Mobility-controlled Method to Construct QPM Devices

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Abstract: Periodically poled quasi-phase-matching (QPM) devices were studied by means of mobility-controlled method to realize the ferroelectric domains at desirable quasi-phase-matching periodicity and duty cycle. Fidelity of domain shape and duty cycle were ascribed to the extremely low value of lateral domain mobility of ~0.01 mm^2/kV-sec found on the –Z face of PPLT and ascribed to the +Z face anchoring effect from the charged barriers formed by the diffusion process. Examples were illustrated on 20mm-long PPLT optical parametric oscillator with low threshold of 30 MW/cm^2 and slope efficiency of 45% for broad 1060nm-band generation.

Introduction: The quasi-phase-matching (QPM) materials represent an important selection as laser light sources for scientific investigation and industrial application. Entangled photon pair-generation for quantum information process, multi-harmonics generation for optical pulse synthesis, parametric generation of mid-infrared (IR) sources for spectroscopy and bio-imaging are the representative applications benefited from the QPM devices[1]. For the QPM materials made on the ferroelectric nonlinear crystals such as lithium niobate ($LiNbO_3$) or lithium tantalite ($LiTaO_3$), the limiting factors constraining the photon conversion efficiency are due to the inverted domain periodicity and duty cycle. For the conventional wisdom where the inverted domains were formed by the pulse electric poling method, the fringing field effect plays an essential role in affecting the domain fidelity. The fringing field, however, was known to arise from the dielectric discontinuity across the corrugated interfaces between the poling electrodes and the ferroelectric crystals, and was an inherent issue in dealing with the periodically poled devices.

In this work, we reported the use of a two-step of diffusion-poling scheme to control the lateral motion of inverted domains in PPLN/LT. Our model led to a high-field mobility of ~0.01 mm^2/KV-s in constraining the lateral motion of inverted domains in LT. This number is two-order of magnitude lower than that (~1.6 mm^2/KV-s) previously observed in poling of LN[2]. It therefore allows us to realize 20mm-long PPLT with good control of domain fidelity and reach slope efficiency of 45% when degenerately-pumped by 532nm Q-switched laser to render broad-spectral generation of 1060nm-band infrared sources.

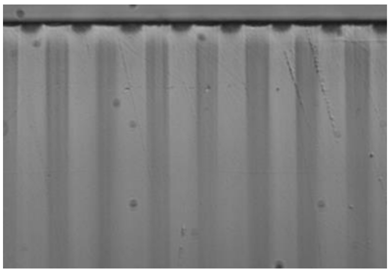
Fig. 1: PPLN sample made by the proposed two-step poling process.

Experiments and Results: Our device fabrication procedures first began with deposition of a thin layer of stripe pattern of Ni/Zn on the +Z face of the $LiTaO_3$ or $LiNbO_3$ substrate. The coated substrates were then subject to a thermal diffusion process at temperature slightly lower than the material's Curie temperature. The purpose of this treatment is to introduce periodically inverted surface domains which can serve as distributed charged barriers against the merging with the nearby electrically poled domains. The latter phenomenon can be seen from Fig.1 where an external voltage of 16KV was applied across a 0.5mm-thick Z-cut LN substrate. We notice that the inverted vertical domains (dark regions in Fig.1) can be well confined between the hemispheric-shape of inverted domains. The latter reflects regions where the process of Li out-diffusion can cause thin surface inverted domains (dark regions), thereby forming charged barriers due to the divergence effect of the polarization (P_s) against the virgin crystal.

In order to quantity the parameters responsible for the lateral expansion of the inverted domains, we analysed the digital images taken from the optically polished y-faces of PPLN or PPLT. Sketched in Fig. 2 are (a) our suggestive trapezoidal domain shape analysis for (b) inverted domain at the –Z face of our study. By examining the sidewall expansion distance as a function of the polarization switching field and the switching time, we observed in Fig.2(c) an extremely low value of domain mobility 0.01 mm^2/kV-sec on the –Z face of PPLT. We note this value is two-order of magnitude lower than that of free expansion value in the –Z face of inverted LN domains. The latter can be ascribed to the surface constraint exerted by the charged barriers underneath the +Z face of this study.

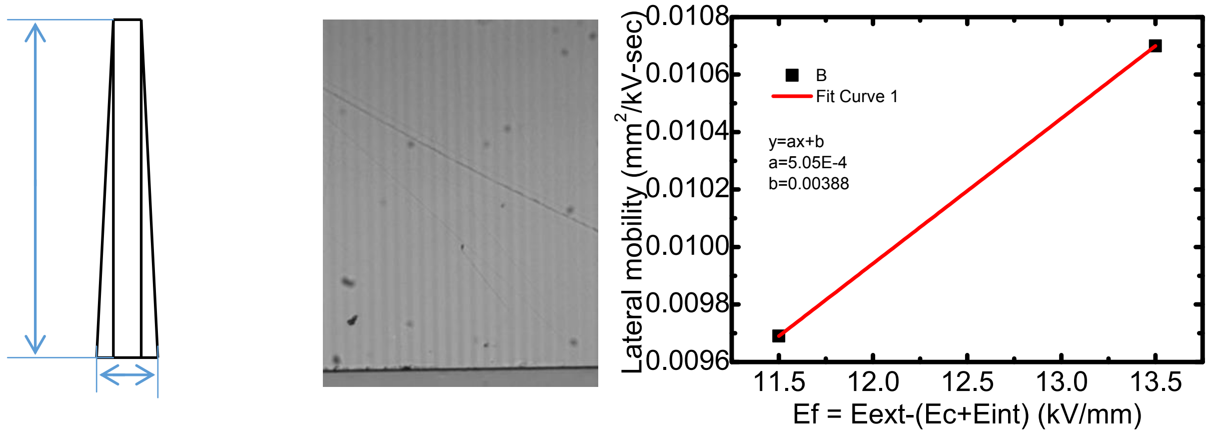

Fig. 2 (a): Trapezoid domain shape analysis, (b) inverted domain, (c) field-dependent mobility for Z-cut PPLT.

We further applied this proposed method to realize a 20mm-long PPLT crystal and built up a spectrally-tuned infrared OPO. The latter was degenerate-pumped by a Q-switch 532nm SHG green laser of 5ns width and 500Hz repetition rate. The corresponding (a) temperature-dependent IR OPO output spectra and (b) conversion efficiency, were displayed in Fig.3, respectively. Here we denote a continuously shift of the 1060nm-band lasers to 1060± 50nm with ± 5°C temperature tuning. The splitting of signal/idler spectra can be analysed to have a Lorentzian gain profile of 20nm (~140cm^{-1}) width and dispersed with ~14cm^{-1} mode spacing. The latter is ascribed to a thin (~250μm) OPO output mirror which also plays a role of intra-cavity etalon. The OPO characteristics data in Fig. 3(b) reveals a threshold of 85mW and slope efficiency more than 45%.

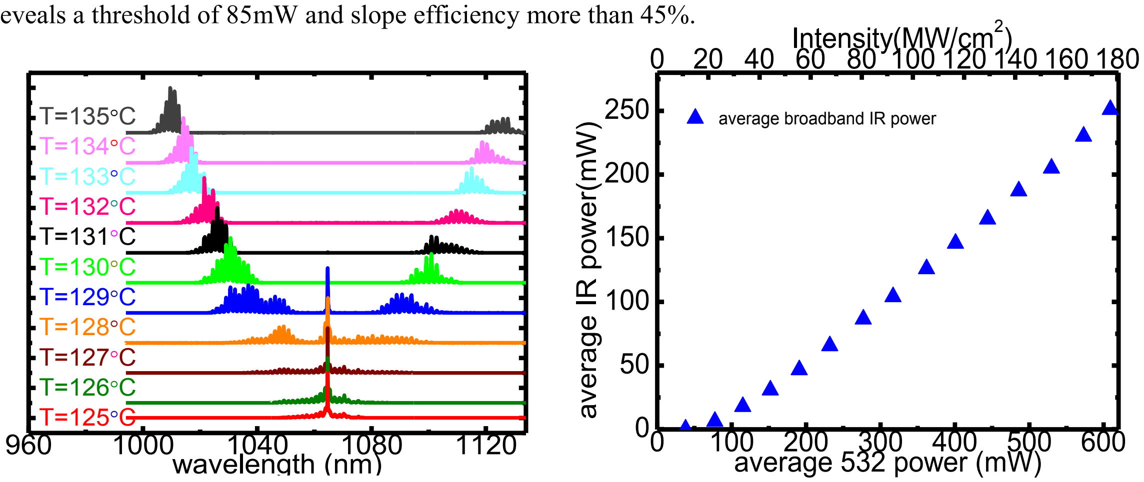

Fig. 3 (a)Temperature-tuning, and (b) slope efficiency of a 20mm-long PPLT-OPO build-up by this proposed method.

Conclusions: We demonstrated the use of two-step, i.e., diffusion followed by pulse field poling procedure to realize QPM devices on PPLN and PPLT. An extremely low value of lateral domain mobility of ~0.01 mm^2/kV-sec can be found on the –Z face of PPLT and was ascribed to the +Z face anchoring effect due to the charged barriers formed by the diffusion process.

References

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2. L. -H. Peng, Y. -C. Fang, and Y. -C. Lin, "Polarization switching of lithium niobates with giant internal field," Appl. Phys. Lett. **74**, 2070 (1999).