Domain patterning by strongly absorbed UV light in $LiNbO_3$ crystals

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Abstract: Short-term exposure of the surface of lithium niobate crystals to focused strongly absorbed UV light leads to persistent inhibition of subsequent ferroelectric domain reversal on the +*z* face at the irradiated site. The same procedure can be adopted to directly generate domains on the non-polar faces. Investigation of the UV-irradiated tracks by piezoresponse force microscopy reveals the connection between the inhibited domains on the +*z* face and local lithium depletion, while thermoelectric fields can be invoked to generate the domains on the non-polar faces.

Introduction

Domain engineering in lithium niobate ($LiNbO_3$) has become a topical field of research and enables numerous advanced applications that can be realized employing tailored domain structures. The most prominent example is frequency conversion using quasi-phase matching in periodically poled crystals. Strongly absorbed UV light recently has become a tool for domain structuring in $LiNbO_3$. So-called poling inhibition (PI) [1] on the +*z* face of $LiNbO_3$ enables domain patterns that can be utilized in photonic micro-structures [2]. On the non-polar faces, UV light offers a method to generate tailored domains for applications such as specific waveguide configurations [3,4].

Experimental methods

To investigate the mechanism of PI, the +*z* face of different types of $LiNbO_3$ crystals (stoichiometric, congruent or Mg-doped) is exposed, creating the so-called "latent state". The focus of a beam of strongly absorbed UV light at 275 nm wavelength, generated by an argon ion laser, is scanned across the surface of the crystal at intensities around 10^5 W/cm^2. Domain growth can be visualized during subsequent electric-field poling, while the latent state can be investigated by annealing experiments and by local poling by piezoresponse force microscopy (PFM), respectively.

Furthermore, ferroelectric domain reversal has been achieved by the same scanning procedure on the non-polar faces, i.e. *x*-face and *y*-face, of $LiNbO_3$ crystals. The focused laser beam is scanned parallel and perpendicular to the polar *z*-axis, and the resulting domains are investigated by PFM.

Results and discussion

In the case of PI, the latent state is robust against thermal annealing up to 520 K and uniform illumination. With the tip of a scanning force microscope the coercive field is mapped (see Fig. 1), showing not only the expected resistance against domain reversal in the UV-irradiated region, but also

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easier poling adjacent to the UV-irradiated section. Furthermore the latent state does not translate into PI domains after poling in stoichiometric $LiNbO_3$. These results point to the following mechanism of poling inhibition: the UV light-induced heating results in a local reduction of the lithium concentration, generated via thermodiffusion. The required charge compensation is provided by UV-excited free electrons/holes. After cooling, the lithium ions become immobile, and the reduced lithium concentration causes a strong local increase of the coercive field in the exposed area, while the increased Li concentration next to this area reduces the coercive field [5].

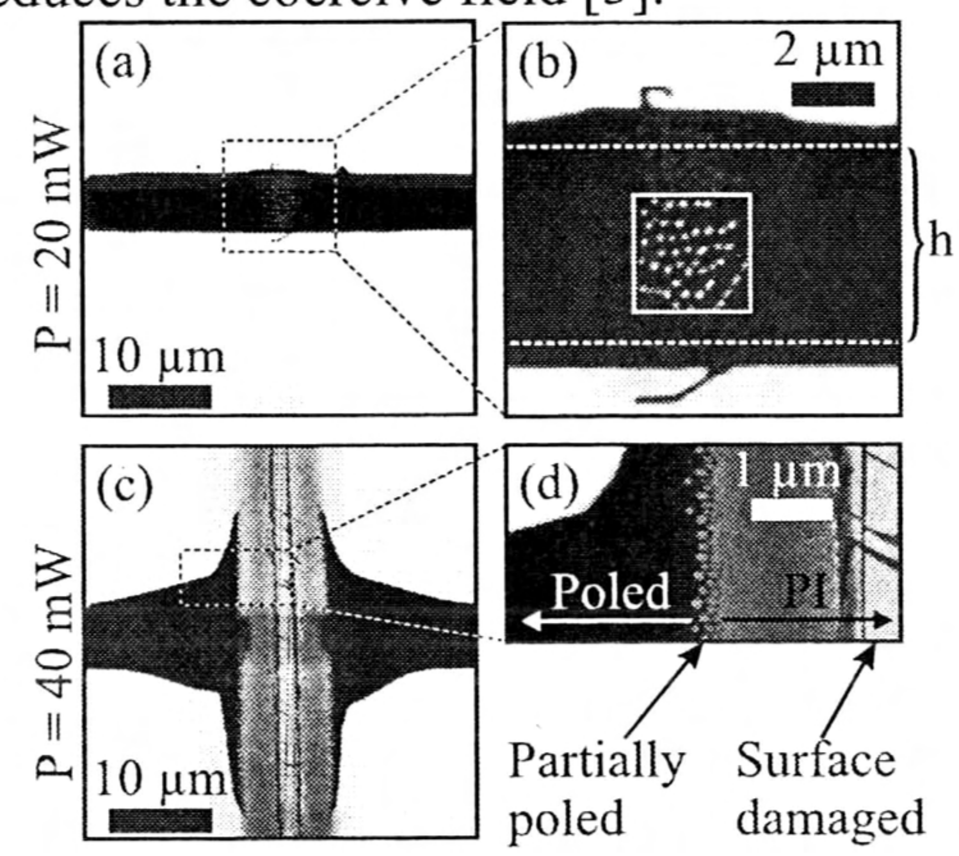

Fig. 1. Piezoresponse force microscope images obtained on Mg-doped congruent $LiNbO_3$ after locally poling a horizontal stripe of h = 5 µm height with the scanning force microscope tip. For the generation of the latent state, vertical laser tracks written with (a) laser intensity below the threshold for poling inhibition (1×10^5 W/cm^2) and (c) laser intensity above the threshold for poling inhibition (2×10^5 W/cm^2). The zoomed image (b) shows the generation of nano poling-inhibited domains within the UV laser-irradiated track. In (d) the formation of nano domains is seen only at the transition region between poled and poling-inhibited area.

In the case of the non-polar faces, the domains were investigated by PFM. The emergence and width of any domain was found to depend on the scanning direction of the irradiating laser beam with respect to the polar *z*-axis. Full width and half width domains, or no domain formation at all could be achieved for scanning along specific directions. We interpret the results by the induced temperature gradients and the resulting thermoelectric fields [3].

Summary

We have shown that ferroelectric domain patterning can be performed by UV irradiation on the polar and non-polar faces of lithium niobate crystals. In the case of poling inhibition on the +*z* face of the crystal, lithium redistribution due to strong local heating is the driving mechanism. For the non-polar faces, we suggest that the mechanism for domain formation could be attributed to a thermoelectric field that builds up during laser irradiation. It is therefore now possible to generate domain patterns on all crystal faces, thereby allowing for a wealth of possibilities for application-relevant domain structuring.

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