High Resolution Investigation of the Domain Kinetics in Lithium Niobate and Lithium Tantalate Single Crystals

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Static domain patterns produced by application of the external electric field in wide temperature range in single crystals of congruent, stoichiometric and MgO doped lithium niobate $LiNbO_3$ (**LN**) and lithium tantalate $LiTaO_3$ (**LT**) were investigated experimentally in great detail. Moreover the domain kinetics has been studied by computer simulation and experimentally in model structure in order to check applicability of the kinetic approach to explanation of the individual domain shape and domain structure evolution for switching from multi-domain initial state [1].

The step-by-step kinetic model of the domain growth was realized in the model experiment. Evolution of two-dimensional (**2D**) domain patterns has been investigated in CLN produced by application of external electric field by **2D** electrode grating (Fig. 1). The grating structure has been produced by photolithography and the field has been applied using liquid electrolyte.

It was shown that the domain kinetics in this case is governed primarily by merging of individual hexagon domains. It is clearly seen, that the formed individual macro-scale domains are very similar to the usual static domain structures obtained in real samples including full variety of possible shapes from triangles to hexagons and even concave shapes. The only difference is the domains sizes. Since, the artificial domain grating, used for the modeling, has 10 μm period; all the details of the domain configuration are easily distinguishable by the optical microscopy.

High-resolution study of the domains using Scanning Probe Microscopy allows us to reveal the similar special features of the domain shape in submicron- and nano-scale.

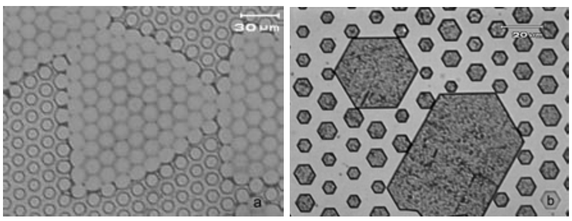

Fig. 1. Optical observation of the model step-by-step domain growth in periodically poled **CLN** with **2D** grating: a) triangle domains; b) hexagon domains.

Computer simulation based on the step-by step domain growth kinetic model has been used for explanation of the obtained domain patterns. The simple local switching rules have been proposed for domain growth in terms of cellular automata. The results of application of the proposed model (Fig.2c) are in good agreement with experimentally observed domain patterns (Fig. 2b).

Scanning probe microscopy: contact and non-contact atomic force (**AFM**) and piezoelectric force (**PFM**) modes has been used to compare the results of the model experiments and computer simulation to the micrometer scale domain patterns. Proposed kinetic model allows to explain all observed domain shapes both in macro-and micro- scales (Fig. 3).

During experiments we place high emphasis on the domain kinetics in MgO doped **LN** at elevated temperatures up to $140^{O}C$, which shows the unusual domain kinetics with formation of the individual domains with coexistence of X and Y oriented domain walls.

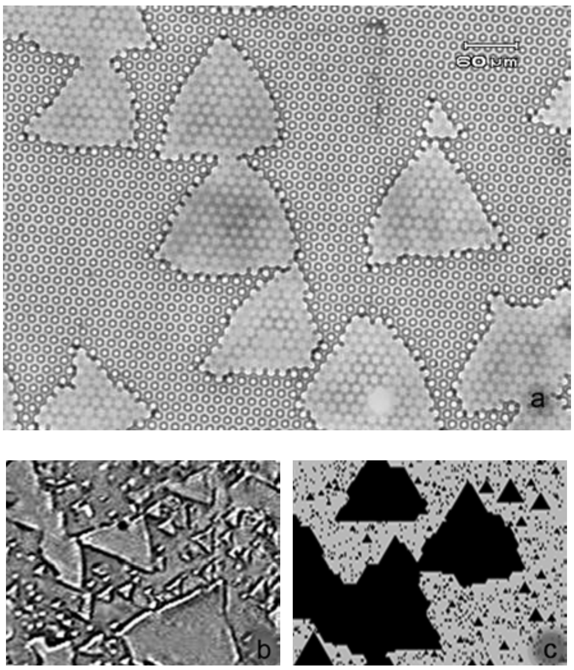

Fig. 2. a) Optical observation of the model step-by-step domain growth in the **2D** periodically poled **CLN**; b) *in-situ* optical observation of the domain kinetics in **CLT**; c) computer simulation.

One of the main consequences of the proposed model is that the domain shape is governed by the kinetics and strongly affected by such experiment's conditions as electric field pulse parameters and screening properties. Original scenarios of the domain structure evolution were revealed experimentally and discussed accounting for the decisive role of the retardation of the screening process.

It was shown that the domain evolution during decay of the highly-nonequilibrium state represents a self-organizing process, in which the screening of polarization reversal plays the role of feedback. In the case of suppressed screening (artificial dielectric layer under the electrode) the complicated dendrite domain structures (Fig. 4) have been obtained in different materials.

The screening is also ineffective when specially designed short electric pulse shapes are used with sharp switching off. In this case uncompensated depolarization field drastically change the domain kinetics and produce the equidistant arranged arrays of small sub-micron size domains (Fig. 5).

It has been shown both experimentally and by computer simulation that the correlation length of such quasi-periodic self-assembled nano-domain structures is determined by the thickness of the intrinsic or artificial surface dielectric layer.

Finally it must be pointed out that the discussed results of the fundamental investigations are of a great interest as a physical basis for a modern field of technology denoted as "domain engineering".

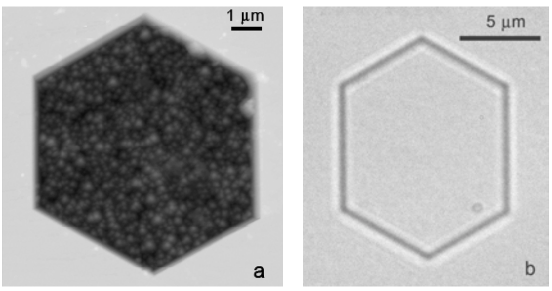

Fig. 3. Hexagon domains in **CLN**: a) **AFM** measurement of the relief revealed by selective chemical etching, b) optical observation without etching.

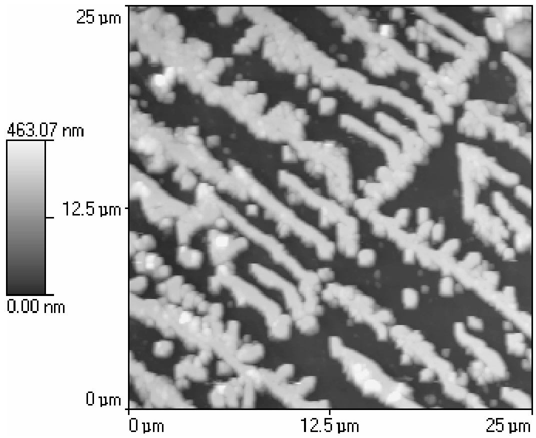

Fig. 4. Self organization in the domain kinetics: dendrite domain structure obtained by switching with artificial dielectric layer in **CLN**.

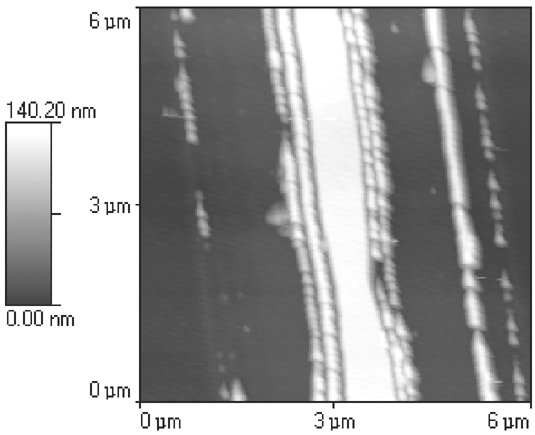

Fig. 5. Self organization in the domain kinetics: arrays of arranged sub-micron domains formed during spontaneous backswitching in **MgO:LN**.

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