Integrated high-speed mid-infrared electro-optic modulator for free space optical communication

Optica 20th Anniversary Challenge: Information

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Mid-infrared (Mid-IR) spectral regime from 3-5 μm is well-known as robust optical carriers for free space optical communications due to the low absorption atmosphere window and the higher tolerance to scattering than the near-infrared. However to produce high data rate optical link, direct current modulation of a quantum cascade laser is often deployed either at cryogenic temperatures up to 20 GHz modulation speed or at room temperature up to a few GHz speed. It is because that the high-speed low-loss electro-optic modulator is lacking in the mid-IR due to the material absorption and lack of individual control of both microwave and optical properties. We propose to overcome this limitation by using the integrated photonic technology where the tightly confined nanophotonic waveguide can be used to tailor the optical property via dispersion engineering and the microwave field can be tuned via electrode design.

Thin film lithium niobate (LN) technology has recently attracted significant interest in data center applications due to its excellent electro-optic performance in terms of low insertion loss (< 0.5 dB), high EO bandwidth (> 100 GHz) as well as low $V_{pi}L$ (2 V*cm) demonstrated at telecommunication wavelengths near 1.5 μm. In addition, LN is a long-sought-after integrated photonic material due to its wide transparency window from 400 nm to 5 μm, large second order and third order nonlinearities as well as large piezo-electric response. It has superior advantages for reconfigurable mid-IR photonics, as compared to silicon-based photonics which intrinsically lacks EO response and different frequency generation. We propose to design and develop a low-loss integrated EO modulator on thin film LN in the mid-IR from 3-4.5 μm with > 50 GHz EO bandwidth and 10 V·cm $V_{pi}L$. The operating bandwidth and power consumption for switching is an order of magnitude beyond the state-of art mid IR modulators (of a few GHz, 20-50 V·cm). We will explore two potential geometries including suspended LN and LN on sapphire platforms to overcome the absorption-induced loss of silicon dioxide. Furthermore, we propose to develop a flat-top optical frequency comb (OFC) driven by cascaded EO modulators for wavelength division multiplexing (WDM). The device consists of an amplitude modulator and a phase modulator, where the amplitude modulator carves a flat-top temporal pulse and phase modulator imposes a quadratic temporal phase. The system transfers the flat-top profile from time to frequency. This approach would enable a high and uniform signal to noise ratio across the optical bandwidth, featuring a high pump-to-comb conversion efficiency of up to 50%. Such approach overcomes the low conversion efficiency and the exponentially decaying intensity profile of the integrated microcombs technology, and could be a highly desired WDM source for mid-IR optical communication. Together with the compatibility of high speed EO modulators, we envision a fully integrated EO-comb-driven optical data link with the potential for aggregate transmission rates of tens of Tb/s. The mid-IR nanophotonic technology will also have profound impact in areas including precision spectroscopy and imaging.