Ultraviolet direct domain writing on 128° YX-cut $LiNbO_3$: for SAW applications

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Abstract— **Domain engineering 128° YX-cut lithium niobate crystals by ultraviolet direct-domain writing is reported. The evidence of the inverted domains were shown from both piezoresponse force microscopy and hydrofluoric acid etching.**

lithium niobate; domain inversion; SAW; UV laser processing

I. INTRODUCTION

Lithium niobate ($LiNbO_3$) is a ferroelectric crystal with interesting properties such as piezoelectricity, pyroelectricity and optical nonlinearity [1]. These properties lead to various exciting applications, especially in the optical and electromechanical fields. Domain engineering of $LiNbO_3$ is an active field of research due to the demand of periodically poled lithium niobate (PPLN) for nonlinear optical processes, using quasi-phase matching. However, PPLN has recently also been employed for electromechanical applications such as bulk or surface acoustic wave (SAW) devices [2,3]. Electric field poling has been regarded as ad hoc technique to fabricate PPLN, but it is limited to crystals with polar faces [4]. This technique becomes impractical for crystals with an inclined polarization axis such as 128° YX-cut $LiNbO_3$ [5]. However, in many SAW applications, this cut is preferable because of its higher electromechanical coupling constant (5.3%) as compared to Z-cut $LiNbO_3$ crystals (0.53%) [4]. Other fabrication techniques such as titanium in-diffusion [6] have been reported for achieving domain inversion on various cuts. This domain engineering method requires a clean room facility and is processed at high temperatures (~1040°C), where a carefully controlled environment is needed.

Recently, UV direct domain writing has been reported [7,8]. This domain engineering technique uses a focused UV laser beam for locally inverting the polarization of the $LiNbO_3$ crystal. Significant advantages of this method are that no clean room facility is necessary and also that the domains can be written at a room temperature. In addition, the desired domain pattern can be achieved by simply controlling the translation stages, which makes it a fast and powerful tool for fabricating prototypes.

In this contribution we report PPLN fabrication on 128° YX-cut $LiNbO_3$ crystals applying UV direct-domain writing.

II. EXPERIMENTAL METHODS

The PPLN was fabricated by scanning a focused UV laser beam across the surface of a 500-µm-thick 128° YX-cut $LiNbO_3$ crystal (Figure 1). The UV laser source used in this experiment was a frequency doubled argon ion laser (wavelength λ = 244 nm). An objective lens with focal length of 40 mm was used to focus the laser beam to a focal beam diameter of about 6 µm and an intensity of 3.2×10^5 W/cm^2. To fabricate the PPLN, the crystal was placed on a computer controlled *xyz*-translation stage, which was moved alternating, perpendicular to the crystallographic X-axis. The scanning velocity was maintained at 0.1 mm/s for all written patterns and the distance between the scanned lines was 25 µm, defining the PPLN period. The UV-written domains were visualized by using piezoresponse force microscopy (PFM) [9]. The inverted domains were also partially polished under an angle of 6° [10], which reveals the depth profile of the UV-written domains and also stretches it by a factor of ~10 (Figure 3 (a)). The UV written domains where then visualized by hydrochloric acid (HF) etching, which transfers the domain pattern into a topography that is imaged by SEM.

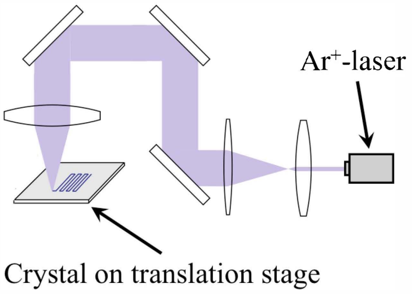

Figure 1. Sketch of UV direct domain writing setup.

III. EXPERIMENTAL RESULTS

Figure 2 shows PFM measurement result. In the figure, the bright stripes indicate domain inversion as expected. The width of the stripe is close to the focal beam diameter. We also observe a faint area vicinity to the bright stripes. In the picture is also evidence of surface damage such as cracks. The cracking pattern itself seems to depend on the scanning direction, as the first and the third bright stripe and the second and the fourth bright stripe look similar.

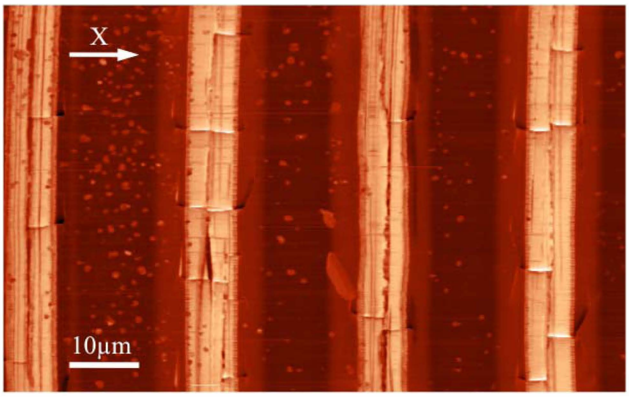

Figure 2. PFM picture of the UV-written domains (four bright stripes) on a 128° YX-cut $LiNbO_3$ crystal. Surface damage such as cracks on the UV-written domains is visible.

Figure 3 (b) shows the SEM picture of the angle polished crystal after HF etching. The white dashed line illustrates the edge of the angle polishing. The depth profile of the top domain is highlighted with a thin white line for guiding the eye. The shape of the depth profile indicates that the polarization is not only inverted where the crystal was irradiated with the UV laser beam, but also on both sides of the irradiated area. The depth of the domain at the irradiated area is ~2.7 μm deep, which is deeper than the side domains that are only ~0.8 μm deep. It can also be seen that the cracking pattern of the UV-written domains in both Figures (2 & 3) look similar and also that the cracks appear to be deeper than the UV-written domains (Figure 3 (b)).

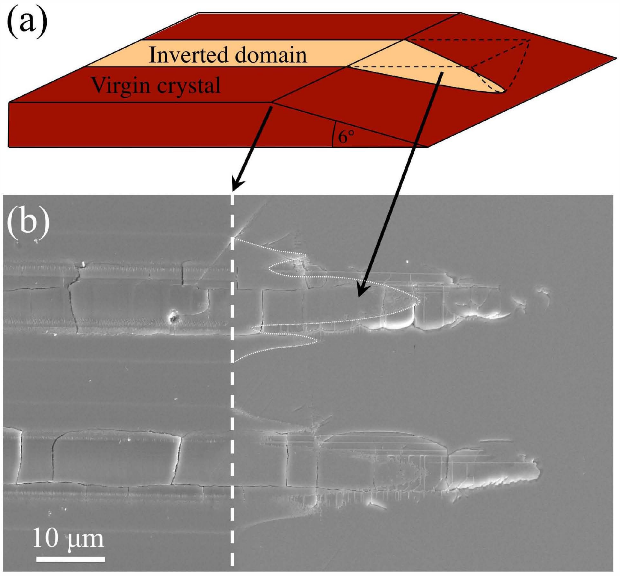

Figure 3. (a) shows the sketch of the angle polsihing and the strechting of the domain depth. (b) presents the SEM picture of the angle polished, HF-etched domains. The white, dashed line indicates the edge of the angle polishing. The thin white line highlights the depth profile of the top domain, where side domains can be observed.

IV. DISCUSSION AND CONCLUSION

The surface damage on the UV-written domains, which can be observed in Figures 2 and 3 (b) is a common property of the UV domain writing method and was also observed in Ref. 7 and 8. The cracks can be attributed due to the thermal stress, which is induced by the high temperature gradient. The brighter area on both sides of the UV-written domains in Figure 2 can be explained by the depth profile of the UV-written domains in Figure 3, where there is not only the center of the irradiated area inverted, but also the neighboring area on both sides. The difference of the PFM signal of the inverted domain in the center and the neighboring domains in Figure 2 can be explained by the depth resolution of the PFM, which is ~1.7 μm [11]. However, the domain depth profile with the two side domains cannot be explained and needs further investigations.

UV direct domain writing technique has been employed to achieve PPLN on 128° YX-cut $LiNbO_3$ with micrometer domain size. The presence of the inverted domain is evidenced by both PFM and HF etching. This domain engineering method can potentially be used to realize an acoustic superlattice transducer on 128° YX $LiNbO_3$ for efficient SAW generation as reported in a distinct contribution to this conference [12]. Promising methods to overcome surface damage are also under investigation.

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