Optically Probed Time Dynamics of $\chi^{(2)}$ Grating Inscription in SiN Waveguides

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Silicon Nitride (Si_3N_4) waveguide platforms have seen significant interest in the recent years, motivated by several advantageous properties such as compatibility with CMOS fabrication standards, low propagation loss, high refractive index and optical nonlinearity suggesting multiple applications in integrated linear and nonlinear optics. Unfortunately, Si_3N_4 does not exhibit second order nonlinear optical properties due to its amorphous nature. Yet, recently several groups showed a build-up in time of a second harmonic (SH) when a pulsed high power pump is coupled in an Si_3N_4 waveguide [1-3]. This phenomenon, referred to as all-optical poling, is explained by the growth of an harmonic space-charge modulated $\chi^{(2)}$ grating which quasi-phase matches the pump and its SH [4].

However, optimal parameters for high poling efficiency, grating properties and time dynamics are still not fully understood. Here we use optical means to observe the time dynamic variations of inscribed grating properties by changing the pump laser wavelength and power coupled to Si_3N_4 waveguide. During poling, we inject 1 ns long pulses at a repetition rate of 5 MHz with up to 35 dBm of average power. Probing of the phase matching condition is done with injecting continuous wave light and collecting spectra at the output of the sample with an optical spectrum analyzer (OSA). In Fig. 1A we show SH generation for a waveguide pumped at different wavelengths. Initially the waveguide was fully poled (i.e. SH power had reached saturation) with a pump at 1540 nm. The top graph in Fig. 1A clearly shows the expected phase-matching peak at 770 nm. The pump wavelength was then tuned to 1550 nm and the waveguide was probed at several instances in time during the poling. We observe that the SH at 775 nm increases while the one at 770 nm reduces (middle panel) until a new steady state is reached (bottom panel) with a saturated 775nm SH and erased 770 nm one. Evidently, changing the pump wavelength is sufficient to update the period of the $\chi^{(2)}$ grating arising from the all-optical poling. Due to the time dynamics, several grating periods can exist in the waveguide simultaneously, potentially allowing multiple phase-matching wavelengths although with lower efficiency. Fig. 1B illustrates this dynamics in time for two full poling cycles.

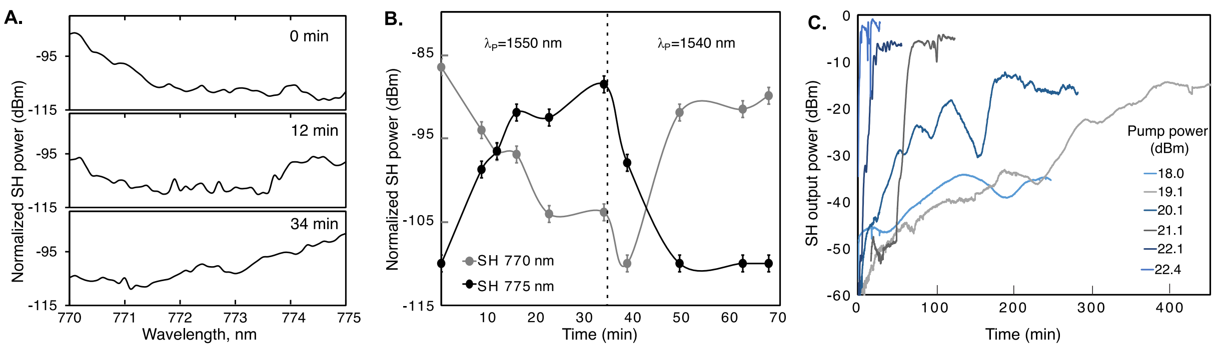

Fig. 1 A. SH generation wavelength sweep registered by OSA after sample poled at 1540 nm (0 min), then after poling at pump wavelength of 1550 nm for 12 min and 34 min, respectively. **B.** SH power versus time measured at 770 nm and 775 nm. Waveguide: width 1.3 µmm, height 0.87 µm, length 58 mm. The SH power is normalized to the pump power squared **C.** SH output power as a function of time for an identical pump wavelength but with different pump powers measured at the output of the chip. Waveguide: width 1.6 µm and height 0.87 µm, length 40 mm.

Alternatively, the grating can be fully erased in couple of seconds by injecting a kW peak power laser in the waveguide, possibly due to the strong generation of third harmonic light. Sequential poling and erasing experiments were conducted using different pump powers. Evidently the poling speed increases significantly with higher pumping levels (Fig 1C). These temporal behaviors further support a model based on asymmetric photoelectron emission from defect states as responsible for grating inscription, which foresee a saturated exponential growth of the SH by increasing the pump intensity [4]. The TH photons would quickly and directly excite the trapped charges to the conduction band and their relaxation would in turn lead to erasing of grating. Several other studies are foreseen to build a complete picture of such all-optical poling temporal dynamics.

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