High Resolution Fourier-Transform Microspectrometers in Silicon-on-Insulator Waveguides

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In the past years, there has been an increasing amount of attention paid to the development of compact high-resolution spectrometers for a wide range of applications such as optical communication networks, health diagnosis, environmental sensing and space instrumentation, to name a few [1]. In particular, planar waveguide Fourier-Transform (FT) spectrometers based on the principle of Spatial Heterodyne Spectroscopy (SHS) have been recently proposed [2,3], overcoming the light throughput (etendue) limitation of other devices such as Arrayed Waveguide Gratings [4]. The SHS interferometric technique is based on the principle Michelson interferometer [5], and it allows simultaneously obtaining the outputs for a plurality of sampled path by replacing moving mirrors with diffraction gratings [6]. It is also possible to implement the SHS concept with a waveguide array of Mach-Zehnder interferometers (MZI) with increasing path differences [2,7]. The stationary patterns at the output of the MZI array $F(x_i)$ are then numerically analyzed with Fourier Transform techniques, obtaining full retrieval of the input spectrum (p_{in}) within the Free Spectral Range (FSR) of the device with a single measurement. Additionally, the output of each MZI can be analyzed individually to compensate the amplitude and phase errors associated with waveguide loss and dimensional inaccuracies of the fabrication. In this work, we present two types of SHS-FT spectrometers for the submicron silicon-on-insulator (SOI) platform, demonstrating their high performance by accurately retrieving the spectra of experimental input signals.

The first SHS-FT spectrometer is based on an array of N silicon wire waveguide MZIs with an increasing path length difference ΔL_i (Fig. 1a). Each MZI comprises an arm with a straight waveguide and another arm with a spiral waveguide of increasing radius. The high contrast index of the SOI platform allows implementing long optical path lengths within a compact footprint. In particular, SHS-FT spectrometers comprising spiral waveguides up to 1.13 cm long were implemented within a footprint of only 12 mm^2. In the spirals, a minimum waveguide bend radius of 5 µm is used.

In the second device (Fig. 1b), the increasing optical path differences along the interferometer array are implemented with subwavelength grating (SWG) delays [8]. By periodically alternating along the waveguide thin transversal segments of silicon core and cladding material with a period below one half of the wavelength of the guided light, the effective index of the waveguide can be modified by design over a wide range. The optical path difference can thus be adjusted by varying the length of the SWG delays sections, or by modifying its duty cycle. In particular, the fabricated device comprises 32 MZI with SWG sections ranging from 0.46 mm to 1.5 cm. The periodic SWG structures were designed with a 400 nm pitch, a width of 300 nm, and a constant duty cycle of 50%. One of the main advantages of this device is that all the MZI present the same physical length and similar losses, thus achieving a more stable visibility of the MZI outputs along the array.

For both devices, the same spectral retrieval technique was used. The oscillations at the output of each MZI were calibrated by a high-resolution wavelength scan within the free spectral range (FSR) of the device, and used to define a transformation matrix T such that $F(x_i)=p_{in}\times T$. The input spectrum of the actual measurement was obtained by multiplying the output pattern by a pseudoinverse T^+ of the transformation matrix, computed by Single

Value Decomposition [9]. The matrix T^+ includes all the fabrication errors of the device and corresponding fluctuations in both amplitude and phase of the optical signal. This yields more robust results than the traditional cosine transform, which requires an active compensation of the phase errors before the spectral retrieval can be performed [7]. Figure 2 shows signal spectra experimentally retrieved using both types of devices. The spiral waveguide SHS-FT spectrometer has a spectral resolution of 42 pm and a FSR of 0.75 nm. The SHS-FT spectrometer with SWG delays has a resolution of 50 pm and a FSR of 0.78 nm. For both cases, the original spectrum is retrieved with low crosstalk. Truncation ripple is reduced by applying an apodization window on the output pattern.

In conclusion, two planar waveguide SHS-FT spectrometers have been demonstrated in submicron silicon-on-insulator waveguides, showing high spectral resolution, low crosstalk and a compact footprint.

References

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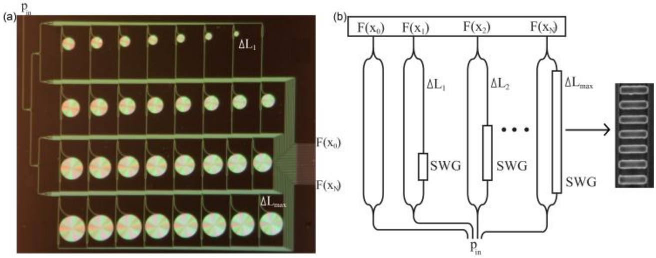

Figure 1: (a) Spatial-Heterodyne Fourier-Transform (SHFT) spectrometer implemented with planar spiral waveguides. (b) Schematics of a SHFT spectrometer implemented with subwavelength grating (SWG) phase delays, and SEM micrograph of a SWG section.

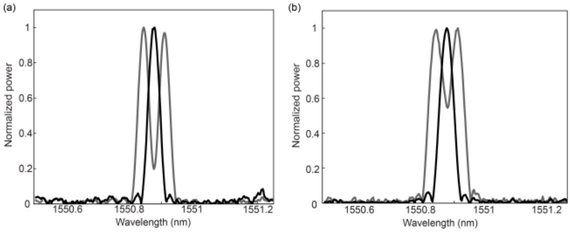

Figure 2: Spectra of a single narrowband laser source (black) and a doublet of two monochromatic lines separated 65 pm (grey) retrieved from the experimental measurements of Spatial-Heterodyne Fourier-Transform spectrometers implemented with (a) planar spiral waveguides; and (b) subwavelength grating (SWG) phase delays.