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Virtual experiment of pyroelectric fusion

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ABSTRACT

The virtual experiment of pyroelectric fusion was conducted by Geant4 simulator. Despite the limitations of the code for simulating the pyroelectric fusion experiment precisely, the following interesting results were obtained. Two crystals were separated by a certain distance. A constant electric field with varying intensities was applied between the crystals. As initial particles, deuterium ions were emitted to deuterated polypropylene (CD_2). This virtual experiment showed that the number of ions that hit the target, for different distances between the crystals, increases with the increase of the intensity of the electric field; however, further increase of the electric field results in the reduction of the number of hit ions, which attains a constant value of about 57% of the initial number of ions. For a (D, D) fusion reaction to occur, the distance between the two crystals should be <1.5 cm and for a (D, T) fusion reaction to occur, this distance could be up to 2 cm. The energy spectra of ions for low and high electric fields were narrow and long and wide and short, respectively.

1. Introduction

The well-known X-ray generator manufactured by Amptek Inc. operates using a pyroelectric crystal. This is a good example that in some cases, the common X-ray tube generators could be replaced by this new technology in the future. This technology has advantages such as low energy consumption, small size, and simplicity, which could be the reasons for its recent application in X-ray fluorescent spectroscopy [1]. Brownridge innovation, using $LiTaO_3$ or $LiNbO_3$ as electron accelerator in X-ray generators, created an outstanding opportunity to downsize the common X-ray generators [2]. The electric dipoles of a typical pyroelectric can produce an electric field of up to 1.35×10^7 V/m by heating and cooling the crystals with temperature of about $\Delta T \approx 70$ °C [3]. Because of this strong electric field, the electrons accumulated on the surface of the crystal would be emitted to the space. A vacuum condition, in the range of mTorr, is required for this effect to occur; otherwise, the electrons accumulated on the surface of the crystal will be absorbed by surrounding particles in the space, such as water vapor, which prevent the emission of electrons from the crystal surface.

The production of X-rays using a pyroelectric crystal was explained. In 2005, Naranjo et al. [4], at University of California, Los Angeles (UCLA), showed that neutrons can be produced using a pyroelectric crystal by the following fusion reaction:

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

They used only one pyroelectric crystal for their experiment that could accelerate deuterium ions up to 115 keV energy. In another experiment conducted by Geuther and Danon [5] two crystals were placed facing each other with −z and +z surfaces. The reasons for this type of arrangement are a stronger electric field can be produced between the two crystals, the possibility of the number of deuterium ions produced can be increased, and the energy of these ions can also be increased. Several experiments were conducted by varying the crystal dimensions – length or width – and the distance between the crystals. It was reported that the maximum neutron production efficiency could be achieved by increasing both the emitter length and target width [6]. The accumulated charges Q on either of the surfaces, +z or −z, can be obtained by the following equation:

$$Q = \gamma A_{cr} \Delta T, \quad (2)$$

where γ is the pyroelectric coefficient, A_{cr} is the crystal surface, and ΔT is the differential temperature applied to the crystal. The arrangement of two opposing crystals could be considered as a parallel-plate capacitor; therefore,

$$C_{cr} = \varepsilon_{cr} \varepsilon_o (A_{cr}/d_{cr}), \quad (3)$$

where C_{cr} is the capacitance of the two-crystal system, ε_{cr} is the two-crystal relative static permittivity, ε_o is the permittivity of vacuum (8.854×10^{-12} F/m), and d_{cr} is the thickness of the crystals. The electric potential of the system could be obtained by:

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$$V = 2Q/C_{cr}. \quad (4)$$

Substituting Eqs. (2) and (3) into Eq. (4) will give:

$$V = 2\gamma\Delta T d_{cr}/\varepsilon_{cr}\varepsilon_o, \quad (5)$$

which shows that the electric potential is independent of the crystal surface size. Therefore, for crystals with constant thickness, increasing or decreasing the surface area (that is accumulated with charges) has no effect, and the accelerating energy of charged particles between the two crystals would remain within a certain limit. In the pyroelectric fusion method, the crystal(s) and the heater/cooler systems are sealed in a chamber containing deuterium gas at low pressure of mTorr level. The crystal with positive charges on its surface will ionize the deuterium atoms with the same charge; consequently, the ionized atoms will be repelled and accelerated toward the other crystal with negative charges. However, because of surface charge density, reducing the surface size would increase the ionization capability. In order to drive ions better, in most experiments, a needlestick-type conductor – in the range of micrometers – was used [7].

This article simulated the pyroelectric fusion experiment by the well-known Geant4 code. Unfortunately, there were some limitations in using this code for the experiment, that is, the code could not define: the pyroelectric property, and as a result, the accumulated charges, ionized gas atoms, and most importantly, the (D, D) and (D, T) reactions. Therefore, this virtual experiment concentrates on the D+ activity when it is placed in an electric field.

2. Virtual experiment

As depicted in Fig. 1, a virtual experiment was arranged with two cylindrical $LiTaO_3$ crystals of 1-cm diameter and 2-cm length, placed facing each other with a distance of 1 cm between them. It should be noted that the Geant4 code cannot process pyroelectric properties, and therefore, the crystal dimensions will not affect the final result of the code. An electric field with varying intensities was applied between the crystals. The entire system was placed in a chamber filled with deuterium gas under 1 mTorr pressure. Fig. 1 depicts the arrangement of the virtual experiment for electric field intensities of 50, 80, 100, and 150 kV/cm. In the electric fields with low intensities of 50 kV/cm, the ions lose their energy at the very beginning, and with increasing intensities of the electric field, they regain enough energy to move toward the target.

The surface of the crystal on the left-hand side of Fig. 1 is layered with copper, and a tungsten needle is inserted in the middle. It should be noted that their sizes would not have any effect on the simulation process and results. On the right-hand-side crystal surface, 0.5-mm-thick deuterated polypropylene (C_nD_{2n}) is layered as a target. This compound is the same as C_nH_{2n}, with hydrogen replaced by deuterium. In a real experiment, when the crystal is heated, the density of created positive charges is increased, and they are pushed to the needle tip. Because of the high concentration of positive charges on the tip of the inserted needle, the deuterium atoms near the needle became ionized. In view of the fact that the polarities of D+ ions and the needle were equal, the D+ ions were repelled and accelerated with an initial energy toward

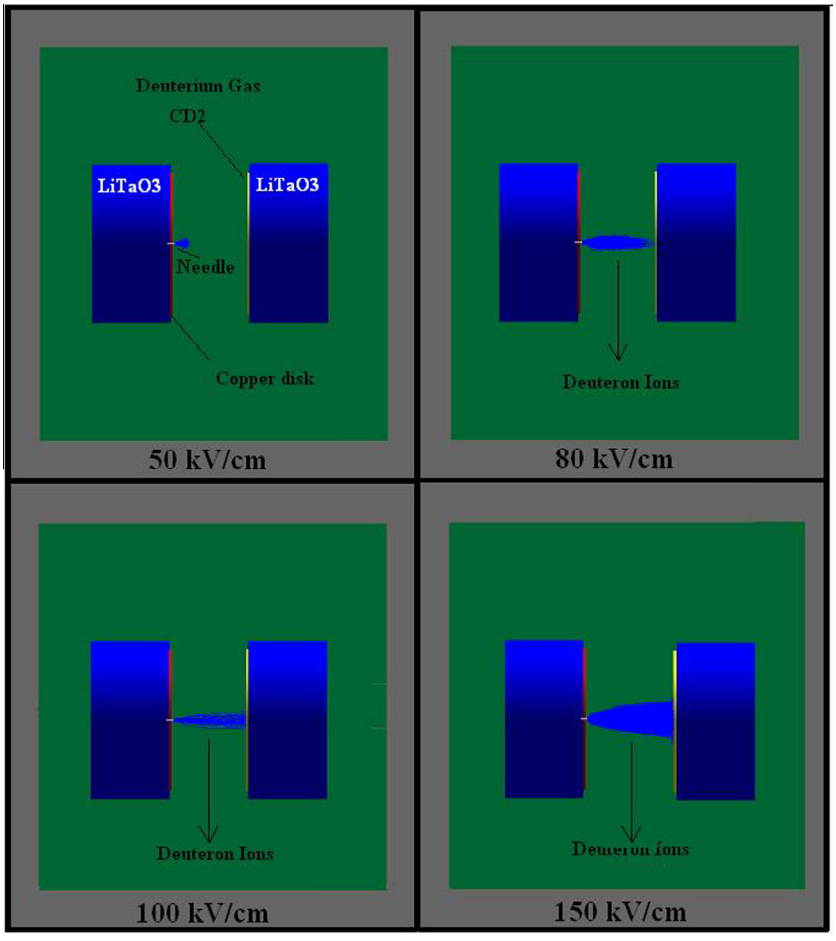

Fig. 1. Schematic view of the virtual experiment for pyroelectric fusion.