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Formation of $MgO:LiNbO_3$ domain-inverted grating for quasi-phase matching by voltage application with insulation layer cladding

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Abstract: We demonstrate a new method for formation of domain-inverted gratings in $MgO:LiNbO_3$ for quasi-phase matched nonlinear-optic devices. It was found that domain-inverted gratings could be obtained by application of voltage pulses with SiO_2 insulation layer cladding, and quasi-phase matched second harmonic generation was demonstrated.

$LiNbO_3$ is often used for implementation of quasi-phase matched (QPM) nonlinear-optic (NLO) devices[1] because of the large NLO coefficients. However, photorefractive damage (optical damage)[2] caused by propagation of a short-wavelength beam may make stable operation rather difficult. An effective method is to use MgO-doped $LiNbO_3$ ($MgO:LiNbO_3$), which exhibits high resistance to the damage.[3] Several techniques for formation of ferroelectric-domain-inverted gratings for QPM in $MgO:LiNbO_3$ have been reported[4-8]. However, the techniques have not been fully established. In this paper, we report experimental insights leading to a new method for QPM grating formation in $MgO:LiNbO_3$ by voltage application with insulation layer cladding.

We first tried to fabricate domain-inverted gratings using conventional electrodes. Z-cut $LiNbO_3$ crystals of 0.5mm thickness doped with 5mol% of Mg were used. Periodic and uniform metal-film electrodes were formed on the +Z and –Z faces, respectively. The crystal was heated to 170°C in silicone oil, and voltage pulses (typically 1.8kV) were applied. Inverted domains were observed only below the outer edges of the periodic electrode fingers, *i.e.*, the obtained structure was domain-inverted dots (see Fig.3(b)) rather than a domain-inverted grating. A large leakage current[8] was observed during the voltage application. It seemed that electric resistivity became low in the domain-inverted dot regions. Formation of the low-resistivity (semi-conducting) domain-inverted shoots gives rise to electric field concentration and completion of domain-inverted dot formation. However, the resultant short circuit would have prevented effective application of electric field to the crystal. To examine the leakage current phenomenon, the change of leakage current after the domain inversion was measured by applying 100V probe pulses. The measured current I was converted into the resistivity $\rho = SV/dI$ with the probe voltage V = 100V, crystal thickness d = 0.5mm and inversion area S = 1.5mm^2. Figure 1 shows the dependence of resistivity of domain-inverted region on elapsed time after application of a 1.8kV inversion pulse. The resistivity of domain-inverted region recovered over time. This result suggests that the leakage current can be reduced by applying inversion pulses with long intervals.

To avoid formation of the short circuit through the inverted shoots, we inserted a thin insulation layer between the crystal and the uniform electrode. The flow of inversion current and leakage current charges the insulation layer capacitance and reduces the voltage across the crystal. However, effective voltage application can be repeated many times by using multiple pulses.

Figure 2 shows the setup for fabrication of domain-inverted gratings by voltage application with insulation layer cladding. As an insulation layer, a SiO_2 film (thickness ~2μm) was deposited by RF sputtering on the –Z face of the crystal. A uniform metal(Au)-film electrode was formed on the SiO_2 film. On the +Z face, a periodic metal(Al)-film electrode of the period Λ = 18μm, finger width w = 6μm, electrode length 10mm and finger length 1mm was formed. The crystal was heated to 170°C in silicone oil, and voltage pulses were applied. Figure 3 (a) and (b) show the structure (after etching) formed on +Z face by application of 100 pulses

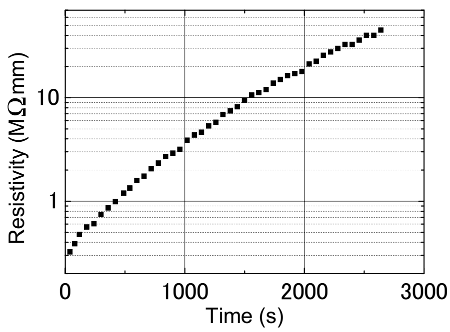

Fig.1 The dependence of resistivity of domain-inverted region on the time after an inversion pulse application.

of effective voltage across the crystal V_{eff} = 1.4kV, pulse width τ = 0.25ms and pulse period T = 10s with and without the insulation layer cladding, respectively. The inverted regions of (a) are longer than those of (b). Current observed during the voltage application with insulation layer was lower than that without insulation layer. The result shows that formation of the short circuit was avoided by the insulation layer.

We tried to increase more the length of domain-inverted lines by increasing V_{eff}, τ and pulse repetition. The attempt, however, was not successful, since the domains were extended not only in the length but also in the width even below the electrode finger gaps. It turned out that the situation could be improved by depositing another SiO_2 layer over the periodic electrode. Figure 4 shows the structure formed on the +Z face by voltage application of 100 pulses of V_{eff} = 1.4kV, τ = 100ms and T = 60s with 2μm-thick SiO_2 layer on the –Z face and 1μm-thick SiO_2 layer over the periodic electrode on the +Z face. A periodic electrode with the same period Λ = 18μm and narrower finger width w = 3μm was used. High-quality domain-inverted gratings were obtained over the entire electrode area as shown in Fig.4(a). The cross section of the structure observed after dicing the crystal and etching is shown in Fig.4(b). Domain-inverted regions continuing from +Z face to –Z face were obtained.

A second harmonic generation (SHG) experiment with domain-inverted gratings of period Λ = 18μm and interaction length L = 10mm formed by this method was performed by using a tunable InGaAsP laser and an Er-doped fiber amplifier as a pump source. QPM-SHG was achieved at a pump wavelength of 1553nm, with FWHM bandwidth of 1.4nm which is close to the theoretical prediction of 1.2nm.

In conclusion, we have presented a new method for fabrication of domain-inverted gratings in $MgO:LiNbO_3$ by voltage application with insulation layer cladding. We obtained high-quality domain-inverted gratings suitable for quasi-phase matching in nonlinear-optic devices.

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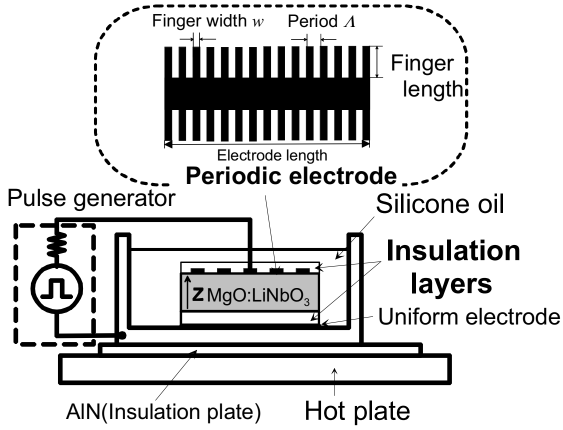

Fig.2 Setup for fabrication of domain-inverted grating by voltage application with insulation layer cladding.

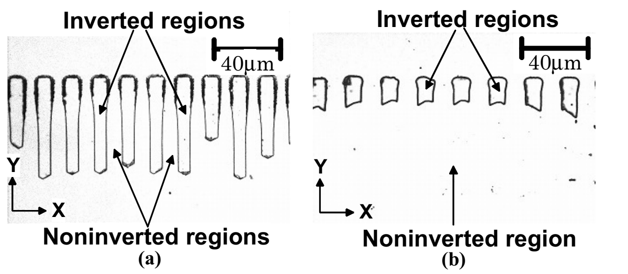

Fig.3 Microphotographs (+Z face, after etching) of the structures formed with insulation layer (a), and without insulation layer (b).

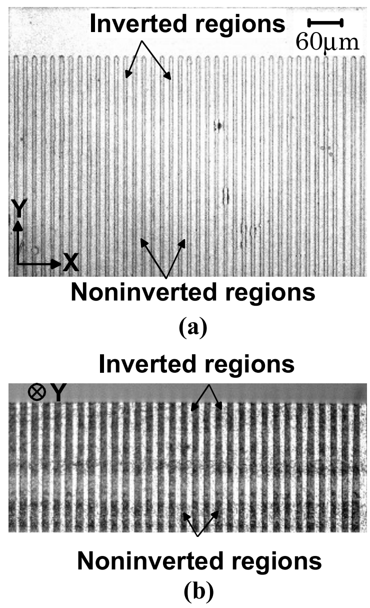

Fig.4 The structure formed with insulation layers on +Z and –Z feces: +Z face (a), and cross section (b).