In Situ Temporal Periodic Poling of Lithium Niobate Thin Films

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Abstract: We repeatedly pole and unpole a lithium niobate thin film second harmonic generator while monitoring the switching of the optical output. Increasing asymmetry in the poling waveform results in increasing optical extinction ratio.
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1. Introduction

Periodically poled lithium niobate (LN) is widely used for quasi-phase matching of nonlinear optical processes such as second harmonic generation (SHG). Typically, devices are poled during the fabrication process by applying high voltage pulses to lithographically defined electrodes. The electrodes are then subsequently removed. The domains are rendered inaccessible and static thereafter. In situ periodic poling can be performed, however, while monitoring the SHG output power and has been shown to be a useful tool to study domain dynamics in Rb-doped KTP [1], and to help increase the SHG efficiency in lithium niobate thin films [2]. In this work, we consider in situ poling as a mechanism to turn the second harmonic (SH) signal on and off. Using a magnesium oxide (MgO) doped lithium niobate thin film waveguide, we characterize the dependence of the SH extinction ratio on the poling waveform voltage, duration, and time between pulses.

2. Experimental Setup

The SHG device is fabricated in-house and consists of an x-cut, 700 nm thick, 5 mol% MgO:LN thin film-on-insulator loaded with a silicon nitride strip. Coplanar poling electrodes with a period Λ = 6.13 µm and gap G = 15 µm are patterned on top of a 100 nm SiO_2 insulation layer which reduces the leakage current [3]. Details of the device design and fabrication are reported in [3]. Figures 1(a) and 1(b) show the experimental setup and waveguide cross-section. Light from a tunable laser (1549 nm wavelength) passes through a polarization controller (PC) and an erbium doped fiber amplifier (EDFA) and is then coupled on and off chip using tapered lensed fibers. The polarization is set to excite the fundamental quasi-TE mode to utilize LN's d_{33} nonlinear coefficient. On the output, the pump and SH signals are separated with a wavelength division multiplexer and detected using InGaAs and Si photodiodes, respectively. The poling waveforms are generated with an arbitrary waveform generator (AWG) and high-voltage amplifier (HVA) and applied to the sample with contact probes. An oscilloscope (OSC) monitors the poling voltage and current. A drop of silicone oil is placed on the sample to avoid air breakdown during poling.

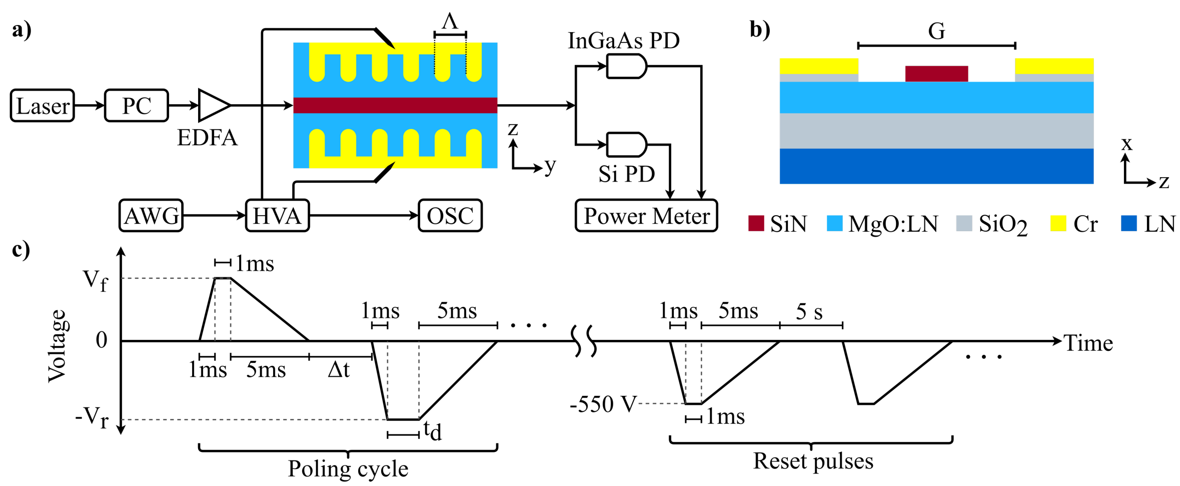

Fig. 1. (a) In situ poling experimental setup; PC: polarization controller, EDFA: erbium doped fiber amplifier, PD: photodiode, AWG: arbitrary waveform generator, HVA: high voltage amplifier, OSC: oscilloscope. (b) Cross-section of x-cut MgO:LN thin film SHG device. (c) Poling waveforms showing one bipolar cycle used to pole and unpole.

Poling and unpoling is monitored over a series of 10 bipolar pulse cycles as shown in Fig. 1(c). The +V pulse poles in the forward direction and turns on the SH signal. The -V pulse poles in the reverse direction and turns off the SH. The voltage, V_r, and the duration, t_d, of the reverse pulse, as well as the time between pulses, Δt, are varied, while the ramp rates and the forward pulse voltage, V_f, remain fixed for all tests. After all 10 bipolar cycles are complete, a series of 10 reset pulses are used to unpole and bring the SH power below the noise floor of the power meter, allowing for all data to be collected from the same device.

3. Results

We first set Δt = 5 s and apply a symmetric poling cycle, i.e. same forward and reverse pulse ($V_f = V_r$ = 550 V, t_d = 1 ms). Figure 2(a) shows the SH power switches on and off with each poling cycle. The SH power in the 'off' state gradually increases over the first few cycles and then saturates. It is believed that residual domains are left behind such that the next pulse results in over-poling and reduced SH power. Subsequent unpoling pulses leave behind even wider residual domains than before and the process continues until reaching a steady state. We conclude that the symmetric reverse pulse is not sufficient to fully unpole and turn off the SH signal, however, increasing V_r as shown in Fig. 2(b-c) can turn off the SH more effectively. Also, increasing the reverse pulse duration, t_d has a similar effect. Results from switching cycles are summarized in Fig. 2(d) which shows the extinction ratio increases steadily with larger V_r and t_d. Lastly, the time between pulses, Δt, is varied while keeping V_r and t_d fixed at 550 V and 1 ms, respectively. Figure. 2(e) shows that Δt = 1 s has a higher extinction ratio than the 5 s and 10 s periods. These results suggest that longer Δt stabilizes the domains making them more resistant to unpoling. Also, the Δt = 1 s case requires more cycles to saturate, however, the total time duration is approximately the same for all cases.

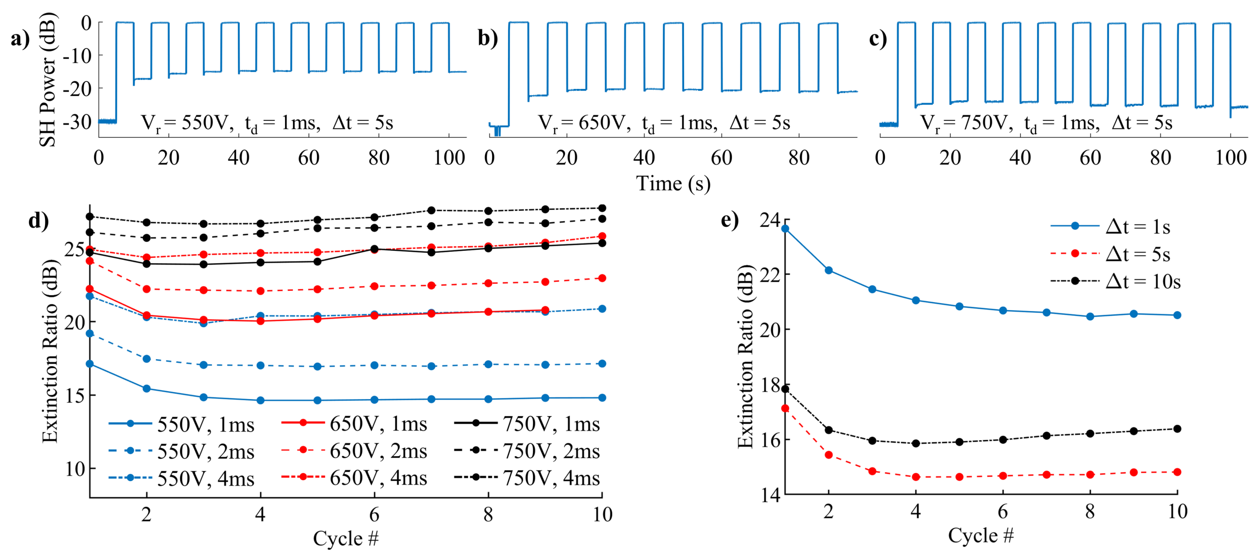

Fig. 2. Switching of second harmonic power on and off by poling with Δt = 5s and t_d = 1 ms. (a) V_r = 550V, (b) V_r = 650V, (c) V_r = 750V. (d) Second harmonic extinction ratio dependence on reverse poling voltages, V_r, and durations, t_d, with Δt = 5s. (e) Extinction ratio dependence on time between pulses, Δt, with V_r = 550V and t_d = 1 ms.

In summary, we have demonstrated temporal periodic switching of the SH power by in-situ poling. A reverse poling pulse with a larger voltage and/or duration than forward poling is found to achieve a higher extinction ratio. Also, a short time between pulses leads to more effective unpoling. These results pave a route to the control of optical output via electrical poling electrodes in thin film lithium niobate integrated photonic devices.

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4. References

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