MEMS-Based Optical Modulator

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Principal Investigator(s): Prof. Sunil Bhave
User(s): Suresh Sridaran

Affiliation(s): Electrical and Computer Engineering, Cornell University
Primary Research Funding: Defense Advanced Research Projects Agency
Contact: sunil@ece.cornell.edu, ss625@cornell.edu
Web Site: http://oxidemems.ece.cornell.edu/

Abstract:
We report on the co-fabrication of radio frequency microelectromechanical systems (RF MEMS) radial contour mode resonators and photonic whispering gallery mode disk resonators on the same SOI substrate. By mechanically coupling the MEMS and photonic resonators, we have demonstrated a silicon RF MEMS based optical modulator which can modulate a 1550 nm laser at 235 MHz.

Summary of Research:

Commercial off-the-shelf acousto-optic modulators work by launching a traveling acoustic wave with an inter-digitated transducer into a non-linear medium, thereby creating a modulated refractive index in the medium. Incident light is diffracted and frequency shifted from this index modulated region, and can be processed depending on output direction. To shrink the acousto-optic modulator to chip-scale, we propose a scheme of modulation using MEMS disk resonators for exciting mechanical motion, and to use the mechanical motion to modify the intensity transmission characteristics of a photonic disk resonator.

As significant mechanical motion in the disk is only excited when the electrical drive is at the resonant frequency, our modulator is narrowband. A particular application for the modulator is in the monolithic integration of opto-electronic oscillators [1] into silicon. The modulator monolithically integrates the signal processing into one device by elegantly combining the filter and modulator into one unit.

The schematic of the modulator consisting of two disk resonators coupled to each other by a mechanical beam is shown in Figure 1. The resonator with electrodes acts as the electrical to mechanical transducer. By coupling vibrations to the photonic resonator through the coupling beam, the changing radius causes the optical resonant wavelength to shift back and forth. For a fixed input laser wavelength, the shifting of the optical resonance curve leads to intensity modulation at the output. The principle of operation is similar to electro-optic modulators that have been demonstrated [2]. In electro-optic modulators, the effective index is changed by charge injection to obtain a resonance wavelength shift. In an AOM, the radial vibrations change the radius by a small displacement $\Delta r$. This in turn changes the resonance wavelength by $\Delta \lambda = (\lambda / R) \Delta r$. If we are biased at the 3dB point of resonance as shown in Figure 2, we observe maximum modulation in the transmitted output.

The modulator is fabricated using a two mask process on a silicon-on-insulator (SOI) wafer (undoped 250 nm device
layer for low optical loss and 3 µm thick buried oxide for isolation of the waveguides on device layer from the silicon substrate). The top silicon is oxidized down to 220 nm with the thin oxide on top acting as the hard mask. Ma-N 2403 electron beam resist is then spun and patterned. The pattern is transferred into the oxide by a CHF₃/O₂ reactive ion etch (RIE) and the oxide hard mask is used to transfer the pattern into silicon using a chlorine RIE. The top oxide is then removed and photoresist is patterned to open regions to be released. A timed buffered oxide etch is then used to release the mechanical and optical resonators and the chips are dried using the critical point dryer. 

Figure 3 shows the test setup used for measuring the response of the modulator. TE polarized light from a tunable laser is into the waveguide through a grating coupler. The output from the waveguide after passing through the device is measured on a high speed photodetector and is connected to Port 2 of a RF network analyzer. The output of Port 1 from the RF network analyzer is connected to the electrodes surrounding the mechanical disk resonator via a bias T. The bias T is used to add a DC bias to the RF signal while the body of the resonator is grounded. The S21 plot is measured on the RF network analyzer. By sweeping the tunable laser an observing the output, an optical Q of 16600 is obtained for resonance at 1583.3 nm with an extinction of 20 dB. We then actuate the MEMS resonators by applying 10 dBm RF power from the network analyzer along with a DC bias. The measured transmission (S21) plot is shown in Figure 4. It is seen that the peak height increases with increasing bias. This is due to increased force on the mechanical structure with larger bias and thereby an increased displacement which leads to larger output powers. By back calculating from the power at the photodetector, the displacement of the mechanical structure is estimated to be 2.1 pm. The presence of two modes at the output is due to the coupling spring which splits the radial vibrational mode of the single disk into the in phase and out of phase modes.

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