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Orientation effect in d(d,n)^{3}He reaction initiated by 20 keV deuterons at channeling in textured CVD-Diamond target

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ABSTRACT

Orientation effect of increasing the enhancement factor of DD-reaction in CVD-Diamond was investigated by simulation. It is obtained that the flux peaking effect up to 2.2 times increases the relative enhancement factor for a parallel beam and up to 1.2 times for the deuteron beam with angular divergence equals 3 critical channeling angles. Qualitative agreement with the experiment was obtained.

1. Introduction

During the last fifteen years, a series of works have been published, which theoretically and experimentally investigated growth of DD-reaction yield, occurring in deuterated metals at low collision energies [1–5]. The authors [3] explained this effect by a strong increase in electron screening of nuclei Coulomb interaction due to the influence of the metal matrix electrons. The authors of [4,5] suggested a different explanation using channeling effect.

The interactions of deuterium beam with deuterium enriched fixed targets are investigated in [6–10] using HELIS accelerator facility at the P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI). In the Ref. [10] authors investigated neutron yield in the reaction:

$$d + d \rightarrow n(2.45\ \mathrm{MeV}) + {}^3\mathrm{He}(0.8\ \mathrm{MeV}) \tag{1}$$

using textured CVD-Diamond target and 20 keV deuterium beam from HELIS accelerator which delivers the beam with small angular and energy divergences.

To clarify the role of channeling in enhancement of neutron yield DD-reaction in CVD-Diamond crystal target, we present here the results of computer simulations. The deuterons trajectories in crystal are simulated using the computer code Basic Channeling with Mathematica™ (BCM-1.0) [11]. This code allows calculate angular and spatial distribution of channeled particles in thin crystals and was successfully applied for explanation of recently performed experimental results, see e.g. [12,13].

2. Experimental setup and results of experiment

The investigation of DD-reaction yield was performed at HELIS accelerator facility. This multi-purpose accelerator facility operates continuous ion beams with currents up to 50 mA and energies up to 50 keV. A schematic diagram of the HELIS setup is shown in Fig. 1.

The nuclear DD-reaction of interactions of the deuterium ion beam with fixed targets was conduct using a 400 μm thick polycrystalline deuterium-enriched CVD diamond. The method of target formation was the follows. The film was grown on a 57 mm diameter silicon substrate using the microwave plasma-assisted chemical vapour deposition (MPCVD) system [14]. The black diamond film was obtained, with numerous structural defects in the crystallites, such as twins and amorphous carbon inclusions with a size up to 1 nm. Further the diamond film was separated from the substrate by etching of silicon in a mixture of hydrofluoric nitric and acetic acids, and cut by a Nd: YAG laser into discs of 18 mm diameter. The structure of polycrystalline diamond is anisotropic and not homogeneous. The crystallites are growing in the form of columns, perpendicular towards the surface. The transversal size of crystallites increases from ≈1 μm in the layer

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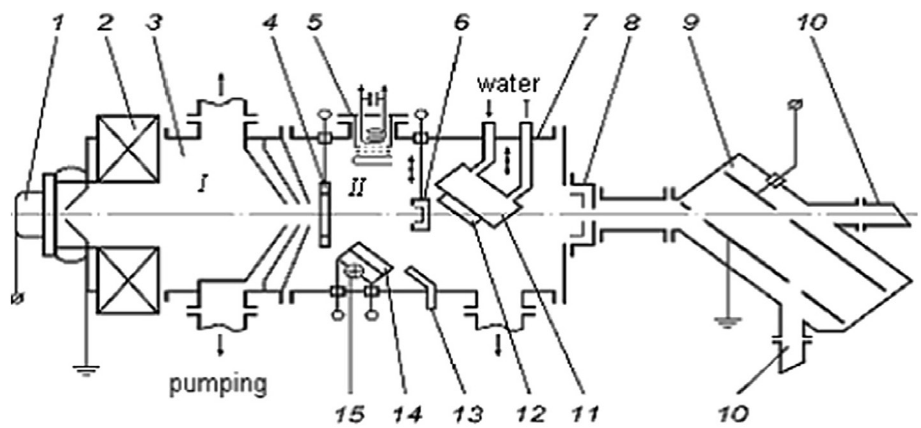

Fig. 1. Schematic diagram of the HELIS setup: 1 is the ion source (duoplasmatron); 2 – electromagnetic lens; 3 – three-stage chamber of differential pumping; 4 – non contact current meter; 5 – auxiliary ion source; 6 and 10 – Faraday cages; 7 – targets chamber; 8 – the device for calorimetric measurement of the ion beam current; 9 – electrostatic analyzer; 11 – water cooled target holder; 12 – target; 13 – feeder of gas in vacuum chamber; 14 – substrate; 15 – substrate heater.

close to the substrate to about 50 μm on the growth side. The growth surface of the sample shows a clear crystalline structure with (100) grain orientation.

The neutron flux, produced in the DD-reaction, was measured in the longitudinal and transversal direction with respect to the beam axis by using a multichannel neutron detector based of ^{3}He counters. The relative yield of the DD-reaction was determined as $Y_{dd} = n_n/(S\,I_d)$, where n_n is the neutron flux, S is the irradiated area of the target and I_d denotes the ion beam current. The neutron yield measured as a function of the angle between the beam direction and the norm to the target plane is shown in Fig. 2. The enhancement of the DD-reaction yield with decreasing angle is clearly observed. This could be connected with the channeling of ions in the oriented crystallites.

3. Simulations results and discussion

In the first calculation we suggest that deuterium atoms are arranged in perfect diamond lattice between the (400) planes (see, in Fig. 3). In this case, channeled deuterium ions move mainly

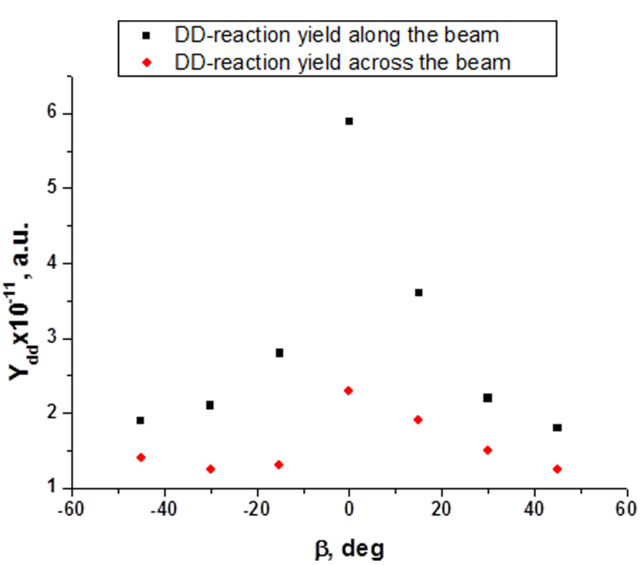

Fig. 2. The relative neutron yield obtained with the CVD-diamond sample as a function of the angle β between the beam and the target plane norm, measured in longitudinal (■) and transverse (◆) directions with respect to the ion beam. Ion beam with the energy of $E_d = 20$ keV and the current of 50 μA [10].

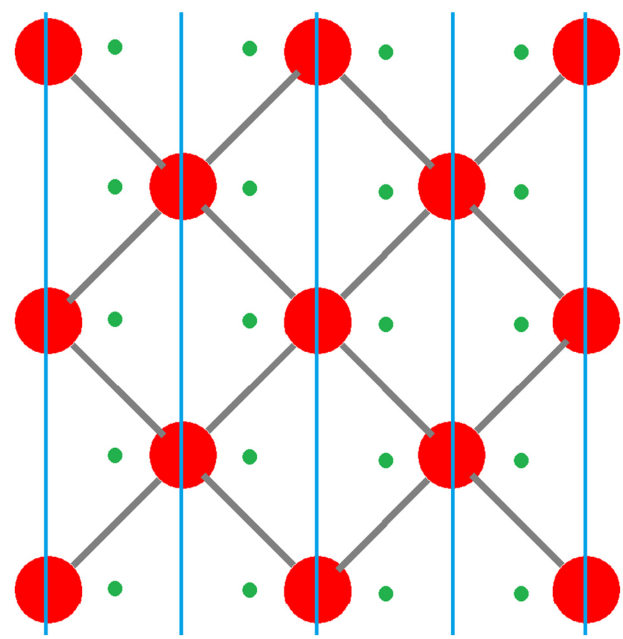

Fig. 3. Diamond lattice for ⟨1 0 0⟩ direction. Small green circles are positions of deuterium atoms, and large red circles are positions of carbon atoms. Blue vertical line are the (400) channeling planes.

between the channeling plane and passes near the deuterium atoms situated in the target, which should lead to the enhancement of the DD-reaction yield.

The simulations of the ions trajectories are carried out using the code Basic Channeling with Mathematica™ (BCM-1.0) [11]. This code computes numerical solutions of the classical equations of motion using the model of continuum potential. Results of calculation of trajectories for 20 keV deuterium ions in a C crystal channeled along (400) plane are depicted in Fig. 4. Because the potential for planar-channeled positive particles is close to harmonic, the trajectories are characterized by a single oscillation wavelength λ and the oscillation period weakly depend on initial transversal coordinate. So the bright flux peaking effect is clearly observed. For the crystal thickness equal to 0.06 μm can be observed the 12 maxima on the flux density function for ideal parallel beam (see, in Fig. 4b). Due to these maxima we expect the enhancement of the DD-reaction yield.

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