Electrically pumped high power laser transmitter integrated on thin-film lithium niobate

Amirhassan Shams-Ansari[1*], Dylan Renaud[1], Rebecca Cheng[1], Linbo Shao[1], Lingyan He[2], Di Zhu[1], Mengjie Yu[1], Hannah R. Grant[3], Leif Johansson[3], Mian Zhang[2], and Marko Lončar[1*]
John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 021382
HyperLight, 501 Massachusetts Avenue, Cambridge, MA 021393
Freedom Photonics, 41 Aero Camino, Goleta CA, USA
**Corresponding author: ashamsansari@seas.harvard.edu, loncar@seas.harvard.edu,*

Abstract: We demonstrate an integrated high-power laser on thin-film lithium niobate with 60-mW of optical power in the waveguides. We use this platform to realize a high-power transmitter consisting of an electrically-pumped laser integrated with a 50-GHz modulator.

As internet data traffic surges, realizing high speed and cost-efficient data transmission has become increasingly important. This demand has motivated exploring high-density microwave to optical interconnects, as they promise ultra-wide bandwidth through up-conversion of high-frequency radio signals to the optical domain. Such systems require linear and efficient modulators, low-loss waveguides, and high-power and low-noise lasers. To date, thin-film lithium niobate (TFLN) has achieved nearly all of these benchmarks [1]. However, integrated lasers remain the key missing element. For optical links, high-power is especially paramount as the gain for such links scales quadratically with optical power. Distributed feedback lasers (DFB) are excellent candidates for hybrid-integration because of their low cost, small footprint, and large output powers exceeding 100 mW [2]. In this work we present a critical step in TFLN photonics by integrating pre-fabricated high-power DFB lasers onto TFLN using flip-chip bonding. Our integration is achieved by developing a novel fabrication process to optimize mode overlap between the TFLN and DFB waveguides, while simultaneously enabling electrical control over the DFB. Our demonstration will open the door for future high-performance fully-integrated optical links with numerous applications in data-telecommunication, positioning, and timing.

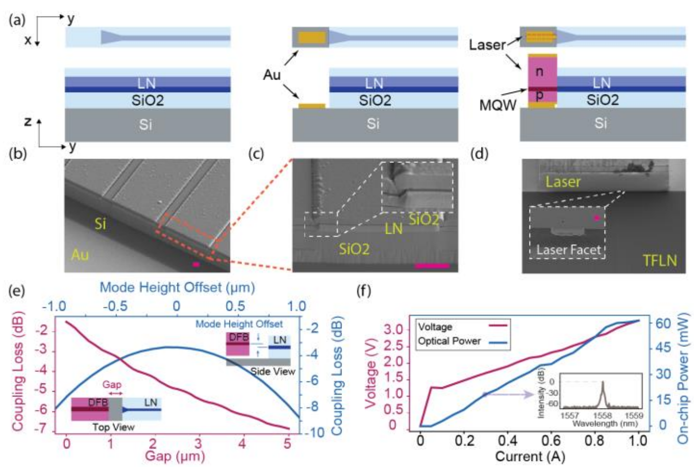

Fig. 1. (a) Fabrication Steps for integration of DFB Laser on TFLN Platform (b) SEM images of the fabricated recessed region and the bonded laser. (c) Simulation results for coupling loss vs the gap and mode-height offset between the laser and the TFLN waveguide, (d) LIV curve for the laser bonded to the passive TFLN circuits.

Figure 1 shows the concept behind our laser on TFLN platform. LN waveguides are prefabricated on 600nm X-cut lithium niobate bonded onto a 4.7μm layer of thermally grown SiO_2 (NanoLN) with 1μm of cladding. For fabrication details, see [3]. At the DFB-TFLN coupling site, we choose the waveguide width to be 8.2μm. Based on simulation, this geometry allows for high tolerance to lateral bonding misalignment (X axis, Fig. 1a) between the DFB and TFLN waveguides. The waveguide adiabatically tapers down to 0.8μm to ensure single mode operation. To fully integrate the DFB laser with the fabricated TFLN device, we fabricate a recessed region through a multi-step etching process. First, the upper cladding, LN layer, and buried oxide are etched through to the silicon carrier. A critical step in this deep-etch process is to produce vertical sidewalls at the coupler interface. The sidewall angle sets the minimum coupling gap between the DFB and TFLN waveguides. As a result, a smaller sidewall angle increases the coupling efficiency. We evaluate the sidewall angle to be ~85°, which sets the minimum achievable gap between the laser and the waveguide to be ~500 nm (Figs. 1(b-c)). The laser is flip-chip bonded onto a recessed region in TFLN chip using gold-gold thermo-compression bonding. This gold layer also serves as a contact for electrically injecting or depleting carriers from the DFB. For our devices, we choose to orient the P-side contacting the gold in the recessed region (Fig. 1d). This enables efficient conduction cooling of the P-side as it is in direct contact with the silicon carrier. The coupling loss introduced by the mode height offset and gap distance is quantified by finite difference eigenmode simulations (Fig. 1e).

Fig. 1f presents electrical and optical characterization of an integrated DFB. LIV measurements are performed by contacting a sourcemeter (Keithley 2400) to the N- and P-surface of the laser and increasing the current up to 1.0 A. The laser emission is collected from the TFLN device facet using a single lens. The resulting on-chip power is then calculated by factoring in the lens coupling loss, which we measure to be 4.8±0.5dB. As shown in Fig. 1a, we realize a record-setting on-chip optical power of over 60 mW at 1 A under an uncooled testing environment. This is a median estimate, and assumes a coupling loss of 4.8 dB, while the upper bound yields nearly 80 mW on-chip. This amount of on-chip power is one of the highest ever reported in the literature in integrated platforms [4,5]. To ensure the DFB performance is maintained after bonding, single mode operation is confirmed using a delayed self-heterodyne technique [6], and the linewidth is measured to be below 1 MHz. The inset of Fig 1c displays the DFB lasing wavelength of 1558 nm. The depicted linewidth is limited by the OSA resolution and is provided only to demonstrate the operational wavelength. Finally, the stability of the DFB is revealed by the absence of mode hopping in the LI spectrum. This behavior is found to be common over multiple integrated devices.

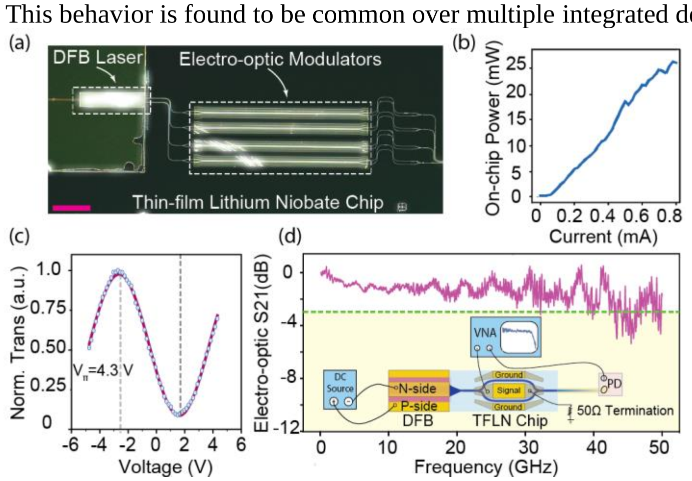

Fig.2 (a) Micrograph image of the integrated DFB-TFLN laser-transmitter. (b) Measured LI curve for the device shown in (a). (c) Measured V_π (d) electro-optic response of the integrated transmitter (S21)

To illustrate the full potential of our approach, DFB lasers are integrated with a TFLN EO-modulator (Fig. 2a). In this device ∼25 mW of optical power from the DFB laser (current: 0.8 A) is coupled into a Mach-Zehnder interferometer based amplitude modulator with 5-mm long travelling wave electrodes (Fig. 2b). To illustrate the envisioned functionality of our chip as an integrated high-bandwidth transmitter, we evaluate its EO response (S_{21}). Our device features a V_π=4.3V and a 3-dB bandwidth > 50 GHz (Figs. 2c and d). Cable losses, probes, and detector response are subtracted from the measured frequency response. The response fluctuation beyond 45 GHz is due to the limited bandwidth of the photodiode. In summary, we showed the first high-power hybrid integrated transmitter on TFLN by flip-chip bonding a DFB laser. The bonding design allows efficient thermal anchoring for the laser which allowed uncooled operations with 60 mW in the waveguides. Our high-power transmitter platform will enable a new class of applications in digital and analog communication spaces.

Funding: Defense Advanced Research Projects Agency (DARPALUMOS) (HR0011-20-C-0137). Air Force Office of Scientific Research (AFOSR) (FA9550-19-1-0376)

Disclaimer: The views, opinions and/or findings expressed are those of the author and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government

[1] D. Zhu, *et al.*, "Integrated photonics on136thin-film lithium niobate," Adv. Opt. Photonics13, 242–352 (2021).1372
[2] L. Johansson, *et al.*, "Advanced high power components for rf photonic applications," in 2019 IEEE Research and Applications of Photonics in Defense Conference (RAPID),(IEEE, 2019)
[3] M. Zhang *et al.*, "Monolithic ultra-high-q lithium niobate microring resonator," Optica4,1431536–1537 (2017)
[4] M. Theurer *et al.*,"Flip-chip integration of inp and sin," IEEE Photonics Technol. Lett.31,147273–276 (2019)
[5] D. Huang, *et al.*, "High-power sub-khz linewidth lasers fully integrated on silicon," Optica6, 745–752 (2019)
[6] T. Okoshi, *et al.*, "Novel method for high resolution measurement of laser output spectrum," Electron. letters16,153630–631 (1980)
[7] P. Kharel, *et al.*, "Breaking voltage–bandwidth limits in integrated lithium niobate modulators using micro-structured electrodes," Optica8, 357–363 (2021)