sci., **37** (10), 1901 (2009).

Carbon, Al, Cu
ion diode

Plasma compression effect



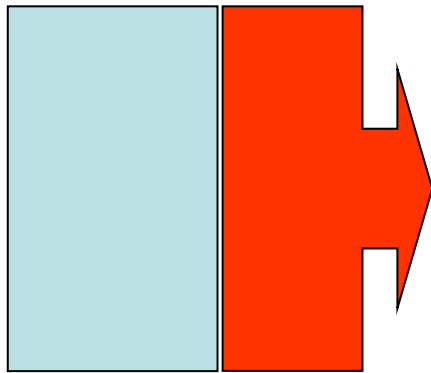
$$R_{calc} = \frac{U}{S_0 \cdot J_e} = \frac{(d_0 - v \cdot t)^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot U^{1/2}} \quad (1)$$

$$R_{calc} = \frac{[d_0 - v \cdot (t - t_0)]^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot 1.86 \cdot U^{1/2}} \quad (2)$$

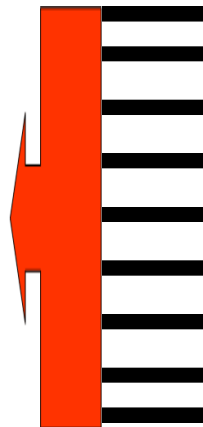
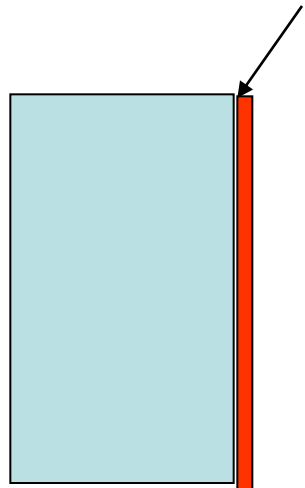
$$R_{calc} = \frac{[d_0 - v \cdot (t - t_0)]^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot 1.86 \cdot U^{1/2}}$$

potential electrode (cathode)

grounded electrode (anode)

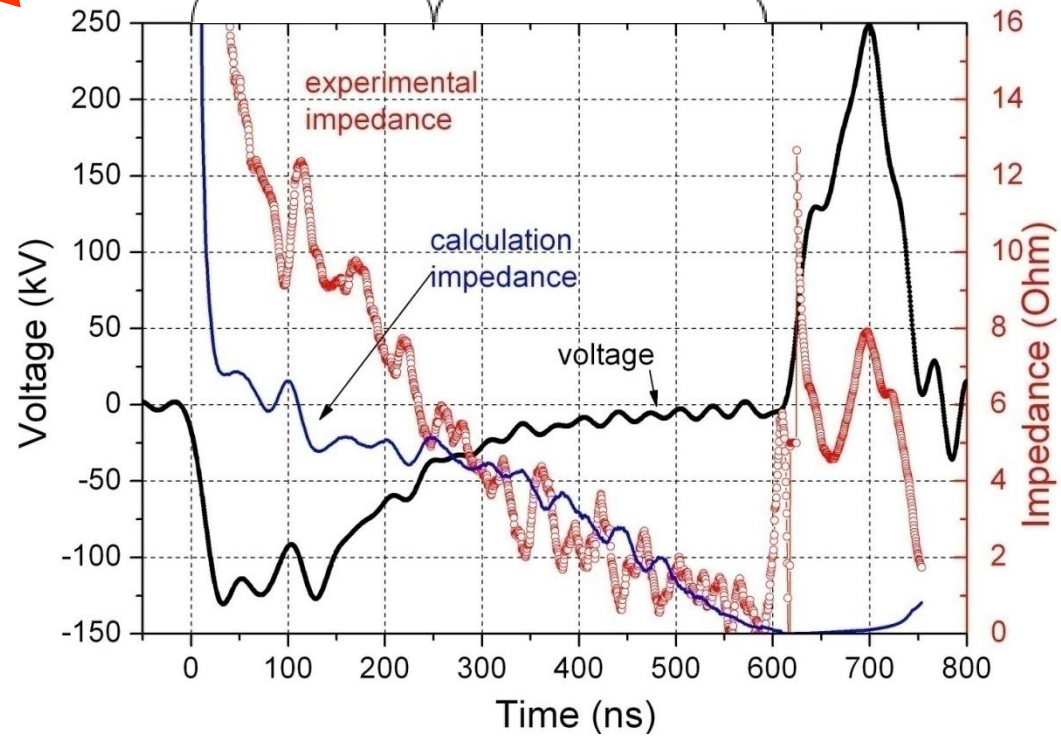


explosion-emissive plasma



discrete emissive surface mode

Space charge limitation mode



MAGNETIC SELF-ISOLATION MODE

CONCLUSION

1. During plasma formation on the potential electrode (first pulse, 200-600 ns), the plasma expands and the anode-cathode gap reduces. The plasma expansion speed is constant and equal to 1.3 ± 0.2 cm/ μ s.
2. After the voltage polarity on the diode changes (second pulse) the anode-cathode gap is restored to its geometric original value (plasma compression effect).
3. The plasma compression effect significantly increases the stability of ion beam generation.
4. The ion diode with magnetic self-insulation is a convenient tool for studying the processes of high-power ion beam generation:
 - the dynamics of explosive-emission plasma can be controlled by VACs of the diode,
 - the process of ions generation - by the ion current density.
 - both independent diagnostics use the VAC measurements, which provides very high temporal resolution.

THANK YOU FOR ATTENTION!

QUESTIONS?