Slow wave and resonator structures to enhance silicon photonic modulator performance

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High speed modulators will play a crucial role for the development of all optical networks. Future all optical networks will require operating speeds higher than 40 Gb/s specially in the metro network scenario which is expected to become the capacity bottleneck of the next coming years. Modulators are also key building blocks in important processing applications such as routing, tunable filters, optical gating, logic gates or switching. Silicon photonics is a promising platform to develop high performance modulators due to the potential of building cost-effective devices at industrial scale by making use of the already existing silicon processing technology and manufacturing infrastructures. Furthermore, electronic and optical functionalities can be monolithically integrated on the same chip.

Several ways have been investigated to develop silicon based modulators [1]. Among them the plasma dispersion effect has been demonstrated as the most effective way to modulate the refraction index in silicon. In this case, the free carrier concentration is altered by an external electrical field resulting in a change of the refractive index. So far, the highest speed operation was demonstrated by Intel in 2007 in a depleted vertical PN diode. However, a reduced modulation depth of only 1dB was achieved and the device size was in the millimeter range. Therefore, the ceaseless effort towards modulator performance enhancement in terms of speed, size and power consumption is still underway.

Slow-wave and resonator structures has been proposed as promising structures to enhance modulators performance. In both cases, the interaction between the free carriers and the optical structure is strengthened. This can lead to a significant reduction of the interaction length and hence allows for device shrinking down to a few hundred microns. Improvement in device size and power consumption can reach in practice up to one order of magnitude depending on the structure. In this paper, a qualitative study of modulator performance improvement due to slow wave and resonator structures is presented. Furthermore, experimental results are also shown demonstrating simulation and theoretical results.

Figure 1 shows a SEM image of (a) a corrugated waveguide and (b) a ring resonator structure. Corrugated waveguides are first analyzed and designed. This slow-wave structure consists of a rib waveguide with one-dimensional periodical transversal corrugation elements. The main characteristic of such structures is their capability to decrease the group velocity of the propagating wave. Passive design is first carried out. Up to ten times smaller interaction length with respect to conventional rib waveguides can be obtained for group velocities around 0.01c and a refractive index variation of 10^{-3}. Experimental results are then carried out to validate passive design showing group index values up to n_G=72 at wavelengths around 1.55µm. Electrical simulations are also carried out and DC and transient results analyzed. Figure 2 shows the transient change in effective index for different group velocities and for voltage varying from 0 to-3V (rise time) and -3V to 0V (fall time). A modulation bandwidth up to 24GHz is derived from the obtained results.

Different configurations of ring resonator structures have also been investigated to enhance modulator performance in terms of extinction ratio and required voltage. Modulation based on the intensity and phase response of a ring resonator is analyzed and their performances compared. In both intensity and phase modulation approaches, extinctions ratios higher than 20dB can be achieved considering effective index changes lower than 10^{-4} and device sizes smaller than 100µm. However, it can be concluded that better robustness against fabrication deviations can be easily achieved with phase modulators with respect to intensity modulators. Experimental results of a compact silicon ring resonator operating in depletion mode in a lateral PN junction are also shown. Figure 3 shows pictures of the experimental set-up and the amplitude variation of ring resonator based silicon modulator operated under forward bias. An extinction ratio up to 6dB for only 3V is demonstrated for forward bias operation. Furthermore, the device exhibits an electrical small signal bandwidth of 19GHz.

References

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Figures

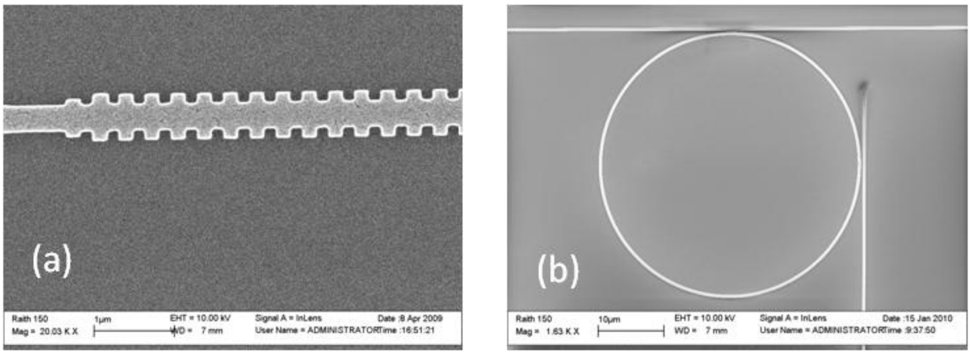

Figure 1.- SEM image of (a) a corrugated waveguide and (b) a ring resonator.

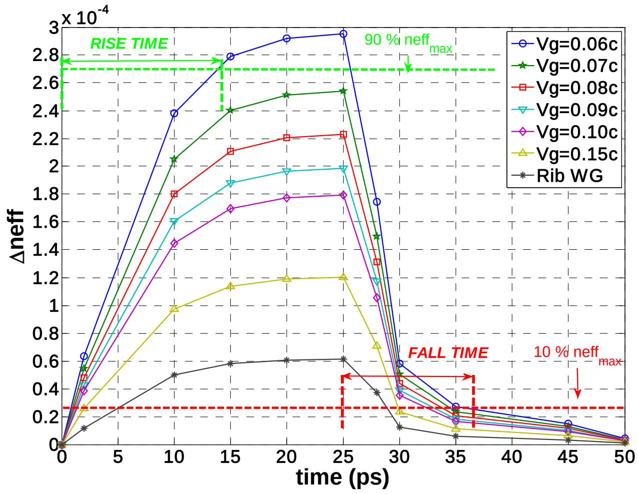

Figure 2.- Temporal variation of the effective index in a corrugated waveguide taking into account different group velocities. Result for a rib waveguide is also shown for the sake of comparison.

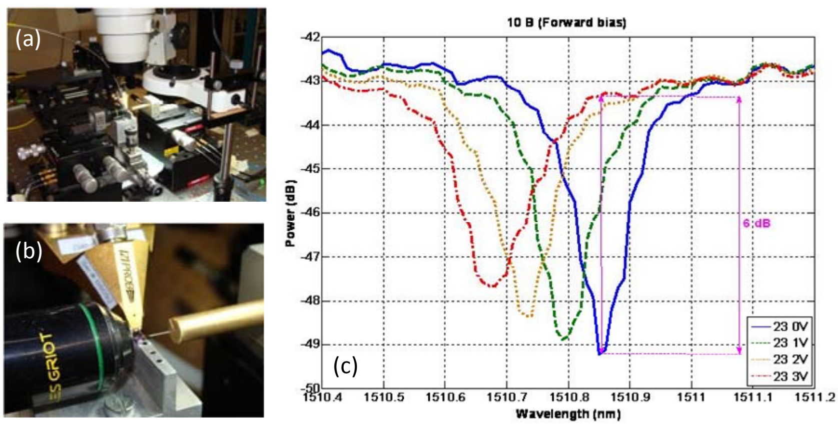

Figure 3.- (a)-(b) Pictures of the experimental set-up and RF probe and (c) amplitude variation in a ring resonator based silicon modulator operated under forward bias.