Large-scale ferroelectric domain inversion in thin-film periodically poled lithium niobate photonics

Ashutosh Rao[1,2,3] and Kartik Srinivasan[1,2,4]

[1] *Microsystems and Nanotechnology Division, Physical Measurement Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA*
[2] *Joint Quantum Institute, NIST/University of Maryland, College Park, MD 20742, USA*
[3] *ashutosh.rao@nist.gov*
[4] *kartik.srinivasan@nist.gov*

Second-order ($\chi^{(2)}$) nonlinear photonics is integral to the miniaturization of systems for a range of applications, including time and frequency metrology[1], imaging[2], and quantum information processing[3]. To this end, different integrated photonic material systems have been investigated, including III-Vs, silicon, silicon nitride, aluminum nitride, and lithium niobate[4]. Thin-film lithium niobate (LN) in particular has attracted strong interest[5], given the access to low-loss photonic devices along with the strong $\chi^{(2)}$ nonlinearity and wide transparency of the material. A key difference between LN and the aforementioned nonlinear materials lies in utilizing ferroelectric domain inversion to realize periodically poled LN (PPLN) via quasi-phase matching (QPM), which confers significant design flexibility compared to traditional methods of realizing $\chi^{(2)}$ interactions such as modal phase matching. Advances in periodic poling are required to support growing demands in quantum information processing, such as quantum frequency conversion of quantum emitters to telecom wavelengths, and scalable generation of coherent light to support deployable quantum emitter systems and quantum computing efforts. Here, we report on approaches to dry etching of LN, large-area ferroelectric domain inversion, and periodic poling periods of 500 nm in thin-film LN. Each of these presents their own challenges – dry etching based on argon plasma requires careful optimization of redeposition as well as mask materials. Periodic poling in thin-film LN across narrow stripes (≈ 25 μm by 4 to 6 mm) has thus far reported to present limited yield or require careful in-situ monitoring, we increase this approximately 100X to 6 mm by 8 mm areas. Our approach is amenable to implementing a wide range of poling periods simultaneously. Finally, ultra-short poling periods < 500 nm have so far only been realized using non-conventional techniques (e.g. focused ion beams) that are challenging to scale to larger areas, while our results here rely on traditional electrical voltage based periodic poling. Our results indicate a promising path toward scaling thin-film PPLN enabled by large-area ferroelectric domain inversion to support growing requirements in quantum information processing and communication.

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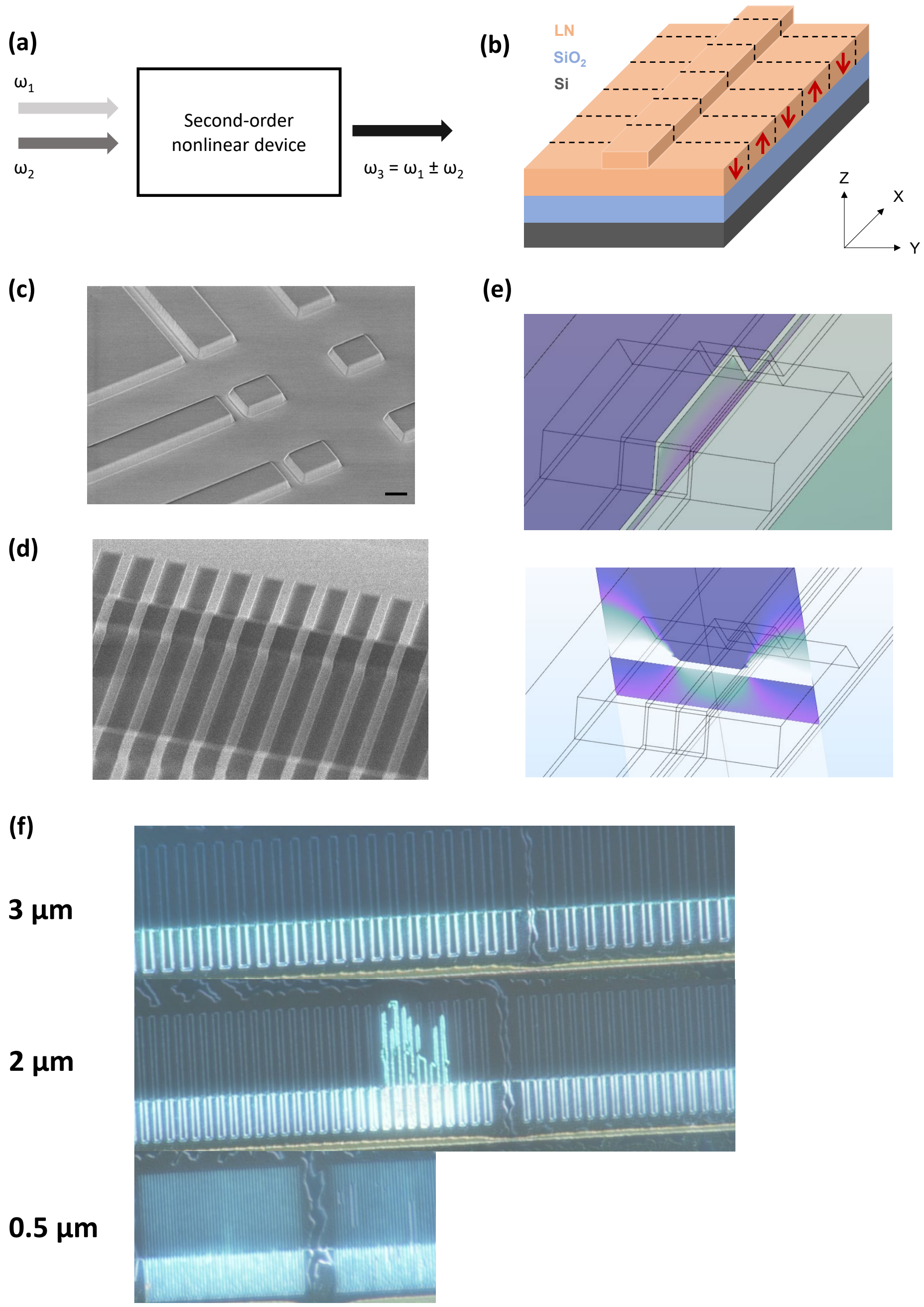

Figure 1. (a), (b). Schematics showing second-order nonlinear devices and their waveguide implementation in a Z-cut thin-film lithium niobate photonic platform. (c) Dry etched test structures showing smooth etched profiles. The scale bar is 1 µm. (d) SEM showing periodic metal electrodes on dry etched waveguides used for periodic poling. (e) 3D simulations corresponding to the SEM in (d) showing electric field distribution during periodic poling. (f) Micrographs showing periodic poling with periods of 3 µm, 2 µm, and 0.5 µm. Wet etching with hydrofluoric acid is used to selectively etch the inverted regions.