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Surface engineered ferroelectric domains in congruent lithium niobate crystals

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We report on the fabrication of high quality, fine period (~1 μm) surface ferroelectric domains in congruent lithium niobate single crystals suitable for first order quasi-phase-matched nonlinear interactions in lithium niobate channel waveguides.

Ferroelectric domain engineering in lithium niobate ($LiNbO_3$) is used extensively for quasi-phase-matched (QPM) nonlinear optical interactions which utilize the d_{33} nonlinear coefficient [1]. Commonly used domain inversion methods in bulk materials can routinely produce periods of a few μm in thick wafers (~500 μm) but domain spreading effectively reduces the domain grating quality when periods of ~1 μm are attempted.

For waveguide applications however, it is not necessary for the periodic domain structures to extend throughout the full crystal depth, provided there is good overlap with the optical fields involved in the nonlinear interaction.

Here we report on the fabrication of periodically poled domain structures near the surface region using a modified electric field poling technique. The advantage of this method is that the aspect ratio of the produced inverted domains is significantly reduced enabling the fabrication of finer periods while maintaining good overlap with optical fields in waveguide structures.

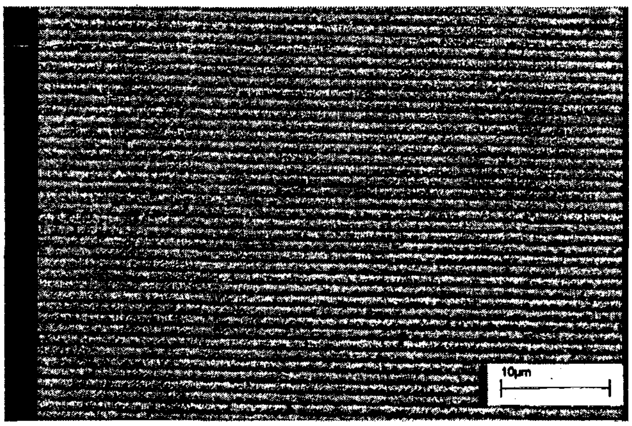

Figure 1 Scanning electron microscope (SEM) photograph of an HF-etched surface poled sample. The period of the inverted domain structure is 1.077 μm.

The poling process is the one followed in [2] but in our case the sample is forced to *overpole*. After poling in this manner the sample appears to be uniformly poled when examined between crossed polarizers. However, after etching with HF acid a periodic relief pattern corresponding to the surface domain structure is revealed. We believe that this is due to surface charges which are trapped at the interface between the photoresist and $LiNbO_3$ that prevent the dipoles near the surface from inverting under the influence of the applied electric field.

Using this method periodic domain structures having a width less than 0.5 μm have been obtained as seen in figure 1. Fabrication of finer period domains should only be restricted by the resolution of the photolithographic process.

Periodically poled ferroelectric domain structures have also been fabricated over optical waveguide structures (Ti indiffused and proton exchanged) and uniform domain gratings for second harmonic generation (SHG) at blue wavelengths (460nm-400nm) has been achieved.

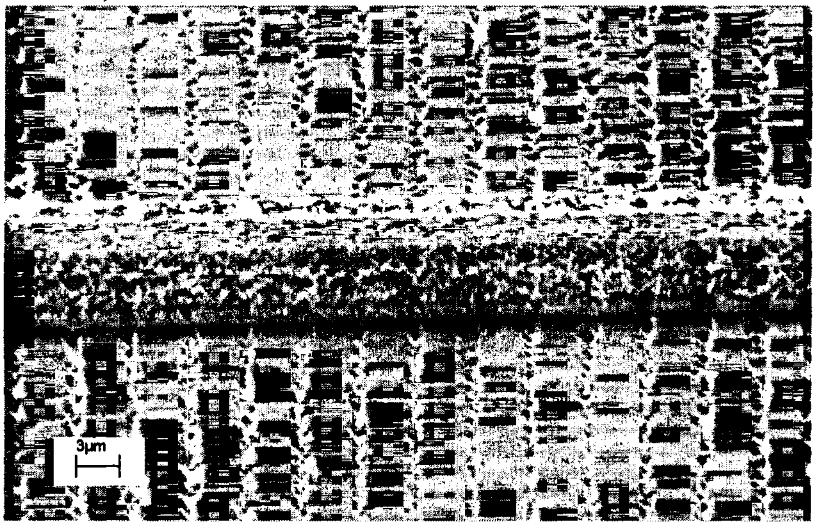

Figure 2. SEM photograph of a titanium indifused $LiNbO_3$ ridge waveguide with periodically inverted surface domain structures after HF-etching. The height of the ridge is ~4 µm and the period of the inverted domain structure is Λ=3.2 µm.

To measure the depth of these ferroelectric domains in the guiding structures ridge waveguides were fabricated by ion beam milling on a periodically poled titanium indiffused $LiNbO_3$ planar waveguide. The sample was etched to reveal the domain structure, as shown in figure 2, which is seen to extend throughout the 4 µm vertical dimension of the ridge.

Preliminary non optimized second harmonic generation results in these guiding structures have been obtained and a tuning curve of a QPM device fabricated on an annealed proton exchanged $LiNbO_3$ channel waveguide is shown in figure 3.

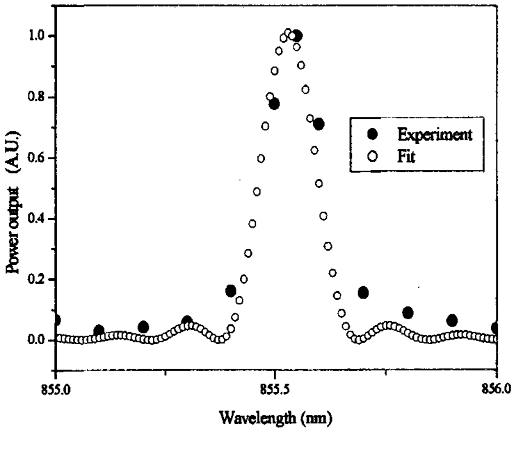

Fig. 3 Tuning curve showing the second harmonic power versus input wavelength from a periodically poled annealed proton exchanged $LiNbO_3$ channel waveguide. The solid dots are the experimental points while the open dots correspond to a fitted sinc function for the same device length.

In conclusion a method for the construction of periodically inverted ferroelectric domains near the surface region of congruent $LiNbO_3$ and $LiNbO_3$ waveguides has been investigated. For periods as short as 1 µm the domain inverted area overlaps well with the guided optical fields in these structures presenting a promising route for the fabrication of efficient first order QPM nonlinear optical devices. Further work on the conditions for the optimization of the mark-to-space ratio for the periodic domains as well as characterization of the waveguide-SHG devices is under way.

References

1. J. A. Armstrong, N. Bloembergen, J. Ducuing abd P.S. Pershan, " interactions between light waves in a nonlinear dielectric" Phys. Rev. 127, 1918-1939 (1962)
2. I. E. Barry, G. W. Ross, P. G. R. Smith, R. W. Eason, G. Cook "Microstructuring of lithium niobate using differential etch-rate between inverted and non-inverted ferroelectric domains" Mat. Lett. **37**, 246-254 (1998)