Tunable dual wavelength laser on thin film lithium niobate

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***Abstract*—We experimentally demonstrate a tunable dual wavelength laser on thin film lithium niobate. By combining a micro-transfer printed amplifier with a Vernier cavity containing a periodically poled region, we realize a tunable laser in the telecom band and partially convert it to its second harmonic.**

***Index Terms*—Lithium niobate, Second harmonic generation, heterogeneously integrated laser, micro-transfer printing**

I. Introduction

Thin film lithium niobate (LN) photonic circuits [1], which combine low losses with strong $\chi^{(2)}$-nonlinearity, electro-optic effect and piezoelectricity, are rapidly maturing. Integrated LN circuits enable applications in telecommunications, sensing and quantum photonics. However, many applications would benefit from electrically pumped on-chip lasers. Recently, on-chip telecom lasers in LN have been demonstrated via micro-transfer printing III/V gain material onto a LN waveguide [2], or by edge-coupling LN waveguides to a distributed feedback laser diode [3] or semiconductor optical amplifier (SOA) [4]. Here, using the transfer printing technique, we demonstrate a tunable intracavity frequency-doubled laser in a heterogeneously integrated LN-on-sapphire platform. Our device has a fundamental wavelength in the telecom C-band and a second harmonic at the edge of the visible range.

A microscope image of the laser cavity is depicted in Fig. 1. It consists of a Vernier filter, a transfer printed gain section, a phase tuning section, and a Sagnac reflector. While the Sagnac reflector has a constant reflection over a broad bandwidth, the Vernier filter consists of two add-drop racetrack resonators with a slightly different free spectral range (FSR) reflecting only over a narrow bandwidth where their resonances overlap. This filter ensures that only one longitudinal mode resonates within the gain bandwidth of the printed III/V material, leading to single mode lasing.

II. Measurements

Using Ti/Au micro-heaters we shift the ring resonances to tune the laser cavity wavelength, and we update the phase shifting section to ensure constructive interference of the resonating light with itself. Additionally, we incorporate quasi-phase-matching by periodically poling (PP) the LN within the Vernier cavity (in between the 2 rings) to achieve frequency doubling. This design harnesses the circulating pump power within the cavity to achieve higher second harmonic (SH) powers [4]. The cavity is not designed to be resonant for the SH light which leaks out into an output waveguide and is coupled out of the chip with edge coupling to a lensed fiber.

The device is fabricated by first periodically poling the 500 nm thick LN through a $850\,\mu\mathrm{m}$ long section of the Vernier cavity. We then define the LN ridge waveguides with a 300 nm-deep masked etch [5]. Afterwards, we deposit $1.5\,\mu\mathrm{m}$ thick silicon dioxide and define the Ti/Au micro-heaters (thickness $100\,\mathrm{nm}/15\,\mathrm{nm}$) via lift-off photolithography. The printing process for the gain region is described in [2] and [6].

To demonstrate tunable laser operation, we drive the gain section at $145\,\mathrm{mA}$ and tune the laser by changing the voltage of one of the rings in steps from 0 to $25\,\mathrm{V}$. We ensure the selected wavelength interferes constructively with itself by optimizing the phase shifter voltage to achieve maximum optical power at a power meter for each ring voltage. After this optimization, we record the spectrum on an optical spectrum analyzer. Fig. 2(a) shows tuning of the fundamental wavelength over a range of 15 nm and 10 nm around 1540 nm and 1565 nm respectively. The two different bands are a result of the Vernier filter allowing multiple modes within the gain bandwidth. This imperfect filtering of the Vernier filter can be resolved by optimizing the coupling gap and Q factors of the rings. In the intracavity periodically poled section (see Fig.1) the generated light is frequency doubled. This second harmonic light is detected by a separate OSA for visible wavelengths. We observe that it follows the fundamental tuning with an effective tuning bandwidth for the SH of ~ 5 nm, limited by the phase-matching bandwidth of the poled region. On a test device ($5\,\mathrm{mm}$-long PPLN section) we measure the power dependence of the SH signal using an external Santec TSL 510 laser and observe the expected quadratic dependence (see Fig. 2(b)).

III. Conclusion

In conclusion, we demonstrate a heterogeneously integrated tunable dual wavelength laser on lithium niobate. Modifications to the device design and fabrication should allow us to increase the output power of the fundamental light by an order of magnitude. Furthermore, the conversion to the second harmonic could be increased by improved micro-heater design

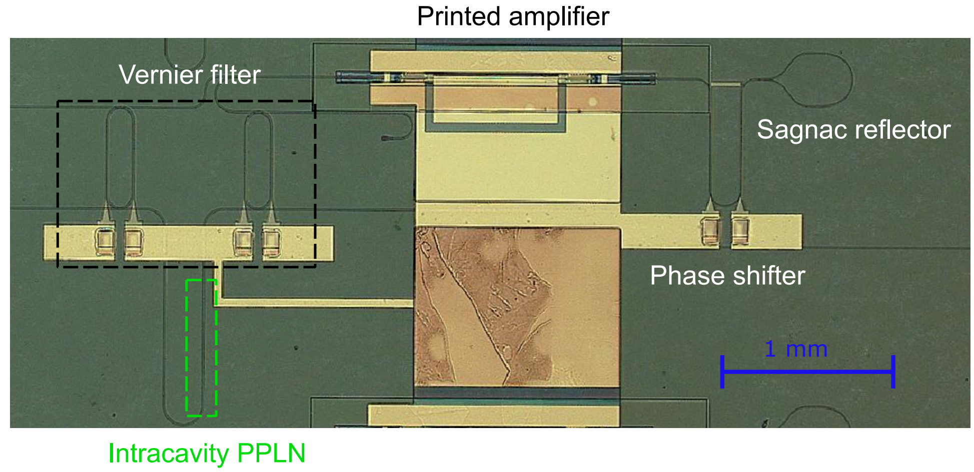

Fig. 1. Optical microscope image of the laser cavity. Using the Vernier effect, we can thermally tune the cavity resonance over a large frequency range. A section of the cavity is periodically poled to generate frequency doubled light.

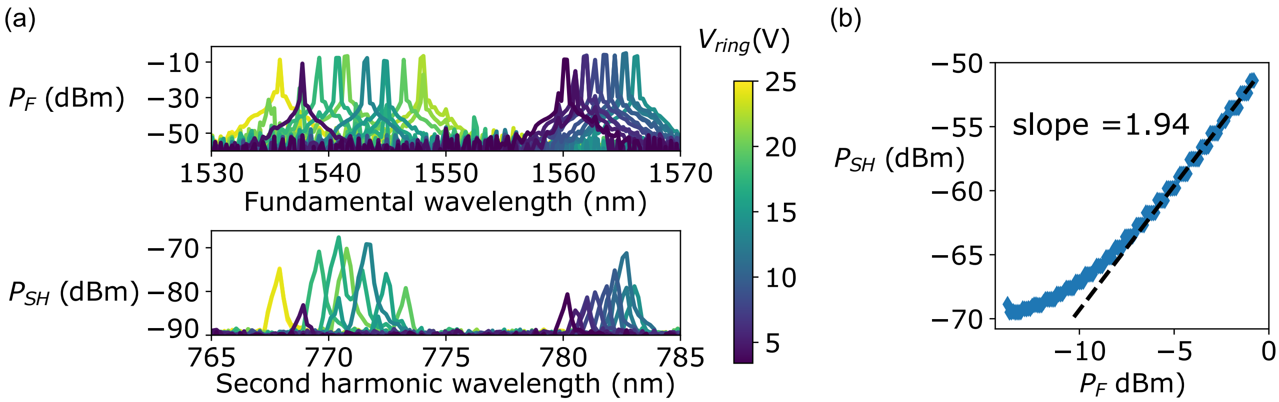

Fig. 2. (a) Thermal tuning of the laser using the Vernier resonance. Top: On-chip laser output power at the fundamental wavelength. Bottom: Second harmonic power at the detector for a sweep of the fundamental wavelength. (b) Power sweep on a test device with a 5 mm-long PPLN section using an external pump laser at 1595 nm showing quadratic dependency of the second harmonic power at the detector with respect to on-chip pump power.

as the current design prevents us from easily tuning the laser into the peak quasi-phase-matching region.

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