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Review article

Neutrons in a nanosecond low-pressure discharge in deuterium

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Abstract

Stable neutron generation with a yield of ~1.2 × 10^4 neutrons per pulse was obtained during d(d,n)^{3}He reaction initiated by the high-voltage nanosecond discharge in a gap with a potential tungsten cylinder (anode) and a grounded deuterated zirconium plate (cathode) filled with deuterium at a pressure of ~10^2 Pa. Estimated duration of the neutron pulse was ~1.5 ns. Less intensive neutron emission was registered without deuterated plate. Splashing of material of the tungsten electrode was observed during the high-voltage nanosecond discharge in the deuterium, hydrogen, helium and argon at pressures of 10^2–10^4 Pa.

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1. Introduction

Creation of neutron sources with a pulse duration of several nanoseconds or less is a topical problem. Such sources can be used for solving various problems of applied nuclear physics and other areas, e.g., radiography of fast processes, spectrometry at elemental analyses, studying of kinetics of nuclear reactions, testing of pulse detectors of neutrons, detection of explosives, drugs and fission materials, etc. [1–3] One way to obtain neutron pulses of short durations is via the impact of ultra-high-power laser pulse with pico- or femto-second duration on targets enriched with deuterium or tritium [1,3,4].

Also, neutron pulses with a duration of 10–10^3 μs can be obtained using the particle accelerators based on vacuum neutron tubes [2,5,6]. The neutron yield of such devices reaches ~10^{11} neutrons per pulse and they are widely used in practice, e.g. logging.

It is known about the possibility of neutron emission during high-voltage nanosecond discharge in a gap filled with deuterium at low pressure (hundreds of Pascal) [7–9]. Such neutron sources are simpler and cheaper than laser-based ones. In this case, potential electrode with small radius of curvature (anode) and grounded plate enriched with deuterium or tritium (cathode-target) are used. Emission of neutrons occurred due to d(d,n)^{3}He (DD-reaction) and t(d,n)^{4}He (DT-reaction) thermonuclear reactions described by equations (1) and (2), respectively. These reactions are initiated by deuterium ions accelerated in the gap interacting with cathode-target.

$$D + D \rightarrow {}^3He + n + 3.269\ MeV \quad (1)$$

$$D + T \rightarrow {}^4He + n + 17.577\ MeV \quad (2)$$

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In Ref. [8,9], stable neutron emission due to DT-reaction initiated in high-voltage nanosecond discharge in deuterium at pressures of 10–100 Pa was registered. The maximal yield was ~1.5 × 10^6 neutrons per pulse.

For the first time, stable neutron emission provided by DD-reaction was demonstrated later, in Ref. [10]. It should be noted that the yield was several orders of magnitude smaller than the one of DT-reaction. This is conditioned by a lower value of DD-reaction cross-section at identical values of deuterium ions energy. Despite this, the DD-reaction-based neutron sources allow to form neutron pulses with durations of several nanoseconds or less, which are less harmful than DT-reaction-based ones. Wherein, such devices are promising for numbers of practical applications.

The objective of this paper is to study the possibility of stable neutron emission due to DD-reaction during the high-voltage nanosecond discharge in the gap filled with low-pressure deuterium with the electrode non-enriched with deuterium or tritium. Another objective is to obtain the maximum possible neutron yield at a discharge in the gap with a deuterated target.

2. Experimental equipment

The experiments were carried out on the setup which schematic is presented in Fig. 1. A discharge was ignited in the 56-mm-diameter gas-filled cylindrical metal chamber which was connected with a pulser (RADAN-220 [11]). A system consisting of a forevacuum pump, metal pipes, gas cylinders and pressure sensors was used for filling the chamber with gas, controlling its pressure and its evacuation. The pulser can form voltage pulses of both positive and negative polarities with an amplitude of ~220 kV at the high-resistance load. The duration of a voltage pulse at the matched load and its risetime in the transmission line is ~2 ns and ~0.5 ns, respectively. This pulser was operate in single-pulse mode. A voltage pulse from this pulser was applied across the interelectrode gap in the discharge chamber.

Since the experiments were carried out at low pressure of a gas medium, a lead shield with 7-cm-thickness walls was used to protect equipment and personnel from the influence of powerful X-ray pulses.

To measure the yield of neutrons appeared in d(d,n)^{3}He reaction, a ^{3}He-detector [12] with an efficiency of 0.0058 ± 15% was used. This detector consists of ten tubes filled with ^{3}He-Ar-CO_2 mixture surrounded by polyethylene. Each tube is a counter of thermal neutrons. The ^{3}He-detector was located at the side of the discharge chamber with a distance of 30 cm from it. The lifetime of a neutron in the detector is ~57 μs. Because the registration interval was 350 μs, the probability of the registration of a neutron was ~100%.

The neutron pulse duration was measured with a scintillation detector (SD) [13] consisting of a photomultiplier tube (PMT) XP-2020 (Philips) and a parallelepipedic plastic scintillator. The efficiency of this detector was 6 × 10^{-4}. The SD was located on the longitudinal axis of the discharge chamber with a distance of 100 cm from it. This detector was operated in one-neutron registration mode (neutron counting mode).

Signals from the ^{3}He-detector and SD were registered with the real-time digital oscilloscopes Tektronix TDS3054B (B_w = 500 MHz) and TDS3032B (B_w = 300 MHz), respectively. A sync pulse was a signal from the capacitive voltage divider (11 in Fig. 2). Acquisition and processing of experimental data were carried out with a personal computer.

The schematic of the discharge chamber is shown in Fig. 2. The chamber was made of steel in the geometry of a cylinder with an inner diameter of 54 mm. The potential electrode with small radius of curvature and the flat grounded electrode formed the interelectrode unit. The potential electrode with a cylindrical geometry was made of stainless steel or tungsten. The grounded electrode was made of aluminum plates. Deuterated zirconium (ZrD_2) and deuterated titanium (TiD_2) plates were mounted to the aluminum plate via brass ring (2 in Fig. 3(d) and (b)). Interelectrode distance and gas pressure in

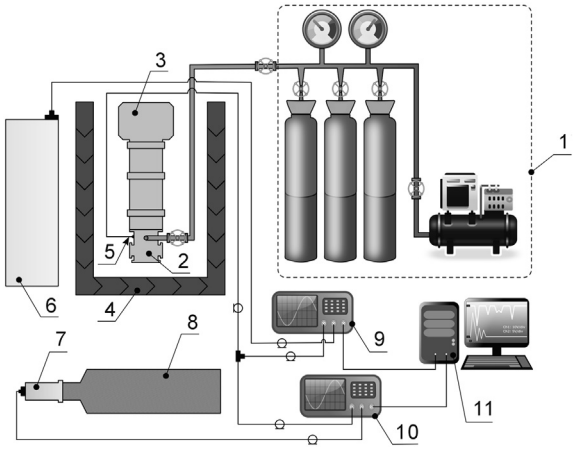

Fig. 1. Schematic of the experimental setup. 1 – gas system; 2 – discharge chamber; 3 – RADAN-220 pulser; 4 – lead shield; 5 – voltage sensor; 6 – ^{3}He-detector of thermal neutrons; 7 – photomultiplier tube XP-2020; 8 – plastic scintillator (scintillator detector); 9, 10 – digital real-time oscilloscopes; 11 – personal computer.

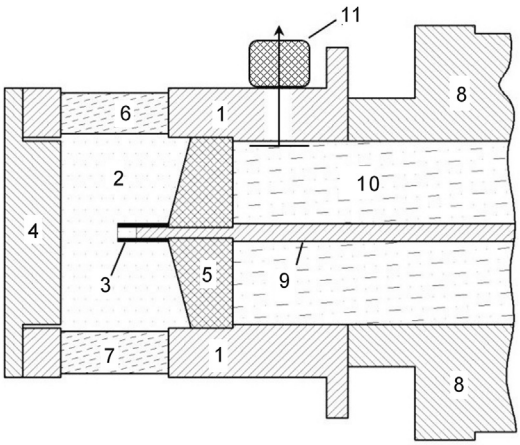

Fig. 2. Schematic of the discharge chamber. 1 – chamber housing; 2 – gas medium; 3 – potential electrode; 4 – grounded electrode; 5 – insulator; 6, 7 – quartz windows; 8 – transmission line of the RADAN-220 pulser; 9 – potential input; 10 – transformer oil; 11 – capacitive voltage divider.

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