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Resonant, High-Frequency Acousto-Optic Modulators (AOM) Fabricated in a MEMS Foundry Platform

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Abstract: We report the design and characterization of high frequency, resonant acousto-optic modulators in a MEMS foundry process. The doubly-resonant cavity design allows us to measure acousto-optic modulation at frequencies upto 4 GHz with high modulation efficiency ($V_\pi \approx$ 350mV, $f_{res} \approx$2 GHz). © 2019 The Author(s)

OCIS codes: 120.4880, 230.1040, 130.4110, 050.2230, 130.3120

1. Introduction

While acousto-optic (AO) interactions [1] have been exploited for a wide variety of signal processing applications, they have been limited to low frequencies (typically $<$ 500 MHz) and have conventionally been built with materials like quartz and tellurium dioxide, which are not available in commercial CMOS foundries. The lack of foundry compatibility has prevented AO devices from achieving the integration, cost and complexity that has revolutionized integrated electronics and photonics. In this work, we demonstrate the operation of high frequency acousto-optic modulators using a MEMS foundry (Piezo-MUMPS) platform [2]. The use of a suspended MEMS platform allows us to achieve modulation at higher frequencies (measured up to 4 GHz). The device is operated as a doubly resonant (acoustic and optical) cavity which significantly enhances the modulation efficiency. The foundry platform, with its inherent repeatability, increases device integration and overall AO system performance. The need for low cost, high efficiency optical modulators as components in passive optical networks (PON) has long been recognized [3]. In addition, an efficient modulator is a key component for optical approaches to radio frequency detection [4] and transduction, which has applications ranging from radio astronomy to MRI. Finally, a 2D array of these devices can be used as a high speed spatial light modulator with MHz bandwidths.

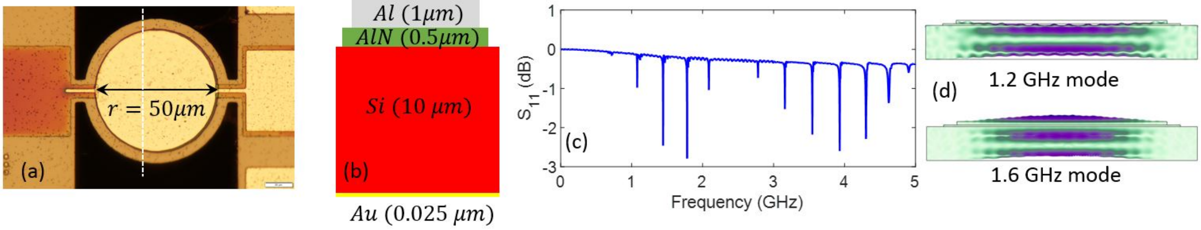

Fig. 1. (a) Optical microscope image of a representative device (b) Device cross-section showing the different layers and thicknesses (c) Measured RF S_{11} of a device showing the successive acoustic resonant modes in the device (d) Finite element simulation of the displacement profile of two of the modes supported by the cavity.

2. Device operation

Figure 1(a) shows a microscope image of a fabricated device. Figure 1(b) shows a cross-section with the materials and corresponding layer thickness. The device operation can be understood as the interaction between co-localized optical and mechanical modes. As studies across a wide variety of cavity optomechanical platforms have shown, co-localization can lead to efficient interaction between optics and mechanics. The mechanical modes of the structure are high overtone bulk acoustic wave resonances [5] (HBAR) that are excited when an RF signal is applied across the piezoelectric aluminum nitride layer. Figure 1(c) shows the measured RF S_{11} (reflection spectrum) response of the system. The periodic series of dips correspond to the successive longitudinal acoustic resonant modes of the device. The displacement profile of two successive modes is shown in Figure 1(d). Working with HBAR modes allows us to utilize the d_{33} coefficient of AlN, which ensures efficient RF to mechanical transduction. In contrast to surface acoustic wave devices [6, 7], HBAR provides a natural route for moving towards very high mechanical frequencies ($>$ 10 GHz) as the transducer performance does not degrade significantly. In our experiments, we have measured HBAR resonances up to 15 GHz, limited by the available instrumentation.

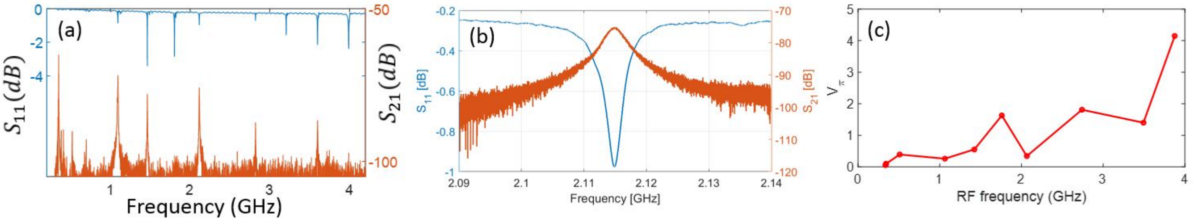

Fig. 2. (a) Broad scan of the S_{11} and electro-optical S_{21} spectra (b) Narrow scan around the 2 GHz resonance (c) Measured V_π voltages for the different modes in (a)

In addition, the device also serves as an optical Fabry-Perot cavity with bulk of the cavity energy confined in the low loss silicon layer (t = 10 μm) and the Aluminum top contact serving as a mirror. By depositing a thin film of gold (25-30 nm) on the bottom side, we can improve the optical quality factor (Q_{sim}≈800, Q_{meas}≈400). We run the modulator in reflection from the (gold coated) side. The laser is parked on the side of the optical cavity fringe. The Lorentzian cavity lineshape transforms the phase fluctuations induced by the mechanics into amplitude fluctuations which are monitored with a high speed photodetector. Figure 2(a) shows the transduction (denoted as an electro-optical S_{21} measurement). The S_{11} spectrum of the cavity is plotted on the same scale for reference. As can be seen, we can measure transduction upto 4 GHz (currently limited by our detector bandwidth). A narrow-band scan of one of the resonances (f_{res}≈2 GHz) is shown in Figure 2(b). Since the opto-mechanical transduction is determined by an overlap integral between the cavity modes (acoustic and optical), not all modes are transduced with equal efficiency. In particular, the mode at 330 MHz has a very high transduction efficiency (high S_{21}, whereas modes at 1.7 and 3.1 GHz have almost zero overlap due to symmetry). We can quantify the efficiency of the modulator by determining its V_π, the voltage applied to get a π phase shift in the device. The measured data is shown in Figure 2c. As the acousto-optic interaction scales proportional to $p_{12}u_{zz}|E|^2$, the doubly resonant design ensures that both the cavity displacement (u_{zz}) and the electric field ($|E|^2$) are resonantly enhanced. This allows us to improve the modulation efficiency significantly, even at very high frequencies as evidenced by the 2 GHz mode showing a V_π of 350 mV, compared with traditional AOMs that require 10s V at 200 MHz.

3. Conclusion

In summary we have demonstrated the design and operation of resonant high frequency acousto-optic modulator built in a CMOS foundry platform. We have observed efficient acousto-optic modulation at frequencies upto 4 GHz (limited by instrument bandwidth). We believe this platform is promising for applications ranging from low cost modulators for passive optical networks, efficient RF receivers incorporating optics and building high speed spatial light modulators (SLM) with MHz bandwidth.

4. Acknowledgement

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References

1. A. Korpel, “Acousto-optics - a review of fundamentals”, Proc. IEEE, 48–53 (1981).
2. A. Cowen at al.,”PiezoMUMPs design handbook”, MEMSCAP Inc. (2014)
3. A. Siddiqui et al., “Direct RF to optical link based on film bulk acoustic wave resonators’ *CLEO* (2016).
4. T. Bagci et al., “Optical detection of radio waves through a nanomechanical transducer” Nature, (2014).
5. S.V. Krishnaswamy, et al. ”Film bulk acoustic wave resonator technology.” IEEE Symp. Ultrasonics, (1990).
6. K.C. Balram et al., ”Coherent coupling between radiofrequency, optical and acoustic waves in piezo-optomechanical circuits” Nature Photonics, 346-352 (2016)
7. S.A. Tadesse and M. Li, ”Sub-optical wavelength acoustic wave modulation of integrated photonic resonators at microwave frequencies” Nature Communications, 5, 5402 (2014).