Ultra-Sharp Double-Sided Fano Resonances from a High-Q SiN Vernier Interferometer

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Abstract: A silicon nitride Mach-Zehnder interferometer with two high-quality factor micro-ring resonators creates Fano resonances via the Vernier effect, achieving steep slope rates of 2.4k and 3.9k dB/nm without the need for tunable components.

Fano resonances offer potential applications such as optical filtering, slow-light, sensing, and switching [1]. In contrast to conventional symmetric Lorentzian resonances, Fano resonances are characterized by the classical Fano formula [2] and occur when a discrete quantum state interferes with a coherent background pathway [3]. Compact on-chip Fano resonators have been realized by incorporating micro-ring resonator (MRR) and Mach-Zehnder interferometer (MZI) using CMOS-compatible photonic integrated circuit (PIC) technologies [4–8], exhibiting enhanced slope rates as high as 2.2k dB/nm [6] and 3.4k dB/nm [7].

Recently, the Vernier effect, which takes place where two sets of resonances at detuned frequency spacings interact, has been numerically simulated to produce a superimposed spectrum with improved spectral sensitivity [9]. But no experimental device has integrated the Fano and Vernier effects. In this work, a low-loss, high-quality (Q) factor silicon nitride Vernier interferometer is developed to generate Fano resonances assisted by the Vernier effect. The dual-MRR MZI PIC is developed with an all-nitride-core technology [10] and demonstrated unprecedented slope rates of 2.4k and 3.9k dB/nm on the sides of the overlapped asymmetric Fano line shapes.

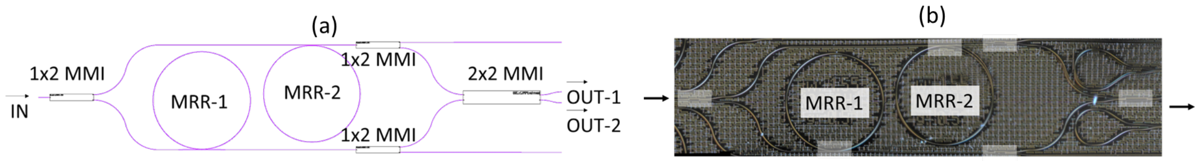

Fig. 1. (a) Layout and (b) photo of the SiN Vernier-Fano dual-MRR-MZI PIC. Coupling regions are highlighted.

We have developed a dual-MRR MZI PIC using a silicon nitride multi-project wafer (MPW) run. The platform is transparent from 400 nm up to 2000 nm and the process is based on an all-nitride-core technology, which results in a low propagation loss of approximately 0.2 dB/cm and a minimum bending radius of 50 µm at 1550 nm and waveguide width of SI1µ. The proposed design and implemented sample are shown in Figure 1, which includes a 1-by-2 multi-mode interference (MMI) splitter and a 2-by-2 MMI combiner. One 1-by-2 MMI tap coupler is placed after one MRR loaded on each MZI arm. MRR-1 has a radius of 221.15 m corresponding to a free spectral range (FSR) of 100 GHz while MRR-2 has a radius of 218.96 m (101 GHz). The straight waveguides in the MZI arm have a length of 0.9 mm and are connected to the MMI splitter and combiner using sinebend waveguides. To couple the light from and to the chip edge couplers, I/O inverted tapers are employed.

The PIC is maintained at a stable temperature of 25°C. The input (IN) and output (OUT-2) waveguides are coupled to lensed single-mode fibers with a mode-field diameter of 3 m. The transmission spectrum is analyzed using a tunable laser source with a linewidth of less than 10 kHz and a sweep step of 0.1 pm, along with a triggered and synchronized optical power meter. As shown in Fig. 2, the measured optical spectrum displays two sets of resonances, with FSR of 100 GHz (due to MRR-1) and 101 GHz (due to MRR-2). Fig. 2(a) shows the transmission (OUT-2/IN), highlighting three selected resonances at 1542.090 nm, 1542.900 nm, and 1543.7100 nm in blue. The insets in Fig. 2(a) provide detailed information about each resonance, with an x-axis range of 0.06 nm and a y-axis range of 15 dB (5 dB/div). The Vernier-induced wavelength detune between two adjacent resonances, each corresponding to either MRR-1 or MRR-2, gradually changes as shown in the inset wavelength windows. This change is accompanied by sudden variations in the overlapping wings around the resonances, with maxima and minima indicated in red. Fig. 2(b) details the resonances highlighted in yellow at 1541.280 nm, where

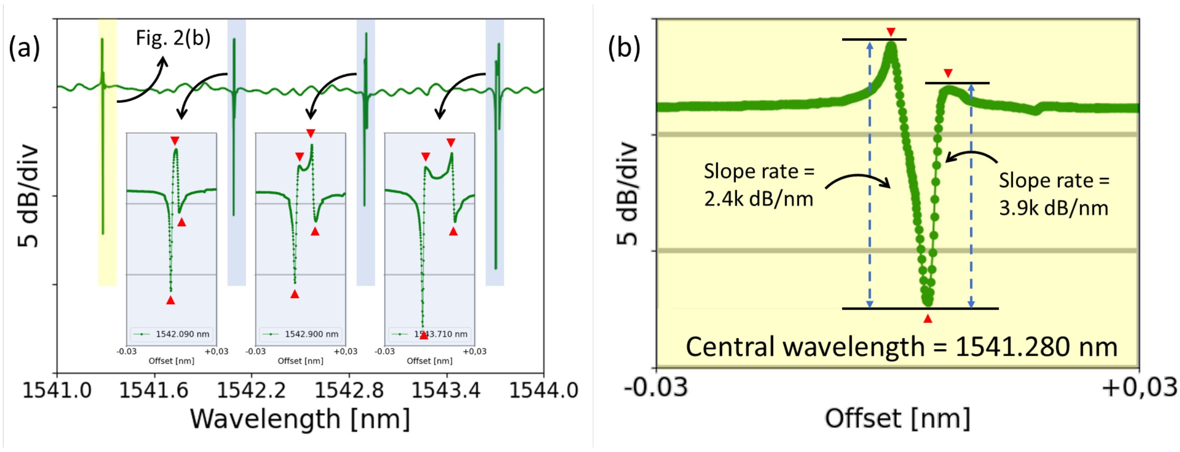

Fig. 2. (a) Transmission spectrum. Wavelength span: 3 nm. (b) Resonances at 1541.280 nm. Wavelength span: 0.06 nm.

the two resonances from MRR-1 and MRR-2 further overlap, producing Fano line shapes with slope rates of 2.4k and 3.9k dB/nm. Notably, the presented PIC device is not reconfigurable; however, the Vernier effect is used to achieve sharp Fano line shapes. The Vernier effect employs the FSR offset between MRR-1 and MRR-2, enabling phase shift along the MZI arms without the need for active tunable components such as PN junctions or heaters.

In conclusion, the proposed dual-MRR MZI PIC, fabricated with silicon nitride foundry technology in an open-access MPW run, has successfully demonstrated the potential of the Vernier-Fano effect to achieve ultra-steep slopes of 2.4k dB/nm and 3.9k dB/nm, outperforming existing configurations. The simplicity of this approach, which requires no tunable components, makes it a promising solution for developing high-performance sensing and switching PICs in the future.

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