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Slow-light enabled photonic integrated microwave filter.

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Abstract— A reconfigurable multi-tap microwave filter is demonstrated on a Silicon on Insulator platform. Compactness and low-power operation are achieved owing to slow-light in photonic crystals. As an example, a microwave band-pass and a stop-band filters are obtained. Channel equalization is also demonstrated on an unitary filter cell.

1. INTRODUCTION

The use of optical technology brings unprecedented advantages to manipulate and process microwave signals. Initially mainly reserved to the distribution of signals over long distance, the Microwave Photonics, which exploits optics to process high-speed analog signals, is quickly advancing owing to the photonic integrated circuits (PIC), promising compact, robust, low-power, lightweight devices which can be mass produced. This will have a tremendous impact in wireless and space communication and radar.

In this context, filtering is considered as the most relevant function[1], as superior agility and broadband operation, in addition to immunity to electromagnetic interference, are expected to be an obvious advantage of a photonic microwave device, compared to its electronic counterpart. Our microwave photonic filter implements a finite impulse response owing to the interference of 4 delayed and weighted replicas of the signal in the optical domain. The coherent summation of the fields allows to cover a broader range of response functions. In this architecture, reconfigurability and tuneability is provided by adjustable switches and optical delay lines. As the size of these devices is constrained by the dispersion of the waveguide, dispersion engineering and slow light are a crucial asset[2].

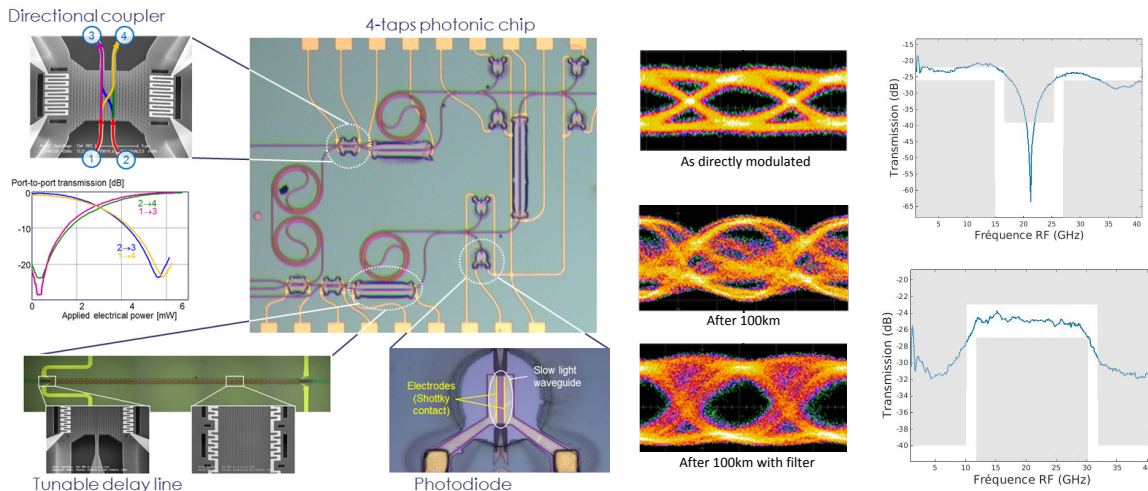


Figure 1: On the left, image of a 4-taps photonic integrated microwave filter and magnified images (SEM) of its constitutive elements: PhC photodetector, PhC tunable delay-line and PhC directional coupler. Signal processing using the device (right): eye diagram before and after dispersion compensation and example of synthesised transfer functions.

2. IMPLEMENTATION OF A SLOW-LIGHT BASED MICROWAVE FILTER

The architecture of the filter (figure 1) is based on nested cells consisting of a Mach-Zehnder (MZ) interferometer formed with a PhC directional coupler (DC), a tunable PhC delay-line (DL) and a 250 μm -long fixed spiral delay ($\sim 25\text{ps}$) and a Multi-Mode Interferometer (MMI). The device shown here uses two lower level cells nested in a third one. The performances of the filter by large depend on the properties of the tuneable delay line, which is a Photonic Crystal waveguide operating in the so-called slow light regime[5]. The range of the delay determines the central frequency and the free spectral range. The dispersion is tailored to provide a very steep change of the delay as the temperature of the PhC suspended slab is modified. A different design of the dispersion is exploited to reduce the size of the directional coupler at the heart of the 2×2 switch to $10\mu\text{m}$ (figure). Because of the tiny active volume and the large thermal resistance of the suspended slabs, the switch provides a large contrast ($> 20\text{dB}$) by consuming only (3 mW) of electric power, and it is also fairly fast ($1\mu\text{s}$). Similarly, the delay line covers a range of 80 ps with a maximum of 80 mW.

The two arms of each interferometer are recombined by a 2×3 MMI interferometer, allowing the use of two photodetectors to measure the state of the interferometer, which is crucial to set the desired parameters of the filter. We use germanium-free photodetectors[4] based on nonlinear and surface absorption, which are remarkably effective in silicon photonic nanostructures in Telecom spectral range. Under the operating condition, the detection efficiency is ~ 0.1 A/W, which is enough for our purpose. The structures were fabricated in a standard environment clean room, on a Silicon on Insulator (SOI) platform.

3. DEVICE OPERATION

Each interferometer is stabilized using a small amplitude and low frequency modulation of the current applied to the heaters of the delay lines. Using a standard lock-in technique, the resulting phase modulation of the optical signal is used to unambiguously measure and stabilize the optical phase. The residual phase error of the stability loop is as low as $\lambda/80$ rms . Using a single stabilized filter cell, we have demonstrated the compensation of the dispersion in a optical link based on a directly modulated laser diode. This is apparent in the eye diagram in figure 1.

The transfer function of the 4 taps filter is measured using a modulator, a detector and a vector network analyser (VNA). This is shown in figure1(right), where a variety of responses are obtained by setting the currents applied to the heaters suitably. As an example, a "stop band" or "bandpass" function are obtained. The slope of the filter edges will increase with the number of coefficients (hence taps), which is allowed by the inherently scalable architecture used here. This opens the way to structures with larger number of taps thanks to Silicon Photonics capabilities in terms of integration.

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