Full-Spectrum Visible Electro-Optic Modulator

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Primary CNF Tools Used: JEOL JBX9500FS Electron-Beam Lithography System, Odd Hour Evaporator, AJA Ion Mill, Zeiss Ultra SEM

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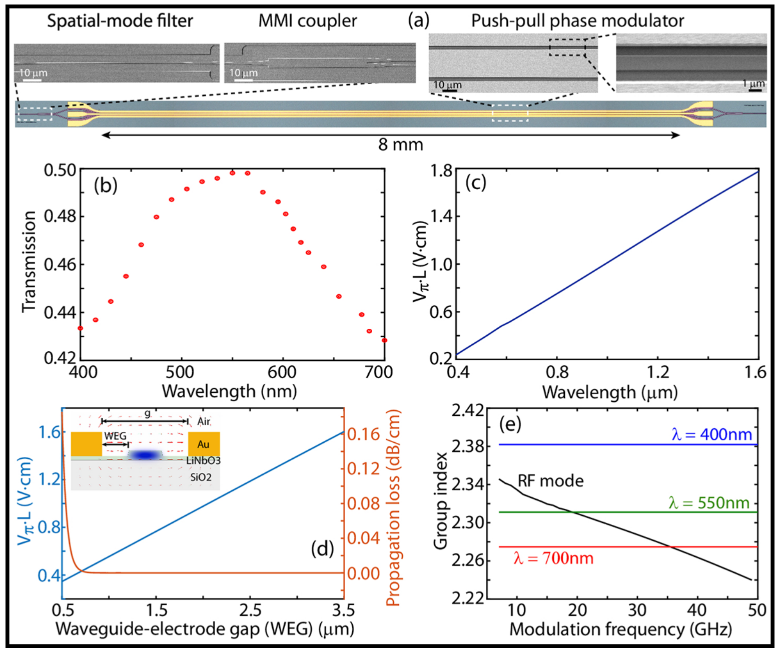
Abstract:

We report an on-chip high-speed visible-band electro-optic modulator that can operate over the full visible spectrum of 400-700 nm, with a record low $V\pi{\cdot}L$ of 0.48, 0.25, and 0.17V·cm at red, green, and blue wavelengths of 630, 520, and 450 nm, respectively, and an operation bandwidth of > 20 GHz.

Summary of Research:

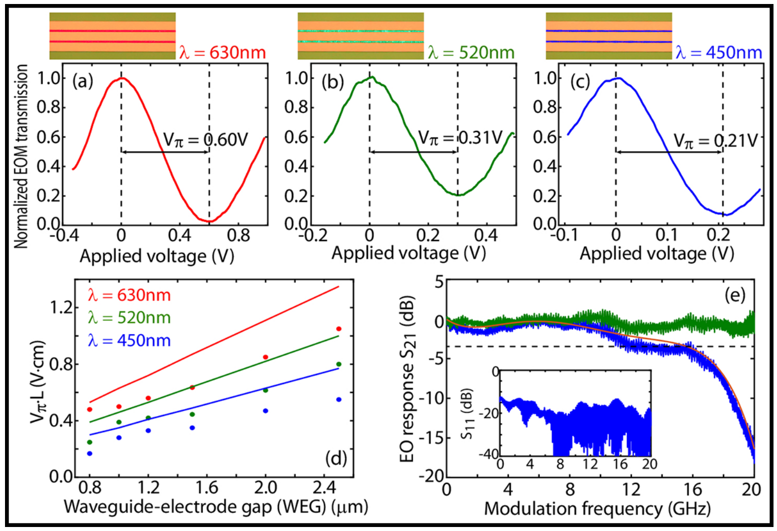
The visible spectral region underpins many important applications including sensing, optical clocks, 3D displays, and augmented/virtual reality (AR/VR). All of these applications rely crucially on precise control and efficient modulation of visible light. Recently, there has been significant interest in transferring these applications onto chip-scale platforms [1,2] that would offer great advantages in size, power, functionality, and design flexibility. However, development of chip-scale electro-optic modulators (EOMs) in the visible band remains fairly limited [3-5]. Here, we demonstrate an on-chip lithium niobate (LN) EOM that can operate over the full spectrum covering the entire visible band from 400 to 700 nm. We show that the visible-band EOM exhibits record high modulation efficiency with $V\pi{\cdot}L$ as low as 0.48, 0.25, and 0.17V·cm at wavelengths of 630, 520, and 450 nm, respectively, which are the smallest ever reported for LN traveling-wave EOMs developed to date.

Figure 1(a) shows a fabricated EOM that consists of a pair of 3 dB multimode interference (MMI) couplers, an 8-mm-long phase modulation section operating in the push-pull fashion, and a spatial-mode filter section placed in the front.



The devices are made on a 300-nm-thick x-cut LN-on-insulator wafer, partially etched down by 180 nm. The modulator waveguide has a width of 1 μm and a waveguide-electrode gap (WEG) of 0.8 μm, with an electrode spacing of 2.6 μm in order to enhance modulation efficiency. The electrodes contact directly with the LN layer to improve the optical-microwave mode overlap. For the EOM to operate over the full visible spectrum, the MMI coupler is designed to be broadband with a transmission of 43.3%, 49.8%, and 42.8% at wavelengths of 400, 550, and 700 nm, respectively [Figure 1(b)]. The SMF is a tapered waveguide to cut off higher-order guided modes to ensure single-mode operation of the EOM.

Figures 2(a)-2(c) show the modulation performance of the EOM. The device exhibits a $V\pi$ of 0.60 V, 0.31 V, and 0.21 V, respectively, at the red, green, and blue wavelengths of 630, 520, and 450 nm, which corresponds to a $V\pi{\cdot}L$ of 0.48, 0.25, and 0.17V·cm. The extinction ratio (ER) is measured to be 16 dB at 630 nm [Figure 2(a)]. The ER decreases to 7 dB and 12 dB at 520 and 450 nm [Figures 2(b) and 2(c)], respectively, which is dominantly due to the green and blue FP lasers (Thorlabs, LP-520 and LP-450) with a poor polarization ER of ~ 10 dB that interferes with the ER characterization. The recorded WEG dependence of $V\pi{\cdot}L$ [Figure 2(d)] shows a slightly better performance than the theoretical expectation, which is likely due to a smaller fabricated WEG than the designed WEG. Figure 2(e) shows that the EOM exhibits a 3 dB bandwidth of 16 GHz (blue curve). This value is simply limited by the frequency response of the optical detector (Newport, 1544-B) [Fig. 2(e), red curve]. By factoring out the detector response, the EOM itself exhibits a 3 dB bandwidth > 20 GHz [Fig. 2(e), green curve]. The insertion loss of the EOM is measured to be 6.8 dB at 630 nm, which is primarily attributed to the fabrication imperfections of the SMF and the MMI couplers.



The demonstrated full-spectrum EOM with record performance achieves a key step toward energy-efficient and high-speed visible photonics, opening up a great avenue toward chip-scale miniaturization and integration of versatile functionalities in sensing, atomic clocks, AR/VR, etc., on the promising thin-film LN platform.

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