Search of Interaction Processes of Plasma Opposing Fluxes

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The paper presents the results of experimental investigation of interaction processes between two opposite deuterium plasma flows generated by discharges in crossed E × H fields counterpropagating in a transverse direction towards the outer magnetic field.

It was shown that neutron emission from the dd-reaction (dd → ^{3}He + n) depends on effective interaction of practically depolarized flows; the magnetic field in the area of deuteron plasma flow collision quickly changes (≈ 10^{11} G/s).

It was experimentally found out that the area of effective interaction of plasma flows with the concentration of n ≤ 10^{16} cm^{-3} moves in the direction along the magnetic field during a discharge. During the measurements the flow energy stock was equal to up to 600 J and flow velocity was $3.5 \cdot 10^7$ cm/s. The obtained results can be used for correct interpretation of experiments on study of reactions between light nuclei in the area of ultra-low particle collision energies in the input channel.

1. Introduction

High-intensity accelerated ion flows are used to experimentally study the reactions between light nuclei (dd, pd, dt, dHe reactions) in the range of ultra-low energies (~ keV), since the cross sections of the processes in the given energy range are low (10^{-35}–10^{-43} cm^2).

High-intensity ion flows generated in direct and inverse Z-pinches produced with the help of a high-current accelerator were used to investigate the dd-reaction at deuteron collision energies of 0.5–3.7 keV (in the center-of-mass frame) [1–4]. However, at high energy densities, the liner undergoes rapid non-linear processes, accompanied by the background radiation (neutrons and gamma rays), which substantially complicates measurement of the reaction yield and interpretation of the results of experiments.

These problems stimulated a search for alternative methods for generating intense flows of low-energy light nuclei [5].

The use of counterpropagating flows with a duration of ~ 10 μs makes it possible to substantially decrease the deposited energy, the energy and density of the plasma flows, and, hence, the intensity of background radiation.

Intense counterpropagating plasma flows are generated by discharges in crossed electric and magnetic fields (Fig. 1).

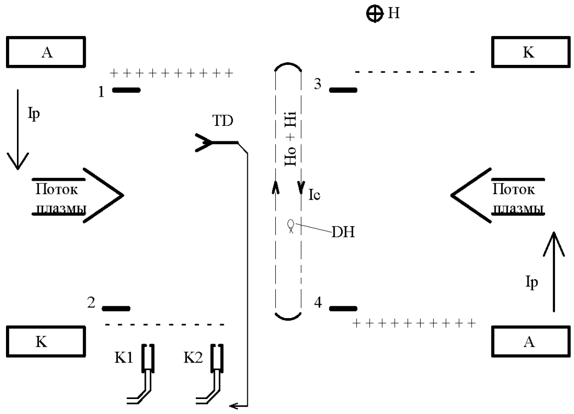

Fig. 1. Arrangement of the detectors in the region of plasma flow propagation. A – anode, K – cathode. H_0, Hi – initial magnetic field and the field with depolarized current I_c. DH – magnetic field detector. 1, 2, 3, 4 – electrodes for measuring voltage at flow boundaries. K1, K2 – collimators of the optical detectors. I_P – discharge current

Space-bound plasma flow propagating across a magnetic field is accompanied by a disturbance in flow quasi-neutrality and emergence of polarization electric fields [5, 6]. The polarization electric field and outer (orthogonal) magnetic field result in flow drift across the magnetic field. Some portion of the flow kinetic energy is used to make the drift channel in the cross magnetic field. In case the flow propagates in the neutral gas environment, some additional losses appear, which are related to gas ionization and participation of newly-formed ions in the drift.

The flows are depolarized as a result of collision of the two opposite flows with counterpropagating polarization fields. The electrical energy deposited in plasma capacitors (polarized flows) is transformed into the magnetic energy in the collision area [5, 6]. In case polarization fields disappear, flow drift ceases and plasmadynamic velocity decreases dramatically. Quasi-continuous flows form drift channels again after having spent some portion of energy and time, we again observe collision and depolarization etc. Collision frequency, collision spatial dynamics, flow depolarization intensity, as well as other processes generally depend on geometry, local and integral parameters of the flows.

The paper aims at study of counterpropagating deuteron flow generation dynamics, testing of methods of flow principal parameter measurement, investigation of background conditions for measurement of dd-reaction characteristics.

2. Experiment

The experiments were carried out using the set-up described in [5]. Fig. 1 shows the schematic of location of emission detectors and diagnostic devices.

The counterpropagating flows are generated in a ceramic chamber with a solenoidal magnetic field ($\approx 10^4$ G). There are two pairs of electrodes in the chamber. After filling the preevacuated chamber with a working gas, the discharge is ignited. The current in two discharge gaps flows in the opposite directions across the magnetic field (Fig. 1).

As a result of Ampere force application, the plasma is accelerated in the discharge gaps. Hence, two plasma flows that move across the magnetic field toward each other and collide in the center of the chamber are generated.

The electrodes 1–4, placed at flow boundaries, were used to measure flow depolarization degree and flow collision time interval. Collimated (spatial resolution equal to ~ 1 mm) optical detectors were used to measure flow front velocities. Collimators were spaced at the distance of 2.5 cm along the flow propagation direction. Single-coil loops with the square of $7 \cdot 10^{-2}$ cm^2 were used to measure magnetic field changes in the area of flow collision. Flow energy density was measured using calibrated calorimeters. The above-mentioned detectors were fixed at a platform movable along the flow fronts. The Rogowsky coil was used to measure discharge current. To measure electrical signals optical isolators were used.

Scintillation detectors protected with a layer of lead with the thickness of 5 cm were used to measure neutrons in the d + d $\rightarrow$ ^{3}He + n reaction. The scintillator of the soft x-ray detector was protected by 40 μm-thick beryllium foil and was installed along the axis of the vacuum chamber outside the magnetic field, 1 m from the interaction region.

The light from the scintillator was supplied onto the photomultiplier tube using the optical fiber.

3. Experimental Results

Characteristic discharge energy parameters are given in Fig. 2.

Figure 3 shows energy density distribution for each flow with respect to the center of electrodes ("zero" point at the abscises scale). The distribution is an integral characteristic and corresponds to discharge duration. The measurements were carried out by moving calorimeters along flow fronts (along electrodes). Using the obtained measurement data one can say that flow effective width along the magnetic field is equal to $\approx$ 10 cm.

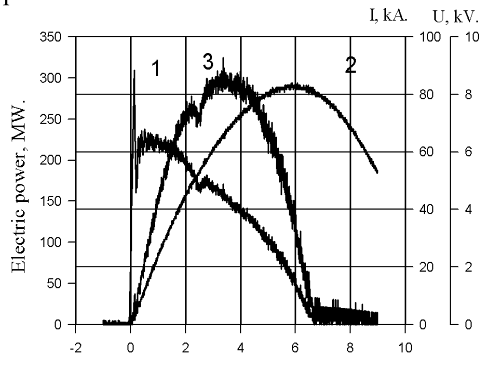

Fig. 2. Discharge energy characteristics: 1 – waveform of the voltage, 2 – waveform of the current, 3 – discharge power

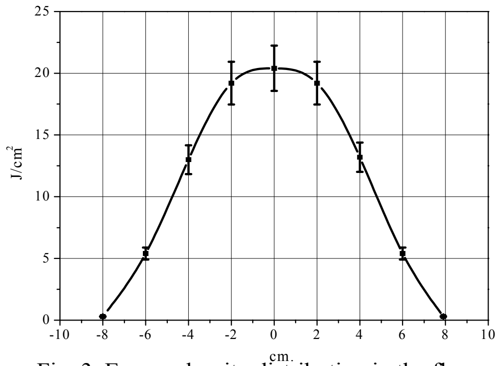

Fig. 3. Energy density distribution in the flow

The calorimeters placed above and under the flow were used to measure energy density, which was 7 times less than energy density in the flow. The flow thickness was calculated to be about 3 cm. Full energy content in each flow was equal to about 600 J. By comparing energy parameters of the discharge and plasma flows we obtained the coefficient of conversion of discharge electrical energy into flow kinetic energy that equaled to $\approx$ 0.45. We should also mention here that the value of conversion coefficient depends on initial pressure of neutral gas (deuteron) in the working volume. Optimal pressure of deuteron under our conditions was $\approx$ 0.5 torr.

The process of flow collision is characterized by decrease in voltage at flow boundaries and sharp change of the magnetic field (up to 10^{11} G/s) in the collision area (Fig. 4).

Neutron emission, and in some cases, soft x-ray emission depend on the collision process (Fig. 4). The first effective collision is observed 2÷2.5 μs after current pulses occur in discharge gaps. During the time interval of 0÷2.5 μs the flow energy is mainly spent on the ionization of the neutral gas and formation of the drift channel. Out of 30 shots (flow generation acts) no neutrons were registered by scintillation detectors S1–S3 in the time interval of 0÷2μs, whereas in the time interval of 2÷7 μs 20 neutrons were detected (see Table 1).

Table 1

Shot number	1	9	11	16	17	18	20	25	27	28	30
S1	+	+++		+	+	+			+	+	+
S2	–	–	–	–	–	–	–	++		+	+
S3	+		+++			+	+	–	–	–	–
V×10^7 cm/s	2.8 (2.8)	3.2 (2.9)	2.8 (2.8)	3.5 (3.7)	3.2 (3.6)	3.2 (3.3)	3 (3)	3.2 (2.9)	3.5 (3.4)	3.5 (3.5)	3.5 (2.5)
N ×10^{15} cm^{-3}	0.9	0.62	0.9	0.85	1	1.3	1	0.65	0.75	0.8	0.6

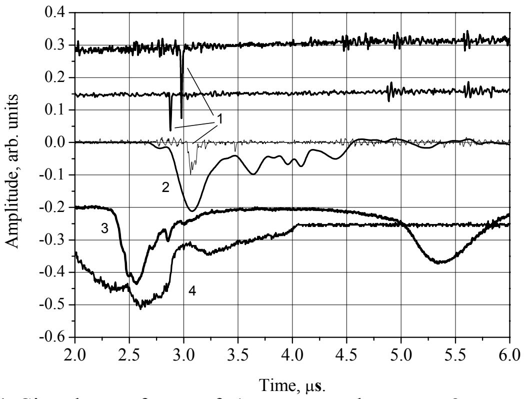

Fig. 4. Signal waveforms of: 1 – neutron detectors; 2 – magnetic field detector; 3 – soft x-ray detector; 4 – detectors of induced voltage between flow boundaries

It means that in this very time interval up to 10 effective flow collisions occur. No neutrons were detected out of 15 control shots with a single flow (i.e. in the absence of the counterpropagating flow).

The results of the preliminary analysis of experimental data show that the maximum neutron output was registered in the 2÷3 μs time interval. The second maximum neutron output was correlated in time with the maximum discharge current. All the detected neutrons occur at the same time as flow collisions (Fig. 4).

The scale of flow spatial heterogeneities is ~ 1 cm. E.g., local velocities of the flow measured by two pairs of optical detectors located at the distance of 2 cm from each other along the magnetic field (along the flow front) differ two times (Fig. 5).

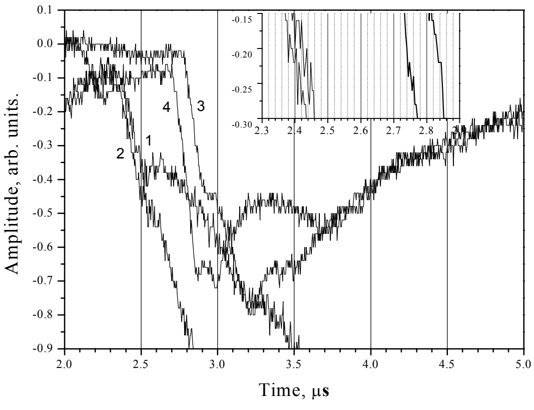

Fig. 5. Waveforms of optical detectors. The distance between the pairs of collimators 1 – 2 and 3 – 4 along the flow front is 2 cm

The experiments showed that the area of flow effective collision expands along the magnetic field into the both sides. This phenomenon can probably be explained by expansion of the current propagation area in discharges.

The table shows flow velocity values measured by optical detectors. In brackets one can see velocity values calculated using the ratios of continuity of mass flow and energy flow in the discharge [5].

The discharge electrical power in the time interval, where the event was registered and the coefficient of electrical power transformation into kinetic one were used for calculations. Values of particle density in flows are given for the above-mentioned conditions.

4. Conclusion

The results presented in this paper show that the developed set-up for deuteron plasma counterpropagating flow generation can be used for experiments on study of the dd-reaction in the area of ultra-low energies.

However, in order to properly interpret the obtained results on change in the dd-reaction characteristics one needs more detailed experimental data on local spatial characteristics of flows, including data on particle velocity distribution in each flow. Moreover, additional investigations of influence of electrical fields induced in the area of flow collision at fast change of the magnetic field on particle redistribution with respect to energy are required.

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