

Suspension Free Acousto-optic Modulator for Near Ultraviolet and Visible Wavelength

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, Heidelberg MLA 150 Maskless Aligner, ASML PAS 5500/300C DUV Wafer Stepper, Metticon, Zeiss Ultra SEM, PT770 Etcher, Woollam RC2 Spectroscopic Ellipsometer, AFM, Furnaces, Oxford PECVD, Keyence VHX-7100 Digital Microscope and Oxford FlexAL.

Abstract:

In this work, we fabricate and characterize suspension-free inter-modal acousto-optic modulator for light modulation near $\lambda = 397$ nm, by taking advantage of a surface acoustic wave mode confinement that is co-localized with the optical mode in a buried optical waveguide. Optical confinement is achieved using waveguides fabricated from the $(\text{HfO}_2)_{0.67}(\text{Al}_2\text{O}_3)_{0.33}$ composite, while surface acoustic waves are confined vertically by SiO_2 and laterally by AlN trenches.

Summary of Research:

Acousto-optic modulators (AOMs) are widely used for frequency, phase, and amplitude modulation in a broad range applications including microwave to optical signal processing [1], quantum information control [2] and atomic physics. Their ability to modulate light with a high extinction ratio (~ 70 dB), fast switching times (tens of nanoseconds), high optical power handling (tens of milliwatts), and wide frequency tunability (tens of megahertz) has made them an inseparable component in atomic physics laboratories. However, conventional bulk AOMs have a relatively large footprint because the acoustic field is not tightly confined to the optical mode. In addition, they typically require 1-10 W of RF drive power, limiting their scalability and compatibility with photonic integrated circuits. To address these limitations, several on-chip AOM platforms have been demonstrated but most of them rely on suspended optomechanical waveguides and limited at telecommunications wavelengths ($\lambda \approx 1550$ nm), which limits power handling, makes them possibly incompatible with low temperature operation and limits integration with a cryogenic ion trap chip [3-6]. In addition, the use of non-standard CMOS materials

and fabrication processes, presents challenges for large-scale integration in commercial foundries. Moreover, the material platforms explored to date generally exhibit significant optical loss at ultraviolet (UV) and visible wavelengths, which are essential for a wide range of applications, including biochemical spectroscopy and quantum control of trapped ions, neutral atoms, and solid-state quantum systems [7,8]. Here, we design and fabricate a material platform which aims to maximize the overlap coupling coefficient by engineering co-propagating acoustic an optical waveguide leveraging surface and lateral acoustic guiding.

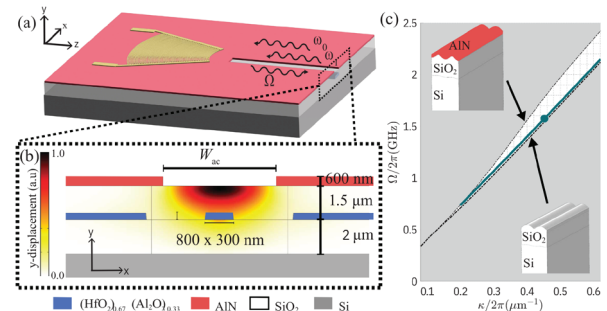


Figure 1: a) Schematic of a release-free AOM with co-confined acoustic and optical modes. b) Cross section showing the dominant (y) displacement of a confined acoustic mode. c) Dispersion of guided mode with top (bottom) light-cone of a $\text{AlN}+\text{SiO}_2$ (SiO_2) RM.

The AOM (shown in Fig.1) is composed of a $(\text{HfO}_2)_{0.67}(\text{Al}_2\text{O}_3)_{0.33}$ multi-mode optical waveguide buried in 1.5 μm of SiO_2 and a 600 nm thick film of sputtered AlN used to launch a counter-propagating acoustic wave via a focusing inter-digitated transducer (Fig. 1a). The film stack-up supports a surface acoustic wave Rayleigh mode (top inset of Fig. 1c), which together with an etched trench of width W_{ac} on AlN , creates a confined acoustic mode that overlaps with the buried optical waveguide (Fig. 1b). This dominant

displacement of the Rayleigh mode along the y-direction, which shifts the top and bottom boundaries of the optical mode, couples the TE₀₀ and the TE₀₁ modes at $\lambda = 397$ nm (optical modes are shown in Fig.2).

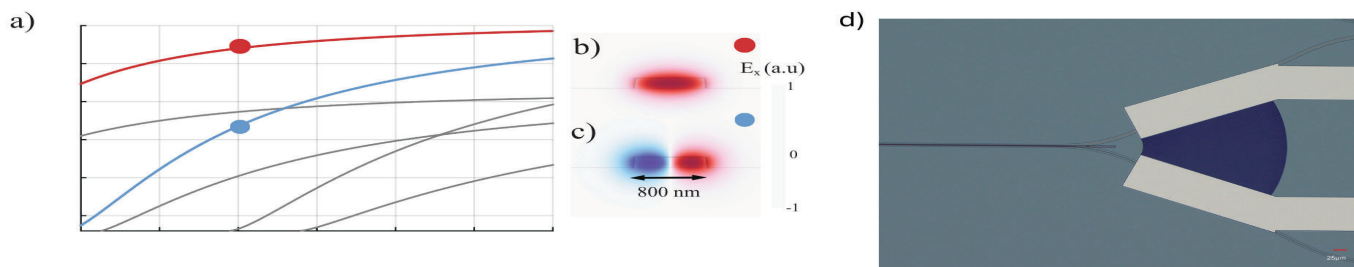


Figure 2: Figure 7.2: a) Effective index of a 300 nm thick waveguide and varying width. b) TE₀₀ mode and c) TE₀₁ mode. d) Micrograph of the fabricated device.

We fabricated the device in CNF. To fabricate the device (shown in Fig. 1) in, we deposit 300 nm thin layer of thermal $(\text{HfO}_2)_{0.67}(\text{Al}_2\text{O}_3)_{0.33}$ composite on a silicon substrate $2 \mu\text{m}$ of thermal SiO_2 by atomic layer deposition (ALD). The optical waveguides are photolithographically patterned by using an ASML 248 nm DUV photolithography system. After that, we deposit a thin layer of thermal Alumina via thermal ALD followed by an approximately $1.5 \mu\text{m}$ of TEOS SiO_2 deposition. The TEOS SiO_2 is planarized to remove the surface morphology by chemical-mechanical polishing (CMP). Next, we deposit 600 nm of AlN as active piezo-electric layer and pattern the electrodes via photolithography followed by 200 nm Aluminum evaporation and lift-off. Finally, the acoustic waveguides are patterned via direct-write lithography. The micrograph of the fabricated device is shown in Fig. 2d.

The preliminary measurements of these fully fabricated devices demonstrate transducer-waveguide coupling efficiency $|\eta| = 17.5 \pm 0.23$ dB and waveguide loss $\alpha_{\text{wg}} = -16.8 \pm 0.8$ dB/mm. In addition, we measured acousto-optic modulation efficiency -35 dB (our best measured devices) for RF drive power of 63 mW, for devices with $400 \mu\text{m}$ interaction length. The measured modulation efficiency is significantly lower than the theoretical prediction, possibly due to phase mismatch between the optical and acoustic waves. Theoretical calculations predict complete mode conversion at an RF drive power below 3 mW under ideal phase-matched conditions.

In future, we will focus on improving the acousto-optic modulation efficiency by optimizing phase matching between the optical wave and acoustic wave by accurately characterizing the material properties of TEOS, reducing the acoustic and optical waveguide loss and by incorporating new device geometry and acoustic transducer design.

Conclusions and Future Steps:

We have successfully integrated the weak value amplification with the on-chip optical gyroscope devices. Our future research aims to demonstrate the enhancement in gyroscope performance by weak value amplification.

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