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SHORT COMMUNICATIONS

Generation of Neutrons in a Nanosecond Low-Pressure Discharge in Deuterium

M. I. Lomaev[a, b]*, B. A. Nechaev[c], V. N. Padalko[c], G. N. Dudkin[c], D. A. Sorokin[a], V. F. Tarasenko[a, b], and E. N. Shuvalov[c]**

[a] *Institute of High-Current Electronics, Siberian Branch, Russian Academy of Sciences, Akademicheskii pr. 2/3, Tomsk, 634055 Russia*

[b] *National Research Tomsk State University, pr. Lenina 36, Tomsk, 634050 Russia*

[c] *National Research Tomsk Polytechnic University, pr. Lenina 30, Tomsk, 634050 Russia*

**e-mail: Lomaev@loi.hcei.tsc.ru*

***e-mail: nechaev@tpu.ru*

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Abstract—The neutron yield is measured in a high-voltage Townsend discharge in deuterium with a hollow cylinder made of tungsten or steel used as a polarizing anode of electrons. A flat metallic plate covered by a layer of deuterated zirconium is applied as a grounded cathode. The highest yield of neutrons in the reaction $^2H(d,n)^3He$, $\sim 1.2 \times 10^4$ neutrons per pulse, is observed in the case of the tungsten anode at a deuterium pressure on the order of 100 Pa. The pulsed neutron flux duration estimated with data obtained from a scintillation detector is roughly equal to 1.5 ns.

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INTRODUCTION

The sources of short-pulse neutron sources used to generate isotopes and study the nuclear transmutation of elements, as well as in other problems of nuclear physics, are usually based on ultra-high-power short-pulse lasers [1–3]. Short pulsed neutron fluxes can also be generated in a high-voltage low-pressure discharge in deuterium [4, 5]. A stable yield of neutrons in the D–T reaction can be obtained using tritium-saturated target cathodes. Later [6], it was demonstrated that the neutron yield can also be stable, first, in the D–D reaction initiated in a high-voltage low-pressure nanosecond deuterium discharge with deuterated targets. Second, an also stable, although an order of magnitude lower, neutron yield was observed in the absence of deuterium-saturated target electrodes. This means that the D–D reaction, and hence, the neutron generation not only were triggered by fast neutron–target interaction but also took place in the gas-discharge volume.

Cheap short-pulse compact stable sources of neutrons are in demand in a number of applications, specifically, for calibrating detecting systems entering into experimental complexes used in nuclear physics experiments. Here, it is necessary to raise the neutron yield in setups based on high-voltage low-pressure deuterium discharges initiated by compact high-voltage generators.

This work elaborates upon previous investigations [6]. Its aim was to (i) measure the neutron yield in a high-voltage low-pressure nanosecond deuterium discharge with polarizing anodes in the form of a hollow cylinder made of tungsten or stainless steel and (ii) estimate the duration of the neutron generation process.

EXPERIMENTAL

The experimental setup was the same as in [6]. A discharge was initiated with a RADAN-220 high-voltage pulse generator [7]. The voltage pulse rise time in the transmission line and the voltage pulse width on a matched load were 0.5 and 2 ns, respectively. A flat metallic plate covered by a layer of deuterated zirconium (ZrD_2) is applied as a grounded electrode. A hollow polarizing anode 6 mm in diameter was prepared of 100-μm-thick steel foil or was composed of thin tungsten wires 0.2 mm in diameter. The wires were placed so as to cover the generating line of a stainless steel tube to form a hollow tube with an outer diameter of 8 mm (Fig. 1). The ends of the wires facing the anode were split into three to five filaments. In this way, the radii of curvature of the surfaces were minimized and the electric field strength near the filaments was enhanced. The discharge chamber was evacuated with a fore pump to a residual pressure of 1–10 Pa and filled by deuterium at a pressure of 10 to 5×10^2 Pa. A voltage pulse was detected using a capacitive voltage divider inserted into the transmission line of the RADAN-220 at a distance of 6 cm from the anode.

The neutron yield was determined with a ^3He detector. It characteristics are described elsewhere [8].

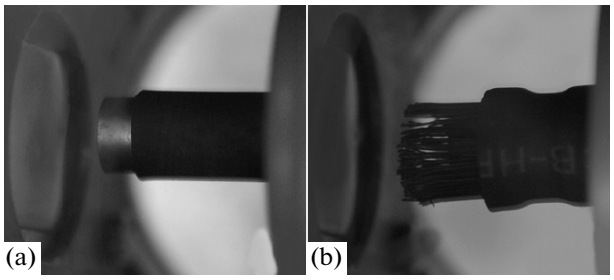

Fig. 1. Photos of the discharge gap with the anode made of (a) steel foil and (b) tungsten wires.

The detector, being 30 cm distant from the target, was protected against a powerful X-ray pulse by a 7-cm-thick lead layer. For such a target–detector distance, the detector efficiency was $0.0058 \pm 15\%$. The neutron lifetime in the detector was $\tau = 57$ μs. A logging interval of 350 μs provided an almost 100% probability of neutron detection.

Duration τ_n of the neutron generation process was estimated with a scintillation detector. It consisted of a plastic scintillator measuring $40 \times 10 \times 10$ cm the luminescence of which was recorded by an XP-2020 photoelectric multiplier. The detector was 1 m distant from the target. The fraction of the electron flow falling on the scintillator was equal to 0.003, and the intrinsic efficiency of detecting a parallel flux of 2–3-MeV neutrons was equal to 0.2. That is, the total efficiency of the scintillation detector was about 6×10^{-4}.

Time τ_n was estimated from data obtained under the conditions when the scintillation detector recorded signals from, on average, one neutron. In this case, the dispersion of the time instants the neutron pulse is detected, $\sigma^2(t_n)$, depends both on the dispersion of the time instants a neutron is emitted from the target, $\sigma^2(t_{ne})$, and on the time resolution of the scintillation detector characterized by dispersion σ^2_{pmt},

$$\sigma^2(t_n) = \sigma^2(t_{ne}) + \sigma^2_{pmt}. \quad (1)$$

With regard to our experimental conditions (the range of neutron energies is 2–3 MeV, a light flash on the photocathode is observed after one neutron falls on the scintillator), the time resolution of the scintillation detector ($\sigma_{pmt} = 310$ ps) was refined by taking test bed measurements. From (1) τ_n can be estimated as

$$\tau_n \le 2.36\sigma(t_{ne}) = 2.36\sqrt{\sigma^2(t_n) - \sigma^2_{pmt}}. \quad (2)$$

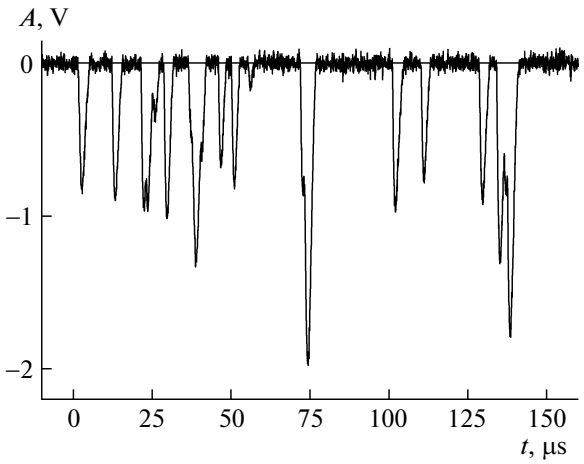

Fig. 2. Waveform of the pulse from the ^{3}He detector in the case of the steel anode at a deuterium pressure of 100 Pa.

Quantity $\sigma^2(t_n)$ was determined from the pulse waveforms. Preliminarily, the peak in the waveform of the neutron signal from the scintillation detector was interpolated by a Gaussian curve. Then, half-maximum time t_n is fixed in the leading edge of the pulse described by the Gaussian curve relative to the voltage pulse onset time, which is taken for zero on the time scale. The dispersion of this parameter, $\sigma^2(t_n)$, is subsequently used to estimate τ_n by (2). The signal from the scintillation detector and the voltage pulse were recorded with a TDS3032 oscilloscope, and the signal from the ^{3}He detector was recorded by a TDS 3054 oscilloscope in the interval 0–350 μs. Both oscilloscopes were started by the leading edge of the voltage pulse.

EXPERIMENTAL DATA

Neutron Yield Versus the Anode Material

The neutron yield in the presence of the steel or tungsten anode was optimized based on the interelectrode gap and deuterium pressure. For both anodes, optimal conditions were achieved at a deuterium pressure of 100 Pa and an interelectrode gap of 5 mm. The maximal neutron yield was 1.2×10^4 and 3.1×10^3 neutrons per pulse for the tungsten and steel anodes, respectively (see the table).

A typical waveform of the signals from the ^{3}He detector is shown in Fig. 2. In experiments, we also

Table

Series no.	Number of shots	Number of neutrons per series	Mean number of neutrons per shot	Maximal number of neutrons per shot	Maximal neutron yield per shot	Note
1	50	589	11.8 ± 3.9	18	3100	Steel anode
2	20	489	24.5 ± 11	70	12000	Tungsten anode

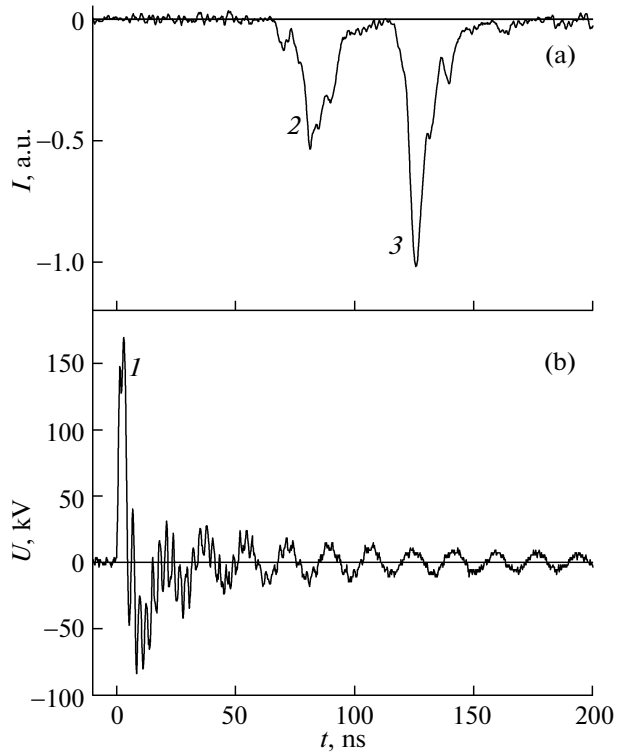

Fig. 3. Waveforms of the (*1*) voltage pulses and (*2*) X-ray radiation-induced and (*3*) neutron-induced pulses from the scintillation detector in the case of the steel anode at a deuterium pressure of 100 Pa.

fixed the time delay between the starting (zero) point and the neutron detection time. The amount of detected neutrons as a function of time is well described by an exponential: $N(t) = N_0\exp(-t/\tau)$. The fall time constant determined by approximating the experimental data, $\tau = 60 \pm 5$ μs, was found to be close to that obtained in [9] for the lifetime of a neutron in the detector, 57 μs. This supports the circumstance that precisely neutrons are detected by the ^{3}He detector.

In the case of the tungsten anode, not only the mean and maximal neutron yields rise but also the intensity of the X-ray pulse grows. The rise in the neutron yield results from the one-and-a-half times increase in the breakdown voltage, which is observed in the case of the tungsten anode. When the breakdown voltage grows, so does the rate of the D–D reaction because of the rise in the deuterium ion mean velocity and concentration and also in the D–D reaction cross section.

Duration of the Neutron Generation Process

By the duration of the neutron generation process we mean the FWHM of the distribution of time instants neutrons escape from the target. Parameter τ_n was estimated from data obtained in experiments with the steel anodes. The fact is that the X-ray pulse was weak and the neutron pulse was well resolved in this case (Fig. 3). Since breakdown delays, the pulse base width is about 4 ns. The waveform of the signal from the scintillation detector exhibits two peaks corresponding to X-ray and neutron pulses. The time interval between the pulses is 40 ns, which equals the difference between the times a neutron and a gamma-quantum arising in the D–D reaction take to travel a distance of 1 m.

From the tabulated data and the detector efficiencies in the case of the steel anodes, the mean numbers of neutrons generated into a full angle and those recorded by the scintillation detector are estimated as 2034 and 1.2 neutrons/pulse, respectively. Then, expression (2) can be used to estimate τ_n. The value of $\sigma(t_n)$ determined from the experimental data equals 0.7 ns. According to (2), we have $\tau_n \le 2.36\sqrt{\sigma^2(t_n) - \sigma^2_{pmt}} \approx 1.5$ ns.

CONCLUSIONS

Using a polarizing anode made of tungsten wires, we managed to raise the neutron yield in the ^{2}H(d, n)^{3}He reaction to 1.2×10^4 neutrons/pulse under the condition when deuterium is excited by a nanosecond high-voltage pulse at a pressure of 100 Pa. Remarkably, the neutron yield increases both with an increase in the breakdown voltage and with an increase in the X-ray radiation intensity. The duration of the neutron generation process estimated from data obtained with a scintillation detector equals 1.5 ns.

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