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FORMATION OF FERROELECTRIC DOMAIN STRUCTURE FOR SOLAR CELLS

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An innovative method for the formation of ferroelectric regular domain structures by rapid quenching of a sample in the ferroelectric phase and exposure of a high-frequency electric field is proposed. It is shown that polydomain structures form at any quenching depth, at frequencies above the critical value and amplitudes below the critical one. A model for calculating of parameters for controlling the process of domain ordering and changing the period of the expected regular domain structure has been developed.

Keywords: *Ferroelectric, Regular Domain Structure, Nonequilibrium, Electric Field, Frequency, Self-Organization.*

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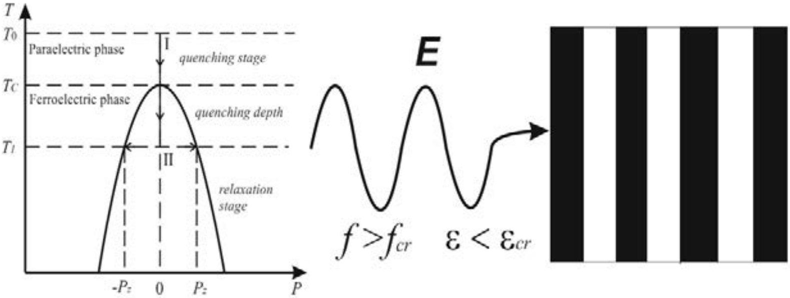

Solar cells are the most promising materials for green energy development. At the moment, silicon is mainly used in the production of solar cells. On average, their efficiency is 5-6% for amorphous thin film and 10-17% for mono- and polycrystalline samples. The most expensive silicon cell has 31-32% efficiency.

Ferroelectric materials are one of the most promising alternatives. This is facilitated by unique advantages such as the switchable photocurrent and photovoltage. A large amount of research has already accumulated and many developments have been proposed on the use of multiferroics, organic ferroelectrics and heterostructures in the production of solar panels. The efficiency of some perovskite samples reaches 26%, and the production cost is 5-6 times less than that of silicon solar cells. However, mass production of perovskite solar cells is hindered by high crystal fragility, moisture susceptibility and low service life. Therefore, the efforts of many researchers are aimed at increasing the corrosion resistance of these materials. One another important task is the development of methods of control of domain structure (especially in micron and nanoscale region) which defines the unique properties of every certain ferroelectric.

Experiments show that formation of polydomain structures in submicron region has self-assembling character and is accompanied by the appearance of isolated, striped, and fractal domains. Application of such classical methods as exposure of a sample to an electric field or an electron beam is limited by a number of technological problems: the growth of domains outside the electrodes, partial reverse polarization, uncontrolled fusion of domains etc. As an alternative, it is proposed to control the process of self-organization of the domain structure under highly nonequilibrium conditions created by laser [1], acoustic interference [2] or thermal influences [3].

Creation of highly nonequilibrium conditions by rapid quenching of the sample from the paraelectric phase to the ferroelectric phase has a number of advantages: minimal risk of sample destruction, initial formation of domain structure, high susceptibility of a nonequilibrium system to external changes. Current technologies make it possible to quench a sample in the vicinity of Curie temperature T_C ($T_C - T = 0.1$ K) and observe a phase transition «extended in time» [3]. The next step in this direction is the development of practical approaches for directing the relaxing system to the formation of a domain structure of the required type – single-domain, polydomain, or partially ordered state.

Within the framework of the proposed method, rapid quenching of the sample from paraelectric phase ($T > T_C$) into ferroelectric one ($T < T_C$) is considered. As a result, the sample falls into the region of thermodynamic nonequilibrium, where even very weak external influences can significantly affect the domain kinetics and its final result. Therefore, at the stage of further relaxation of the system to a state of thermodynamic equilibrium, an external electromagnetic field in the form of a monochromatic plane-polarized standing wave is imposed on the sample. This field is created due to the interference of the incident and reflected high-frequency electromagnetic waves and has the form:

$$\vec{E}(x,t) = 2\vec{E}_m \cos(kx)\sin(\Omega t), \quad \Omega = \frac{2\pi c}{\lambda n} \tag{1}$$

Here $\left|2\vec{E}_m \cos(ikx)\right|$ is an amplitude of electric field (V/m), k is a wave vector of standing waves (m^{-1}), Ω is a frequency of electromagnetic waves that create a standing wave (rad/s), λ is a length of electromagnetic wave that defines the period of regular domain structure (m), c is speed of light in vacuum (m/s), n is a refractive index of electromagnetic waves, x is the direction of propagation of electromagnetic waves that create a standing wave.

The amplitude and frequency of this field are control parameters and allow us to control the type and the period of the domain structure. The sample is kept in an external high-frequency electromagnetic field for the time required for the domain structure formation. After this, the field is abruptly turned off, and as a result, some regular domain structure is formed in the sample (fig. 1).

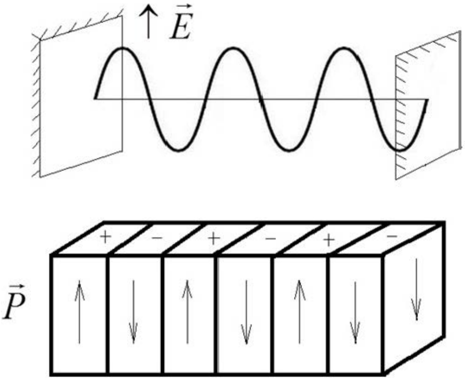

Fig. 1. Schematic representation of the method of regular domain structure formation under the influence of a high-frequency electric field

Within the framework of the proposed method, it is necessary to determine the values of the control parameters at which the formation of single-domain and polydomain structures will occur. For this, within the framework of the Landau - Ginzburg - Devonshire phenomenological theory, a kinetic model to describe the dynamics of ordering of domain structure that undergo a phase transition and relax under external influences was developed [4].

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