National Aeronautics and Space Administration

Low-power Integrated Acousto-optic Modulators

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Program: FY22 R&TD Innovative Spontaneous Concepts

Objectives:

The objective of this work is to demonstrate a path to high-performance acousto-optic modulators (AOMs) with sub-milliWatt power consumption, orders of magnitude below that of conventional AOMs. Building on the world's first demonstration of practical integrated acousto-optic modulators in silicon photonics at JPL's Microdevices Laboratory [Kittlaus et al., Nat. Photonics 15, 43–52 (2021)], we seek to establish a path to centimeter-scale acousto-optic interactions.

Background:

Acousto-optic modulators (AOMs) are components that allow electrical control of the frequency, phase, or intensity of laser light using interactions with a piezoelectrically-driven acoustic wave inside of a crystal. These devices have numerous applications in optical sensors, communications, quantum optics, and signal processing. Commercial AOMs are mature bulk-optical components already used in space. However, they are bulky, and require RF drive powers ~1 W—corresponding to wall-plug power in excess of several Watts per component. This large power consumption poses a challenge for platform-constrained applications, such as future space-deployable quantum sensors, that rely on numerous AOMs to precisely control the amplitude and frequency of optical signals.

Approach and Results:

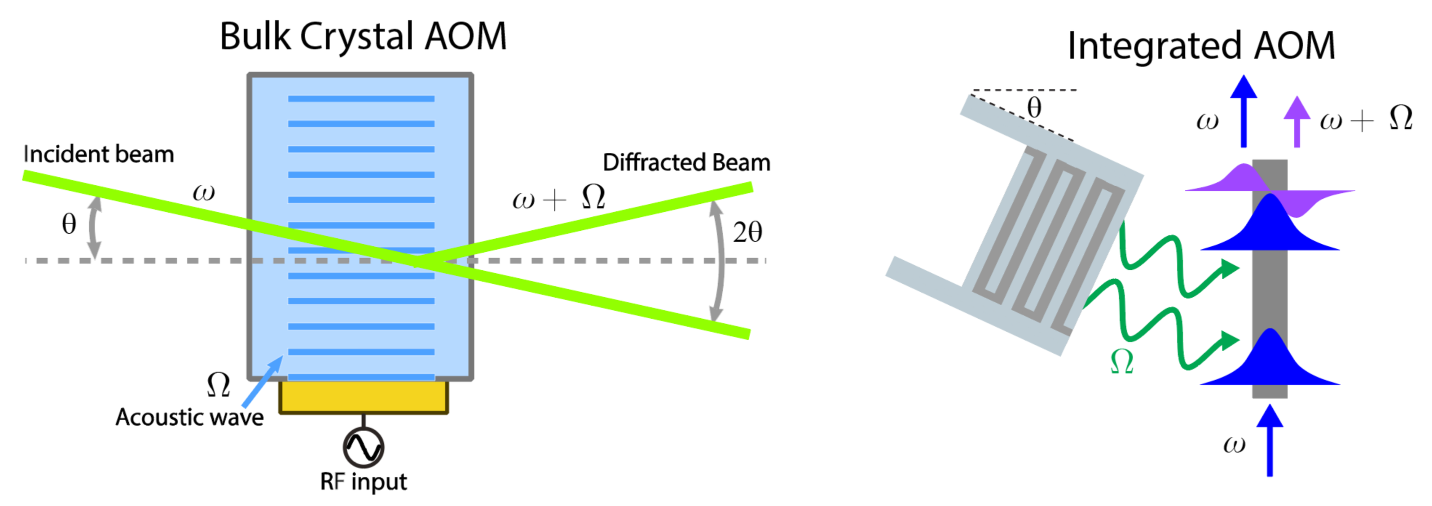
The AOM device design leverages guided-wave modulation of light in integrated optical waveguides using surface acoustic waves generated on the surface of a photonic chip. Because both optical and acoustic fields can be confined and controlled with nanoscale precision, tailorable control and substantial enhancement of the acousto-optic interaction becomes possible. For these second-generation devices, we designed and fabricated serpentine waveguide structures consisting of 10-50 waveguide segments that experience acousto-optic coupling to the same travelling surface-wave.

Device characterization and test consisted of RF measurements of transducer performance, and heterodyne measurements of modulator response. The interdigitated transducers (IDTs) used to excite surface waves consisted of 50-100 pairs of sub-micron scale teeth patterened in 200-nm thick AlCu metal alloy atop 480 nm of *c*-axis-oriented AlN. Experimental results show roughly 50% of the applied RF power is converted to acoustic energy at the resonant frequency.

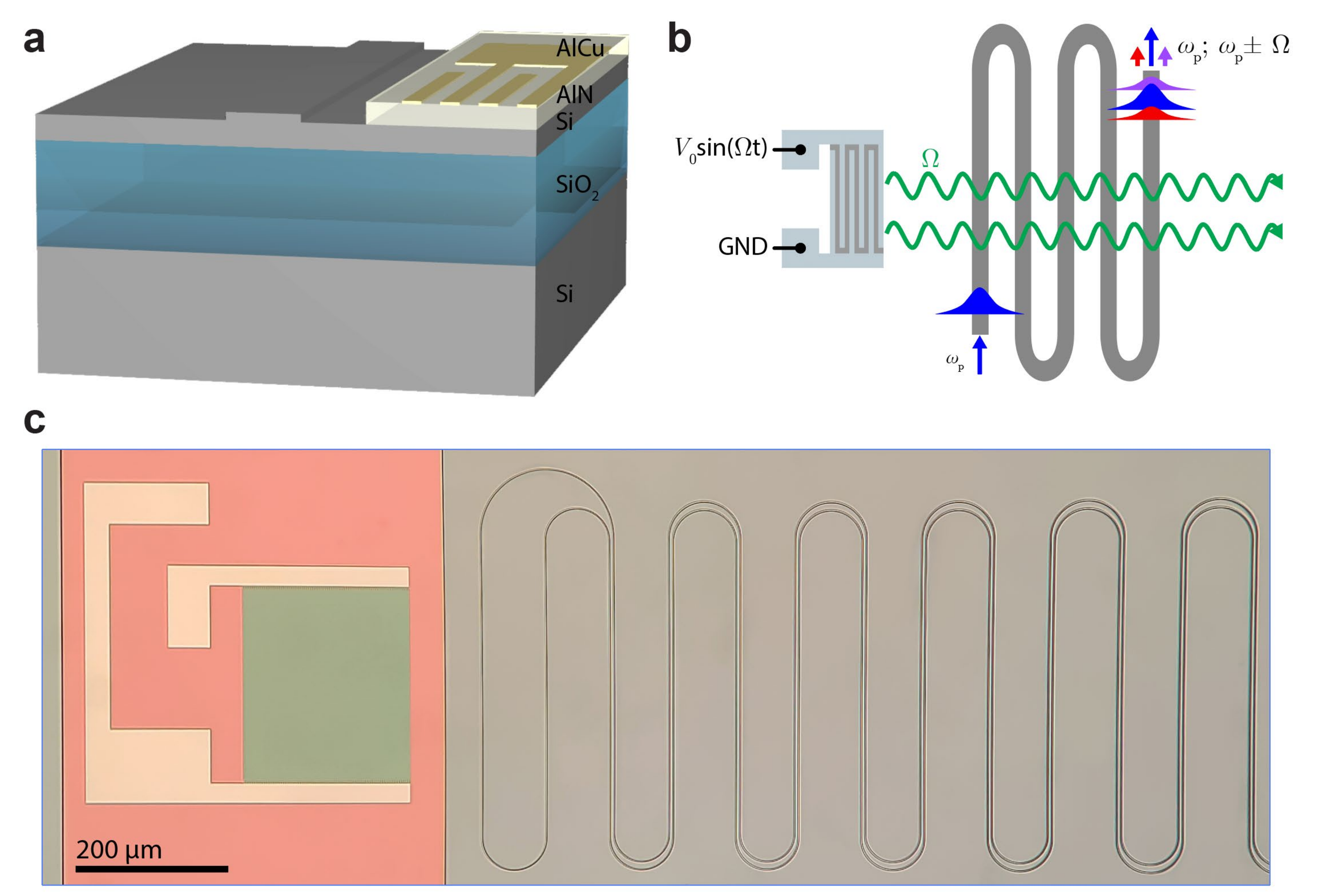
Optical modulation is measured as energy transfer to frequency-detuned sidebands at multiples of the RF drive frequency. One example device (shown in the figures) operates around 1.2197 GHz with a FWHM bandwidth of 2 MHz. At the highest tested power of 10 dBm (1 Vp), complete (>99.9%) energy transfer away from the carrier is observed. These data correspond to a half-wave voltage of Vpi = 1.3 V, and required operation power of <16 mW, more than a factor of 20x improvement over existing AOM devices. These results successfully validate the proposed scaling approach.

Significance/Benefits to JPL and NASA:

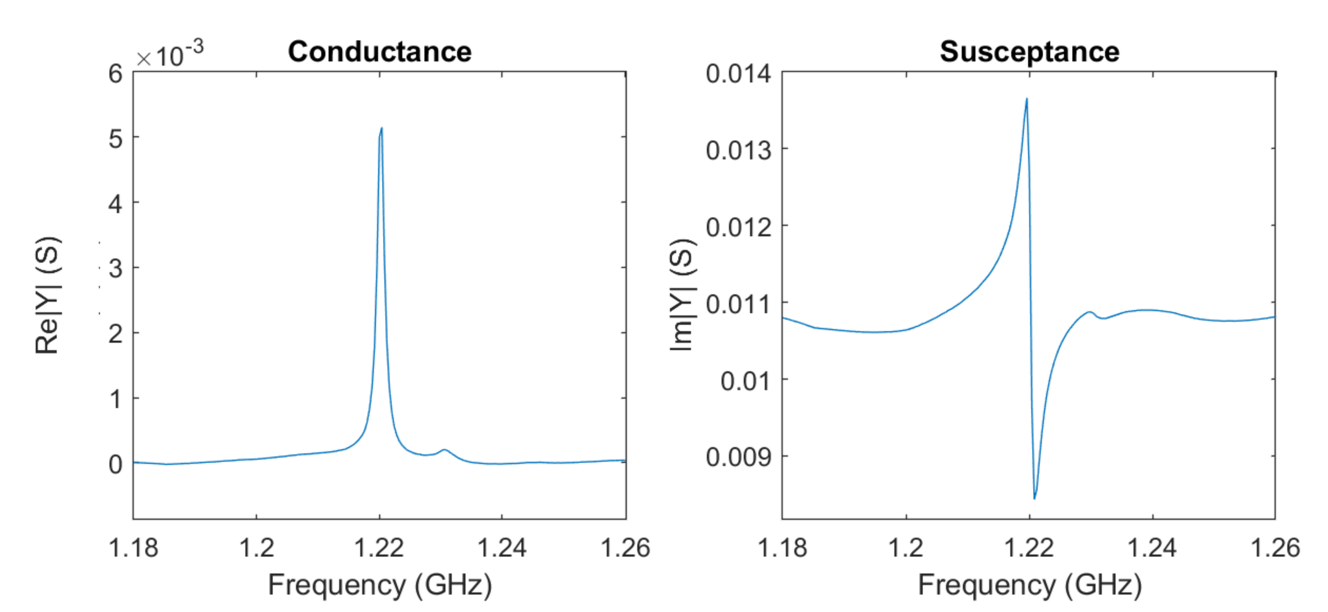
The results of this R&TD effort successfully validate the feasibility of low-power integrated AOMs. Such devices are used in a wide variety of optical metrology techniques, and are key components of laser systems for future cold-atom quantum sensors (e.g. atom interferometers, Rydberg radar, ultra-stable atomic clocks) that are of interest for JPL/NASA applications.



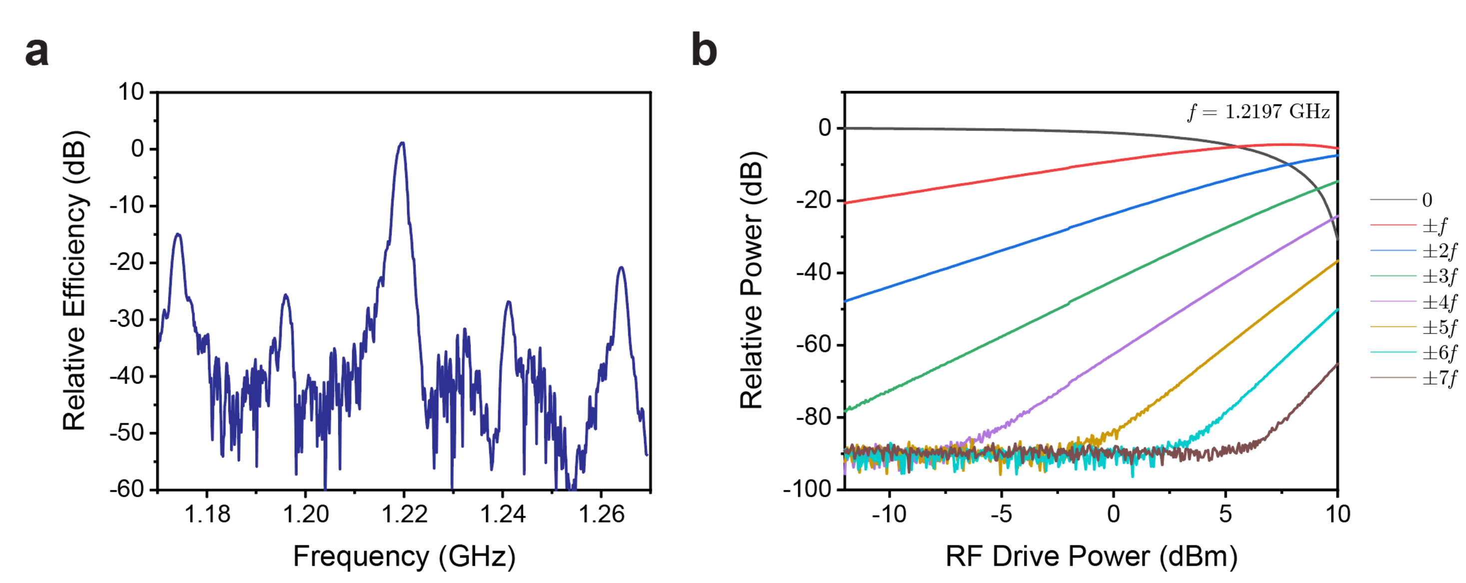
Comparison of bulk crystal AOM (left) and integrated photonic AOM (right)



(a) Depiction of device cross-section and material stack. (b) Operation scheme of the serpentine AOM. (c) Top-down micrograph of part of one device.



Impedance of one transducer around its resonant frequency, showing the electromechanical response.



Demonstration of acousto-optic phase modulation. (a) Normalized frequency response around the resonant frequency. (b) Cascaded energy transfer to 7 pairs of sidebands at multiples of the RF drive frequency.

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