Submicron domain inversion in Mg-doped Li Nb O 3 using backswitched poling with short voltage pulses

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Submicron domain inversion in Mg-doped $LiNbO_3$ using backswitched poling with short voltage pulses

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The authors describe a technique for fabricating submicron domain inversion structures in $MgO:LiNbO_3$. The method is based on controlled backswitched poling with short voltage pulses. Using this method, short periodic structures consisting of submicron domain patterns have been achieved in *Z*-cut MgLN crystal. The structure is fully compatible with nonlinear optical integrated waveguide applications. High performance of the submicron domain inversion structure is also demonstrated by evaluating its potential as second harmonic generation. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2437126]

Ferroelectric domain engineering is important for nonlinear optical frequency conversion by quasiphase matched (QPM).[1] In recent years, there has been increasing interest in the use of QPM nonlinear crystals for a variety of frequency conversion applications.[2–4] Periodically poled $LiNbO_3$ crystal (PPLN) has been demonstrated to be a practical QPM device for generation in blue, green, or violet ranges.[5–7] However, the PPLN has significant problems for visible light radiation, such as green or blue induced infrared absorption and optical damage.

Recently, periodically poled Mg-doped $LiNbO_3$ (PPMgLN) crystal has been anticipated as the most practical QPM material.[8] However, unexpected leakage current and the strong effect of domain widening out of the electroded area impose limitations on the period of short-pitch domain inversion patterns. To overcome this apparent limit in domain period, three techniques have been applied to fabricate submicron domain inversion patterns. The first technique is to generate short periods in congruent lithium niobate crystal by controlling the spontaneous backswitching.[9,10] The second technique is based on conventional electric field poling with an intentional overpoling step, generating domain periods as small as $\sim 1\ \mu m$ in congruent lithium niobate crystal.[11] The third technique which applied to MgLN with multiple short current pulses, generating a period of $2.2\ \mu m$ and depth of $1.5\ \mu m$, which when used in conjunction with a waveguide geometry, has produced a high conversion efficiency.[12]

In this letter, we study a method for fabricating submicron domain inversion structures in MgLN by using backswitched poling with short voltage pulses. This technique is greatly favorable for the fabrication domain inversion periods in MgLN crystal because it reduces leakage current and domain widening during the poling. We believe that the structure is fully compatible with nonlinear optical integrated MgLN waveguide applications. We also demonstrated the performance of the submicron domain inversion structure by evaluating its potential as second harmonic generation.

The samples were cut from a 1 mm thick MgLN crystal, whose *Z* axis was perpendicular to the surface. For conventional electric field poling, the established practice is to first calculate the charge *Q*. The charge *Q* transferred to the sample is required for the compensation of the reversed orientation of the spontaneous polarization, and the total charge *Q* in the transient current signal on domain reversal can be obtained by integrating poling currents over the whole poling time. The total charge *Q* is equal to $2AP_s$, where *A* is the area of the domain reversal region, which is measured carefully from the images of the photolithographic pattern under a polarized light microscope, the factor of 2 accounts for the polarity reversal, and P_s is the spontaneous polarization of MgLN. The charge delivered to the sample, during the poling pulse, is proportional to the volume of reversed domains and thus determines the average domain duty cycle. The stages of domain growth have been observed during conventional poling.[13,14] The process starts with the creation of new domain seeds at the $+Z$ surface along the electrode edges [Fig. 1(a)]. The second stage, these domains grow forward along the sample [Fig. 1(b)]. The third stage, the domains propagate through the sample and merge under the electrode

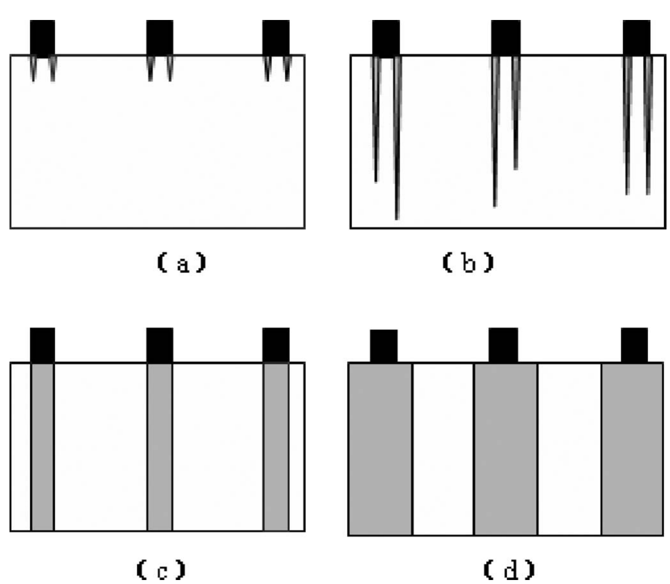

FIG. 1. Stages of domain growth during poling.

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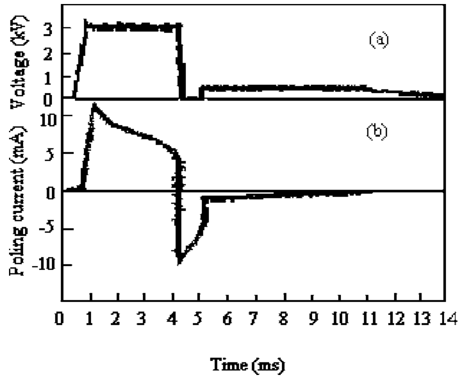

FIG. 2. Backswitched poling wave form of applying voltage and poling current.

[Fig. 1(c)]. Finally, the domain broad out of the electrode area [Fig. 1(d)]. It is clear that both the electric field and the duration of the field application are the functions of the pattern of the domain inversion.

The four regimes, according to the domain growing, are illustrated schematically in Fig. 1. Concentrating our attention on Fig. 1(b) which shows the domain inverted under the electrode edges. Domain evolution in both uniform electrode and patterned electrode is driven by the total electric field. The total electric field is comprised of the applied external field and the internal field.[15] After rapid decreasing of the applying field, the internal field results in spontaneous backswitching. The backswitched poling can shrink the domains by the backward wall motion and nucleation along the electrode edges.[16,17]

Using backswitched poling with short voltage pulses, PPMgLNs with submicron domain structures were fabricated. The samples were cut from 1 mm thick MgLN wafer with 5 mol % MgO dopant, whose c axis was perpendicular to the surface. The wafers were photolithogarphically patterned with a periodic stripe Al metal electrode pattern deposited on the $+Z$ surface and oriented along the Y axis. The uniform metal film is deposited as a ground electrode on the $-Z$ face. To reduce the coercive field, the high temperature poling was also important. To heat up the samples from 25 to 100 °C, the coercive field could be reduced from 5 to 3 kV/mm. The current in the external circuit indicates the domain evolution during poling. Wave forms of the backswitched poling voltage and poling current are shown in Fig. 2. The 3 kV voltage is applied for 3 ms, and rapidly removing the external voltage for 1 ms, finally increasing the voltage to 500 V for 8 ms. Several backswitched poling voltage pulses were used in our experiment for a relatively deep domain structure. During the backswitching occurs, the internal field creates a negative switching current [Fig. 2(b)]. The stabilization of the domains is accomplished by applying a lower external voltage as the backswitching stopped. The backswitching with short pulses leads to domain nucleation under the edges of electrodes.

A variety of surface poling results can be observed by backswitching with short pulses. Following acid etching, Fig. 3 shows the details of a ~2 μm periodicity $+Z$ surface structure. Figure 4 shows the cross-sectional photographs of ~2 μm PPMgLN. It is clearly seen that the domain depth was shallower than that of the PPMgLN with a longer period using conventional forward poling. The depth of the domain inversion as a function of the period of the imposed photo-

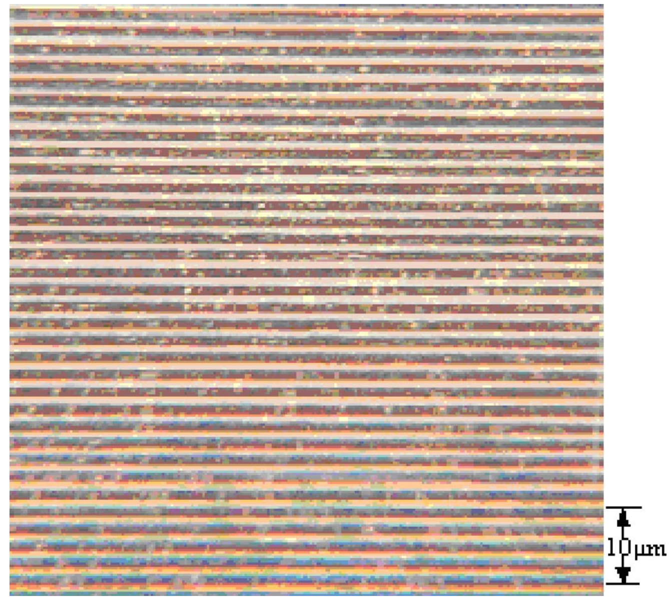

FIG. 3. Photograph of the etched $+z$ surface of PPMgLN with a 2 μm period.

lithographic pattern was measured. Figure 5 shows the measured domain depth with periodic from 2 to 5 μm. The domain forward growth depends on the period of the domain inversion. It is obvious that the domain depth was shallow, and this is suitable for intended waveguide applications. Theses results indicate that backswitched poling with short pulses application in MgLN crystal is effective to realize submicron periodic structure.

Using a multi-longitudinal-mode cw Ti:sapphire laser, the second harmonic generation (SHG) characteristics were examined in 15 mm PPMgLN at room temperature. The pump laser was focused on a waist spot diameter about

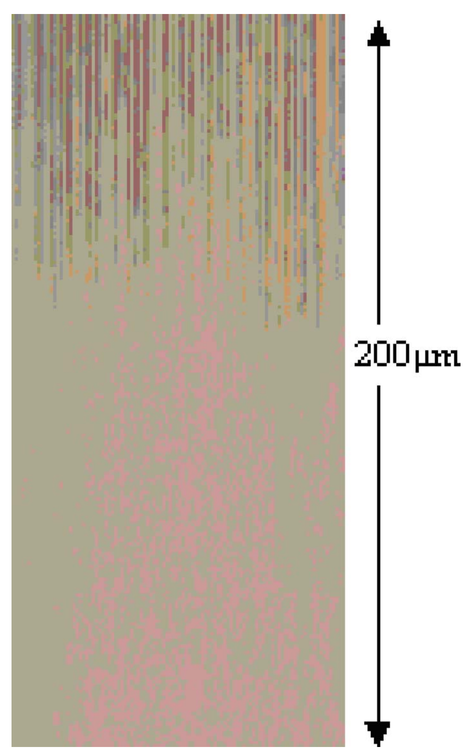

FIG. 4. Cross-sectional view (y face) of the PPMgLN with a 2 μm period.

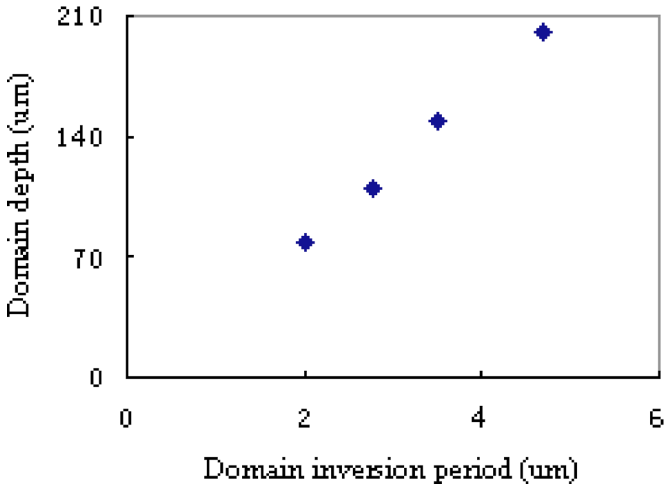

FIG. 5. Experimental measurements of domain depth vs domain period which determined by optical microscopy.

25 μm. SHG and pump powers were measured as the output facet near the surface of the +Z surface. For the PPMgLN sample, the SHG power was proportional to the square of the pump power and no sign of photorefractive damage was observed. Ultraviolet light of 2.7 mW at the normalized conversion efficiency of 6.5%/W was obtained for the SHG wavelength of 372 nm. To examine the homogeneity of the poling sample, we measured the SHG power along the sample's Z axis, as shown in Fig. 6. Figure 6 shows that maximum SHG power is maintained from the surface to about 80 μm deep and is reduced to zero within the fifth thickness of the crystal. This result was matched to the observation of the cross sections of PPMgLN.

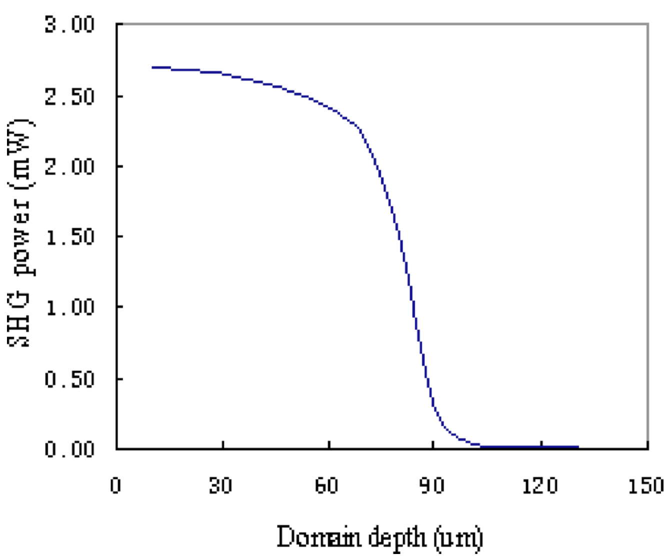

FIG. 6. Variation of the SHG power with the domain inverted position.

In summary, we have presented a promising method of controlling domain inversion structure in MgLN using back-switched poling with short voltage pulses. Using this method, a 2 μm periodically poled structure with uniform periodicity and a 15 mm interaction length was achieved in the MgLN crystal. Since MgLN can be poled at low electric field, periodic poling of thicker crystals is of interest for high power operation of QPM optical frequency converters. Future work will utilize the technique to pole the thicker MgLN crystals(thickness of >1 mm). Future studies to examine the optimum choice for the duty cycle of the electrodes and duration of backswitching, and to fabricate submicron domain structures in waveguide application.

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