Compact High-Voltage DC/Pulsed Power Source

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ABSTRACT

The proposed device can generate DC and pulsed high voltage without any electronics with versatile power supplies (sun-light, laser, heat/cold, mechanical stress). The pulse mode of high-voltage generation can be controlled or can be achieved in self-pulsing regime. This pulse mode can be remotely activated by the pulsed laser or modulated sunlight.

The self-pulsing mode may transform CW laser light or CW incoherent illumination (for example, a sunlight) into short (millisecond-nanosecond) high-voltage pulses. Placed in modest vacuum, this power supply can be used as a compact crystal accelerator.

An early version of this technology has already reached a market as a compact and safe hand-held electron beam and X-ray source, powered by a small 9V battery. Additional potential applications are also predicted. They include a highly efficient conversion of the concentrated solar power into electricity, using a novel photo-galvanic effect (also called a bulk photovoltaic effect).

The developed compact, safe and cheap high-voltage source can be employed in materials science, radiation physics, space industry, medicine, food industry, and education.

Keywords: high voltage power supply, crystal accelerator, X-ray/electron beam source, self-focused electron beam, self-pulsing.

1 INTRODUCTION

We will describe a novel technology for high-voltage generation based on the ferroelectric material. Relatively new Bulk Photovoltaic Effect, also called a Photogalvanic Effect (PGE) [1-6], was discovered in ferroelectric materials, and has proved to be efficient in the generation of nanosecond high-voltage pulses (several hundred kV) as well as a DC high voltage. Technical applications of the photogalvanic effect are in the beginning state and all the potential advantages are still not widely publicized. To initiate PGE ferroelectric sample is illuminated by a proper light radiation that induces photoionization with generation of electrons and/or holes. At the same time, the absorption of photons may heat material, producing additional pyroelectric charging of the illuminated ferroelectrics. As an example, we have already successfully used a ferroelectric-based high-voltage pulser for a compact crystal accelerator that generates and accelerates an electron beam. Also, the feasibility of a crystal-based electron gun at >100 keV was illustrated by the development of a low-voltage (9 V) battery-operated ferroelectric electron gun used to generate X-rays in a commercial hand-held device [7].

Satisfying all the requirements on the regulated high voltage/short pulse output, a unique feature of the proposed device is its naturally small size due to the absence of any traditional external high-voltage source and that the device can be remotely powered with an infrared or visible light source, including concentrated Sun-light.

2 PHYSICAL BACKGROUND

An equivalent electric circuit of the photosensitive ferroelectric placed between electrodes in shown in Fig1

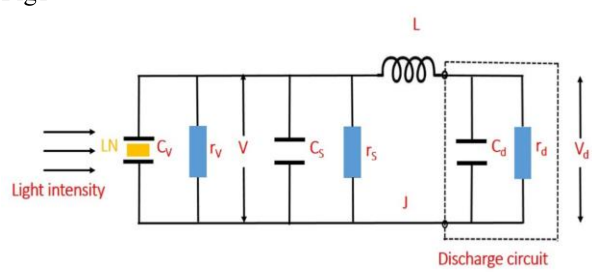

Fig.1 Equivalent electric circuit of photogalvanic/pyroelectric crystal: C_v, r_v –capacitance and resistance of the crystal volume. C_s, r_s – effective capacitance and resistance of crystal surface. L – inductance of the effective discharge circuit. V, J, V_d, C_d, r_d - output voltage and current, voltage, capacitance and resistance of the discharge circuit.

Our model includes both the photogalvanic and the pyroelectric contributions to the crystal charging [8].

To check the validity of this model, we have compared experimental results of paper [6] with our theory

A comparison with experimental results of [6], shows a reasonably good correlation with theory. In our modeling, a discharge voltage reaches 25 kV and the discharge current is 8 mA, the duration of the current pulse is 5 ms, period of pulsation T = 0.05 s. (sunlight experiment, T = 0.04 s)

3 EXPERIMENTAL RESULTS

Experimental results on the generation of electrical pulses under the concentrated sun illumination are shown in Figs 2, 3.

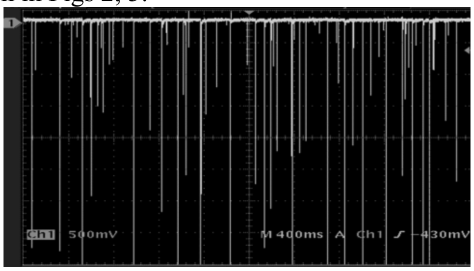

Fig.2 Electrical pulsations picked-up by a grid electrode from 0.1 % Fe:LN crystal illuminated by the concentrated solar light.

The electrical pulsations induced by the concentrated sun-light are shown in Fig.2, indicating that the detected frequency of electrical pulsations was about 15 Hz. A single current pulse with amplitude more than 30 A and a half-width ~ 0.5 ms is shown in Fig.3 .

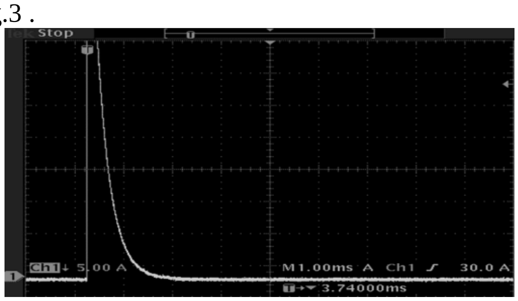

Fig.3. Current pulse observed in the sun-illuminated LN crystal (more than 30 A!)

The described above experimental results (Figures 2,3) show that we have observed electrical pulses in the Fe:LN-crystals illuminated by both pulsed and CW (including the sunlight) light sources. These electrical pulses have a different nature for CW (sunlight) and pulsed laser illumination.

4 COMPACT CRYSTAL ACCELERATORS

It was shown, that charging of pyrelectric crystal in modest vacuum by simple temperature cycling can create ionization of surrounding gas and acceleration of electrons and ions in a simple arrangement [1]. This effect was realized by Amptek in a commercial hand-held crystal X-ray generator [7].

A significant advantage of our compact electron-beam gun/crystal accelerator is that it is possible to achieve the optimal shape of the electron beam by choosing the optimal geometry of the crystal. Illustrated in Fig. 4 are circular and line-type focusing of the electron beam [1].

(a) (b)

Figure 4. Various shapes of focusing by a pyroelectric crystal generator electron beam visualized on ZnS: (a) Circular beam generated and focused (f=21 mm) by a cylinder LiNbO3 crystal 4 mm in diameter and 10 mm long; (b) Focusing electron beam as a line by a planar crystal 2 mm thick, 21 mm wide, and 10 mm long (along z-axis) [1].

In addition, we used this electron beam gun to generate X-rays, and took an image of a two-letter copper mask (TN). This is shown in Fig.5

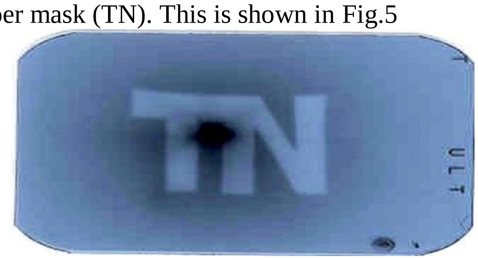

Figure 5. X-ray image, powered by a high-voltage generator on a ferroelectric crystal using photogalvanic/pyroelectric effects. Dark spot in the center illustrates a focusing effect of the generated electron beam that produced X-rays from the copper target.

A compact version of free electron laser (FEL) based on three crystals that serves as crystal electron beam generator [8] of a focused sheet-shape electron beam, electrostatic accelerator and electrostatic undulator is shown in Fig. 6

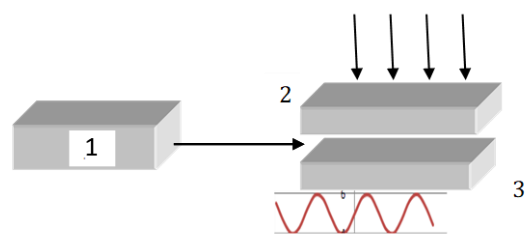

Fig.6. Schematic for modeling a plane electrostatic crystal undulator 1- Crystal accelerator, 2, 3- wave guided crystals, 3- crystal - modulator

An electrostatic undulator is formed by the fringing electric-field grating that may be holographically recorded in the photosensitive ferroelectric crystal.

Estimations show that for THz radiation gain may be reasonably good.

Another interesting effect, namely the generation of bright optical pulses, synchronized with the electrical pulses, is shown in Fig.7.

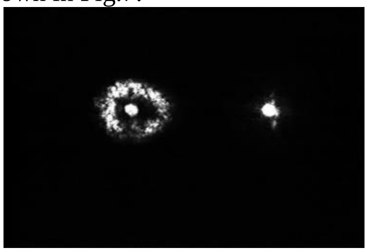

Fig. 7 Self-visualization of electrical photo-induced discharges, observed by illumination of ferroelectric crystal by a CW green laser

This effect can be called self-visualization of the photo-induced electrical discharges because electrical pulses modulate an effective reflection coefficient of the ferroelectric material under study.

5 DISCUSSION AND CONCLUSIONS

High voltage charging of ferroelectric materials by pyroelectric and/or photogalvanic effects is a physical basis of the compact crystal accelerator. It has been shown, that at high light intensity (when the generation rate of photoelectrons is higher than the recombination rate and the photogalvanic current depends on light intensity in a non-linear way) a conversion efficiency from light to electricity can be very efficient in photogalvanic crystals. Estimations performed for $LiNbO_3$ result in the conversion efficiency value of 80% for light intensity of $10^5 W/cm^2$ with external load resistance of 1 MΩ [5,9].

Another possible application of the compact electrical high-voltage source is water splitting for generation of hydrogen and oxygen gases. In the short-pulse mode of operation, high-voltage pulses can be generated in the nanosecond range (nanopulser).

Nanopulser now is in demand for biological and bio-medical applications (2 topics in the DOD SBIR-2018 solicitations [10]).

REFERENCES

[1] N. Kukhtarev, T. Kukhtareva, M. Bayssie, J. Wang, J.D. Brownridge, ”Generation of focused electron beam by pyroelectric and photogalvanic crystals,” Journal of Applied Physics, Vol.96, no.11, p.6794, 2004.

[2] N. Kukhtarev et al, “Photoinduced Optical and Electrical High-Voltage Pulsations and Pattern Formation in Photorefractive crystals,” (invited paper), JNOPM, Vol.11, No.4, 2002.

[3] N. Kukhtarev et al. “Continuos wavegeneration of nanosecond electrical and optical pulses from photorefractive lithium-niobate fibers,” CLEO/QELS’05, Abstracts, P.13, 2005.

[4] N. Kukhtarev, et al “Photogalvanic pulsator,” CLEO '2002, Technical Digest.

[5] N. Kukhtarev et al., Journal of Physics: Conference Series, V. 867,**2017**.

[6] M. Kösters, C. Becher, D. Haertle, B. Sturman, K. Buse, “Charge transport properties of undoped congruent lithium niobate crystals,” Appl Phys B Vol. 97: p.811–815, 2009

[7] http://amptek.com/products/cool-x-pyroelectric-x-ray-generator/

[8] N. Kukhtarev, T. Kukhtareva, “Compact crystal accelerator-undulator based on fringing E-field super lattice,” Proc. of SPIE Vol. 8847 88470F-1, 2013.

[9] N. Kukhtarev, T. Kukhtareva, J. Geng, X.Z. Zhang and J.J. Xu, “Photogalvanic /pyroelectric power conversion and self-pulsing of electro-wetting of LC droplet on lithium niobate (LN)-crystal,” Journal of Molecular Liquids

[10] DOD SBIR -2018, research topics AF181 -002, DHA18 -005