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Pyroelectric accelerator and X-ray source in pulsed mode

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Abstract: The conception of operation of the pyroelectric accelerator and X-ray source in pulsed mode is at first proposed and demonstrated experimentally. The pulsed mode became possible due to application of the additional controlled source of electrons in the pyroelectric accelerator. In the proof-of-principle experiment, the power of X-ray radiation in pulsed mode increased one in common quasi-continuous mode in more than two orders of magnitude. Perspectives for further increasing of the power and application of pulsed pyroelectric X-ray source in fast X-ray imaging are discussed.

Keywords: Accelerator Applications; Interaction of radiation with matter; X-ray detectors; Lasers

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1 Introduction

To date, there are a few kinds of the miniature pyroelectric accelerators of charged particles and X-ray sources. They are based on a single pyroelectric crystal [1–6], or pair of the pyroelectric crystals [7, 8] or ferroelectric ceramics [9, 10]. Such accelerators operate in the quasi-continues mode, when electrons produced in residual gas around the pyroelectric crystal or target accelerate in the electric field of the pyroelectric crystal up to the energy about 100 keV during minutes until the pyroelectric discharges. Such sources can be used as electron and ion emitter [11], neutron source [12–15] and in X-ray fluorescence measurement setups [16], mass spectrometry [17], electron probe microanalyzer [18], cathodoluminescence spectrometer [19]. Here, we at first propose and demonstrate experimentally the pyroelectric accelerator and X-ray source operating in pulsed mode. The pulsed mode is possible due to application of additional source of charged particles. In described here proof-of-principle experiment, we used grounded filament with controlled current as the simplest additional source of electrons which further accelerated in the electric field of pyroelectric crystal. The application of such mode allowed to increase sufficiently the pulsed power of observed X-ray flux.

2 Experiment

The experimental setup is presented in figure 1.

Pyroelectric crystal $LiNbO_3$ with base size 20×20 mm and height 10 mm was installed on the grounded aluminum heat-conductor of diameter 40 mm. The Z axis of the crystal was perpendicular to the base. The heating of the pyroelectric crystal was provided by the silicon diode MUR 1560 located on back side of the heat-conductor. New method of crystal heating with use of a semiconductor driver was applied in the experiment. This method is proposed and experimentally verified recently in ref. [20]. In present experiment, the heating of the pyroelectric crystal was provided by the silicon diode MUR 1560 installed in vacuum on back side of the heat-conductor.The X-ray spectrometer consisted of CdTe detector and pulse processor PX-5. The entrance window of

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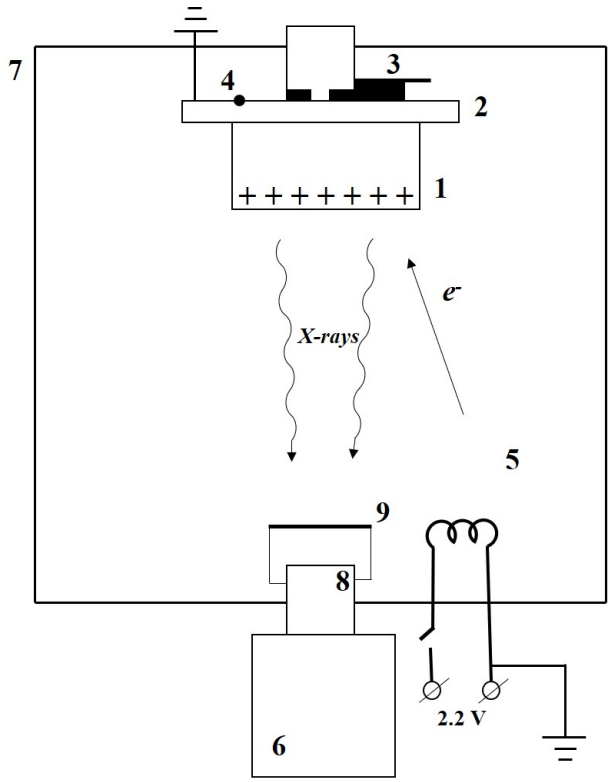

Figure 1. The experimental setup. 1 — pyroelectric crystal $LiNbO_3$, 2 — aluminum heat-conductor, 3 — silicon diode MUR 1560, 4 — thermocouple K type, 5 — filament, 6 — semiconductor X-Ray detector, 7 — vacuum chamber, 8 — entrance Beryllium window of the X-ray detector, 9 — maylar foil installed in front of the entrance window of the detector.

the detector made of 100 μm Be foil was installed in the vacuum chamber at distance 50 mm from the crystal. The Maylar foil of thickness 100 μm was installed in front of the entrance window. The peaking time of spectrometer was 0.8 μs. Energy calibration of the spectrometer was performed using X-ray lines of radioactive source ^{237}Np.

The filament as addition electron source was installed near the detector at the distance about 30 mm from the detector. The construction of the filament is described in ref. [10]. The voltage supply of the filament was 2.2 Volts. The temperature was measured by the thermocouple K type installed on the back side of the aluminum heat-conductor. The experiment was performed at the residual gas pressure in the chamber 0.1 mTorr.

Primarily, the pyroelectric crystal was heating by the silicon diode in 300 seconds from the room temperature to 75°C. This leaded to arising of the positive charge and potential on the free crystal surface due to the pyroelectric effect. Electrons from the residual gas of the vacuum chamber accelerated toward the positively charged crystal surface, struck it and produced X-rays. The X-ray spectrum measured during the 300 second heating is shown in figure 2a. Such quasi-continuous mode is typical for pyroelectric accelerators and X-ray sources, see, e.g. [1–10]. After that the filament was tuned on. The increased electron flux from the filament discharged crystal for 5 seconds and produced much more intensive X-ray flux. This is pulsed mode. The radiation cease after crystal discharge. The X-ray spectrum measured during the 5 second discharge is shown in figure 2b.

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3 Results

Both spectra shown in figure 2 contain spectral peaks of the characteristic X-ray radiation and on the background of the bremsstrahlung. End point of the bremsstrahlung X-rays in the both spectra is 30 keV that means the maximum energy of accelerated electron is 30 keV and maximum potential at the crystal surface is 30 kV. The spectral peaks with the energies 16.62 keV and 18.62 keV corresponded to K_α and K_β lines of the Nb atom composing the pyroelectric crystal. Total number of counts in spectrum measured in quasi-continuous mode (figure 2a) was $3 \cdot 10^4$ and in spectrum measured in pulsed mode (figure 2b) was $3 \cdot 10^5$.

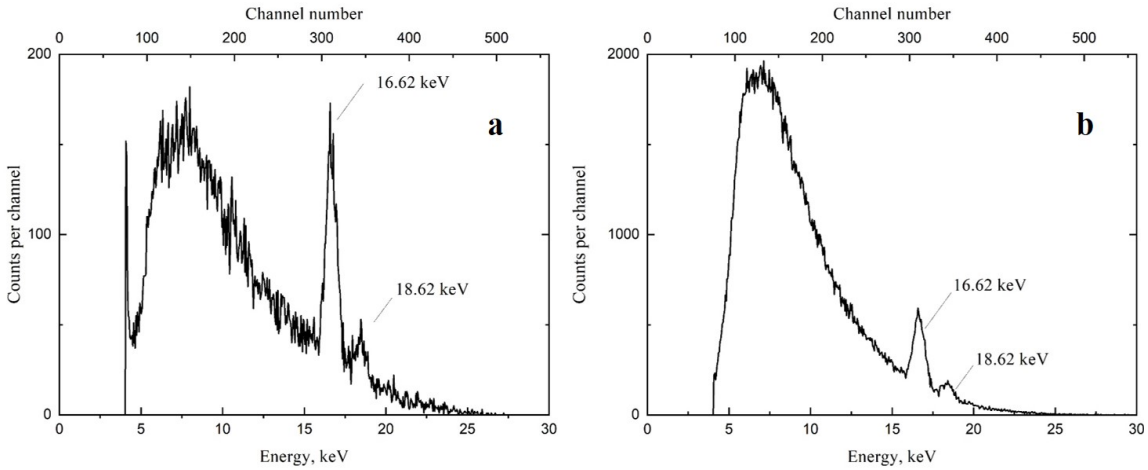

Figure 2. The spectra of X-ray radiation measured in quasi-continuous mode at the heating of the pyroelectric crystal from 25°C to 75°C during 300 s (a), and in pulsed mode after turning on the filament at 75°C during 5 seconds (b).

In spite of both spectra shown in figure 2 have similar shapes, intensity of radiation is different. The average count rate in quasi-continuous mode is 100 counts per second but in pulsed mode it is 60000 counts per second. This means the power of X-ray radiation in pulsed mode exceeds one in common quasi-continuous mode 600 times.

4 Discussion

In present paper we described principle possibility for operation of pyroelectric accelerator and X-ray source in pulsed mode. We used very slow controlled additional source of electrons because the filament is heated and begins to emit electrons during period of time close to one second. One can use much quicker for a few orders of magnitude controlled additional sources of electrons such as controlled by grounded grid cathode or photocathode controlled by short laser pulses. In this case duration of crystal discharge and X-ray pulse would be much shorter and power of the X-ray flux would be proportionally increased for a few orders of magnitude.

The grounded photocathode can be used at positive charge at the crystal surface and the photocathode installed on crystal surface can be used at negative charge at the crystal surface. Application of photocathode(s) will allow operation of pulsed pyroelectric X-ray source at heating

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and cooling of the pyroelectric element. Note at application of two cathodes (one of them grounded and second on the crystal surface) one does not need in a residual gas as a source of electrons. Therefore, the pressure in pyroelectric source can be sufficiently reduced.

Miniature pulsed pyroelectric source without outer high voltage power supply can be used, e.g., for obtaining of fast X-ray images.

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References

[1] J.D. Brownridge, *Pyroelectric x-ray generator*, *Nature* **358** (1992) 287.

[2] B. Rosenblum, P. Bräunlich and J. P. Carrico, *Thermally stimulated field emission from pyroelectric LiNbO3*, *Appl. Phys. Lett.* **25** (1974) 17.

[3] J.D. Brownridge and S. Raboy, *Investigations of pyroelectric generation of x rays*, *J. Appl. Phys.* **86** (1999) 640.

[4] J.D. Brownridge and S.M. Shafroth, *Self-focused electron beams produced by pyroelectric crystals on heating or cooling in dilute gases*, *Appl. Phys. Lett.* **79** (2001) 3364.

[5] J.D. Brownridge and S. M. Shafroth, *X-ray fluoresced high-Z (up to Z = 82) K X-rays produced by $LiNbO_3$ and $LiTaO_3$ pyroelectric crystal electron accelerators*, *Appl. Phys. Lett.* **85** (2004) 1298.

[6] A.S. Kubankin, A.S. Chepurnov, O.O. Ivashchuk, V.Y. Ionidi, I.A. Kishin, A.A. Klenin et al., *Optimal speed of temperature change of a crystal in a pyroelectric x-ray radiation source*, *AIP Adv.* **8** (2018) 035207.

[7] J.A. Geuther and Y. Danon, *Electron and positive ion acceleration with pyroelectric crystals*, *J. Appl. Phys.* **97** (2005) 074109.

[8] J.A. Geuther and Y. Danon, *High-energy x-ray production with pyroelectric crystals*, *J. Appl. Phys.* **97** (2005) 104916.

[9] A.V. Shchagin, V.S. Miroshnik, V.I. Volkov and A.N. Oleinik, *Ferroelectric ceramics in a pyroelectric accelerator*, *Appl. Phys. Lett.* **107** (2015) 233505.

[10] A. Shchagin, V. Miroshnik, V. Volkov, A. Kubankin and O. Ivashchuk, *Ceramic piezoelectric transformer in vacuum for acceleration of electrons and production of x-rays*, *Materials* **11** (2018) 1188.

[11] M. Hockley and Z. Huang, *Strong electron and ion emissions induced by a pyroelectric crystal*, *J. Appl. Phys.* **113** (2013) 034902.

[12] B. Naranjo, J. Gimzewski and S. Putterman, *Observation of nuclear fusion driven by a pyroelectric crystal*, *Nature* **434** (2005) 1115.

[13] J. Geuther, Y. Danon and F. Saglime, *Nuclear Reactions Induced by a Pyroelectric Accelerator*, *Phys. Rev. Lett.* **96** (2006) 054803.

[14] W. Tornow, S. M. Shafroth and J. D. Brownridge, *Evidence for neutron production in deuterium gas with a pyroelectric crystal without tip*, *J. Appl. Phys.* **104** (2008) 034905.

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[15] D. Gillich, A. Kovanen, B. Herman, T. Fullem and Y. Danon, *Pyroelectric crystal neutron production in a portable prototype vacuum system*, *Nucl. Instrum. Meth.* **A 602** (2009) 306.

[16] J. Kawai, H. Ida, H. Murakami and T. Koyama, *X-ray fluorescence analysis with a pyroelectric x-ray generator*, *X-Ray Spectrom.* **34** (2005) 521.

[17] E.L. Neidholdt and J.L. Beauchamp, *Compact ambient pressure pyroelectric ion source for mass spectrometry*, *Anal. Chem.* **79** (2007) 3945.

[18] S. Imashuku and K. Wagatsuma, *Portable pyroelectric electron probe microanalyzer with a spot size of 40* μ*m*, *Rev. Sci. Instrum.* **88** (2017) 023117.

[19] S. Imashuku, N. Fuyuno, K. Hanasaki and J. Kawai, *Note: Portable rare-earth element analyzer using pyroelectric crystal*, *Rev. Sci. Instrum.* **84** (2013) 126105.

[20] O.O. Ivashchuk, A.V. Shchagin, A.S. Kubankin, V.Y. Ionidi and A.S. Chepurnov, *Semiconductor driver of pyroelectric accelerator of charged particles*, *Prob. At. Sci. Technol.* **2019** (2019) 81.

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