

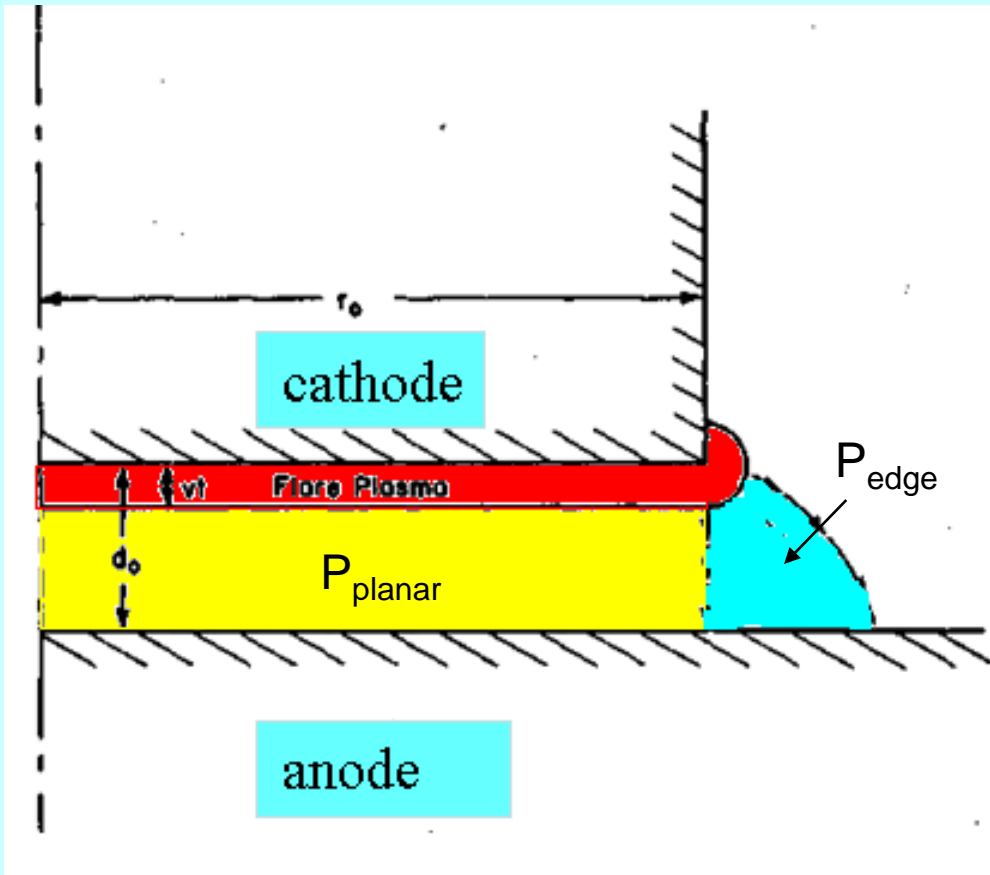
**CONTRIBUTION OF THE EXPLOSIVE EMISSION
CATHODE PERIPHERY ON THE OPERATION
OF A PLANAR ELECTRON DIODE**

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Introduction



for $j_e > 20 \text{ A/cm}^2$

electron current density

$$j = \frac{4\epsilon_0}{9} \left(\frac{2e}{m} \right)^{1/2} \frac{U^{3/2}}{d^2} = 2.33 \cdot 10^{-6} \frac{U^{3/2}}{d^2}$$

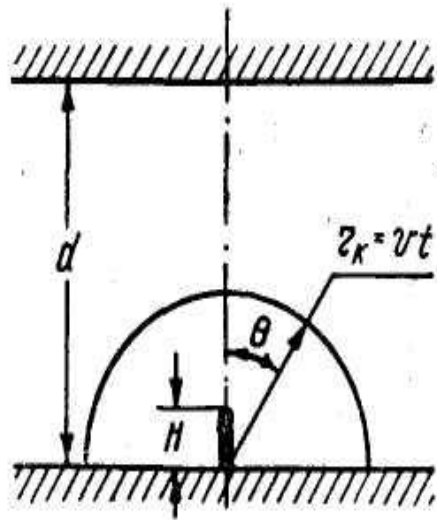
Perveance of diode:

$$P_{calc} = \frac{I_e}{(U)^{3/2}} = \frac{2.33 \cdot 10^{-6} \cdot S}{(d_0 - v \cdot t)^2}$$

This ratio is obtained by one-dimensional solution of the Poisson equation without considering the influence of **edge effects** ($S_0 = \infty$).

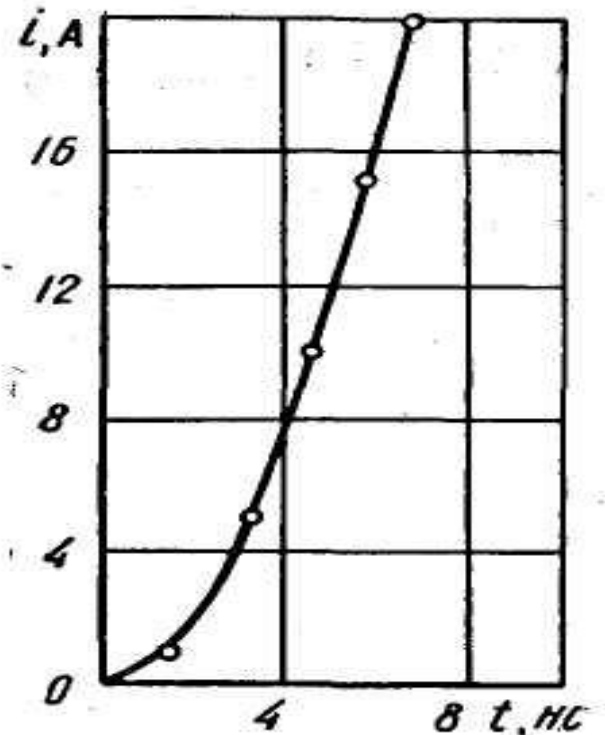
$$P_{diode} \approx P_{planar} + P_{edge}$$

$$P_{edge} / P_{planar} = ?$$



Shubin formula

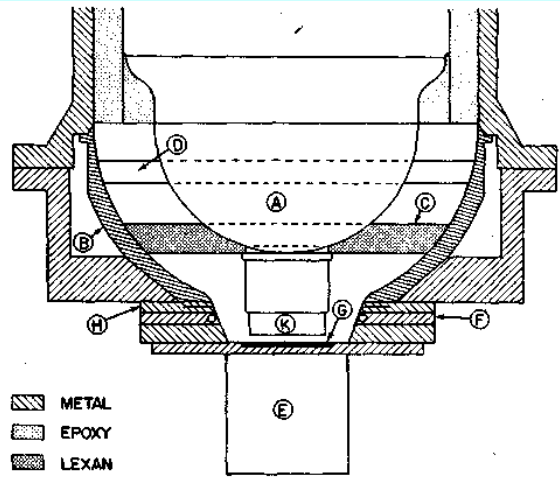
$$i = 2\pi r_{\kappa}^2 \int_0^{\pi/2} j(\theta) \sin \theta d\theta = 4,44 \cdot 10^{-5} U^{3/2} (vt)^2 / d^2.$$



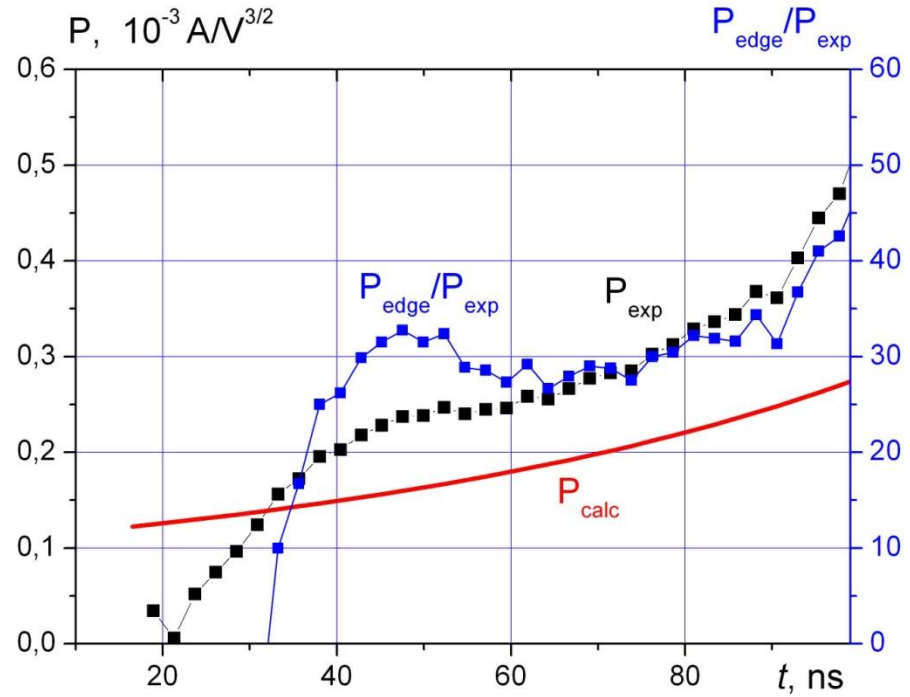
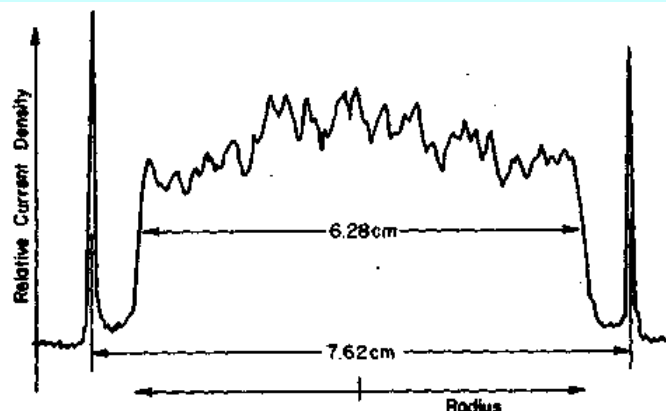
$$I_{C-L} = 2.23 \cdot 6 \cdot \pi \cdot 10^{-6} \cdot U^{3/2} \cdot \left(\frac{v \cdot t}{d_0} \right)^2 = 6 \cdot 2.23 \cdot 10^{-6} \cdot U^{3/2} \cdot \frac{S}{d^2}$$

$$S_0 = 0$$

$$P_{\text{edge}} / P_{\text{planar}} = 6$$



$$P_{calc} = 2.33 \cdot 10^{-6} \frac{\pi \cdot r_0^2}{(d - vt)^2}$$



$$S_0 = 20 \text{ cm}^2$$

$$P_{edge} / P_{exp} = 30\%$$

These observations were made when the impedance of the planar diode was increased to 11 Ohms or more while output resistance of the nanosecond generator was 4.7 Ohms, i.e., **in a mode of imbalance** between generator and load.

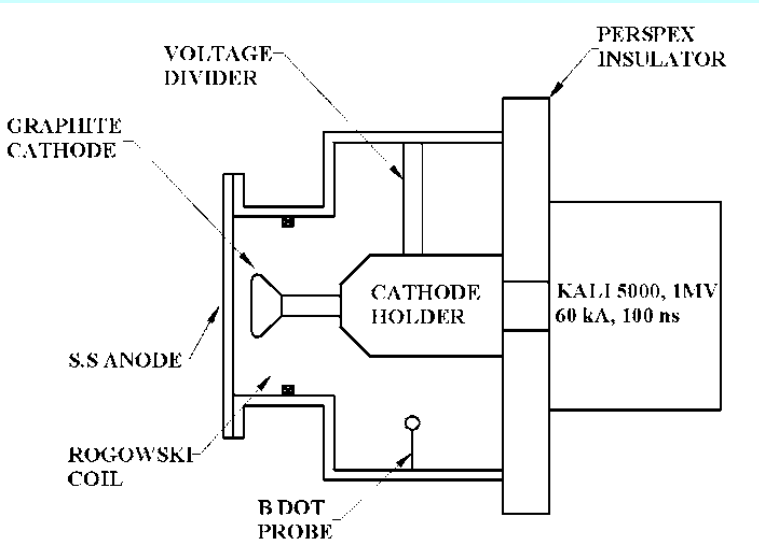
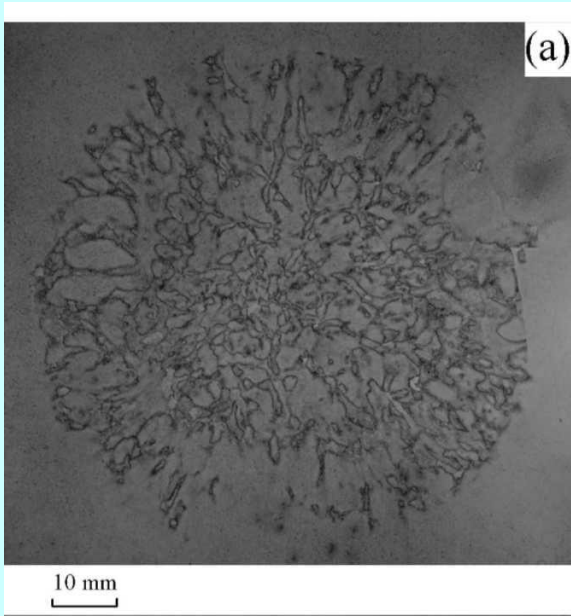
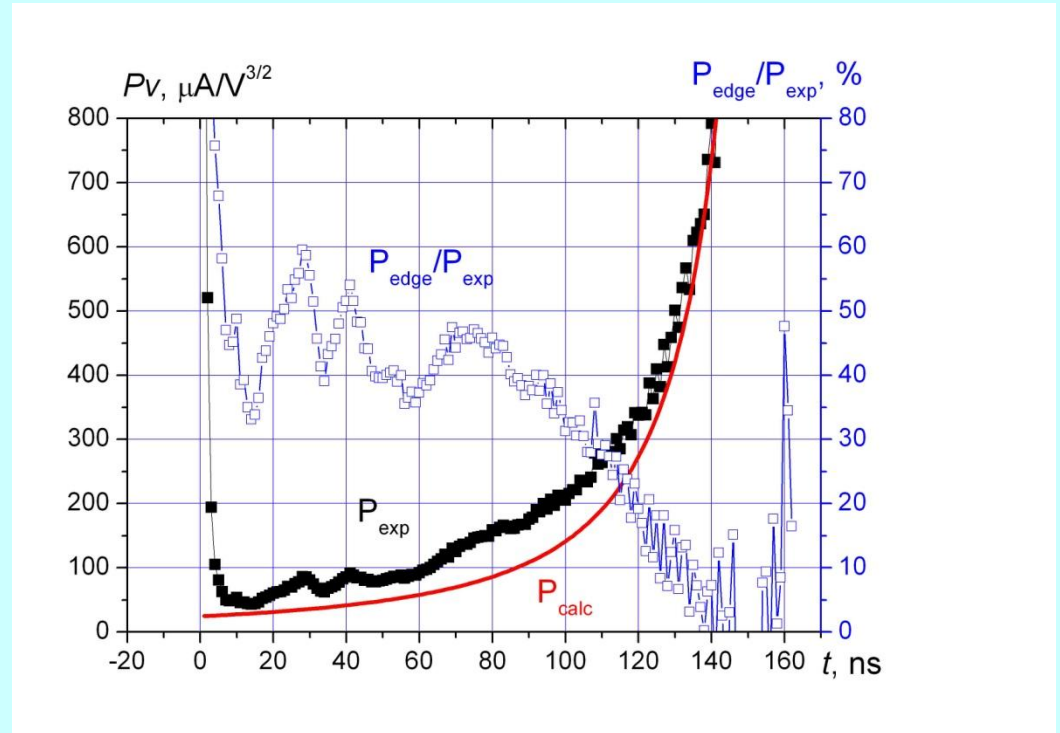
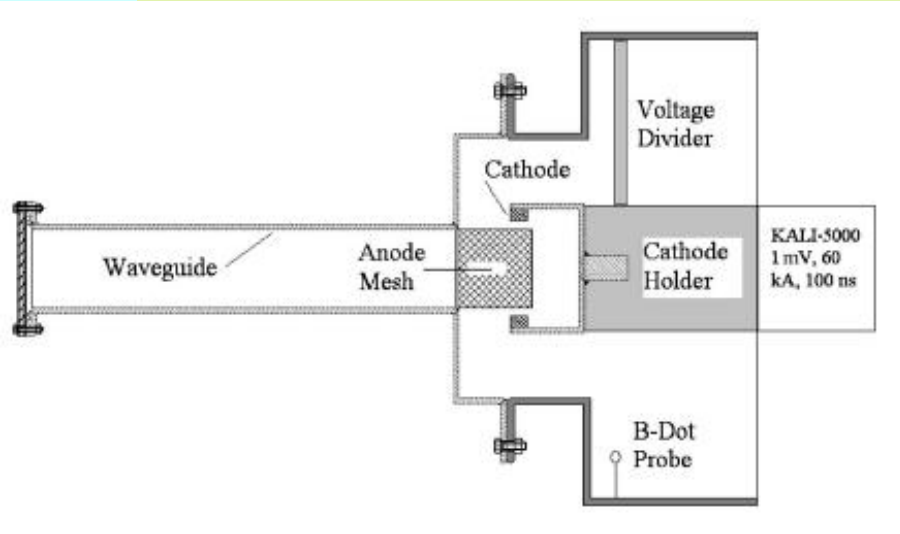


Fig. 1. Schematic of the experimental setup.



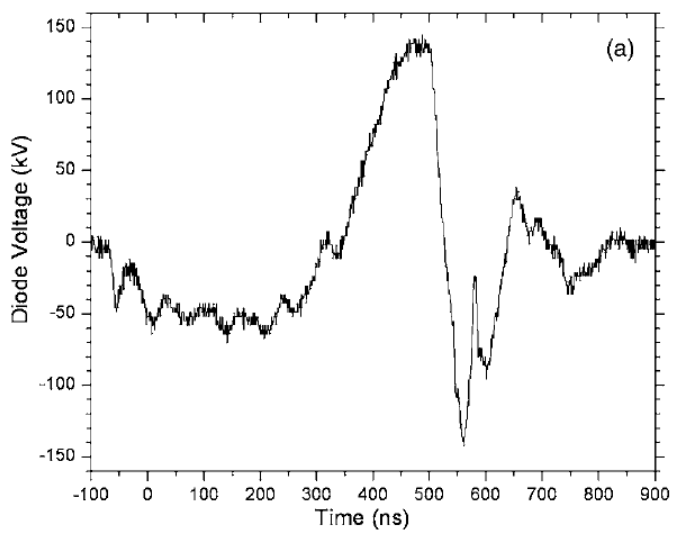
$$S_0 = 20 \text{ cm}^2$$

$$P_{\text{edge}} / P_{\text{exp}} = 40\text{-}50\%$$

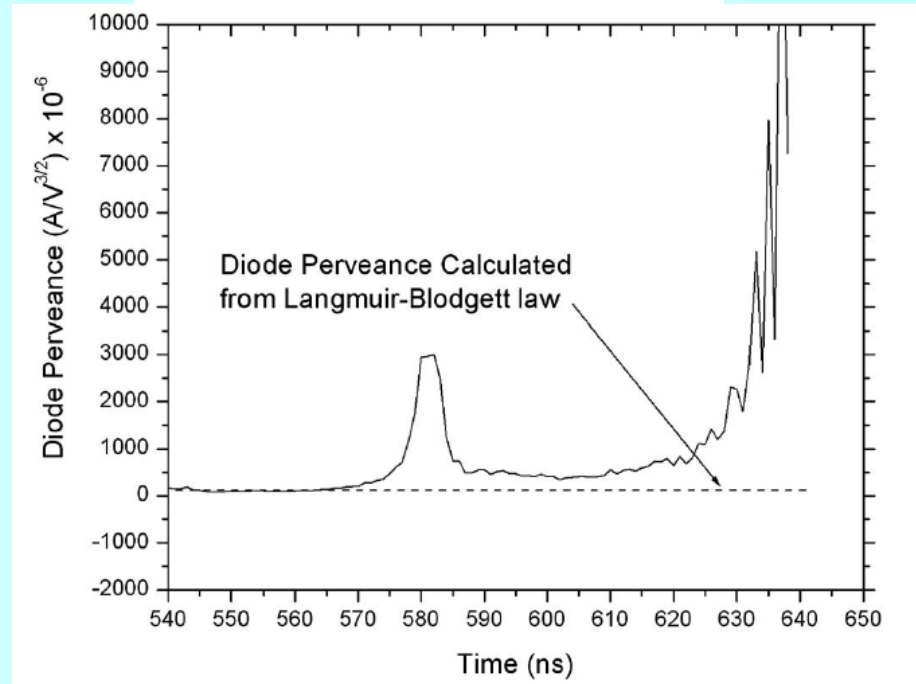


Current per unit length between two **infinitely long** coaxial cylinders is given by the Langmuir–Blodgett law,

$$j_{1D} = \frac{8\pi\epsilon_0}{9} \left(\frac{2e}{m_e} \right)^{1/2} \frac{V^{3/2}}{r\beta^2},$$



The waveform of diode voltage



The temporal behavior of the diode perveance for negative voltage pulse.

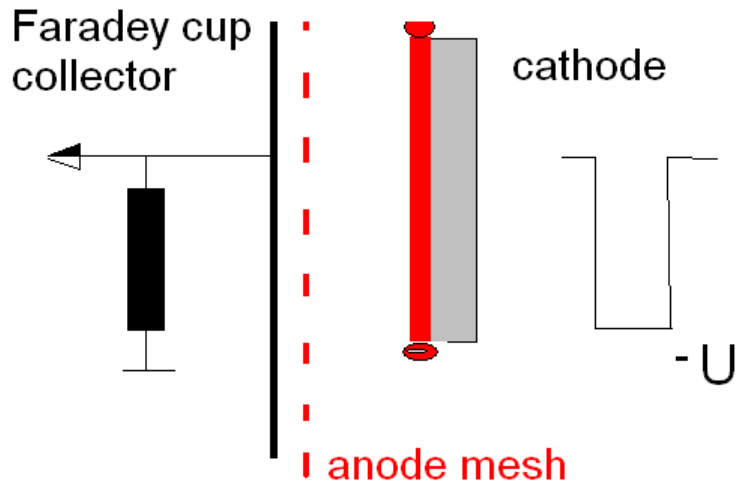
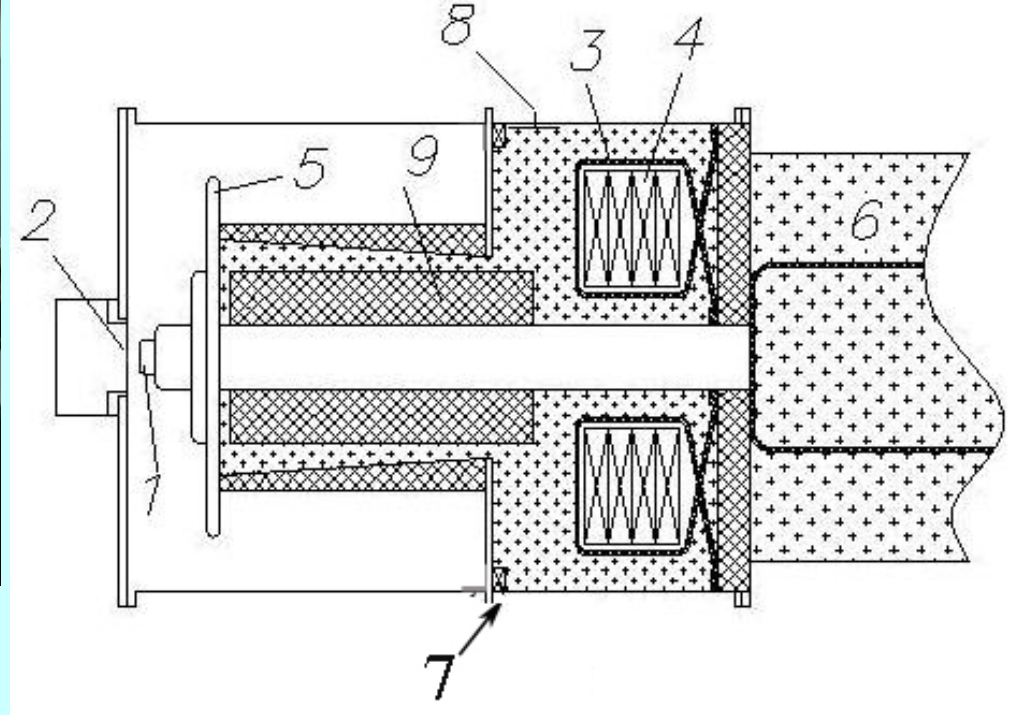
$$S_0 = 69 \text{ cm}^2$$

$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$

	Article	$P_{\text{edge}}/P_{\text{exp}}$	plasma expansion speed	
1	R. K. Parker, R. E. Anderson and C. V. Duncan. J. Appl. Physics. 45, 2463 (1974)	30%	2.5 ÷ 2.8 cm/μs	planar diode
2	R. Schneider and C. Stallings. J. Vac. Sci. Tech. 12, 1191 (1975);	0	2-4 cm/μs	788 kV, the beam current 17 kA
3	G. Djogo and J. D. Gross. IEEE Trans. Plasma Sci. 25. 617 (1997);	0	2 cm/μs	planar diode
4	S. Ya. Belomyttsev, S. D. Korovin and I. V. Pegel. Tech. Phys. 44, 695 (1999);	0	2 cm/μs	planar diode
5	A. Roy <i>et al.</i> J. Appl. Physics. 104, 014904 (2008)	40-50%	15-19 cm/μs	280 kV, 18 kA, 100 ns
6	A. Roy <i>et al.</i> IEEE Trans. Plasma Sci. 37 (1), 67 (2009);	$P_{\text{exp}} < P_{\text{calc}}$		180 kV, 26 kA, 100 ns.
7	L. Li <i>et al.</i> Plasma Sources Sci. Technol. 18 015011 (2009);	0	$v=1$ cm/μs	multipoint explosive emission cathode 500 kV, 50 Ohm, 400 ns
8	A. Roy <i>et al.</i> Phys. Plasmas 16, 033113 (2009);	$P_{\text{exp}} < P_{\text{calc}}$	3 - 6 cm/μs	300 kV and pulse duration 100 ns
9	A. Roy J. Appl. Physics. 103, 096104 (2008)	0		cylindrical diode

The purpose of the current work is to study the perveance of a planar diode with a graphite explosive emission cathode operating in a mode of agreement between diode impedance and output resistance of the nanosecond generator.

1. Experimental setup



Diode unit of pulsed electron accelerator:
1 – cathode; 2 – anode;

Accelerating voltage - 350-450 kV,
Full pulse duration - 100 ns,
Total electron energy in pulse - up to 250 J

The block diagram of diode unit

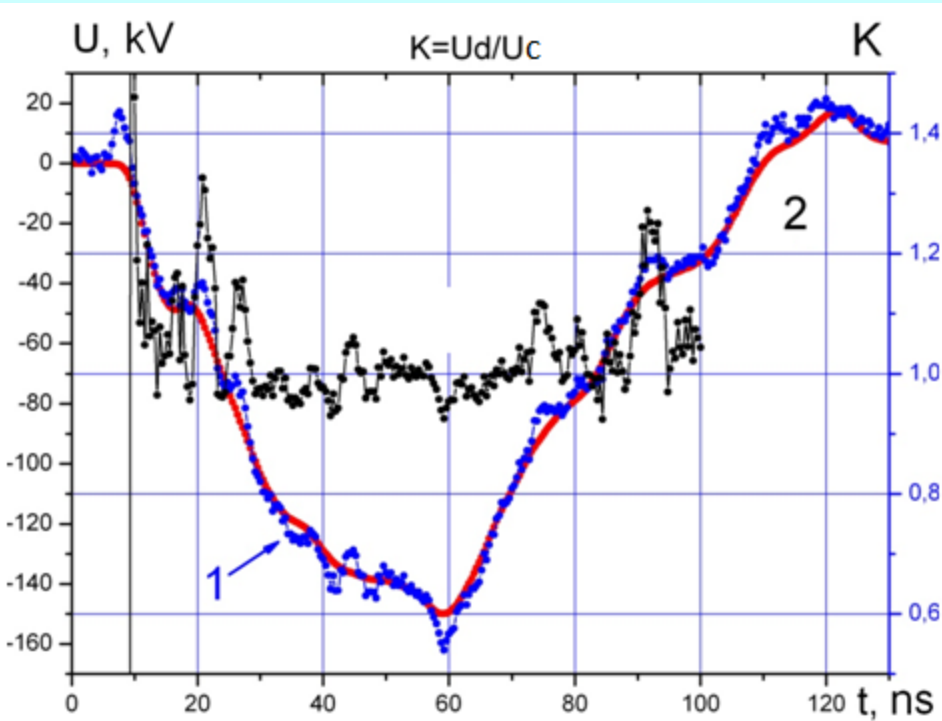
Diagnostics Equipment

U

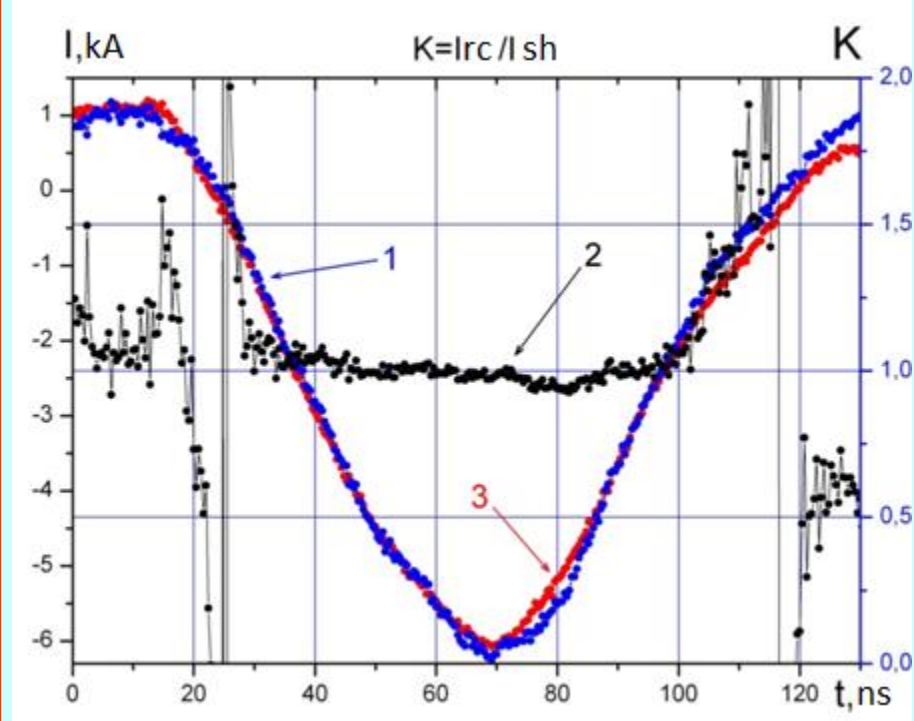
Capacitor divider
Differential divider

I

Faraday cup, $R = 0,0485 \text{ Ohm}$
Rogovski coil

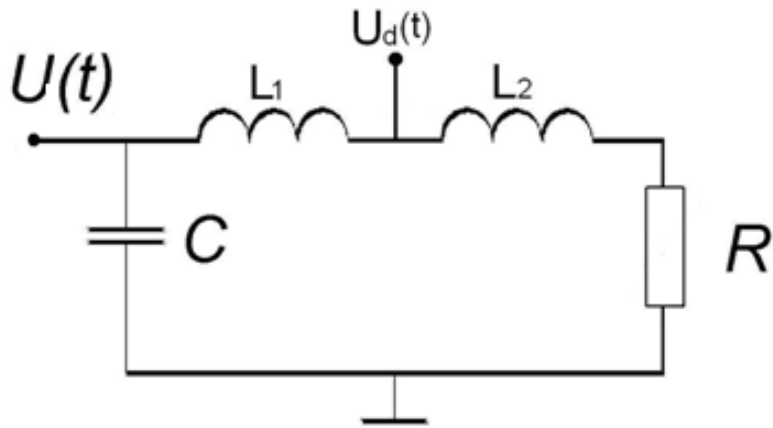


Oscilloscope traces of voltage:
1 - capacitor divider
2 - differential divider (after integration)

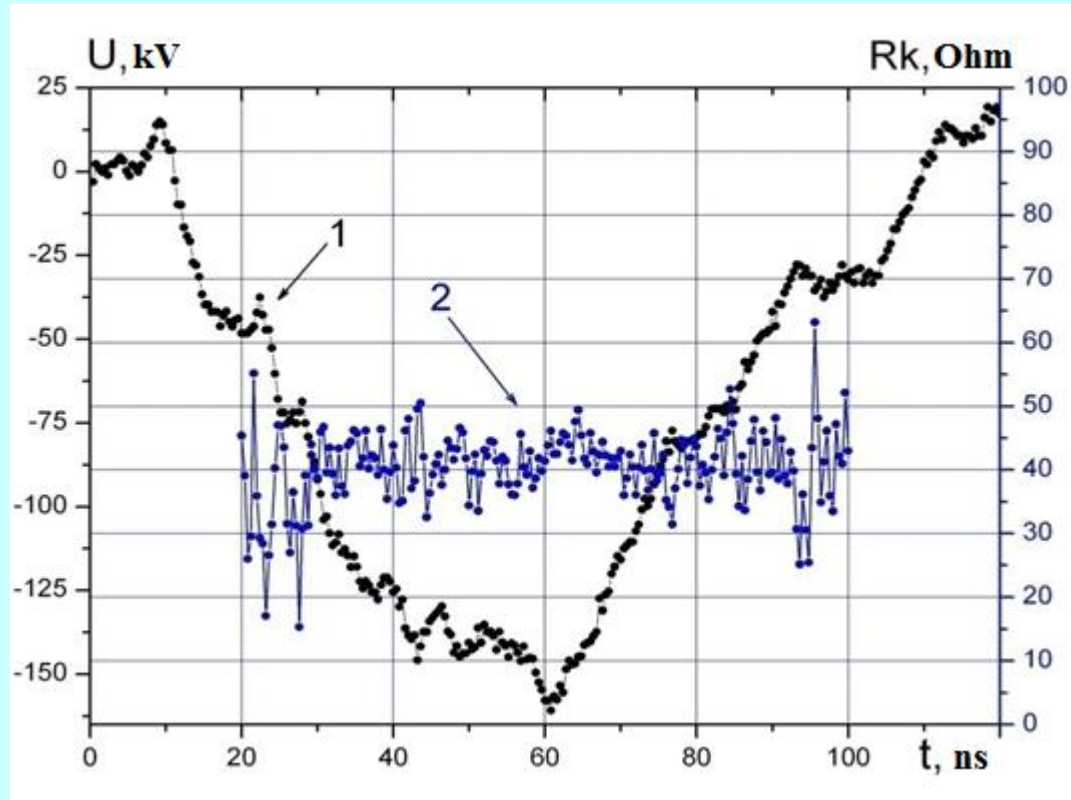


Oscilloscope traces of current:
1 - Faraday cup
2 - Rogovski coil

Calculation of the impedance from voltage/current waveforms

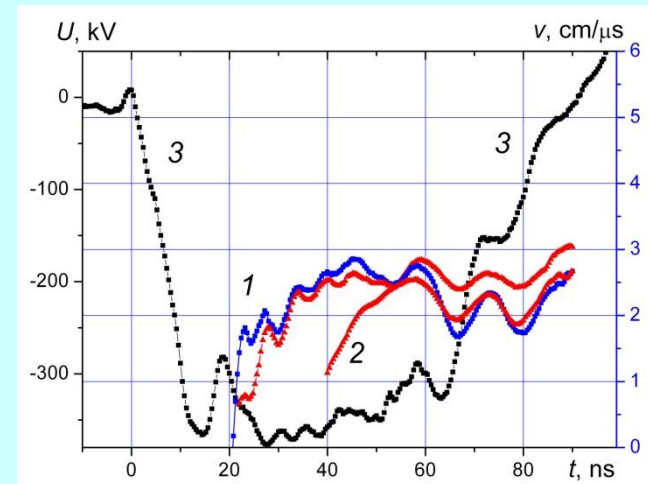
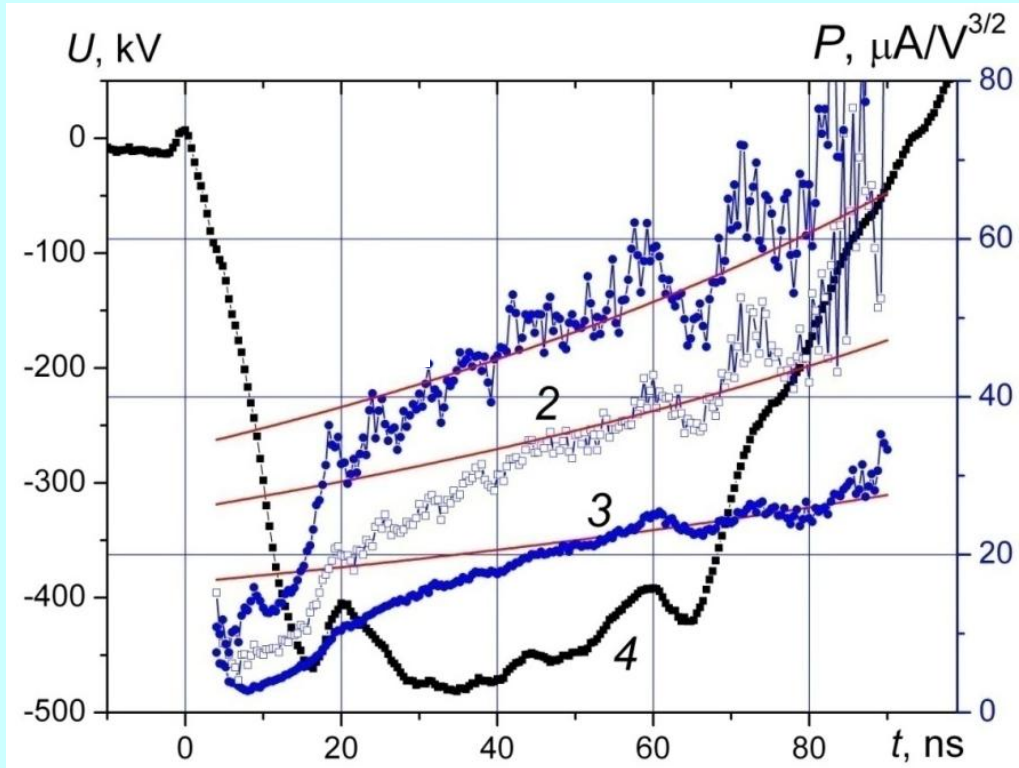


Equivalent circuit of the diode unit of pulsed electron accelerator



$$R = 43.5 \text{ Ohm.}$$

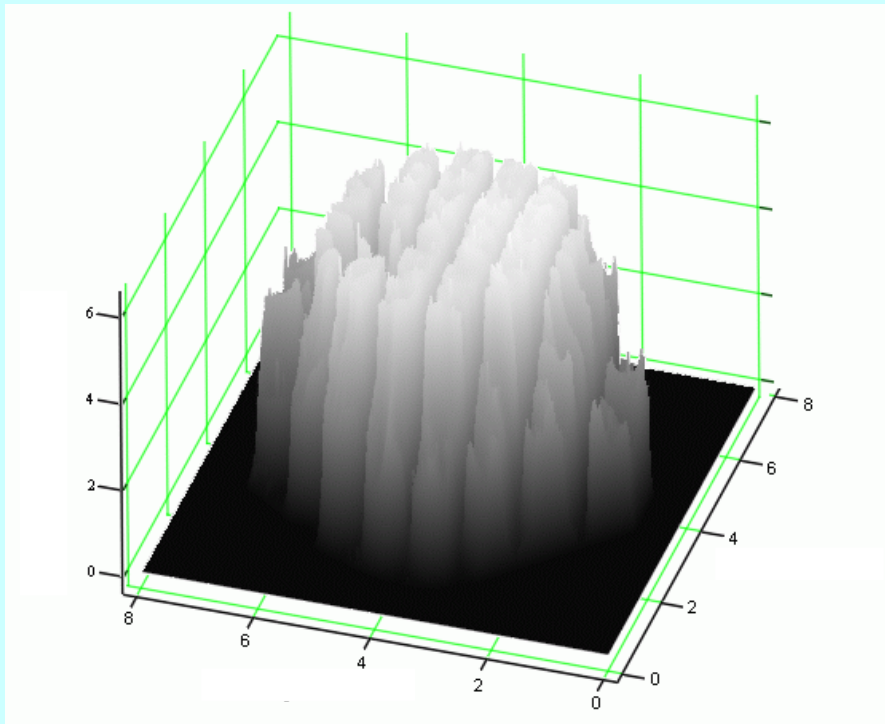
2. Diode with a graphite cathode diameter of 45 mm



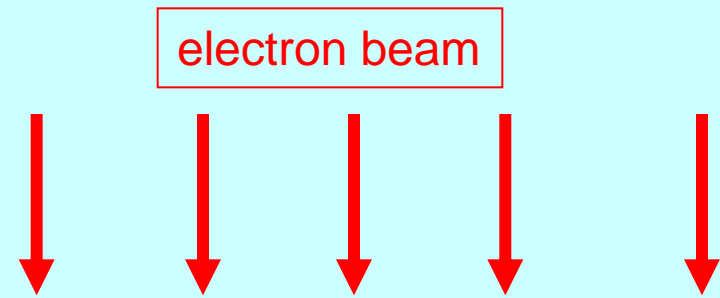
$$P_{calc} = \frac{I_e}{(U)^{3/2}} = \frac{F \cdot 2.33 \cdot 10^{-6} \cdot \pi (r_0 + v \cdot t)^2}{(d_0 - v \cdot t)^2}$$

$$S_0 = 16 \text{ cm}^2$$

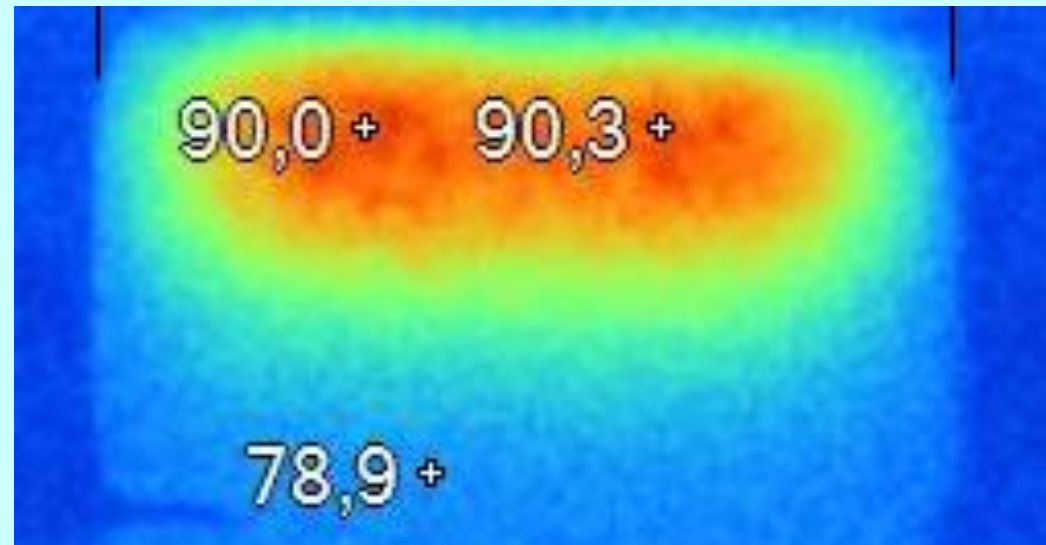
$$P_{edge} / P_{exp} = 0\%$$



The distribution of electron beam energy density, measured using a dosimetric film

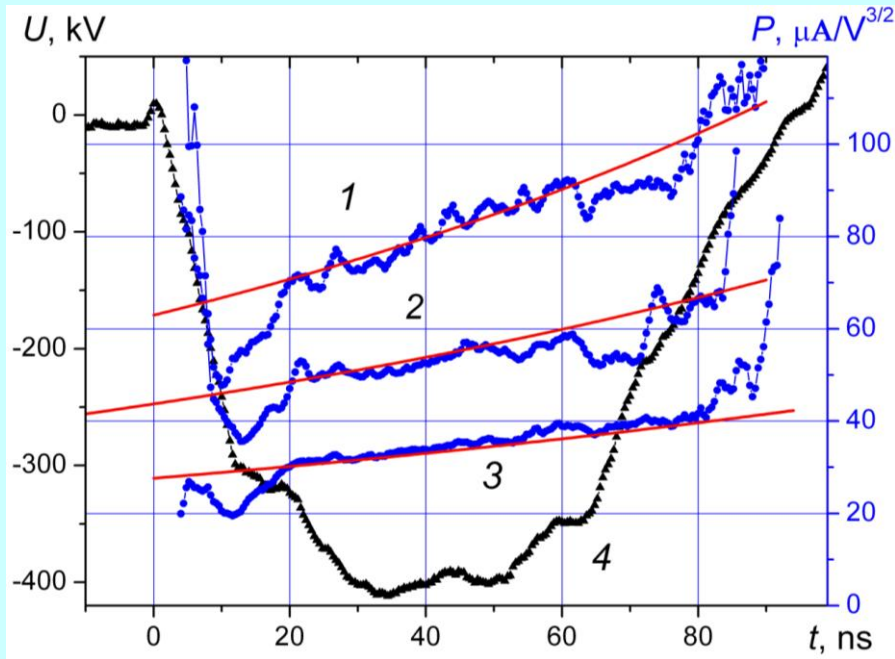


The temperature distribution in a foam volume during the absorption of the electron beam

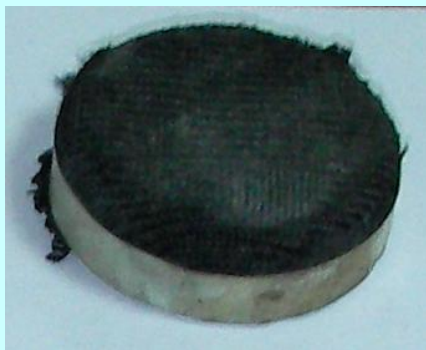
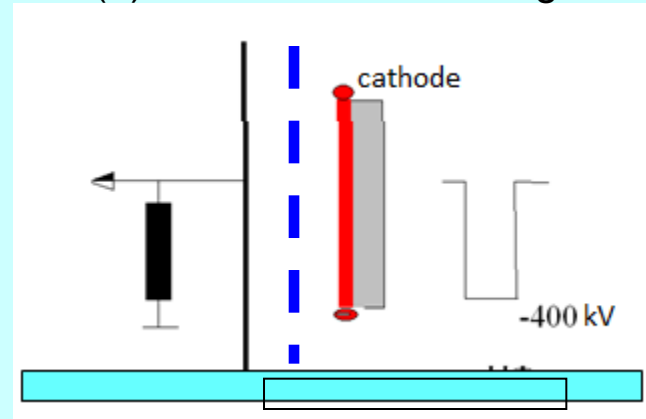


$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$

3. Diode with a carbon fabric cathode diameter of 45 mm



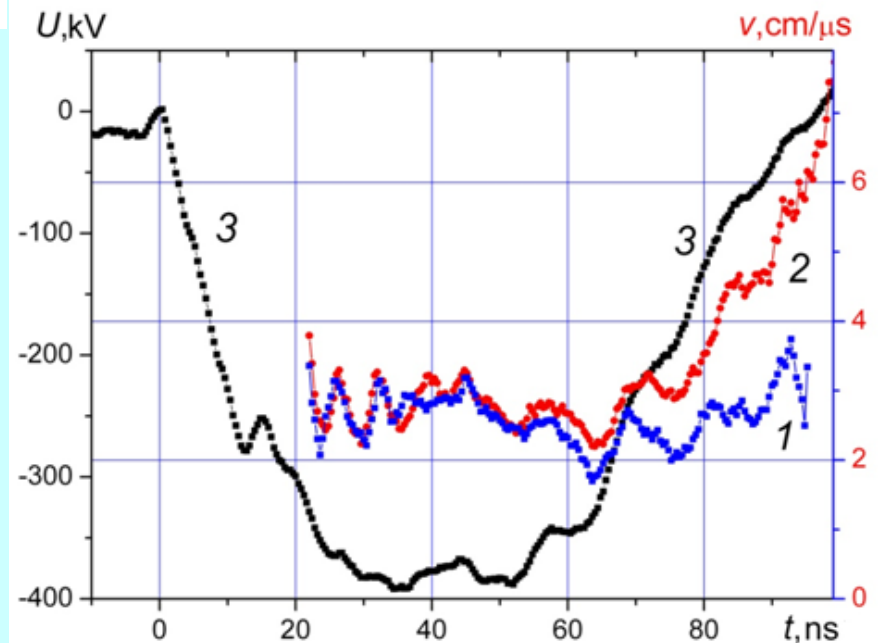
Experimental and calculated perveance of the planar diode with a gap of 11 (1) 12.5 (2) and 14 mm (3). Curve 4 is the voltage



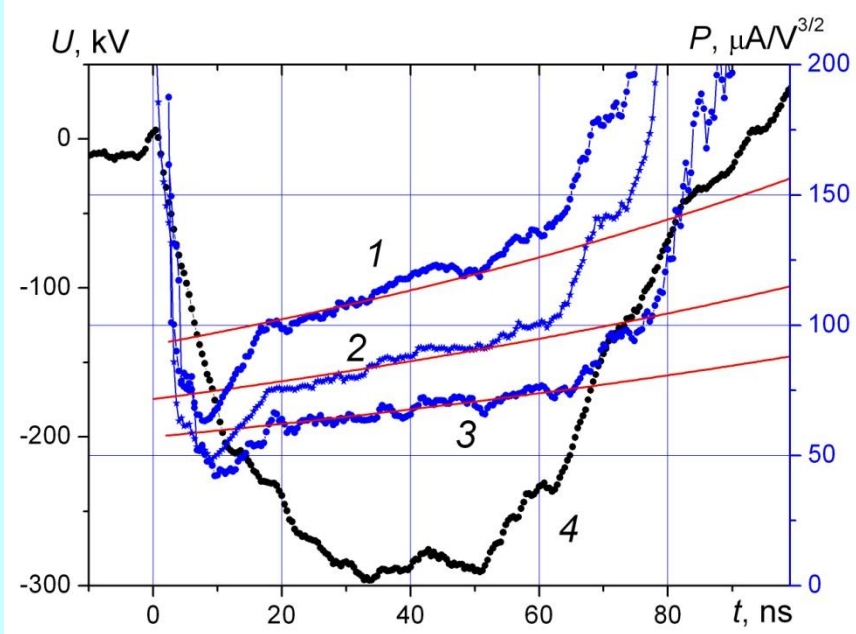
Change in plasma expansion velocity

$$S_0 = 16 \text{ cm}^2$$

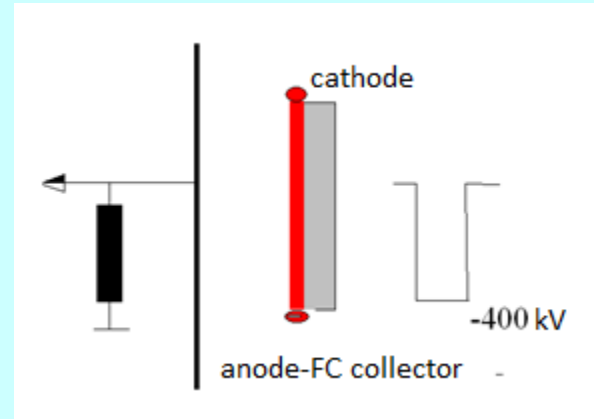
$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$



4. Diode with a carbon fabric cathode diameter of 60 mm



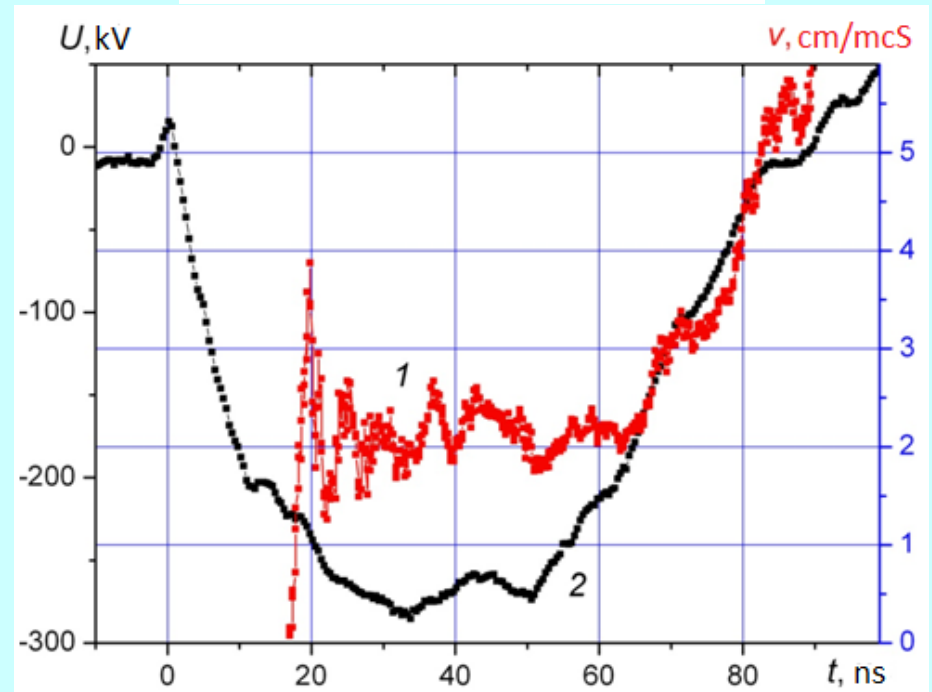
Experimental and calculated perveance of the planar diode with a gap 11 (1) 12.5 (2) and 14 mm (3). Curve 4 is the voltage.



$$S_0 = 28 \text{ cm}^2$$

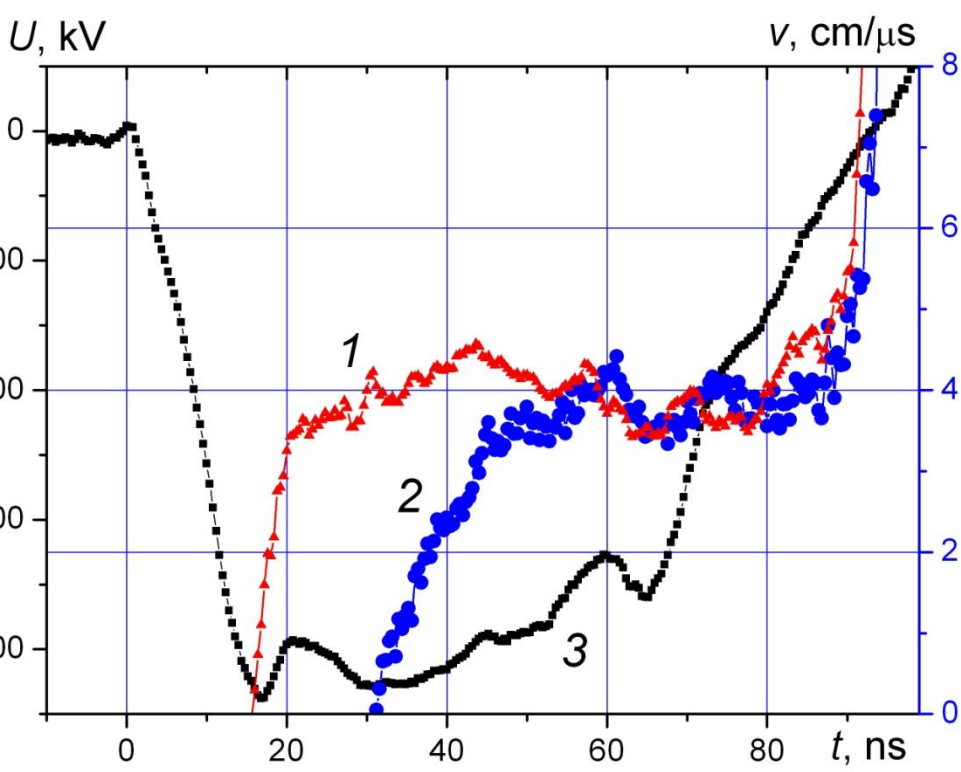
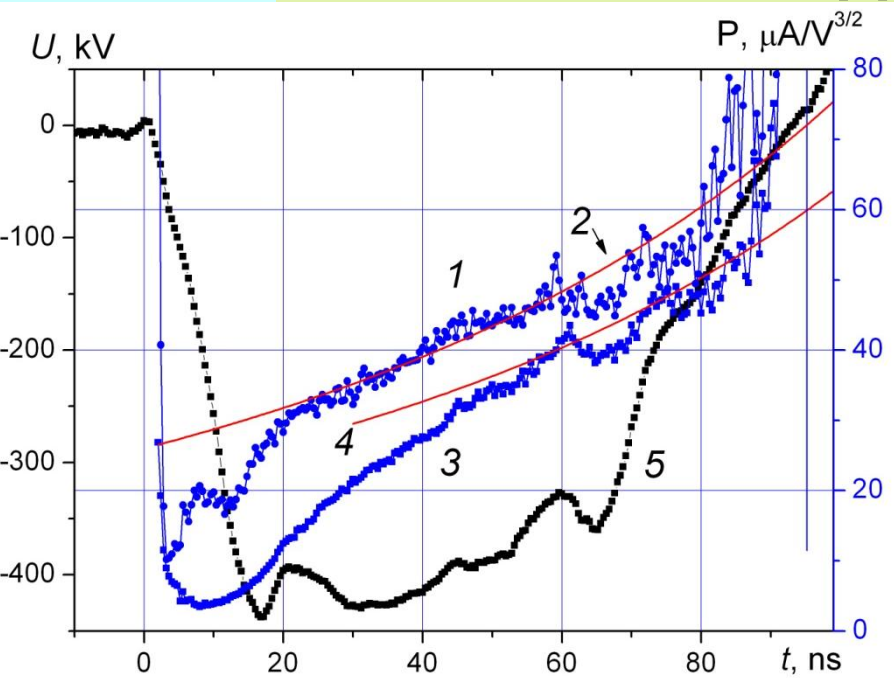
Change in plasma expansion velocity

$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$



5. Diode with a copper cathode

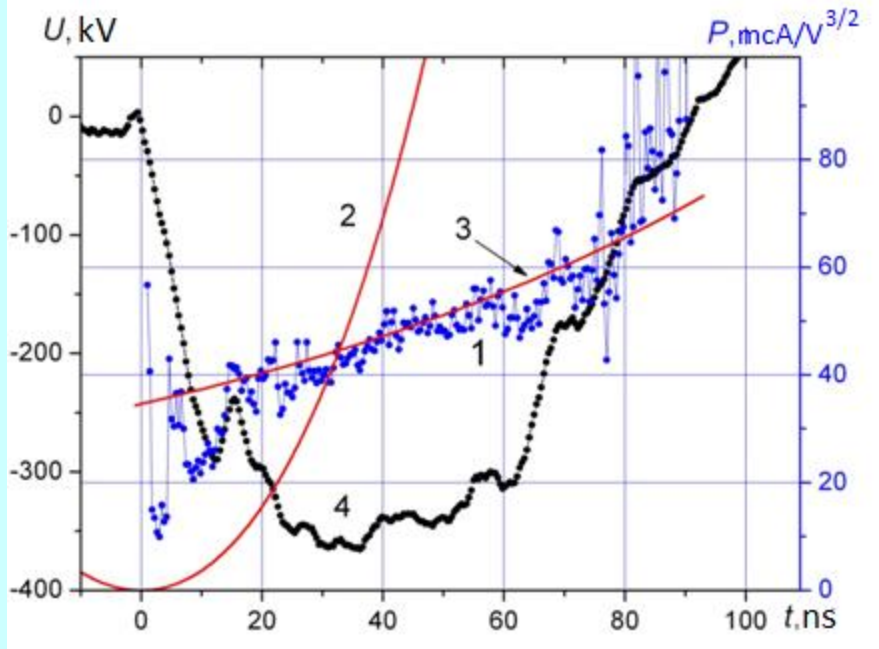
Experimental (1, 3) and calculated (2, 4) perveance of the planar diode with a multipoint (1, 2) and solid (3, 4) copper cathode at a-c gap of 12 mm. Curve 5 - the voltage applied to the diode with a copper cathode.



Change in plasma speed of the diode with multipoint (1) and solid (2) copper cathode for a-k gap of 13 mm. Curve 3 - the voltage applied to the diode with a copper cathode.

$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$

6. Diode with a multineedle cathode

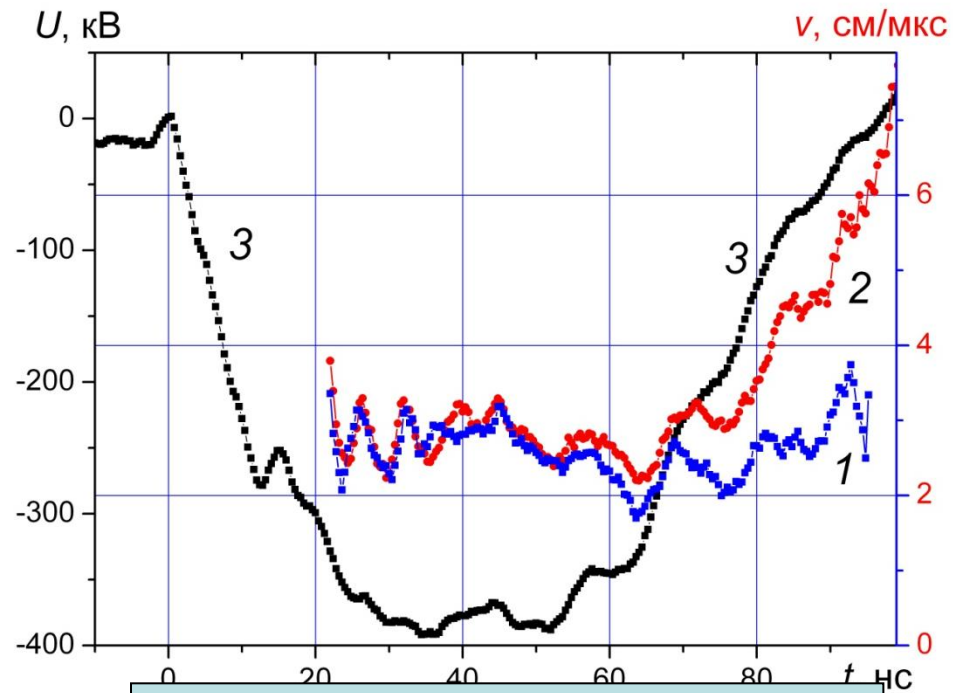


Experimental (1) and calculated (2, 3) perveance of the planar diode with a needle cathode for a-c gap of 12.5 mm.

140 tungsten needles with a diameter of 1 mm. Needle height is 11 mm, the distance between them is 4 mm. The overall diameter of the cathode is 43 mm.



$$S_0 = 14 \text{ cm}^2$$



$$P_{\text{edge}} / P_{\text{exp}} = 0\%$$

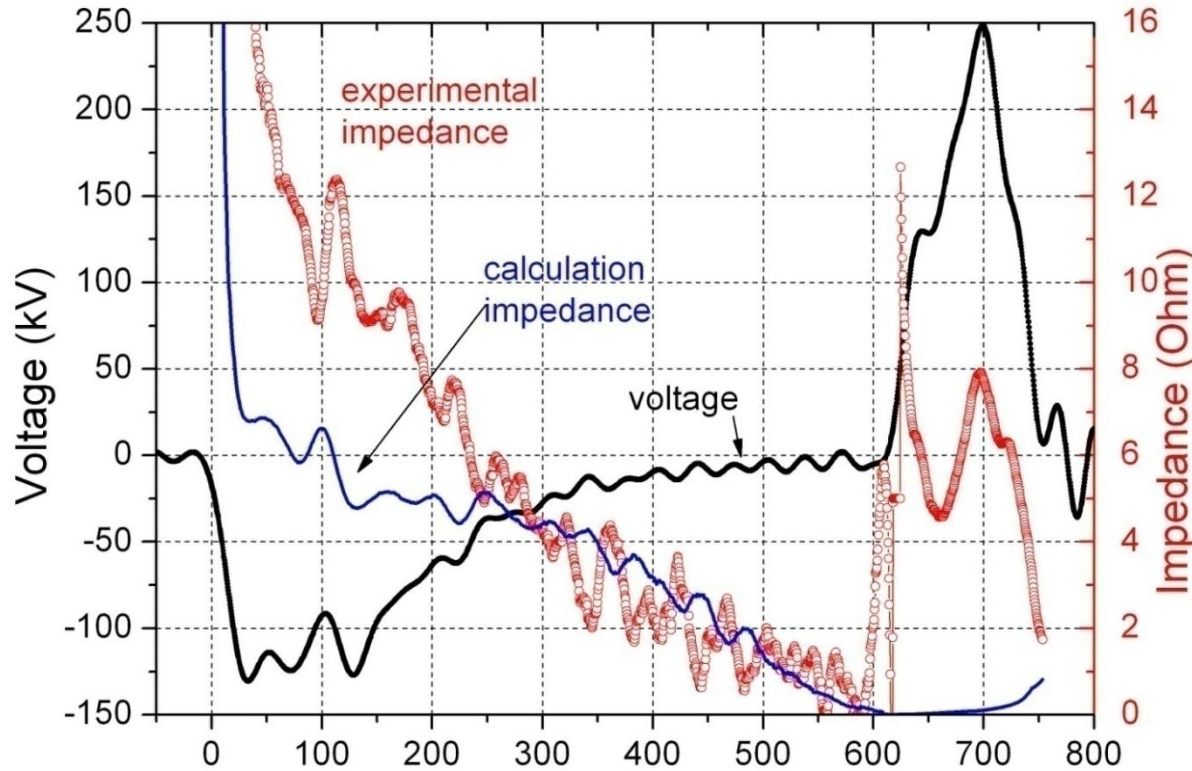
Change in plasma expansion velocity in the diode with a multineedle cathode when as an anode a mesh (1) and FC collector (2) are used. Cathode diameter is 43 mm, gap is 12 mm. Curve 3 is the voltage.

7. TEMP-4M ION ACCELERATOR



G. Remnev, et al
Surface and Coatings
Technol., **114**, 206
(1999).

Accelerating voltage 250-300 kV,
Full pulse duration 100 ns,
Total ion energy in pulse up to 90 J
Beam composition: ions of carbon (C^+ , C^{2+}) and protons



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

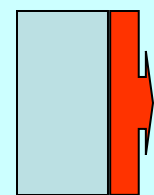
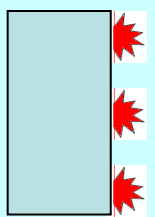
$$R_{\text{calc}} = \frac{U}{S_0 \cdot J_e} = \frac{(d_0 - v \cdot t)^2}{S_0 \cdot 2.33 \cdot 10^{-6} \cdot U^{1/2}}$$

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

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

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

$S_0 = 80 - 100 \text{ cm}^2$



$P_{\text{edge}} / P_{\text{exp}} = 0\%$

Conclusion

- If the area of a flat cathode is more than 15 cm^2 , the influence of edge effects does not exceed the measurement error of the total electron current of the diode.
- If the area of a flat cathode is $15 - 25 \text{ cm}^2$ the contribution of the cathode periphery to total electron current results from an increase in the emissive surface area caused by the expansion of explosive emission plasma across the anode-cathode gap.