FERROELECTRIC DOMAIN PATTERNING BY FOCUSED ION BEAM IRRADIATION OF [100]-CUT [001]-POLED PMN-PT SINGLE CRYSTALS

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The formation of domain structure via charge injection controlled by focused ion beam irradiation by means of a lithographic system in PMN-PT single crystals with a surface artificial dielectric layer has been studied experimentally. The results explained in terms of the kinetic approach.

The Pb(Mn₁/₃Nb₂/₃)O₃-PbTiO₃-PbTiO₃ (PMN-PT) ferroelectric single crystal is an attractive material for nonlinear optical application due to the highly-estimated nonlinear-optical coefficients. This requires methods of precise control of domain wall positions for the creation of precise periodical-poled domain structures [1]. The use of [100]-cuts allows to the realization of the waveguide devices for integrated optical application due to domain formation close to the surface only. Recently it was demonstrated that the irradiation by focused ion beam (i-beam) controlled by the lithographic system is a promising method for short-pitch domain poling [2,3].

The irradiated surface of [100]-cut [100]-poled tetragonal PMN-PT single crystals were covered by 0.5-µm-thick AZ nLOF 1505 (Microchemicals GmbH, Germany) photoresist layer. The opposite surface was deposited by a 100-nm-thick solid Cu electrode grounded during irradiation. The i-beam irradiation was performed by a dual-beam Auriga Crossbeam workstation (Carl Zeiss, Germany) equipped with an i-beam lithography system Elphy Multibeam (Raith GmbH). Piezoresponse force microscopy (PFM) was used for domain structure imaging by scanning probe microscope MFP-3D (Asylum Research, USA).

We used isolated (with a period of 100 µm) and square array (with a period of 20 µm) dot irradiation with an increase of irradiated charge (dose) in the range from 10 to 150 pC at the accelerating voltage of 30 kV and i-beam current of 120 pA.

We have shown that the use of the resist layer allows significantly improves domain growth homogeneity in domain arrays and reduces dose due to high charge localization in the resist layer. The i-beam irradiation resulted in the growth of the wedge-like domains in [001]-polar direction (Figure 1(a)). A similar domain growth was recently observed at the focused-beam irradiated lithium niobate non-polar cuts [4]. The distinctive feature of PMN-PT was the formation of the circular domain around irradiated dot with the size of 1.7 µm² having a more pronounced double-contrast on the PFM image. The light contrast was attributed to charge injection while dark contrast possibly due to higher domain depth in comparison with wedge-like domain part. The increase of the dose up to 100 pC led to a linear increase of wedge-like domain length (Figure 1(b)). The higher doses resulted in the saturation of the dependence caused by domain interaction.
Based on the kinetic approach, the model was proposed for the formation and growth of domains created as a result of irradiation with an ion beam [5]. The driving force of domain growth is the excess over the threshold of the polar component of the electric field created by the space charge arising in the irradiated region.

The results obtained are of considerable interest for the development of methods for creating nanodomain periodic structures to create non-linear optical frequency converters with small periods.

Fig. 1. (a) PFM image of domain created by ion beam, (b) dose dependence of domain length in square array.

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