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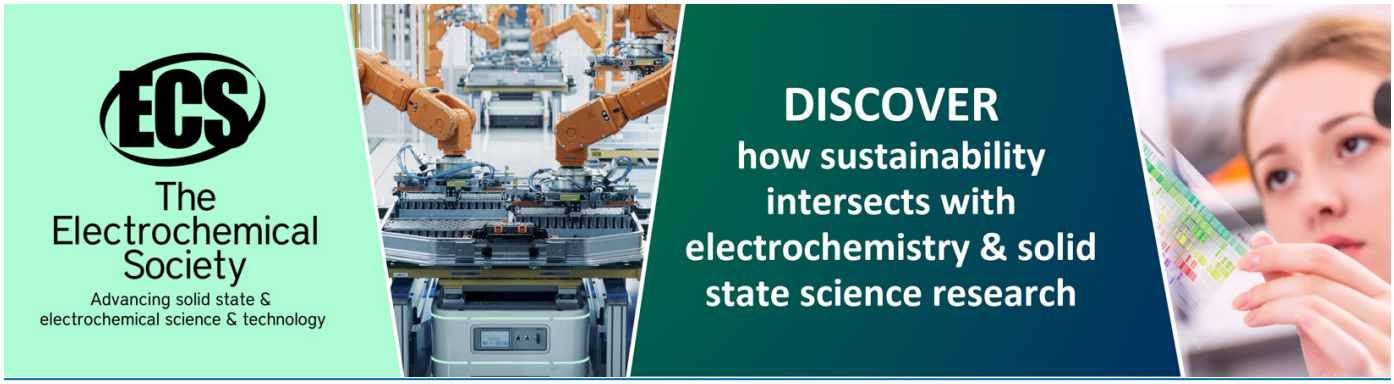

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Nanotubes based neutron generator for calibration of neutrino and dark matter detectors

A S Chepurnov[1,2], V Y Ionidi[2], M A Kirsanov[3], E P Kitsyuk[4], A A Klenin[1], A S Kubankin[1,5*], A N Oleinik[1], A A Pavlov[4], A V Shchagin[1,6]

[1] Laboratory of Radiation Physics, Belgorod National Research University, Koroleva St. 2a, Belgorod, 308034, Russia
[2] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Leninskie gory, GSP-1, Moscow, 119991, Russia
[3] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
[4] Institute of Nanotechnology of Microelectronics of the Russian Academy of Science, Leninskiy Prospekt 32A, Moscow, 119991, Russia
[5] Lebedev Physical Institute, Leninskiy Prospekt 53, Moscow, 119333, Russia
[6] Kharkov Institute of Physics and Technology, Akademicheskaya St. 1, Kharkov, 61108, Ukraine

E-mail: kubankin@bsu.edu.ru*

Abstract. The compact 2.45 MeV fast neutron generator with a reduced supply voltage for calibration of low-background neutrino and dark matter detectors was tested. The generator is based on an array of carbon nanotubes. Neutron generation is carried out by applying a high voltage in the range of +10 to + 25 kV to a nanotube array, which cause an ionization of deuterium molecules with the following acceleration of ions in the direction of the grounded target covered by a deuterated polyethylene film. The d(d,n)^{3}He nuclear reaction happens as the result of ions collisions with the target. The dependences of the neutron yield as functions of the applied voltage were obtained for two different types of carbon nanotubes array. It is shown that the type of nanotubes array does not influence significantly on the neutron yield.

1. Introduction

The generation of neutrons via the d(d,n)^{3}He reaction is widely used in various of neutron sources [1, 2]. This reaction is very convenient because of the low energy threshold, which allows to use low energy ion accelerators and obtain neutron flux up to 10^{10} neutrons per second. Also, the useful advantage in some applications is the monochromaticity of the neutron flux. Such generators are widely used for such applications as a neutron diffraction, a neutron activation analysis, a neutron defectoscopy, etc.

The problem to have low-intensive neutron fluxes (about several hundreds of particles per second to the entire solid angle) for a calibration of low-background neutrino and Dark Matter detectors becomes actual recently [3, 4]. An elastic scattering of monochromatic neutrons on nuclei of the

detector's target (usually liquid noble gases, such as LAr and LXe) causes the motion of nuclei and imitates such effects as coherent neutrino scattering or WIMP particles elastic scattering on baryonic matter. This effect permits to inspect all the detector systems and be sure that useful rare events will be fixed. Almost monochromatic and isotropic neutron yield could be reached via $d(d,n)^3He$ reaction within the neutron generator when the deuterium ions have energy range of 10-30 keV [4]. However, compactness of neutron generator dedicated for a detector calibration is strictly desirable in order to embed it into a low-background detector as close as possible to the sensitive ultra-low-background target. Such requirement makes it difficult to use standard neutron generators in the form of neutron tubes.

It was proposed to use a pyroelectric neutron generator [5, 6] for calibration of low-background detectors, but an instability of the electric potential generated by this source, low deuterium ion current, and a degradation of a deuterium ionizer - a single tungsten tip did not allow to obtain stable neutron flux level and limits life time of the device.

Another possible way to develop a compact neutron generator is to use many ionizers of deuterium molecules to increase an ion current. However, within the pyroelectric neutron generator these improvements will not give serious improvements due to a limited total charge, which is generated due to the a pyroelectric effect. The smaller amount of a charge per an individual ionizer causes consequently a lower efficiency of the ionization of deuterium [7]. Modern advances in semiconductor electronics make it possible to construct extremely compact 10-30 kV controllable high-voltage sources with output current of up to hundreds of microamperes with a primary power from a DC low voltage source or even from compact batteries. Such sources can be used to feed a high potential to initiate the $d(d,n)^3He$ reaction. To increase the efficiency of keeping the compactness we propose to use an array of carbon nanotubes (CNT) as an ionizer of deuterium.

2. The experimental results

Carbon nanotubes have been synthesized by plasma-enhanced chemical vapor deposition (PECVD) process on a n-type high-conductive silicon substrate in Institute of Nanotechnology of Microelectronics of the Russian Academy of Science. Aluminum layer (thickness – 0.5 μm) and catalyst (25 nm Ti and 5 nm Ni) were deposited on a silicone substrate. The CNT array is located in central part on a surface of substrate and forms a circle with a diameter of about 1.5 mm, the substrate itself have a size of 4*4*0.4 mm. The height of CNT array varied from 2 to 4 μm. Two types of CNT array were prepared: substrates with accidentally oriented nanotube bundles and substrates with vertically oriented nanotube bundles, (see Figure 1).

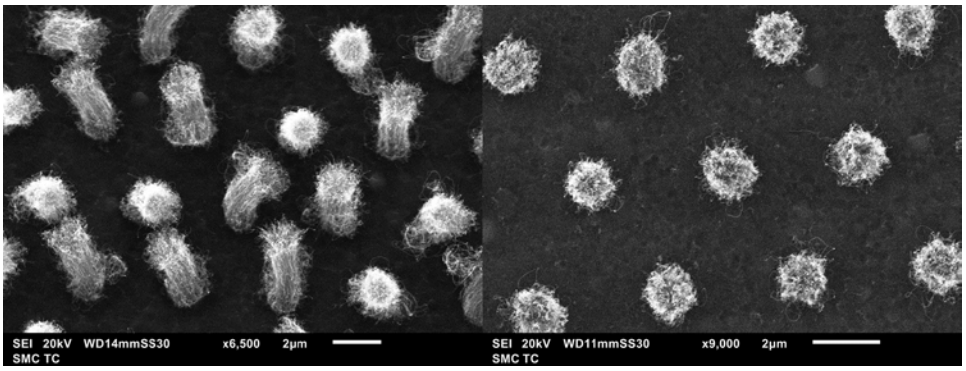

Figure 1. Image of fragments of the array of carbon nanotubes on Si substrate, obtained by scanning electron microscope (Performed in the NME RAS). Right - CNT with vertical orientation, left - with accidental orientation.

The scheme for testing the neutron generator on nanotubes is shown in Figure 2. The substrate with array of CNT (1) was fixed by electrically conductive epoxy glue in the duralumin holder (1), which in turn was fixed to a vacuum high-voltage input. The electric potential was applied to the CNT array via high-voltage positive-polarity source. The stainless-steel target (2), which is covered by deuterated film was mounted opposite the CNT array (dimensions of target: 50 * 30 * 0.8 mm) and grounded.

When high electric potential is applied to the CNT array (1), deuterium molecules are ionized by an electric field near tips of nanotubes and positive ions are accelerated to the target (2). The $d(d,n)^3He$ reaction is becomes possible, when accelerated ions react with a deuterium atom in the deuterated film on a target surface. The neutron yield is almost isotropic relatively a velocity of incident ions, so a position of neutron detectors could be selected according a convenience of the general setup construction. The neutron yield was measured by two instruments in parallel. One detector (4) is the fast neutron spectrometer with an organic scintillator (para-terphenyl) and photomultiplier with implemented digital pulse shape discrimination algorithm for separation gamma/neutron events. The second detector of neutron was ^{3}He-counter (3). Both detectors were located outside the vacuum chamber.

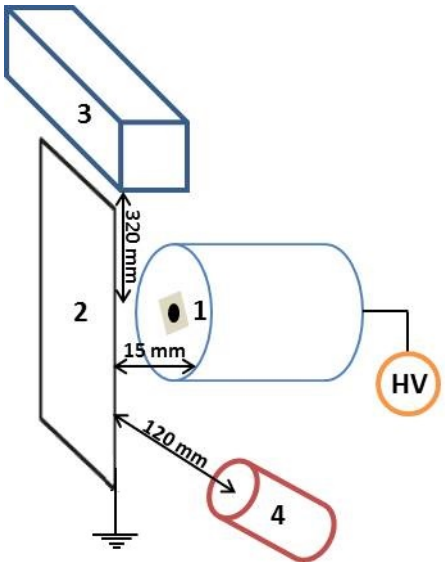

Figure 2. The scheme for testing the neutron generator on nanotubes. 1- duralumin holder with fixed silicon substrate with CNT array, 2 - target with deuterated film, 3 - ^{3}He counter, 4 - neutron scintillation spectrometer.

The neutron yield was measured as a function of a pressure of residual gas and the applied voltage for two different types of CNT arrays. As the residual gas pressure and the potential, which applied to the CNT array rise, the neutron yield increases and reaches about 40-50 neutrons per second at the pressure of 5 mTorr and the potential of +25 kV both for the array of vertically oriented CNT, and for the array with accidentally oriented CNT. There is no visible difference between two types of CNT array from the point of view of the possibility of neutron generation. Comparable amount of neutrons was observed at the same pressure and applied potential parameters with both types of CNT arrays. Figure 3 shows results of the experiment.

Thus, it was confirmed experimentally the possibility of neutron generation via $d(d,n)^3He$ reaction when deuterium ions are created in an electric field near the tips of the carbon nanotube array by applying positive potential of 10-25 kV with the following acceleration by same potential to the grounded deuterated target.

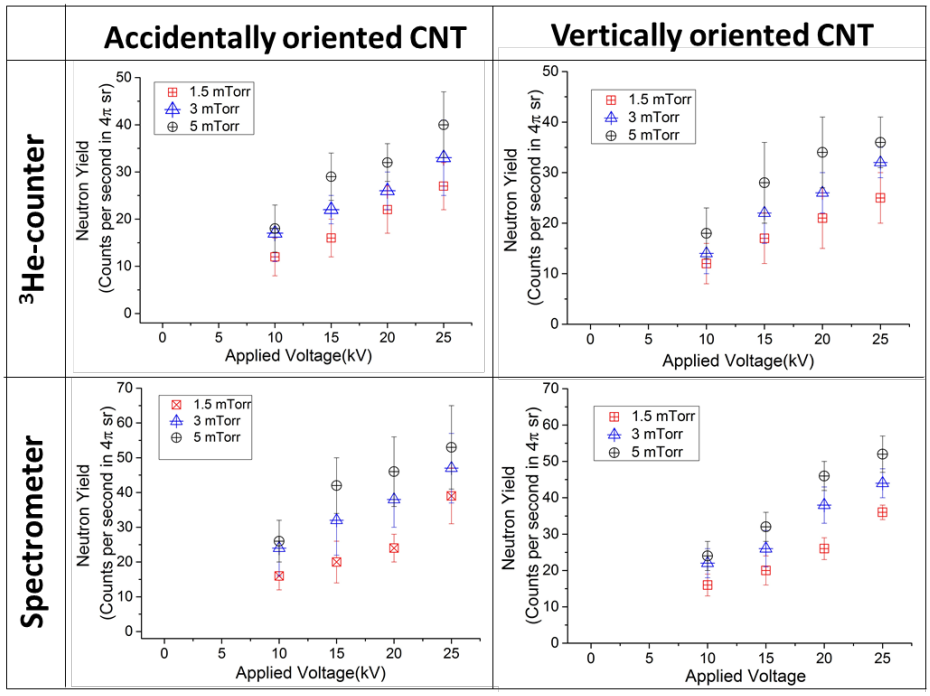

Figure 3. Dependence of the neutron yield on the residual gas pressure and the applied potential for two different types of CNT arrays, which measured using ^{3}He counter and scintillation spectrometer.

3. Conclusion

The experimental results extend an area of carbon nanotubes applications, and shows perspectives to use the phenomenon of atoms and molecules ionization by means of nanostructures. The possibility to construct a compact neutron generator based on the described construction is shown. Such a neutron source can be used, in particular, for a calibration of low-background neutrino and Dark Matter detectors.

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References

[1] Reijonen J, Lawrence E 2005 *Proc. of Part. Acc. Conf.* (Knoxville: Tennessee 49)
[2] Leung K N *et al*.1991 *Rev. Sci. Instrum.* **62 (1)** 100
[3] The DarkSide project 2016 *JINST* **11** C02051
[4] Hagmann C, Bernstein A 2004 *IEEE Trans. Nucl. Sci.* **51**. 2151
[5] Chepurnov A S *et al*. 2016 *J. Phys.: Conf. Ser.* **675** 032031
[6] Chepurnov A S *et al*. 2017 *J. Phys.: Conf. Ser.* **798** 012119
[7] Geuther J A 2007 Ph.D. thesis