UWB Pulses Generation with Fano Resonance Modulation

Zhe Xu, Linjie Zhou*, Shuhuang Chen, Gangqiang Zhou, Liangjun Lu, and Jianping Chen
State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai Key Lab of Navigation and Location Services, Shanghai Institute for Advanced Communication and Data Science, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai, China
*ljzhou@sjtu.edu.cn

Abstract—**We report an integrated method for generating ultra-wideband (UWB) monocycle and doublet pulses based on a reconfigurable silicon microring-coupled Mach-Zehnder interferometer (RC-MZI). When tuned to proper operating conditions, the device can produce Fano resonances with an extinction ratio of more than 20 dB. UWB monocycle and doublet signals with nanosecond pulse widths are produced when the microring resonator is modulated by square and Gaussian electrical pulses.**

Keywords—UWB generation, Fano resonance, intensity modulation, integrated silicon modulator

I. INTRODUCTION

Microwave photonics has developed rapidly in recent years [1]. A lot of functions have been demonstrated, including ultra-wideband signal generation [2], reconfigurable high-resolution RF filtering [3], RF phase shift [4], RF frequency up-conversion [5] and optical phase array beamforming [6]. Microwave photonic systems based on bulky optical components have suffered from large volume, high power consumption, high cost, and low stability. Therefore, it is highly desirable to integrate the microwave photonics system into a single chip to make it more compact and less power-consuming.

Ultra-wideband (UWB) signals regulated by the Federal Communications Commission (FCC) have inherent characteristics such as immunity to multipath fading, wide bandwidth, and low power spectral density. Its application can be divided into two areas. One is short-range high-throughput wireless communication (IEEE 802.15.3a) for wireless transmission of massive multimedia data without delay. The other is low-speed and low-power transmission (IEEE 802.15.4a) for precise indoor positioning. Traditional UWB pulses generation via electrical circuit needs electrical-to-optical conversion to distribute the signal over an optical fiber. Generating UWB signals directly in the optical domain with integrated photonics has many merits including lightweight, small size, large tunability, and immunity to electromagnetic interference [7]. Q. Wang and J. Yao proposed a simple method to generate UWB doublet signals using an electro-optic intensity modulator (EOM) [8]. Other methods to generate UWB signals include phase-to-intensity modulation, optical spectral shaping, and dispersion-induced frequency-to-time mapping, etc. [9]

Here, we present a method to generate both UWB monocycle and doublet pulses by utilizing a reconfigurable microring resonator-coupled Mach-Zehnder interferometer (RC-MZI). Modulation is performed to the microring resonator (MRR) when the device works under the Fano resonances.

II. DEVICE STRUCTURE AND PRINCIPLE

A. Device Structure

Fig. 1 illustrates the device structure of the RC-MZI. The coupling between the MRR and the MZI (parent MZI) is enabled by a small child MZI coupler with two microheaters integrated for coupling tuning. A PN junction is integrated in the MRR for high-speed modulation. We devise the PN junction in a cross-sectional L-shape to enhance the overlap between the optical modal and the PN junction depletion region, increasing the modulation efficiency [10]. The other arm of the parent MZI is integrated with a thermo-optic phase shifter and a PIN diode-based variable optical attenuator (VOA), in order to adjust the phase and amplitude of the light traveling in this path, respectively. It should be noted that the device is highly reconfigurable and the resonance spectrum can be flexibly tailored. In particular, Fano resonances are generated when the phase of the resonance path differs by $\pi/2$ or $3\pi/2$ from the other reference path, i.e., $|\Phi_1 - \Phi_2| = \pi/2$ or $3\pi/2$, where Φ_1 and Φ_2 are the phases of the two arms of the parent MZI. The output spectrum exhibits sharp asymmetric resonance line-shapes [11,12].

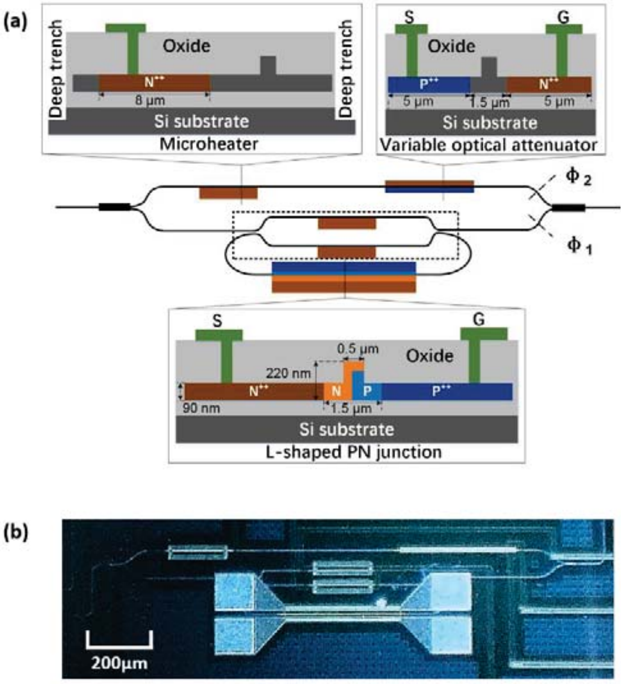

Fig. 1. (a) Schematic structure of the microring resonator-coupled Mach-Zehnder interferometer. The insets show the cross-sections of the L-shaped PN junction, the microheater, and the variable optical attenuator. (b) Microscope image of the fabricated device.

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B. Working Principle

To generate the UWB signal, we modulate at the Fano resonant wavelength. As shown in Fig. 2(a), when an electric square wave pulse is applied to the PN junction in the MRR, the Fano resonance shifts. The operating point moves from point A to point D on the rising edge of the input signal. As a result, the output optical power varies with the Fano resonance line-shape to produce a monocycle UWB pulse. Similarly, when the Fano resonance shifts backward, a UWB pulse of the opposite polarity is also generated on the falling edge.

When the electrical modulation signal changes to a Gaussian pulse, the device generates a UWB doublet signal as shown in Fig. 2(b). During modulation, the operating point moves from point A to point D on the rising edge and then from point D to point A on the falling edge, thereby converting the Fano resonant line-shape into a doublet waveform in the time domain. UWB doublet pulses with two polarities can be generated by selecting the opposite Fano resonance profile similarly.

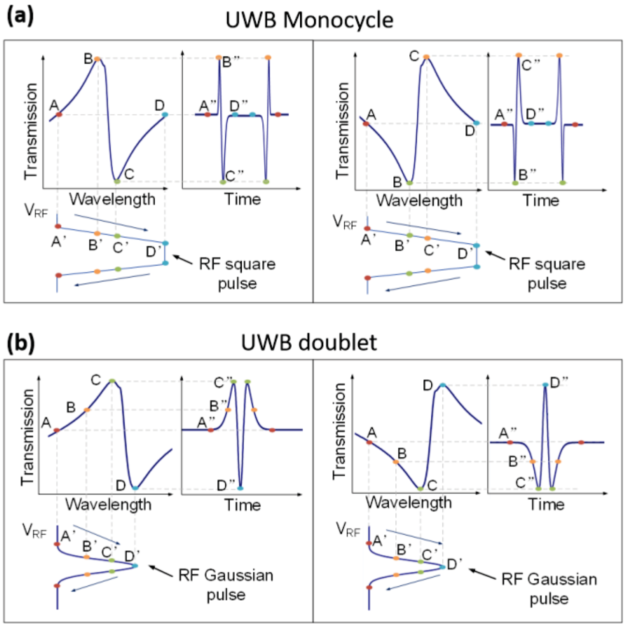

Fig. 2. Working principle illustration for the generation of (a) UWB monocycle and (b) UWB doublet pulses of both polarities.

III. MEASUREMENT AND RESULTS

Fig. 3 shows the experimental setup for measuring UWB signals. Light from a tunable continuous wave (CW) laser passes through a polarization controller before being coupled to the device. A square wave or Gaussian RF pulse generated by an arbitrary waveform generator (AWG) is applied to the MRR of the device by an RF probe for electro-optic modulation. Other phase tuners are controlled by the DC voltage applied through the printed circuit board (PCB). The modulated optical signal from the device is then amplified by an erbium doped fiber amplifier (EDFA) to compensate for device insertion loss, followed by a 3 nm bandwidth optical filter to suppress the amplified spontaneous emission (ASE) noise. Finally, the optical signal is received by the photodetector and measured by an oscilloscope.

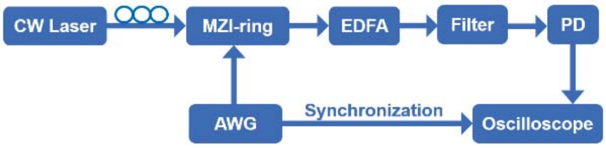

Fig. 3. Experimental setup for measuring UWB signals.

Fig. 4(a) shows the measured device transmission spectrum. It can be seen that typical asymmetric Fano resonances are observed at certain wavelengths. Figs. 4(b) and 4(c) show the magnified spectra of Fano resonances with opposite polarities at 1546.16 nm and 1551.43 nm. The experimental results are well fitted by the theoretical Fano resonance line-shapes. The extinction ratio of the Fano resonance is about 20 dB, which can be further improved by adjusting the VOA and coupling coefficient between the parent MZI and the MRR.

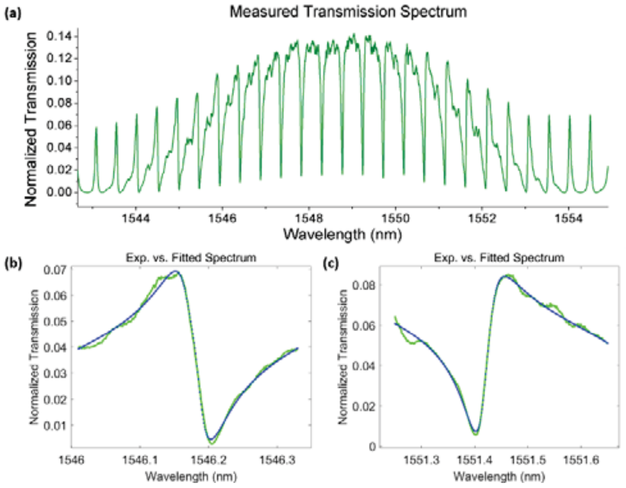

Fig. 4. (a) Measured transmission spectrum. (b) and (c) Zoom-in spectra of the measured and fitted Fano resonance at (b) 1546.16 nm and (c) 1551.43 nm.

Fig. 5 shows the electrical square wave drive signal and the resulting UWB monocycles at the wavelengths of 1546.16 nm and 1551.43 nm. The drive signal has a frequency of 1 MHz, the duty cycle is 30%, and the voltage swing is -1 V to 3.3 V. The rise/fall time of the square wave is set to 80 ns to avoid overshoot on the rising/falling edge of the signal, without which the overshoot will inevitably distort the UWB pulses. The UWB monocycle signal has a pulse width of approximately 9.9 ns and 11.4 ns for the two polarities.

Fig. 6 shows the experimental results for UWB doublet signal generation. The electrical Gaussian pulse has a width of 120 ns. The voltage swing is from -1 V to 6 V. It generates the UWB doublet pulses with widths of 72 ns and 66.7 ns at the wavelengths of 1546.43 nm and 1551.43 nm, respectively.

If we continue to increase the peak-to-peak voltage of the drive signal, the Fano resonance can shift more in the spectrum, making it possible to produce UWB pulses of an even higher order. The high-order UWB pulses can be used in wireless communications with low interference from other signals [14].

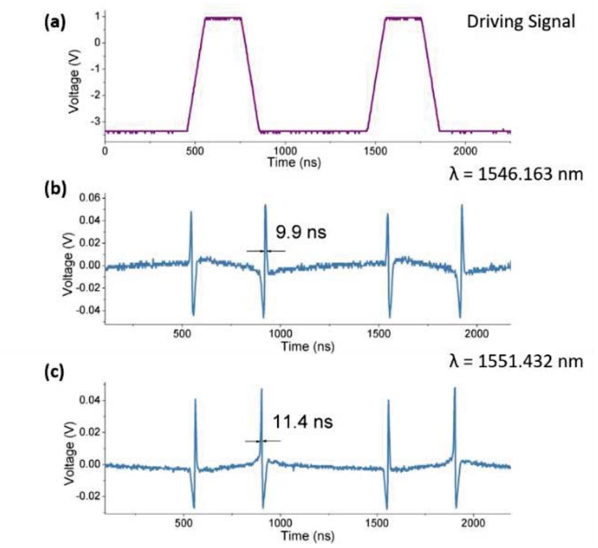

Fig. 5. Generation of UWB monocycle pulses. (a) RF square wave drive signal. (b) Monocycle pulses at the Fano resonance wavelength of 1546.16 nm. (c) Monocycle pulses at the Fano resonance wavelength of 1551.432 nm with opposite polarity.

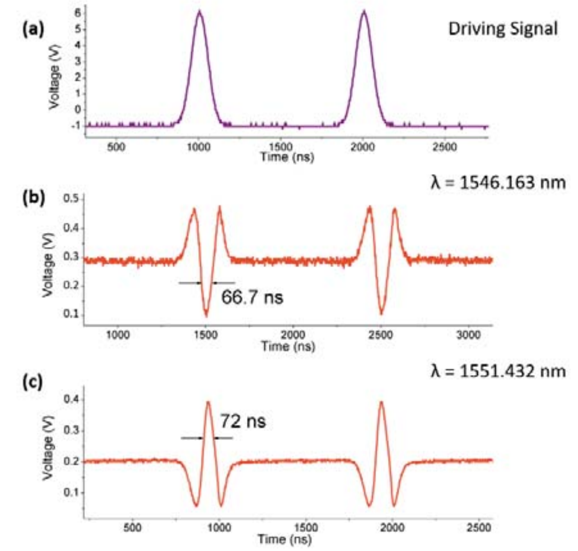

Fig. 6. Generation of UWB doublet pulses. (a) RF Gaussian drive signal. (b) Doublet pulses at the Fano resonance wavelength of 1546.16 nm. (c) Doublet pulses at the Fano resonance wavelength of 1551.43 nm with opposite polarity.

In conclusion, we have implemented a reconfigurable RC-MZI device on the silicon photonics platform. It was used to generate UWB monocycle and doublet signals with both polarities. The UWB signals can potentially be utilized in industrial automation, sensing network, home/office automation, robot motion tracking, and other indoor accurate positioning fields.

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