IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

# COLLECTIVE ION ACCELERATION IN THE VACUUM SYSTEM WITH INSULATED ANODE.

V.M.Bistritsky, A.N.Didenko, Ya.E.Krasik, V.S.Lopatin, V.I.Podkatov

Summary.
Experiments are described of ion acceleration in diode with insulated anode mounted on two E-beam generators that deliver 2 kJ and 1 kJ of energy in 1 MeV, 50 ns and 0.35 MeV, 80 ns pulses accordingly. The maximum yield of protons $10^{14} \pm 3 \cdot 10^{13}$ with energy in (1.9 ÷ 2.7) MeV range were measured with accompanying electron beam current 18 kA and electron energy 0.8 MeV on 2 kJ maching. The suppression of charging prepulse by inserting a dielectric piece in cathode terminal on it resulted in increased ion energy up to 5 MeV and total yield of protons with energy in the (2.7 ÷ 5) MeV region up to $10^{13} \pm 3 \cdot 10^{12}$. By application of several (from 1 to 3) post anode electrodes on 1 kJ machine the energy of ions were increased up to 4.2 MeV, which corresponds to $(E_i/E_e)_{max}$ =14. Reproducibility and effectiveness of acceleration processes were investigated.

## Introduction.

Besides well known methods of the ion acceleration in relativistic electron beams drifting in neutral gases [1] new approaches of ion acceleration are in progress now at several laboratories[2,3]. The simplicity of applied technique and rapid successes in attaining high ion yields and energies stimulate further investigations in these directions.

## Experimental.

We have carried some experiments on collective ion acceleration on the device similar to one proposed in [2,3] using two E-beam machines that delivers 2 kJ and 1 kJ of energy in 1 MeV, 50 ns and 0.35 MeV, 80 ns pulses. Our generators differed from those used in mentioned above works by long pulse rise time (20 ns) and absence of prepulse switch, suppressing the microsecond duration pulse during the charging phase. To investigate the influence of these factors on effectiveness of acceleration processes a lot of experiments were fulfilled on modified accelerator guns, in which suppression of prepulse and some shortening of current rise time were attained by insertion insulators-caprolon pieces (L=5÷9cm) between the needle tungsten cathode and shank. In first experimental run the electron beam from 2 mm in diameter tungsten needle was injected through the central hole in the insulated anode (fabricated from polyethylen, caprolon, teflon and plexyglass) in the vacuum chamber 300 mm in diameter and 300 mm in length and impinged on the target grounded through the resistor of the Faraday cup (F.c.) or directly. The plasma, generated on the anode surface due to the bombardment of electrons and surface breakdown was the source of ions. In another series of experiments on 1 kJ E-beam generator additional floating and grounded (alternatively) electrons in post-anode region were established (see fig. 1).

Institute of Nuclear Physics
P.O.Box 25 Tomsk- 50, USSR.

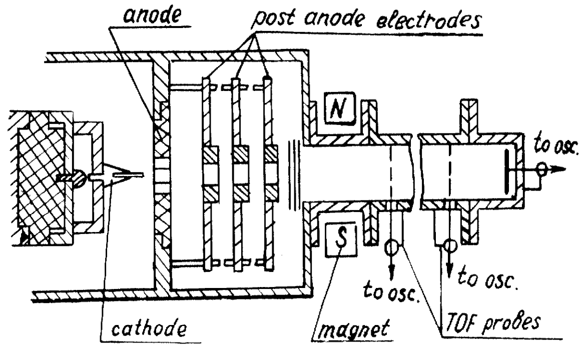


Fig. 1 The scheme of experimental setup with electrodes assembly mounted on 1 kJ machine.

The measurements of ion-electron beam was made by F.c. (R= 50 mΩ) on which litium or multilayered copper foils ( 20 mkm ) were ajusted. The total gun current and voltage were measured by shunt ( R= 0.11Ω ) and capacity voltage divider. The total number of protons was measured by neutron yield in the threshold reactions $Li^7(p,n)Be^7$ and $Cu^{63,65}(p,n)Zn^{63,65}$. The neutrons were detected by silver activation counter situated at 70° angle to the direction of the beam. The energy of protons was determined by the threshold reactions (registration of two annihilation gamma-quants from decay of $Zn^{63}$ on standard coincidence scheme ), time of flight ( TOF ) method ( 30 cm base ), and in several runs - by foil rangr spectrometer[4] adjusted to the vacuum chamber instead of F.c. The photos of the rear anode luminous region were taken by open shutter camera.

The measurements of electron range in the copper foil targets gave the average value 800 keV for 2 kJ machine and 330 keV for 1 kJ one.

## Results.

Briefly the main results are following:

1. In the system anode-grounded target the electron-ion beam was drifting over the distance up to 300 mm with spreading ≈3°. This fact withnessed about high degree of charge neutralisation ( $2 \div 3/\gamma^2 \lesssim f_e \lesssim 1$). The current on F.c. were in the range of (18 ÷ 25) kA.

2. In the experiments carried on 2 kJ machine without an insulator piece between the cathode and cathode shank the maximum energy of accelerated ions did not attain the energy of experimentally established threshold of $Cu^{65}(p,n)Zn^{65}$ reaction. The maximum yield of neutrons in the reaction $Li^7(p,n)Be^7$ was N = $1.2 \cdot 10^9$. This amount cor-


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responds to the proton number $N_p = 10^{14} \pm 3 \cdot 10^{13}$ in the region ( 1.9 ÷ 2.7 ) MeV.

The typical pulses from F.c. with central hole in it for TOF measurements, diode voltage divider, X-ray detector and TOF probes are presented on fig. 2. From the shape of TOF-probes signals we conclude that protons were accelerated in several bunches du-

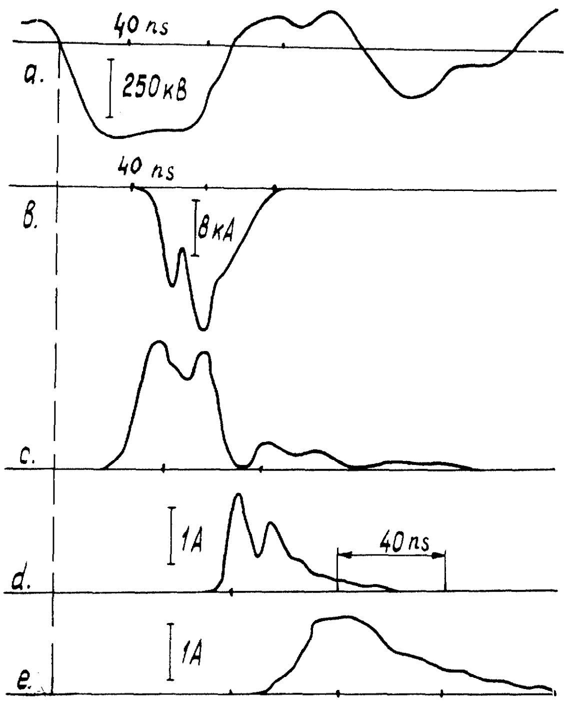


Fig. 2. Typical pulses from various electron-ion diagnostics: a. Voltage divider; b. F.c. signal; c. X-ray signal; d,e. TOF signals.

ring 30 ns. The amplitude of ion current in bunches attained 4.0 kA accompanied by 18 kA of electron current.

Using datas of TOF method and range-spectrometer measurements on 1 kJ machine we calculated the moments of the beginning of ions acceleration. On fig. 3 the values of these moments are given for several $E_i/E_e$. These results are consistent with F.c. datas

In these experiments we investigated the $E_i/E_e$ dependence v.s. anode-rear target distance. ( see fig. 4 ).

3. Suppression of charging prepulse on 2 kJ machine and shortening of the current rise time due to insertion of insulator piece in the cathode resulted in increased proton energy up to 5 MeV with the maximum neutron yield in the reactions $Cu^{63,65}(p,n)Zn^{63,65}$ $N_p = 1.5 \cdot 10^8$, which corresponds to total proton number $N_p = 10^{13} \pm 3 \cdot 10^{12}$ with the energy in the range 2.7 ÷ 5 ) MeV. These values are consistent with the datas from range-spectrometer and TOF measurements.

4. Insertion of several post-anode electrodes ( from one to three ) with alternative or all grounded on 1 kJ E-beam generator resulted in increased energy up to 4.2 MeV ( see fig. 5 ).

The reproducibility was poor and the to-

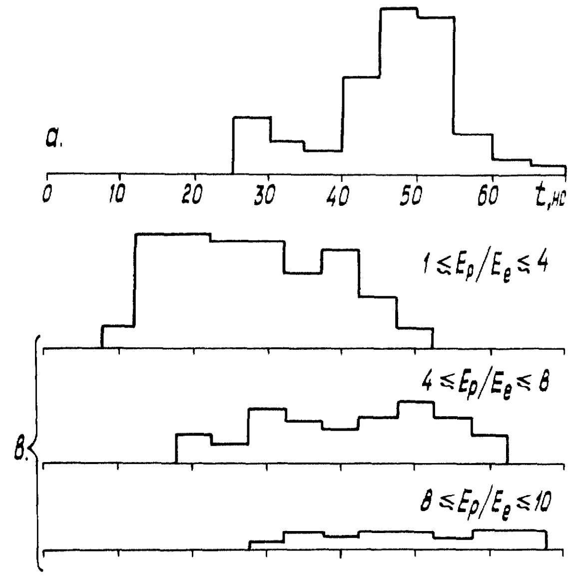


Fig. 3. Gistogramms of : a. Times of E-beam arriving on the F.c.; b. Times of ion acceleration beginnings for three different groups of energy. The zero-time corresponds to the beginning of pulse on voltage divider

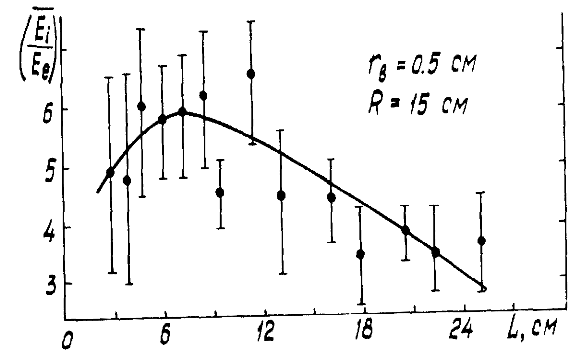


Fig. 4. $E_i/E_e$ dependence v.s. anode-rear target separation.

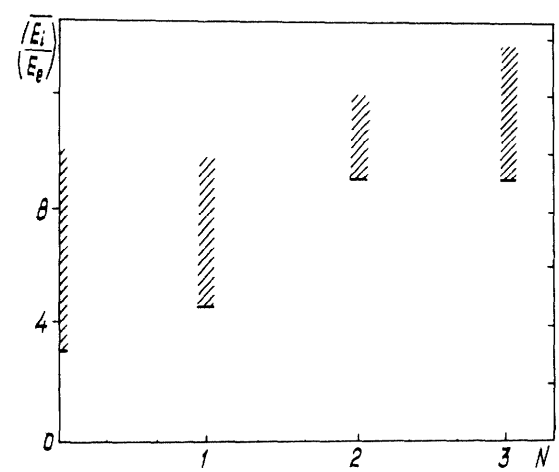


Fig. 5. $E_i/E_e$ dependence v.s. number of post-anode electrodes. The hatched zone- experimental spreading of datas.

tal proton and neutron yields varied from shot to shot up to two orders. As a rule the highest neutron yield were detected in the shots with negligible degree of anode destruction and best reproducibility - when using the caprolon as anode's material.

It was suggested that further development of this simple and effective method of ion acceleration depend upon solving the problem of active control over insulator surface breakdown. We are now preparing experiments in which anode-dielectric breakdown is controlled by the closure of pressurised gas switch inserted between the anode and grounded vessel.

Acknowledgements.

We would like to express our appreciations to Dr.Arbuzov A. for his aid in experimental runs. Also we would like to thank Dr.Usov Yu.P. for helpful discussions.

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