Electro-optic Tuning of On-Chip Optical Transparency

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Abstract- **We demonstrate electro-optic tuning of coupled resonator induced transparency on a silicon chip. We tune the quality factor of the transparency mode between 20000 and 6000.**

On-Chip coherent manipulation of light at room temperature for storing, delaying, stopping and time reversing of light pulses has profound implications for optical communications and quantum information processing. We have recently shown the ability to produce an optical transparency window on-chip using ring resonators [1]. Such optical transparency would enable the breaking of traditional limits imposed by the delay-bandwidth product [2].

Here, we demonstrate, for the first time, electro-optic tuning of such optical transparency on chip. The optical transparency, resulting from coherent interaction of ring resonators is tuned using free carrier dispersion [3]. In light of the recent demonstrations of high speed electrooptic devices integrated into resonators [4] this integration would enable electrically controlled delay, storage, stopping of optical pulses on an integrated silicon chip.

A. Device Description

The device consists of two micro-ring resonators of 14 μm diameter coupled to a pair of parallel waveguides. The coupling waveguides and rings are formed by waveguides of width 560 nm and height 250 nm. The center-to-center (CTC) distance between the waveguides forming the rings and the straight waveguides is 720 nm. The CTC distance between the rings is 22 μm. A small difference in circumference between the rings is introduced to detune the two ring resonances.

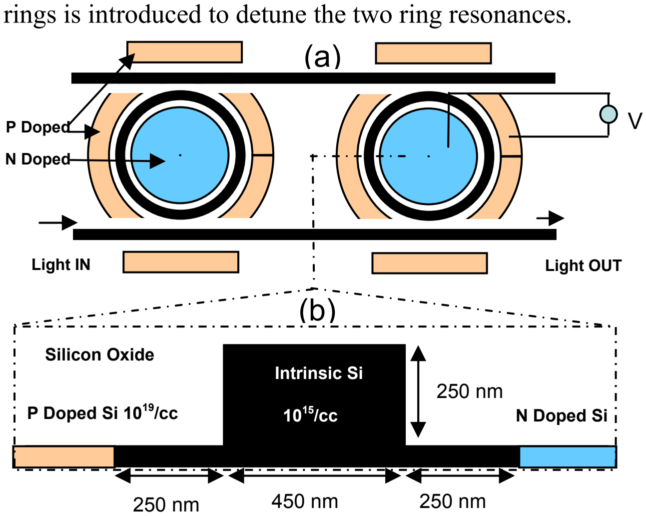

Fig. 1: a) top view schematic double ring resonators embedded in PIN diodes b) Cross section of a waveguide embedded into a PIN diode

Each ring is embedded in PIN diodes formed by concentric doped layers. The doping levels and dimensions of the device are shown in Fig 1. The structure operates by active charge injection and extraction enabling transitions times of 10s of picoseconds [4].

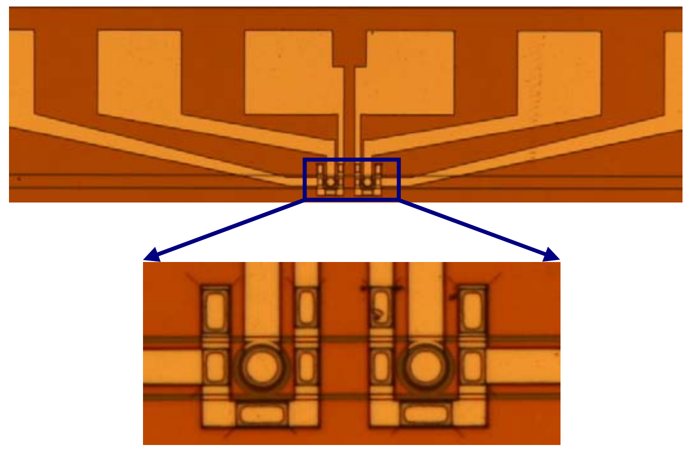

Fig. 2: Top view microscope picture of double ring resonators embedded in PIN diodes

The fabrication process involved defining the wave-guiding structures followed by the fabrication of a PIN diode around the waveguides to inject and extract carriers. The fabricated devices can be seen in figure 2. The wave-guiding structures are defined on an SOI substrate using electron beam lithography (e-beam) followed by reactive ion plasma etching. A silicon slab of 50 nm thickness is left above the buried oxide layer for injection and extraction of carriers from the intrinsic Si waveguide. The doped regions are defined using e-beam with PMMA as implantation barrier. The p^+ doped regions are defined using BF_2 with a dose of $8X10^{14}$ /cm^2 with energy of 20 keV and n+ doped regions are defined using As^+ with a dose of $1X10^{15}$ /cm^2 with energy 15 keV. The device is clad in 1 micron SiO_2 by plasma enhanced vapor deposition. The devices are then annealed to activate dopants (15 min at 100°C for n, followed by 15 seconds at 1050°C for the p). Following the activation, e-beam and RIE are again used to define and etch vias through the cladding down to the doped regions. 50 nm of nickel is evaporated onto the surface and annealed at 500°C for 30 seconds to form NiSi contacts. Aluminum contacts are then defined using e-beam lithography and evaporation followed by lift-off.

B. Optical Transparency Mode

The high Q optical transparency mode is created by the coherent interaction between the micro cavities. We measured the transmission spectrum of the double ring resonator system by using a tunable laser. When both the resonators are off resonance light passes through the waveguide without any effect. When the light is on resonance with one of the resonators, the resonator acts like a mirror reflecting the light into the drop port. When both rings are resonant with the light, therefore couple coherently, a super mode is created which circulates through both resonators and produces a transmission window as shown in Fig. 3. (a)

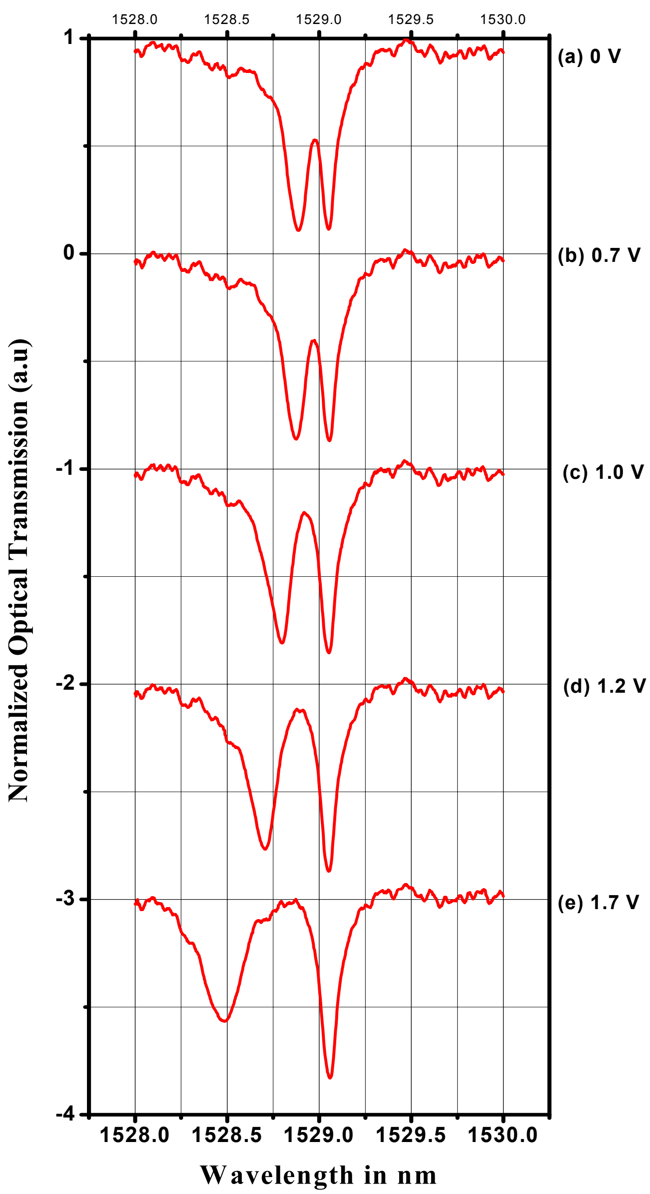

Fig. 3: Measured Optical Transmission Spectra. (a)-(e) correspond to different applied voltages. Successive curves are offset by 1 for clarity. (a) 0 V, 0 A b) 0.7 V, 4 µA c) 1.0 V, 100 µA d) 1.2, 237 µA e) 1.7 V, 637 µA applied to the ring corresponding to the left resonance.

C. Electrical Structure

Refractive index tuning is achieved through free carrier dispersion in silicon [4]. A PIN structure as shown in Figure 1.b is used to inject and extract carriers to tune one of the rings.

The p-i-n diode can be used to induce refractive index changes on the order of 10s of picoseconds. Fundamentally, the carriers can be extracted in ~ 10 ps limited only by time taken by carriers to drift across the waveguide at 10^7 cm/s, the saturation velocity of carriers in silicon. The injection transients can also be as short as 50 ps as shown in [3]. The structure is capable of producing index changes at >10GHz with $\delta n/n > 10^{-4}$.

D. Electrical tuning of on chip transparency

The tuning of the transparency quality factor is obtained through injecting free carriers into one of the rings detuning the rings. In this experiment, carriers were injected to the ring corresponding to lower wavelength resonance. Fig. 4 shows the transmission spectra under different voltage bias showing the tuning of the transmission window. The quality factor of the transparency mode is tuned from 20000 to 6000 controllably by increasing the voltage from 0V to 1.7V. When the rings are well detuned and each dip of the transmission can be treated as an individual ring's resonance, one can see that the injection of free carriers reduces the refractive of the lower resonance leading to a blue shift in the resonance frequency as well as to the broadening of left resonance due to the change in losses inside the ring [4].

E. Conclusion

In conclusion, we show, experimentally, electrooptic tuning of the quality factor of an optical transparency mode. The demonstrated device allows dynamic tuning of the bandwidth of transparency mode. By appropriate electro-optic tuning the resonator system can enable electrically controlled delay and storage of light on-chip using micron scale devices at room temperature.

References

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