ION BEAM ACCELERATION IN NEUTRON TUBE

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Abstract

Deuteron beam acceleration in ion-optic system of gas-filled neutron tubes was investigated. PIC code SUMA [1-2] used for computer simulation of ionization and knock on processes and there influence on deuteron beam parameters. When deuteron and ionized particles space charge self-field forces become the same order of magnitude as external one, virtual cathode may occurs. It is happens because of injected from ion source deuterons cannot overcome their own space charge potential wall and move in transverse direction. However, electrons, produced by ionization, are trapped within the deuteron beam space charge potential wall and decrease it significantly. Thus, space charge neutralization of deuteron beams by electrons, may considerably increase target current and, as a result, output neutron flow. Moreover, own longitudinal electric field rise near the target leads to reduction of accelerating electrode – target potential wall, which was made to prevent knock on emission from the target. As a result, additional knocked on electrons may appear in the region and should be taken into account. The data obtained were compared with experimental results.

COMPUTER SIMULATION

To design neutron tube with assigned flow value and other parameters such as size, service life and so forth, preliminary computer simulation should be fulfilled. PIC code SUMA was used for ion optic system modeling and investigation of ionization processes influence on deuteron beam dynamics and output data of gas-filled neutron tubes. As a sample typical gas-filled pulse neutron tube has been studied (see Fig. 1).

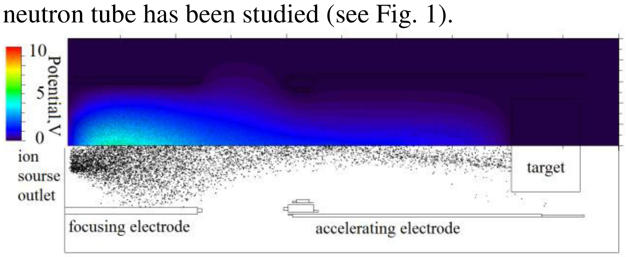

Figure 1: Deuterons distribution (lower) and their self-field potential (upper) in neutron tube.

Accelerated electrode is under -85kV potential, target -83kV, focusing electrode is grounded.

Preliminary ion source deuteron beam parameters has been obtained experimentally. For this purpose alone Langmuir probes, multi-electrode energy analyzer and Faraday cup were used. We obtain following deuteron beam parameter: longitudinal energy 1.7±0.4 keV, current ~150μA for initial gas pressure $0.5\cdot10^{-3}$ Torr. Moreover, some beam density distribution measurement were fulfilled. Nevertheless, it was not enough data for computer simulation. Therefore, the attempt to solve inverse problem was made. As the result to be obtained the experimental deuteron current density distribution on target shown on Fig. 2*a* was used.

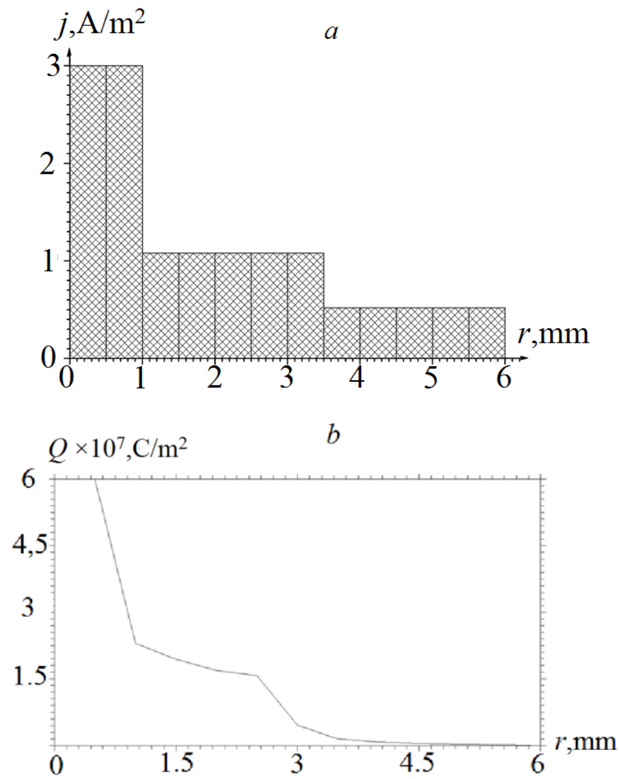

Figure 2: Current density (experimental, *a*) and charge distributions (simulation, *b*) on the target.

Experimental data were rebuild from target depth erosion and target sputtering calculation.

Computer simulation shows that for the following input beam data, experimental and calculated distributions are closed to each other: longitudinal energy 1.9±0.1 keV and transverse energy distribution ~120 eV, current ~150μA (see Fig.2*b*).

Passing through the gas, deuteron beam produce plasma, which consist of electron and slow ion. Their densities under considered gas pressure range approximately equal each other (see Fig. 3.) [3].

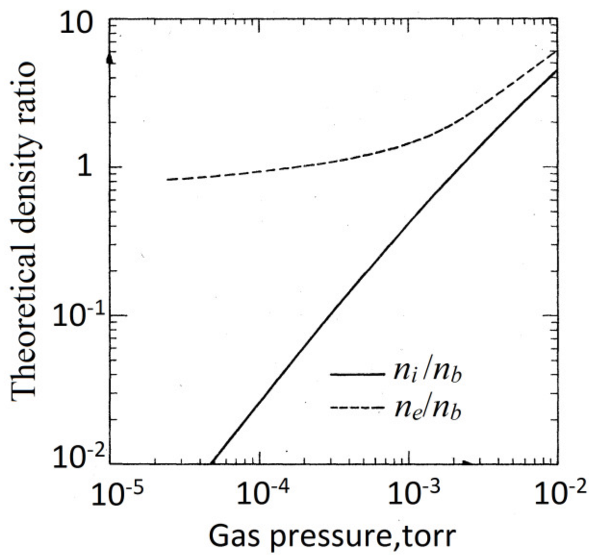

Figure 3: Ratio of electron or ion density as a function of pressure.

Deuteron and ionized particles own space charge forces for this current value are considerably less than that of the external one (see Fig. 4.).

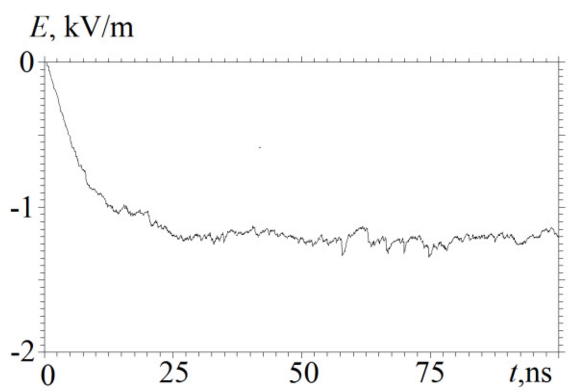

Figure 4: Longitudinal electric self-field time dependence near the cathode.

The value of decelerating deuteron space charge self-field is about 1kV/m, that three order of magnitude less than external accelerating field. Therefore, they cannot effect on deuteron beam propagation. Figure 5 shows that electric field is accelerating for the deuteron elsewhere in the tube.

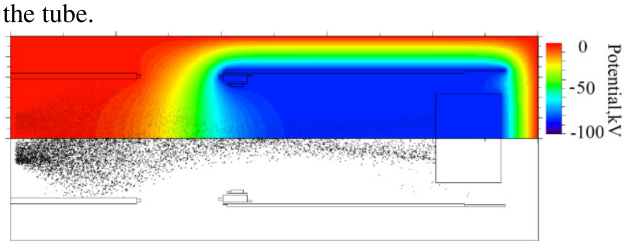

Figure 5: Deuterons distribution (lower) and total field (external and self-field) potential (upper) in neutron tube.

The electrons knocked on from the target by accelerated deuterons cannot pass through the accelerating electrode – target potential wall and cannot effect on deuteron beam propagation either (see Fig. 6).

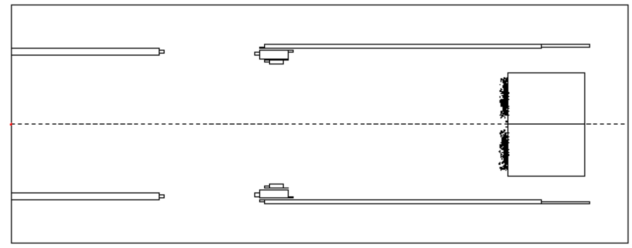

Figure 6: Knocked on electrons distribution.

Current gain leads to deuteron and ionized particles self space charge forces increases and become the same order of magnitude as external one. If we are not taking into account ionization processes, deuteron beam propagation for current 150mA shown on Fig. 7*a*.

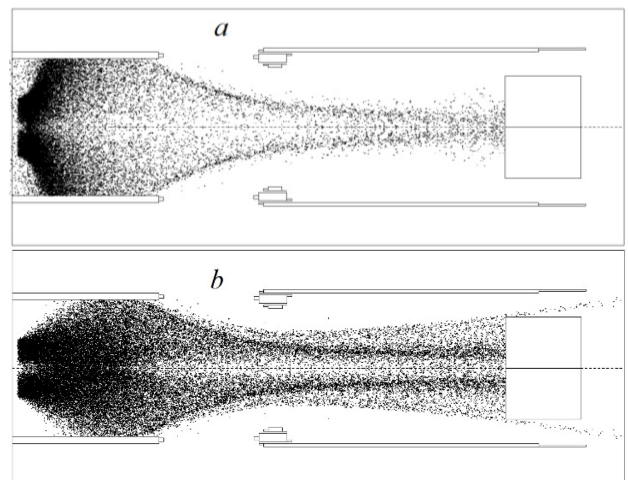

Figure 7: Deuterons distribution without (*a*) and with (*b*) ionization.

Injected from ion source deuterons cannot overcome own space charge potential wall and form a virtual cathode – positive potential value (see Fig. 8).

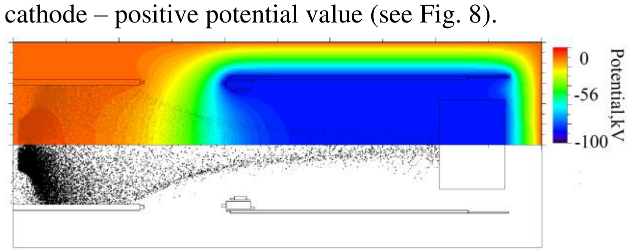

Figure 8: Virtual cathode forming.

Significant part of them leave the region in radial direction and get off to focusing electrode. Target current become four time less than injection one.

If we take into account ionization processes deuteron beam propagation changes considerably (see Fig.7*b*). Electrons, produced by ionization, are trapped within the deuteron beam space charge potential wall and cannot

ISBN 978-3-95450-142-7

leave the interaction region (see Fig. 9*a*), as they did for current 150μA (see Fig. 9*b*).

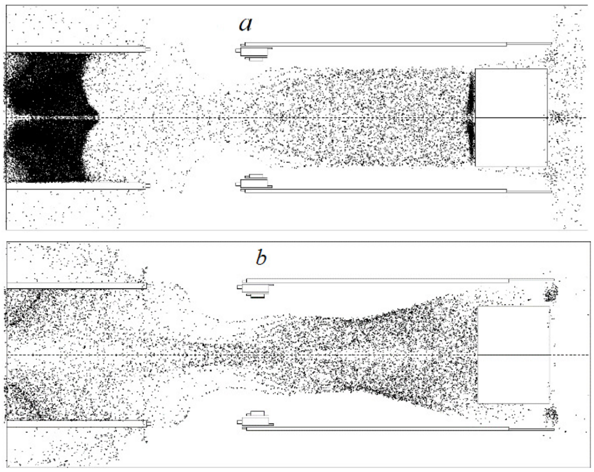

Figure 9: Electrons distributions for current 150mA (*a*) and 150μA (*b*).

Electron accumulation result in decreasing of the potential wall effective depth and deuteron target current rising. Figure 10 shows longitudinal electric field time dependence on the tube axis near the left border for cases without (*a*) and with (*b*) ionization taking into account.

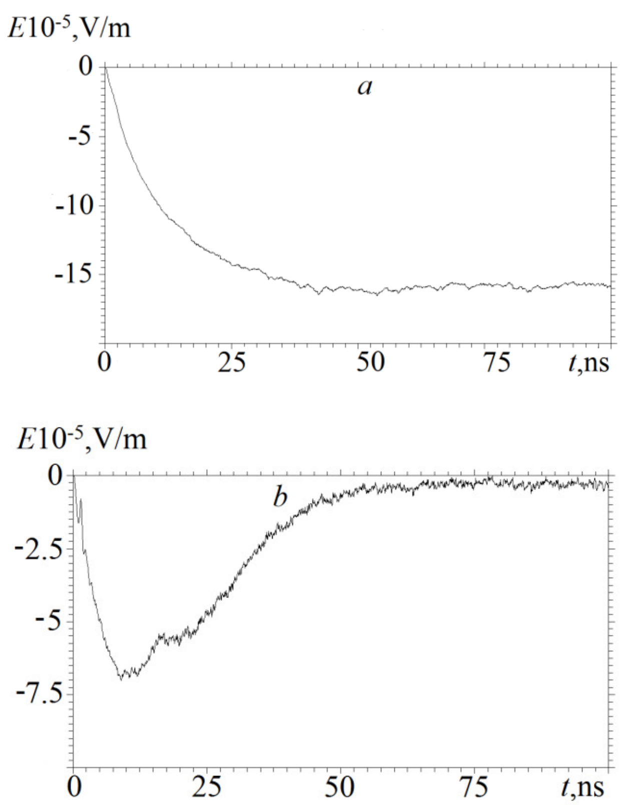

Figure 10: Longitudinal electric field time dependence without (*a*) and with (*b*) ionization taking into account.

The value of deuteron current increases almost three times that result in identical neutron flow increased approximately the same value [4].

$$\Phi = \frac{sn}{e\tau}\sum_i q_i \int_0^{W_i} dW \frac{\sigma(W)}{F(W)},$$

where s – target stoichiometry coefficient, n – target nuclei concentration, e – elementary electric charge, q_i - deuteron charge with energy W_i, $\sigma(W)$- nuclei reaction cross-section on the target, $F(W)$ - deuteron bremsstrahlung loss in the target, τ- pulse duration.

Moreover, own longitudinal electric field rise near the target leads to reduction of accelerating electrode – target potential wall and, as a result, additional knocked on electrons may appear in the region.

Influence of low energy ion, produced by ionization, is not so significant. Slow ion rather quickly obtain radial velocity and move to the tube periphery (see Fig. 11).

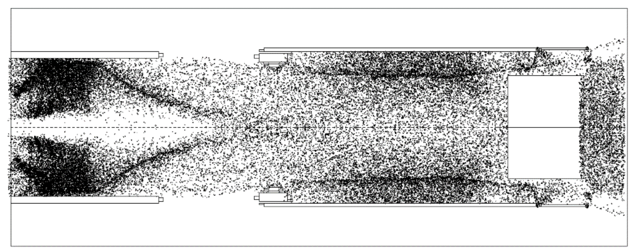

Figure 11: Slow ion distributions in the tube.

Thus, space charge neutralization of deuteron beams by electrons, produced by ionization, may considerably increase target current and, as a result, output neutron flow.

REFERENCES

[1] V. I. Rashchikov, Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations, No. 10 (18), pp. 50 -53, 1990.

[2] A.N. Didenko, V.I. Rashchikov, V.E. Fortov, Technical Physics, Vol. 56, No. 10, pp. 1535–1538, 2011.

[3] A.J.T. Holmes, Phys. Rev. A. , Vol. 19, No. 1, pp. 389-407, 1979.

[4] A.N. Didenko, V.I. Rashchikov, V.I. Ryzhkov et al., Atomic Energy, Vol. 112, No. 3, pp. 182 -184, 2012.