Linear Frequency Chirp Generation Employing Opto-electronic Feedback Loop and Integrated Silicon Photonics

Phillip Sandborn, Niels Quack, Nazanin Hoghooghi, Jeffrey B. Chou, James Ferrara, Simone Gambini, Behnam Behroozpour, Li Zhu, Bernhard Boser, Constance Chang-Hasnain, Ming C. Wu
Department of Electrical Engineering and Computer Science, University of California, Berkeley, CA, 94720, USA
sandborn@berkeley.edu

Abstract: We demonstrate generation of linear frequency chirps exhibiting an excursion of 50 GHz (λ_0=1548nm) using an optoelectronic phase-locked loop and integrated silicon photonics interferometer (FSR=3.0GHz), demonstrating the feasibility of an integrated chip-scale frequency-modulated continuous-wave LADAR source.
OCIS codes: (250.3140) Integrated optoelectronic circuit; (010.3640) Lidar.

1. Introduction

Frequency Modulated Continuous Wave (FMCW) Laser Detection and Ranging (LADAR) is a powerful technique commonly used for 3D imaging [1], offering high accuracy and resolution. Compared to alternative 3D imaging techniques, such as Time of Flight (TOF) measurements [2] or stereoscopic imaging [3], FMCW LADAR offers the advantage of high range resolution at small distances, without the need of high speed electronics: 31 µm range resolution at 1.5m has recently been reported [4]. Such previously reported FMCW LADAR sources include bulky free-space or fiber interferometers [5]. In this work, we use a silicon photonics interferometer with an integrated photo detector to generate the frequency-modulated signal. We demonstrate the generation of linear frequency chirps exhibiting an excursion of 50 GHz at a center wavelength λ_0=1548nm, using an optoelectronic phase-locked loop and integrated silicon photonics interferometer with a free spectral range (FSR) of 3.0GHz. This work demonstrates the potential of an integrated chip-scale frequency-modulated continuous-wave LADAR source.

2. Optoelectronic feedback loop and silicon photonics integrated circuit design

In order to generate the FMCW LADAR source signal, a linear frequency sweep is generated using an optoelectronic feedback circuit, as described by Satyan et al. [6]. Figure 1 depicts a schematic of the implemented optoelectronic phase locked loop (OPLL). In our benchtop system, a commercially available distributed feedback (DFB) laser (JDSU) is current modulated. The optical signal is coupled using an optical fiber grating coupler into the silicon photonics integrated circuit. The photocurrent is amplified and fed to a Field Programmable Array (FPGA), where a digital phase locked loop generates the control signal to the DFB modulation input. In difference to the OPLL presented in [6], we invert the ramp slope at the desired repetition frequency, in order to generate a triangular waveform, rather than a saw tooth shaped form, taking into account the continuous tuning characteristic of the DFB laser. The integrated silicon photonics circuit was fabricated using the OpSIS [7, 8] multi project wafer run. Figure 2 shows an optical micrograph of the integrated silicon photonics circuit indicating the circuit elements.

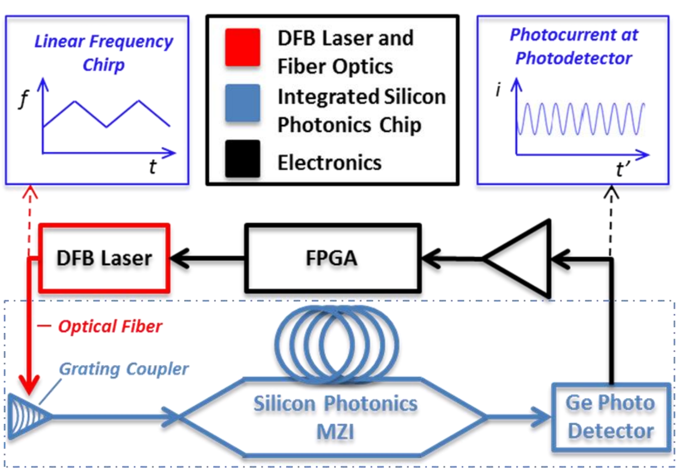

Figure 1: Schematic representation of the implemented optoelectronic feedback loop. The dashed box indicates the integrated silicon photonics chip.

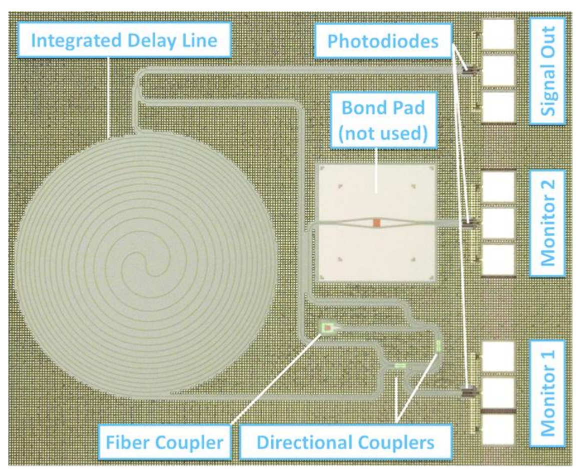

Figure 2: Optical micrograph of the integrated silicon photonics circuit.

4. Results

The silicon photonics integrated circuit design implements a 49mm delay line in a Mach Zehnder Interferometer (MZI), and the corresponding measured sinusoidal frequency response exhibited a free spectral range of 3.0 GHz (Figure 3). Assuming a responsivity of 0.5 A/W of the germanium photodiode, the total insertion loss (including fiber coupler, directional coupler and waveguide losses) was 22dB in the specific device. This loss can be decreased with improved coupler design. The photo detector signal was amplified using an electronic low-noise amplifier.

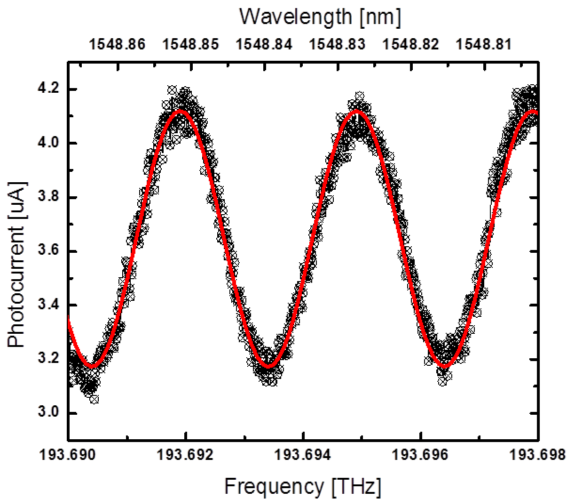

Figure 3: Measured frequency response (black) of the silicon MZI, and sinusoidal fit (red), showing a FSR of 3.0 GHz.

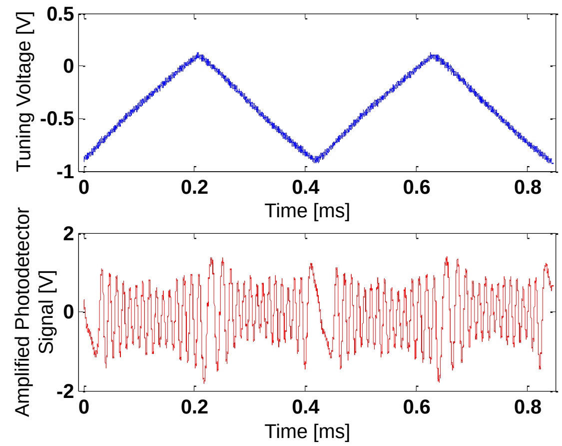

Figure 4: Measured photo detector output: closed loop voltage signal (top; corrected for non-linearities), photo detector output (bottom).

The optoelectronic feedback loop locks the beat frequency of the MZI to 75 kHz (Figure 4). The closed-loop signal, generated without any predistortion offset, settles into a periodic frequency sweep that is, to first order, a triangle wave. The laser frequency sweep has a total excursion of 50 GHz, which corresponds to a total beat frequency of 75 kHz.

5. Conclusions

We have demonstrated the generation of linear frequency chirps using an optoelectronic feedback loop employing an integrated silicon photonics circuit. With an MZI length of 49mm, an FSR of 3.0 GHz was obtained. The implemented phase locked loop stabilized the linear frequency ramp to the reference frequency of 75 kHz. This optoelectronic circuit demonstrates the potential of a fully integrated chip scale FMCW LADAR source for 3D imaging applications.

6. Acknowledgements

This project is supported by the Defense Advanced Research Projects Agency (DARPA) E-PHI program under Grant No. HR0011-11-2-0021.

7. References

[1] M. Juberts, A. Barbera, "Status report on next generation LADAR for driving unmanned ground vehicles," *Proceedings of SPIE, Mobile Robots XVII, edited by Douglas W. Gage*, vol. 5609, pp. 1 – 12, 2004.

[2] B. Schwarz, "Mapping the World in 3D," *Nature Photonics*, vol. 4, no. 7, pp. 429-430, 2010.

[3] J. Smisek, M. Jancosek, and T. Pajdla, "3D with Kinect," *IEEE International Conference on Computer Vision Workshops*, Barcelona, Spain, 6-13 Nov 2011, pp.1154-1160.

[4] P. A. Roos, R. R. Reibel, T. Berg, B. Kaylor, Z. Barber, W. R. Babbitt, "Ultrabroadband optical chirp linearization for precision metrology applications," *Optics Letters*, vol. 34, no. 23, pp. 3692-3964, 2009.

[5] F. R. Giorgetta, E. Baumann, K. Knabe, I. Coddington, N.R. Newbury, "High-resolution Ranging of a Diffuse Target at Sub-Millisecond Intervals with a Calibrated FMCW Lidar," *Conference on Laser and Electro-Optics*, San Jose, CA, USA, May 6, 2012.

[6] N. Satyan, A. Vasilyev, G. Rakuljic, V. Leyva, A. Yariv, "Precise control of broadband frequency chirps using optoelectronic feedback," *Optics Express*, vol. 17, no. 18, pp. 15991-15999, 2009.

[7] OpSIS, http://opsisfoundry.org/

[8] K. Bourzac, "Photonic chips made easier," *Nature*, vol. 483, no. 7390, p. 388, 2012.