Self-Injection-Locked Second-Harmonic Integrated Source

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Primary CNF Tools Used: JEOL 9500, AJA Ion Mill, CVC SC4500 Odd-Hour Evaporator, DISCO Dicing Saw

Abstract:

High coherence laser sources are centrally important to the operation of advanced position/navigation/timing systems [1] as well as classical/quantum sensing systems [2]. However, the complexity and size of these bench-top lasers impedes their transition beyond the laboratory. Here, a system on-a-chip that emits high-coherence visible and near-visible light is demonstrated. The devices use a new approach wherein wavelength conversion and coherence increase by self-injection-locking are combined within in a single nonlinear resonator.

Summary of Research:

Optical frequency conversion based upon a quadratic optical nonlinearity is a powerful technology to transfer high coherence laser radiation to new frequencies [3]. Recently, the development of nonlinear photonic integrated circuits (PICs), particularly the on-chip lithium niobate-on-insulator (LNOI) platform [4-8], have boosted nonlinear conversion efficiency while enabling photonic integration with active and passive waveguide elements. However, to achieve high coherence in these systems bench top source lasers have been used.

Here we demonstrate for the first time a hybridly-integrated laser that produces efficient and ultra-coherent near-visible light. The device combines second harmonic generation (SHG) in an LNOI microresonator that also functions to line narrow a DFB pumping laser through self-injection locking (SIL) [9].

The high-Q lithium niobate (LN) microresonator and distributed-feedback (DFB) diode laser are facet-to-facet coupled as shown in Figure 1a and b. The LN resonator provides both resonantly-enhanced SHG and feedback to line narrow the DFB pump. For SHG, it is periodically poled to quasi-phase match the resonant pump and up-converted modes. For line narrowing, the high-Q mode introduces weak backscattering into the DFB laser to achieve SIL. The pump coherence is readily transferred to the up-converted light, resulting in linewidth narrowing of the frequency-doubled light.

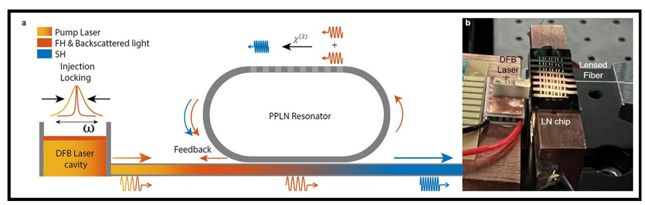

Figure 1: (a) Conceptual diagram of the self-injection locking and second-harmonic generation process. (b) Optical image of the self-injection-locked frequency-doubling chip system.

The race-track LN microresonator device is fabricated on congruent x-cut thin film lithium-niobate-on-insulator (LNOI), with 600 nm LN sitting upon a 4.7 µm silica layer. ZEP-520A resist is used for a first e-beam lithography step (JEOL 9500), followed by 300 nm Ar-ion milling (AJA ion mill) to define the devices. A second e-beam writing step is performed on PMMA resist, and 400 nm electrodes are created using a gold evaporation and lift-off process (CVC SC4500 odd-hour evaporator).

The poling process is similar to previously reported methods [6], but the poling is done after the etching process. The poling uniformity can be observed in Figure 2b. We target SHG of a 1560 nm pump to a near-infrared wavelength near 780 nm.

Maximum conversion occurs at the pump wavelength of 1559.5 nm. By fixing the laser wavelength at this resonance the SHG output power versus coupled power is measured in Figure 3.

Maximum SHG power is 11.3 mW at a pump power of 44.6 mW, corresponding to a conversion efficiency of about 25%. This conversion efficiency is among the highest reported to date for on-chip LN devices [4,5,7,8]. The measurements are in good agreement with the theory (solid curves), which predicts a maximum conversion efficiency of 28%.

The frequency noise of the self-injection locked pump laser is characterized with a self-heterodyne approach [10] while the noise of SHG light is measured with a conventional homodyne detection setup with quadrature-point locking [11]. The results are shown in Figure 4. The high-offset-frequency pump noise is significantly reduced compared to the free-running DFB laser by over 20 dB, demonstrating the effect of the SIL process. The SHG noise reaches a level of 1600 Hz^2 Hz^{-1} at around 3 MHz offset frequency. These data place the SHG short-term linewidth in the range of 10-30 kHz. Because the SHG frequency noise is fundamentally proportional to the square of the doubled pump noise, the SHG frequency noise must therefore be 4× larger (6 dB) than the pump frequency noise.

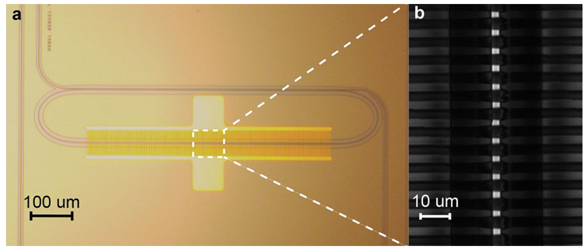

Figure 2: (a) Optical image of the PPLN racetrack resonator. Dashed box gives region of grating imaged in panel b. (b) 2nd-harmonic confocal microscope image of the periodically poled waveguide section showing the uniformity of periodic poling.

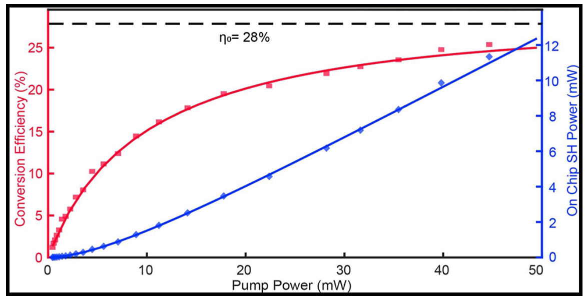

Figure 3: SHG power (blue diamonds) and conversion efficiency (red squares) as a function of the pump power on chip.

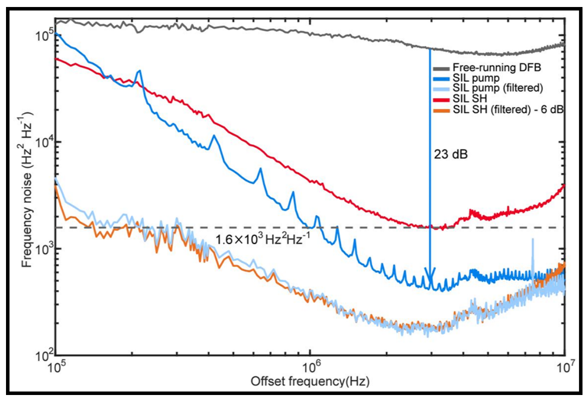

Figure 4: Recorded frequency noise spectrum. Grey, blue and red traces show the frequency noise spectrum of the free-running DFB laser, SIL pump laser, and SIL frequency-doubled light, respectively. The light blue trace and the orange traces show the frequency noise of the pump light and 6 dB down-shifted SHG light when frequency jumping noise is removed from data.

Conclusions and Future Steps:

We have demonstrated a highly-efficient, chip-scale laser that produces high-coherence light by combining SIL and SHG within a single high-Q nonlinear resonator. A SH linewidth as narrow as 10 kHz is achieved by suppression of pump frequency noise. On-chip converted power over 2 mW is obtained in a hybrid-integrated design. An external pump laser yields a maximum conversion efficiency over 25% and maximum SHG power of 11.3 mW. These measurements suggest much higher integrated device performance will be possible by replacing this hybrid design with a heterogeneously-integrated device that features low pump to LN resonator coupling loss. This approach can be applied to other optical frequency conversion processes such as optical parametric oscillation for frequency down-conversion, and third-harmonic generation. Moreover, the on-chip LN platform enables integration with electro-optic components for further functional enhancement.

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