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GENERATION OF HIGH POWER ION BEAMS IN BALLISTIC FOCUSING DIODES.

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Summary.

The main results of High Power Ion Beam (HPIB) generation in the two types of coaxial diodes are given: the first one - with axial orange-type insulating magnetic field and zero flux intercepted by HPIB; the second one - with squirrel-cage type cathode and asimutal insulating magnetic field. The first type of diode displayed nonuniform anode plasma generation and consequently lower that awaited average values of convergent HPIB densities (0.3 kA/$_{cm}$2). The focusing degree in the second case attained 80% of theoretically possible due to cathode slots aberration of HPIB and finite temperature of anode plasma ion source. HPIB densities were 8-10 times higher that corresponding Lengmuir-Blodgett (LB) values [1] and attained 1.3 kA/cm^2. The investigated diodes are promising for HPIB laser pumping.

Introduction.

The first successful experiments on gaseous laser pumping by HPIB [2] are stimulating investigation of ion diodes with high efficiency. Accordingly to this the coaxial cylindrical magnetically insulated diodes (MID) with inner cathodes generating convergent HPIB with linear focus are of very great interest. This paper describes the main construction details and investigation results of two different MID's. The MID's were energized by 0.5 kJ stored energy in 80 ns pulse.

MID with axial B_z field of orange type.

The first diode (fig.1) similar to those described in paper [3] possessed the combination of MID and reflex triode features (at least on initial stage of its operation). The axial pulse magnetic field of orange type created by two coils situated inside hollow stainless thin (200 μm) cathodes (180 mm in diameter) attained the value 0.6 T on the inner surface of annular anode (200 mm in diameter). The short rise time (50 μsec) of magnetic field provided "nontransparency" of massive metallic anode for it. The uncompensated part of axial magnetic flow due to penetration of force lines inside the dielectric layer (epoxy loaded metallic needle brush of 3 mm thickness) and 1 mm skindepth of metallic anode resulted in appearing of velocity asimutal component of convergent HPIB. In this diode the electrons oscillating between two cathodes along magnetic surfaces simultaneously take part in closed asimutal drift of $E_r x B_z$ origin. The existence of J_z current in two opposite direction from diode symmetry plane resulted in electron Z-drift in direction of this plane and accodingly decreased the electron losses on annular anode edges. The typical diode perveance behaviour v.s. magnetic field strength is shown on fig. 2, and pulses for two cases (B=0 and B=0.4 T) on fig. 3.

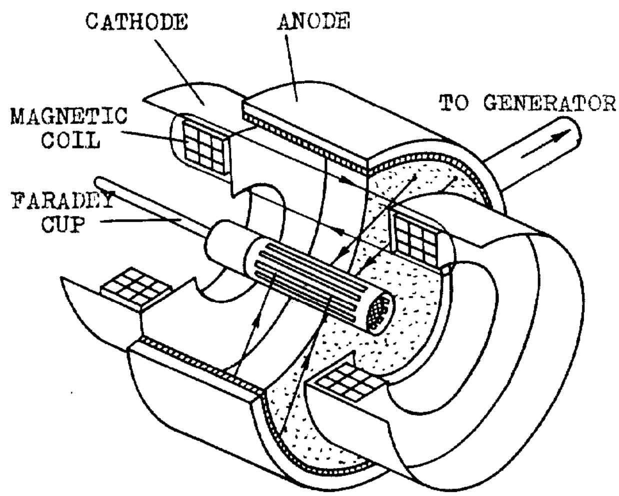

Fig. 1. The scheme of MID with orange-type B_z field.

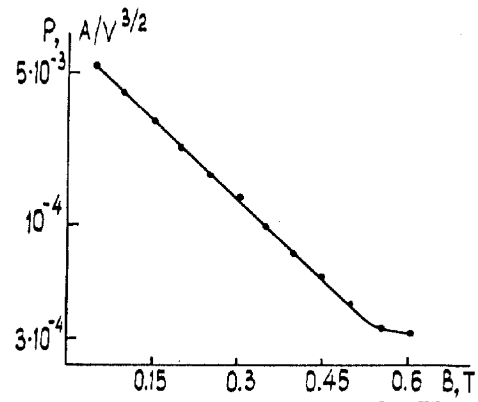

Fig. 2. The perveance of MID with B_z field v.s. B_z value.

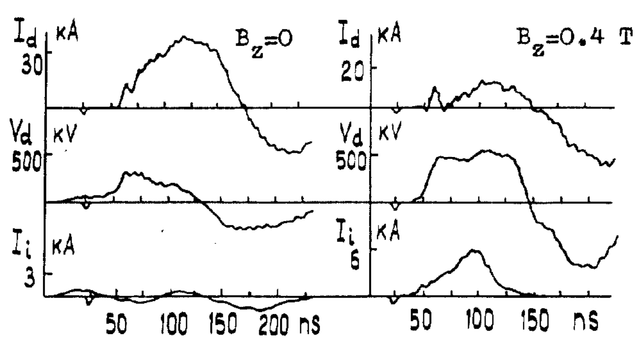

Fig. 3. The typical pulses for two B_z values.

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It can be seen that for $B > B_{crit}$ current neutralization of convergent HPIB across the axial B_z-lines was absent during main pulse and post pulse reverse of anode polarity, (the absence of electron component of Faradey cup (FC) signal). The maximum value of HPIB current measured by cylindrical FC with 30 mm diameter established on axis of MID was 8 kA (V=560 kV), which corresponded to 300 A/cm^2 average density. For comparison the LB current [1] for MID with same parameters equals 10 kA. The efficiency of diode $J_i/(J_i+J_e)$ was 30%. It must be noted that autographes of HPIB on aquadag coated FC and image converter pictures (with 20 ns exposition) of dielectric anode surface displayed nongomogenous plasma formation in asimutal direction. In fact not more that 50% of anode surface (200 cm^2) was luminous. The following experiments showed that the main reason of it was not sufficiently good coaxiality of anode and two cathodes, but due to technical reasons this situation coud not be improved in this çase.

MID with B_Θ field.

The second MID is of coaxial cylindrical type with insulating B_Θ field. generated by the external current flowing along the cathode. The amplitude of this current attained $J_{ext} \sim 200$kA with 15 µsec rise time, that provided $B_\Theta \sim 1$ T, which was 2-3 time more that B_{crit} for chosen anode-cathode (A-C) gap and applied voltages. MID (see fig. 4) consisted

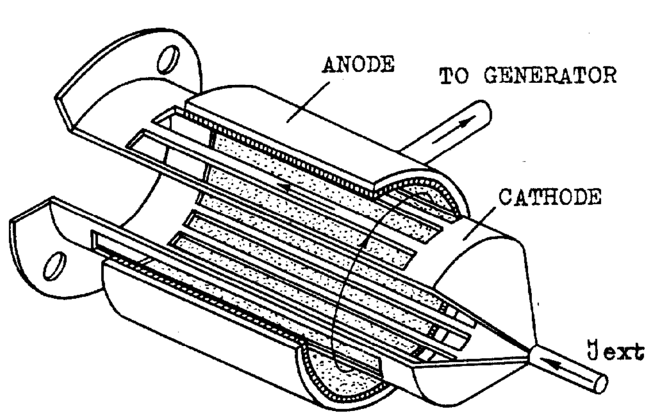

Fig. 4. The scheme of MID with B_Θ-field.

of coaxial anode (inner diameter from 94 to 120 mm) and hollow, squirrel-cage type cathode (outer diameter 79 mm) with longitudinal 12 mm width slots. The overall transparency of this cathode was 58%. Similarly to the first case the short rise time of magnetic field insured "nontransparency" of massive MID electrodes which led to decreasing of axial drift of convergent HPIB during its propagation inside the hollow cathode. The absence of B_z and accordingly $\int_0^R B_z dr=0$ provided the absence of HPIB asimutal velocity, so the attainable focusing degree of HPIB was limited only by the anode plasma temperature, accuracy of assemling and presence of fringes of closed B_Θ-lines across the slots. The last fact is pertinent to the equipotentiality of B_Θ-lines which played role of effective cathode surface [4,5,6]. In difference from situation in the first MID now the electron drift orbits had an axial component and werenot closed, that resulted in higher electron losses and lower operation impedance of MID. The investigation of electron losses and their dependence on value and direction of external cathode current were carried with anodes of different length (60 - 120 mm) and geometries (cylinders, cones, cones conjugated with cylinders), and different A-C gaps. This investigation showed that for the same $(A\text{-}C)_{min}$ gap, the level of the electron losses was approximately constant. It witnessed about edge character of losses due to unclosed electron drift along the cathode surface, which led to their accumulation near the anode edge and consequently decreasing of effective A-C gap, appearing of axial E_z field and $E_z \times B_\Theta$ drift to the anode [7]. The most critical was A-C gap value. For instance increasing it from 7 mm to 10 mm resulted in decreasing of electron current from 16 kA to 6 kA for 460 kV and 530 kV accordingly. The MID perveance behaviour v.s. B_Θ for several types of anodes can be seen on fig. 5.

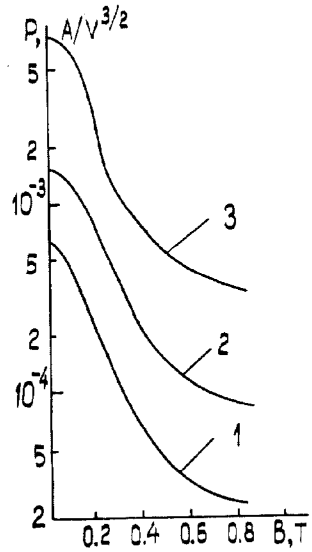

Fig. 5. The perveance of MID with B_Θ field v.s. B_Θ value for cathode Ø 79 mm and different types of anodes: 1- bare copper anode Ø 100 mm; 2- bare copper anode Ø 94 mm; 3- perforated polyethelen anode Ø 94 mm.

In experiments we used two types of anode ion sources: perforated polyethylen sheet of 3 mm thickness (5x5 mm mesh of 1 mm diameter holes) and epoxy loaded metal needle brush. Due to complete current neutralization of HPIB inside the hollow cathode because of absence of B_Θ field there the measurements of ion current were carried by collimated biased FC with applied potential up to -3 kV [5]. The saturation of ion current was attained on the -2 kV level. The typical pulses are given on fig. 6, and distribution of ion current density along the cathode surface - on fig. 7.

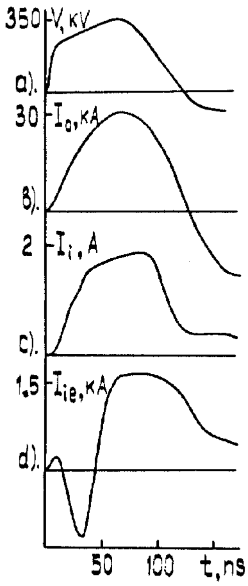

Fig. 6. The typical pulses: a- diode voltage; b- net current; c- wave form from collimated FC with negative shiff 2 kV; d- wave form from integral FC.

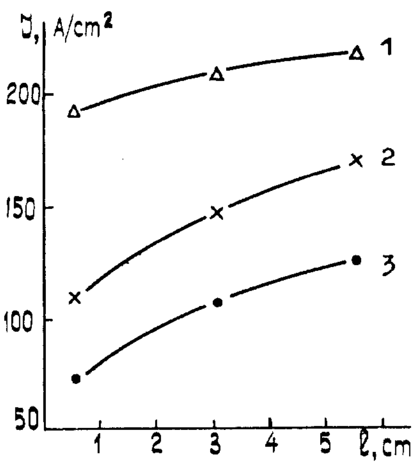

Fig. 7. The distribution of HPIB density along the cathode surface: 1- in the middle of the rib; 2- at the edge of the rib; 3- in the middle of the slot.

Such behaviour corresponds to the picture of effective A-C gap decreasing due to the electron drift accumulation on the edge. The maximum density of HPIB cathode surface attained 220 A/cm^2 for V=350 kV which is at least 8 times more that LB current density for one component ion flow [1]. The azimutal assymetry of ion current density in characteristical points (in the middle of slots and ribs of cathode) $2(J_r-J_s)/(J_r+J_s)$ due to B_Θ-lines fringes equaled ~40%. The calculations of total HPIB current based on collimated FC measurements gave values 10 kA and 11 kA (the voltage 350 kV) for HPIB impinging on cathode ribs and penetrating inside the slots accordingly. The calorimetric measurements of HPIB stored energy by two types of calorimeters gave value 150 J which corresponds to 8.2 kA ion current amplitude that differs not more that 30% from above given calculation results and can be explained by ablation effect from collector. On the base of all measurements we estimated the overall efficiency of HPIB generation as 67% and net efficiency- as 36%.

The investigation of HPIB ballistic focusing by the help of mentioned above FC with different collector diameters (from 3 mm to 30 mm) gave value 24 for maximum degree of focusing, which is 1.3 time lower that theoretically possible. The corresponding half angle of HPIB divergence from radial direction (measured by ratio of ion currents on 3 mm and 30 mm diameter FC collector and by autographes of HPIB on aquadag coated collectors) was not more that 2°. Such low divergence can be explained by the absence of HPIB asimutal velocity, good charge neutralization during beam transportation inside the cathode cavity (see fig. 6d), low temperature of anode plasma source. The presence of negative signal on axial integral FC preceding the ion beam pulse can be explained by neutralizing electron flow penetrating through the frount of slow convergent ion beam. It must be noted that in the experiments with bare metallic anodes the negative FC pulses were also present with ~60 ns duration in the beginning of the voltage pulse. The nature of responsible drift mechanism is under investigation.

Conclusion.

Described above investigations proved perspectiveness of application coaxial cylindrical MID's for HPIB linear focus experiments, especially in last case, where electron losses did not depend on anode length for $B > B_{crit}$. This permits us to pumping by HPIB active media of great length.

References.

1. Lengmuir I., Blodgett K.V. -Phys.Rev., 1923, v.22, p.347.
2. В.М.Быстрицкий, А.Н.Диденко, УФН, т.I32, в.I, I980, с.9I.
3. Kuswa G.W., Bieg K.W., Burns J.T. at.al. Proc. of 3rd Int. Conf. H.P. electron and ion beam. July 3-6, 1979, Novosibirsk, p.416.
4. А.И.Морозов, Л.С.Соловьев. В сб. "Вопросы теории плазмы", вып 8, с.8, I974.
5. Greenspan A.A., Hammer D.A., Sudan R.N. J.Appl. Phys., 1979, v.50, p.3011.
6. Humphries S.Jr. -Ibid., 1978, v.32, p.792.
7. Humphries S.Jr., Eihenbergen Jr.G., Sudan R.N. LPS-217, Cornell University, Ithaca, New York, 1977.