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X-RAY GENERATION DURING PIEZOELECTRIC LIGHTER OPERATION IN VACUUM

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The results of experimental studies on the generation of x-rays when operating a piezoelectric kitchen lighter in a vacuum are presented. For the first time, a new method for increasing the intensity of x-ray radiation in the piezoelectric effect in a high vacuum through the use of an additional electron emitter is proposed and demonstrated. The maximum energy of x-ray bremsstrahlung reaches 14 keV. This means that electrons are accelerated in vacuum in the field of a piezoelectric ceramic to energy of at least 14 keV.

Key words: piezoelectric lighter, generation of x-rays, electron emitter, piezoelectric ceramic.

Recently, several new approaches have been proposed to the development of miniature electron accelerators and x-ray generators with energy up to tens of keV without the use of external high-voltage power supplies.

One such compact source is an electron accelerator and an x-ray generator based on: the pyroelectric effect in vacuum, using single crystals (as a rule, lithium niobate or lithium tantalate) [1 – 3] or ceramics [4, 5] and the triboelectric effect in vacuum [6, 7]. Pyroelectric sources can be used: as an emitter of electrons and ions [8, 9] and a neutron generator [10 – 13]; in installations for measuring x-ray fluorescence [14]; in mass spectrometry [15]; in an electron probe microanalyzer [16]; and, in a cathode-luminescence spectrometer [17]. Research is being conducted on the operation of a pyroelectric source in a pulsed mode [18, 19]. Recently, the generation of x-rays with cutoff energy 12 keV was discovered when a piezoelectric ceramic transformer operated in vacuum [20 – 22]. The possibility of using dielectric channels to control beams of accelerated electrons with energy up to 10 keV is demonstrated in [23]. An electron accelerator

based on the piezoelectric effect in vacuum is of scientific and practical interest. Such an accelerator was first proposed in [24]. The generation of x-rays with limiting energy up to 60 keV in such an accelerator was observed on changing of the mechanical load applied to samples of the piezoelectric ceramic lead zirconate-titanate-borate [24] and quartz single crystals [25] in vacuum.

In the present work we investigate the generation of x-rays when the piezoelectric lighter mechanism [26] operates in a vacuum, which provides sufficient mechanical pressure on piezoelectric samples in vacuum to generate x-rays without resorting to a bulky deformation machine system [24, 25]. This embodiment of the piezoelectric generator can be considered as a miniature device in which the conversion of mechanical energy into x-ray energy occurs. It is assumed that the enhancement of the x-ray generation effect during operation of a piezoelectric lighter in a high vacuum of about 10^{-6} Torr (1.33×10^{-4} Pa) can be observed when using an additional source of electrons, which can be a filament [18].

EXPERIMENT

A schematic diagram of the experimental setup is shown in Fig. 1. Experimental studies were performed in the radiation physics laboratory at Belgorod State National Research University. A mechanically driven piezoelectric lighter with an additional high-voltage electrode, a filament, and an x-ray spectrometer detector are arranged in the vacuum chamber.

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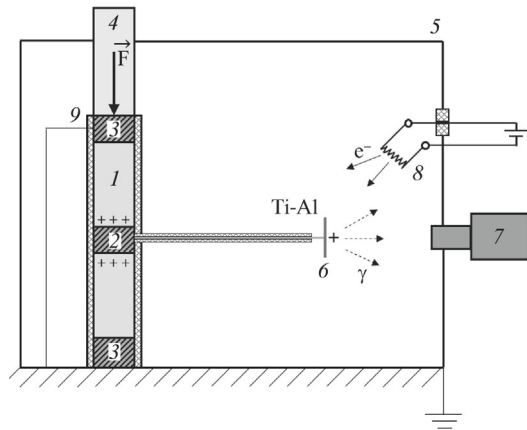


Fig. 1. Schematic diagram of the experimental setup: 1) an assembly of two piezoelectric ceramic samples made of the material TsTBS-3M; 2) central high-voltage electrode; 3) grounded metal disks; 4) metal cylinder providing a force F ; 5) vacuum chamber; 6) additional high-voltage electrode, titanium-aluminum plate; 7) semiconductor x-ray detector; 8) electron emitter; 9) dielectric casing.

A piezoelectric lighter [26] (Monolit plant, Vitebsk, Belarus) with a common body, high-voltage wire, and metal tube, which are missing in its design, was installed in a vacuum chamber (Fig. 2). Its main structural elements are two cylindrical piezoelectric samples made of lead zirconate-titanate-borate ceramic (TsTBS-3M), 6.4 mm in diameter and 15 mm high, installed coaxially and mechanically in series between the power lever and the plate of the drive mechanism of the piezoelectric lighter.

The power lever is capable of providing a mechanical pressure of about several tens of megapascals on piezoelectric samples when a force of the order of several tens of newtons is applied to it from a mechanical manipulator on the outside of the vacuum chamber. A central high-voltage electrode made in the form of a metal disk 6.4 mm in diameter and 1 mm high was situated between the piezoelectric cylinders. The back surfaces of each piezoelectric were fixed on metal grounded disks connected to both parts of the drive mechanism (power arm and metal plate), with a diameter and height equal to those of the central high voltage electrode.

For additional insulation in order to avoid surface breakdowns, the assembly of the piezoelectric samples and the central electrode in the construction of the piezoelectric lighter is situated in a dielectric casing. The spontaneous polarization vectors of each piezoelectric are collinear but oppositely directed. During normal operation of the lighter in air a breakdown in the discharge chamber occurs at a voltage of several kilovolts and no dangerous x-ray radiation occurs.

The filament, which served as an electron emitter in the experiment, was located at a distance of about 200 mm from the central high-voltage electrode. We used a 3.5 V flashlight filament. The bulb glass was removed.

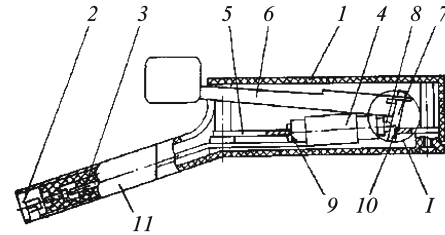


Fig. 2. Scheme of the longitudinal section of a piezoelectric lighter from [26]: 1) common body; 2) discharge chamber; 3) high-voltage wire; 4) block of piezoelectric elements; 5) plane-parallel plate of the drive mechanism; 6) manipulator lever; 7) power lever; 8) metal ball; 9, 10) metal disks; 11) metal tube.

An additional high-voltage titanium-aluminum alloy electrode was placed near the filament at a distance of about 10 mm, which was connected to the central high-voltage electrode of the lighter with an insulated conductor. The distance between the electrode and the detector was about 20 mm.

An x-ray spectrometer was used to register x-rays. It consisted of an Amptek SDD-100 semiconductor silicon detector with a 100 μm thick beryllium input window and a PX5 digital pulse processor. The spectrometer was calibrated with the help of an Amptek COOL-X pyroelectric x-ray source using tantalum L lines [27]. The peak time of the spectrometer was 1 μsec , and its collimated area was 17 mm^2 .

In experimental studies the spontaneous polarization vector of each piezoelectric was directed from the central high-voltage electrode to the grounded metal disks.

RESULTS

The experiments were performed at chamber pressure 3×10^{-6} Torr (4×10^{-4} Pa). A mechanical pressure of about several tens of megapascals, controlled by a manipulator from the outside of the vacuum chamber, was applied to an assembly of two piezoelectric samples situated in vacuum. The bottom of the vacuum chamber served as the base of the drive mechanism of the piezoelectric lighter.

The compression time was about 10 sec. Thus, a positive potential due to the piezoelectric effect was formed on the titanium-aluminum plate. An electric field accelerated the free electrons from the residual gas toward the titanium-aluminum plate. X-rays were generated when electrons were decelerated on the atoms of the plate. The x-ray spectrum measured during the compression of an assembly of two piezoelectric samples in vacuum and for the next 20 sec is displayed in Fig. 3a. Note that the cutoff energy of the x-ray radiation is 9 keV, and the total number of detected quanta within 30 sec (total measurement time) is 3752.

It is worth noting that the intensity of x-ray radiation recorded at the first stage of the experiment is rather low, about 125 quanta recorded per second in the entire spectrum. This

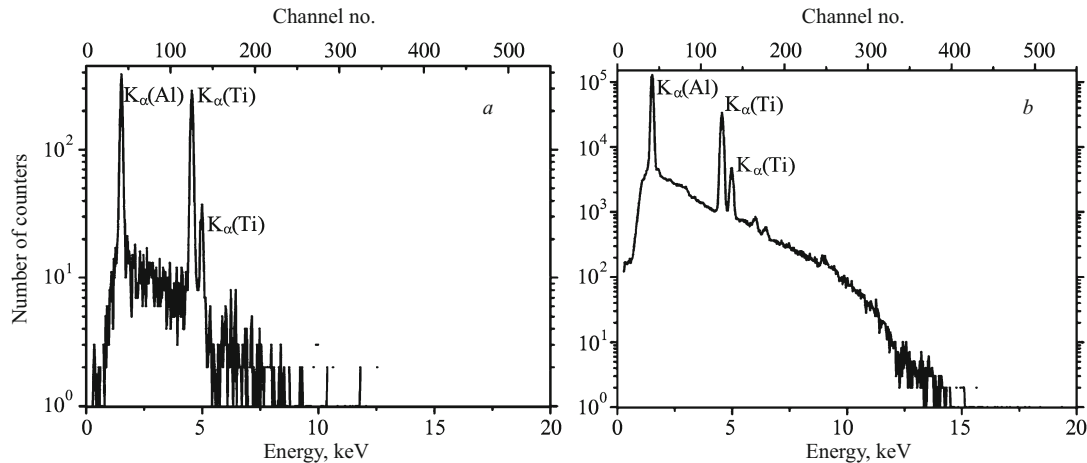


Fig. 3. X-ray spectra measured on compression of the piezoelectric ceramic TsTBS-3M with the help of the piezoelectric lighter mechanism with the filament turned off (*a*) and with compression and subsequent switching on of the filament (*b*) at a residual gas pressure of about 10^{-6} Torr (1.3×10^{-4} Pa).

low intensity can be explained by the low concentration of free charge carriers.

We used an additional emitter of electrons in order to increase the intensity.

At the completion of the first stage of the experiment a voltage of about 3.5 V was immediately applied to the filament. The filament emitted electrons, which gradually discharged the titanium-aluminum plate over the next 60 sec, which was accompanied by intense generation of x-rays.

The x-ray spectrum measured during 10 sec of compression of the piezoelectric ceramic, the next 20 sec, and with the filament turned on for 60 sec is shown in Fig. 3*b*. The spectrum clearly shows the characteristic lines of x-ray radiation with energies of 1.5, 4.5 and 4.9 keV, corresponding to the K_{α} and K_{β} atoms of aluminum and titanium (included in the plate), against the background of smoothly decaying bremsstrahlung radiation. The total number of detected quanta during 90 sec is 878,140. The cutoff energy of x-ray radiation is 14 keV. This means that the energy of the electrons accelerated to the titanium-aluminum plate is at least 14 keV, and the maximum positive potential at the high-voltage electrode is at least 14 kV. When the filament is turned on, the x-ray intensity rises sharply and reaches 14,573 quanta per second. The time for complete discharge of the crystal in this case is about 30 sec.

CONCLUSIONS

In summary, the possibility of x-ray generation when operating a piezoelectric lighter in vacuum has been experimentally confirmed. For the first time, an additional electron emitter was used in a piezoelectric accelerator. The additional electron emitter makes it possible to increase the intensity by two orders of magnitude and the maximum energy of x-ray radiation by approximately 1.6 times. It is worth noting that the proposed electron accelerator based on the piezo-

electric effect in vacuum is capable of generating intense x-ray radiation within a few seconds. The results of the performed experimental studies confirm the possibility of creating a miniature piezoelectric electron accelerator, based on the piezoelectric effect, up to an energy of at least 14 keV and an x-ray generator with a limiting energy of about 14 keV with an increased radiation intensity. In such devices mechanical energy is converted through the piezoelectric effect into the energy of accelerated electrons and the energy of x-ray radiation.

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