Programmable Poling for Electric Field Induced Second Harmonic Generation

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Primary CNF Tools Used: Oxford 100 PECVD, Even-Hour Evaporator, Woollam RC2 Spectroscopic Ellipsometer, Lesker PVD75 Sputter

Abstract:

Programmable photonics plays a vital role in modern technologies because of its low power consumption, high spatially parallelism, and high bandwidth. For most traditional devices, features are etched onto the device during fabrication, defining the device's utility. Recent device improvements enable programmability over a high number of spatial features, allowing a device to move beyond the one device, one function paradigm. Using this device, we demonstrated optical computation with spatially programmable index of refraction, but the same approach underlying this device can be extended into the nonlinear regime by performing electric-field induced second harmonic (E-Fish) generation. This work demonstrates proof-of-concept material development for a nonlinear lithography-free waveguide that converts 1550 nm light into 780 nm light with the ability to shape the wavefront of the generated signal. In the long term, this nonlinear programmability could enable light generation at nontraditional frequencies and spatially parallel computation.

Summary of Research:

Lithography-free photonics has attracted considerable attention in the field of programmable photonics because the large number of programmable parameters allows the device to move beyond the one device, one function paradigm. This means lithography-free devices can perform a large range of tasks and compensate for fabrication error [1]. Recent advances in lithography-free technology have enabled a device with real index of refraction modulation on-chip. In this device, a photoconductor and waveguiding layer with high native χ^2 nonlinearity are stacked in series and placed under high voltage, allowing the two layers act as a voltage divider. Because the index of refraction of the waveguiding layer depends on the electric bias, the index of refraction can be spatially controlled by shining different patterns of light onto the photoconductor [2]. Using the same device concept, the core material can be replaced with a material that displays large induced χ^2 during an electric-field induced second harmonic (E-Fish) process. Silicon nitride has previously demonstrated large induced χ^2 under a large electric bias, and our work successfully reproduced these results [3]. Furthermore, devices fabricated in the CNF displayed programmable E-Fish, showing that we can program the poling period and measure the increased second harmonic signal at the output. Finally, potential doped oxynitride claddings have been fabricated on the PECVD system which have the potential to make a more efficient, continuous-operation device.

Silicon-Rich Silicon Nitride Development. Using a PECVD system, we deposit silicon nitride films with low optical loss over a wide range of visible and infrared wavelengths. By adjusting the silane flow during deposition, we can tune the index of refraction from 1.9 to 2.4 at a wavelength of 1 μm. Moreover, these films display high photoconductivity, with a 100X conductivity switching ratio when pumped with a 532 nm laser. To characterize the film's induced χ^2, we deposit our SiNx films onto conductive Si substrates with 1.4 μm of thermal oxide. After sputtering ITO onto the SiNx layer, we pump the sample with 1535 nm light and record the power of 776 nm light generated as a function of applied DC voltage. By comparing this signal to the signal generated by LiNbO3 (which has a well-characterized native χ^2), we can estimate the effective χ^2 in our films as we increase the applied electric field.

Figure 1 shows the measured χ^2 for our silicon nitride and other similar films, which are consistent with

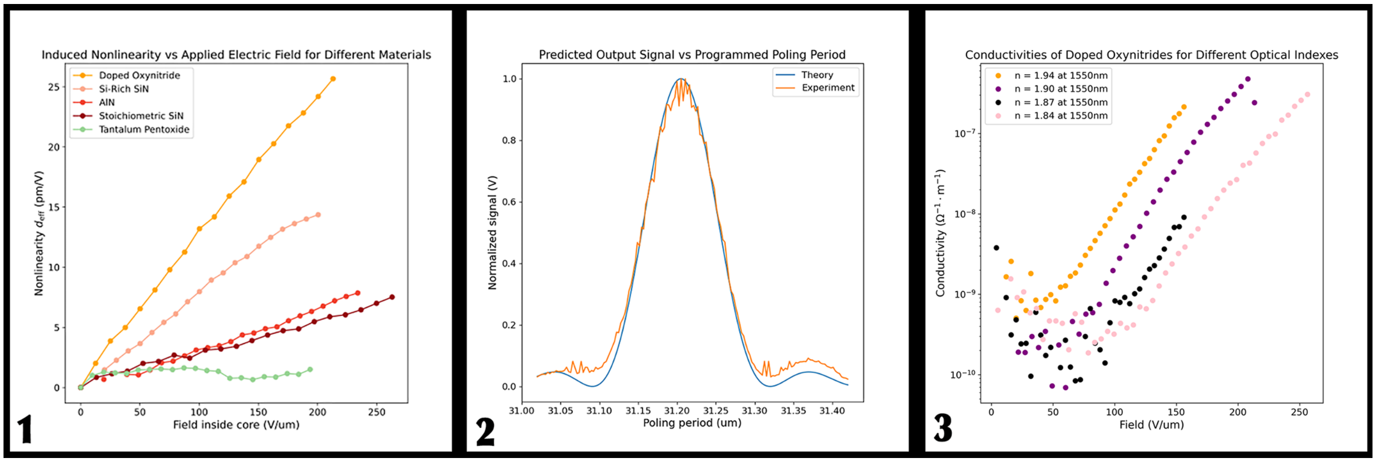

Figure 1: Silicon-rich nitride shows exceptionally high induced nonlinearity under large applied electric fields. When compared to other materials, silicon-rich silicon nitride has high induced nonlinearity. Its high optical index and low optical loss over a wide range of visible and infrared frequencies make it a desirable core material for a programmable nonlinear device.

Figure 2: Comparison of the predicted generated output power versus the experimental output power for different applied poling periods. The close agreement between experiment and theory proves that we can program the poling period to satisfy the phase matching condition for E-Fish. This procedure can be executed for different wavelengths and waveguide dispersions.

Figure 3: Characterization of the electric conductivity of boron-doped silicon oxynitrides. Doped oxynitrides display exceptionally high conductivities given their low optical indexes. Moreover, these conductivity curves show that both index and conductivity can be tuned by adjusting the N2O or B2H6 flow. These characteristics, combined with losses below 5 dB/cm across a broad range of infrared frequencies, make these films ideal claddings for a continuous operation device.

recent measurements on similar materials [3]. When these films are integrated into a programmable device, we can apply different poling periods to satisfy the phase-matching condition for E-Fish. Our device design consisted of SiNx waveguide cores with SiO2 claddings. By applying a low-AC bias to the film, we could optimize the impedance of each film to achieve the highest field contrast between SiNx in the bright and dark state. Figure 2 demonstrates a device where we apply varying poling periods and optimize this period to achieve the largest output signal.

Doped Oxynitride Development. In our current device configuration, there is an impedance mismatch between the cladding and core layers of the device at DC. This means the higher impedance layers (specifically the oxides) will dominate the impedance of the stack at DC and reduce the switching ratio. While we can apply AC voltage to correct for this issue, this causes our devices to have lower modulation efficiencies and to operate non-continuously. One solution to this problem is fabricating low-loss, low-index, conductive cladding materials where we can change the deposition parameters to tune the index and conductivity. Films have already been demonstrated to achieve these types of parameters using boron-doped silicon oxynitrides, so we modified these recipes to integrate them into our devices [4]. Figure 3 shows the characterized conductivities of these films, which are repeatable across different depositions. In the future, we hope to integrate our SiNx and doped oxynitride films to make a continuous operation nonlinear programmable waveguide which can perform E-Fish generation and optical parametric amplification to generate different frequencies.

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