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Experimental Demonstration of MEMS-Tunable Slow Light in Silicon Microdisk Resonators

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Abstract: We present slow light pulse propagation in MEMS-tunable microdisks at telecom wavelength for the first time. Furthermore we obtain delays up to 94 ps, a slowdown factor of 700, and a delay-bandwidth product of 0.5.
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1. Introduction

Tunable optical delays, herby also called slow light devices, are of potential interest for applications such as all-optical networks and optical routing [1]. These applications have in common that they require optical buffering with dynamically adjustable delay. Recent work on compact solid-state slow-light devices can be categorized into three approaches based on (i) material dispersion engineering such as electromagnetically induced transparency (EIT) [2], coherent population oscillation (CPO) [3] and spectral hole-burning [4] (ii) waveguide dispersion [5] and cavity resonances [6-9], and (iii) combinations thereof such as injection-locked VCSELs [10]. Despite recent advances in large slowdown factors, many current schemes suffer from small time delays, limited bandwidth, or lack of tunability. We show that silicon microdisks combined with micro-electromechanical-systems (MEMS) tunability are ideal candidates for providing slow light on the silicon platform with a small form factor.

In this paper, we report the first experiment on tunable pulse delay in MEMS-actuated microdisk resonators at telecom wavelength. We demonstrate a maximum pulse delay of 94 ps, a slowdown factor of 700, and a delay-bandwidth product of 0.5. More importantly, the delay is continuously tunable by voltage.

2. Device Structure and Measurement Setup

The schematic structure of the vertically coupled Si microdisk with tunable power coupling is depicted in Figure 1(a). The device consists of two 0.25-µm-thick single-crystalline silicon layers separated by a 1-µm thick oxide layer. The microdisk (20-µm radius) and the MEMS electrodes are patterned on the bottom layer, while the waveguides (0.8-µm width) are fabricated on the top layer. The waveguides near the microdisk are suspended and can be pulled down electrostatically by the MEMS electrodes, enabling us to vary the coupling coefficient between the waveguide and the microdisk by several orders of magnitude. An SEM image of the device is provided as inset in Fig. 1 (a).The detailed fabrication process is published elsewhere [11].

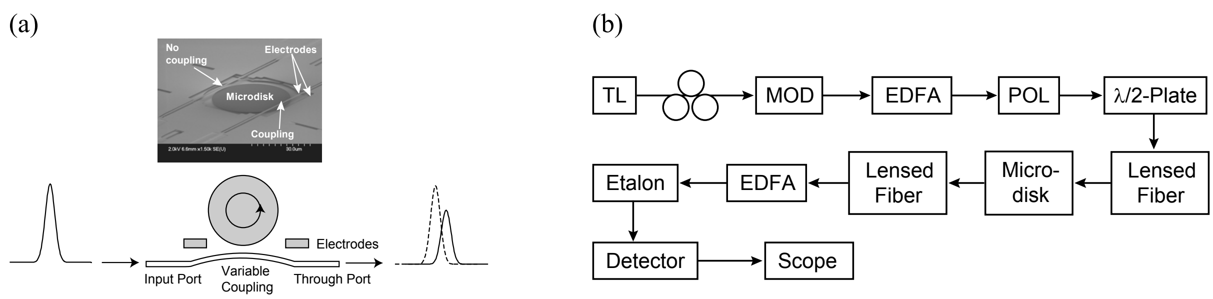

Fig. 1 (a). Schematics of MEMS actuated waveguides providing voltage tunable coupling ratio (inset: SEM image of device). (b) Measurement setup for time-domain pulse delay measurement.

A tunable laser (TL) is centered at a cavity resonance of the microdisk (λ = 1544 nm). The c.w. output of the TL laser light is modulated with a Mach-Zehnder EO modulator. The electrical modulation signal is provided by a 10 Gb/s bit-error rate tester (BERT). The custom bit-sequence allows us to launch a periodic pulse train with a FWHM width of 100 ps. The modulated signal goes through an erbium-doped fiber amplifier (EDFA) to compensate for fiber-coupling loss. Polarizer and half-wave plate are used to launch TE polarized light pulses into the device. The light is coupled into the submicron waveguide by means of a polarization-maintaining, AR-coated lensed fiber with 2.5 µm spotsize and 14 µm working distance. The output of the slow-light device is boosted by another EDFA. The

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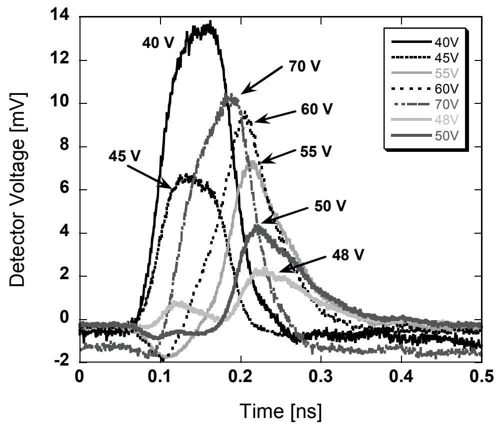
amplified spontaneous emission (ASE) noise is filtered out by a 1 nm bandwidth etalon filter. The optical signal is detected by an Agilent lightwave detector and a 40 GHz sampling scope.

3. Results and Discussion

Pulse transmission was recorded for various actuation voltages that bias the microdisk from under-coupling to over-coupling regimes (see Fig. 2(a)). For voltage below 40V, the pulse propagates through the waveguide without coupling into the disk, therefore providing a timing reference for the other pulses. The pulse delay versus actuation voltage is shown in Fig. 2(b). In the under-coupling regime, the pulses experience a small advance. The maximum delay is reached at voltages slightly below the critical-coupling voltage (53 V). There is obviously a tradeoff between delay and amplitude as well as bandwidth.



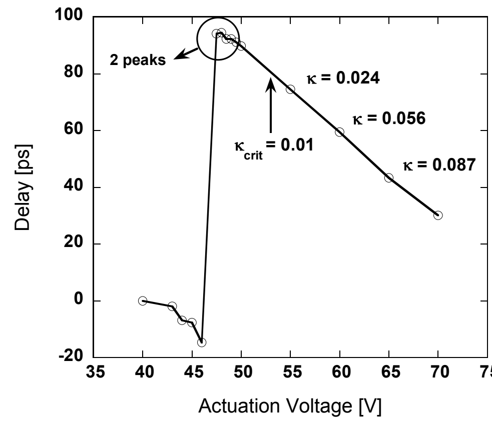


Fig. 2. (a) Transmitted pulses in time-domain for variable coupling/actuation voltages. (b) Experimental delay vs. actuation voltage. The large circle evidences the region where the input pulse is shaped into a doublet pulse.

Since the spectral width of the pulse is comparable to the cavity resonance, the pulse suffers some distortion from the microdisk dispersion. We used a Gaussian fit to determine the exact peak position of the pulse. Delay as high as 94 ps and the group velocity slowdown factor of 700 have been measured. With the measured pulse bandwidth of 5.4 GHz, the delay-bandwidth product, a key parameter in comparing different slow-light devices, is 0.5. As evidenced with the small circle in Fig. 2(b), a region exists where the input peak is converted into two sub-peaks.

4. Conclusion

We have presented the first experimental study of MEMS-tunable slow-light in semiconductor microdisks at telecom wavelength (1544 nm). We studied the transmission of 100-ps long pulses through the microresonator at different coupling regimes, ranging from under-coupling to over-coupling. Delays up to 94 ps, a slowdown factor of 700, and delay-bandwidth product of 0.5 have been demonstrated.

5. References

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