Pulse Compression and Modelocking by Using TPA in Silicon Waveguides

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Abstract: We demonstrate a novel broadband pulse compression and modelocking scheme in silicon waveguides. Experimentally we obtain 25 fold pulse compression and 400ps modelocked pulses. Results are limited by the RC time constant of the diode.

OCIS codes: (130.5990) Semiconductors; (140.4050) Mode-locked lasers

1. Introduction

Because of its promise to deliver low cost optoelectronic solutions to many applications and full optoelectronic integration, silicon photonics technology has attracted enormous research interest recently. Especially, last three years have witnessed rapid development in light generation and amplification [1], fast electrooptic modulation [2] and efficient wavelength conversion [3] in silicon by using its nonlinear properties. Additionally, Two-Photon Absorption (TPA), another nonlinear property of silicon, has been utilized previously to demonstrate silicon based autocorrelators [4]. However, often TPA process and free carrier accumulation induced by TPA have been considered detrimental to active photonic devices using Raman and Kerr nonlinearities of silicon [5]. Here, we propose a novel approach to utilize TPA to facilitate pulse compression and laser modelocking. So far modelocked lasers utilize saturable absorbers based on III-V quantum well structures or thin germanium layers deposited on silicon Bragg reflectors [6-7]. However, laser modelocking by using bulk silicon has never been demonstrated.

In this paper, we demonstrate a novel scheme to facilitate pulse compression and modelocking by using two photon absorption and free carrier absorption in silicon waveguides. Experimentally we demonstrate 25 fold pulse compression by TPA induced free carrier absorption at 1550nm. Additionally, we utilize the same scheme in a laser cavity to generate modelocked pulses <400ps, where the pulse width is limited by the RC time constant of the p-i-n diode. However, theoretical calculations indicate that pulse widths <1ps is achievable by using the same scheme. Furthermore, the proposed scheme is wavelength independent and it will provide broadband modelocking anywhere between 1100 nm and 2200 nm in silicon waveguides. The same scheme can be applied to germanium waveguides to facilitate broadband modelocking at wavelengths up to 3400 nm.

2. Experimental Setup and Results

The working principle of the pulse compressor and modelocking scheme is similar to inverse saturable absorbers demonstrated earlier [7]. Here, nonlinear property of bulk silicon has been utilized as opposed to Si-Ge Bragg reflector. Figure 1 illustrates the schematic description of pulse compression in silicon. Launched high intensity optical pulse stimulates TPA process in silicon waveguide and an electron-hole pair is created instantaneously. Since the free carrier lifetime is much larger than the optical pulse width, free carrier concentration will buildup over the pulse duration. Hence, this free carrier buildup will induce larger loss at the trailing edge of the pulse than the loss at the leading edge and facilitate a pulse compression and modelocking if it is used inside a resonator.

Figure 2 depicts the experimental setup used to demonstrate modelocking in a silicon waveguide. Pulse compressor is a 1.7cm long silicon on insulator waveguide with ~5μm^2 effective area. Additionally, the waveguide has a p-i-n diode structure to inject carriers and remove free carriers from the intrinsic waveguide region. The output of the waveguide is connected to a 10/90 tap coupler where 10% used as an output and 90% is fed into the gain medium, a high power EDFA with 200mW saturated output power. The resonator is formed by launching the EDFA

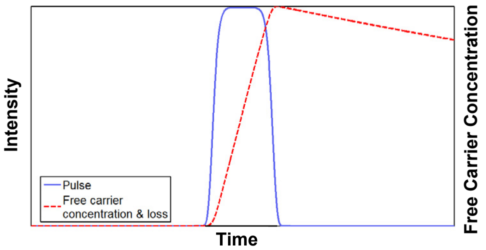

Fig. 1 Optical pulse and free carrier concentration.

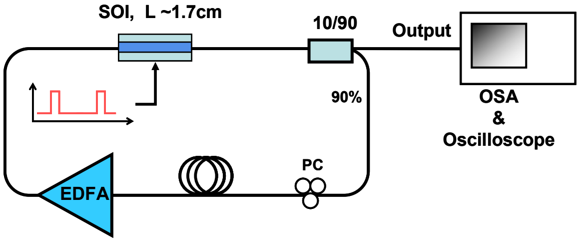

Fig. 2 Experimental setup

output into the silicon waveguide. In order to initiate pulsation and facilitate two-photon absorption at high intensities, RF pulses are used to inject carriers and modulate the transmission of the silicon waveguide at the fundamental cavity frequency. The output of the resonator is connected to an optical spectrum analyzer and a photodetector followed by a 25 GHz sampling oscilloscope to measure output characteristics.

Figure 3 illustrates the laser output measured in a 25GHz sampling oscilloscope. Figure 3a illustrates the temporal profile of 400ps modelocked output pulses measured at 1560 nm. The average output power is measured to be 5mW, which corresponds to >10W of peak power values. Rise and fall time of the output pulse are measured to be 150 ps and 250 ps, respectively. To confirm the modelocking we also monitor the pulse width as we tune the modulation frequency. We observe that the output pulse width will increase significantly (50x broadening) as we move the modulation frequency by as low as 15Hz away from the fundamental cavity frequency.

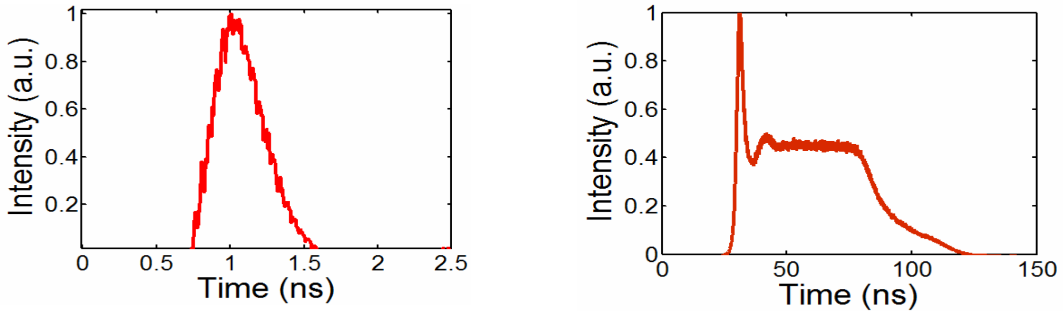

Fig. 3 (a) 400 ps modelocked pulses measured at the output. (b) Effect of modulation signal on laser output and formation of pedestal.

We also study the output pulse characteristics to determine parameters affecting the output pulse width and achieve pico-second output pulses. Experimental and theoretical results indicate that rise and fall time of the modulation are the most critical parameters in pulse compression and modelocking. We observe that as pulses are compressed they tend to move towards to the front edge of the modulation signal where they will suffer from high losses due to injected carriers. Experimentally we change rise/fall times of modulation signals from 8ns to 100ns to determine output pulse characteristics. Figure 3b illustrates the laser output when the rise/fall time increased to 100ns. At steady state, the output pulses have two components. The first component is 5ns compressed optical pulses. The second component is less compressed 50ns pedestal. This formation of pedestal is explained by the large difference between free carrier lifetime, ~10ns, and the modulation signal which is 200 ns wide. As illustrated in Fig 3b, the free carries generated by the compressed region recombine quickly and permit reconstruction of large pedestal. These results indicate that in addition to rise and fall time, the width of modulation signal should be narrower than the free carrier lifetime to prevent pedestal formation. By considering these two parameters, we estimate that modelocked pulses as short as 1 ps are achievable with a proper modulation scheme. Since the TPA process is present between 1.1µm and 2.2µm, the proposed method is wavelength tunable within this spectral range.

3. Summary

We demonstrate a novel pulse compression and modelocking scheme by utilizing two photon absorption and free carrier absorption in silicon waveguides. Experimentally we show 400ps modelocked pulses at 1560 nm by using a 1.7 cm silicon waveguide. The pulse width is determined by the RC time constant of the silicon p-i-n diode used in the experiment. The proposed method is wavelength independent which can operate between 1.1µm and 2.2µm in silicon. The same scheme can be extended to germanium waveguides to facilitate modelocking up to 3.4µm.

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