A Phase Coherent Octave Spanning Mid-Infrared Supercontinuum Generated in a Silicon Photonic Wire

Bart Kuyken[1,2], Takuro Ideguchi[3], Simon Holzner[3], Ming Yan[3], Theodor W. Hänsch[3], Joris Van Campenhout[4], Peter Verheyen[4], Roel Baets[1,2], Nathalie Picqué[3], Gunther Roelkens[1,2]

[1]*Photonics Research Group, Department of Information Technology, Ghent University–imec, Ghent, Belgium*

[2] *Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Ghent, Belgium*

[3] *Max Planck Institut für Quantenoptik, Garching Germany*

[4] *imec, Kapeldreef 75, Leuven, Belgium*
Email: Bart.Kuyken@intec.ugent.be

Abstract

A mid-infrared octave spanning supercontinuum is generated in a silicon Photonic wire. The supercontinuum extends over more than an octave, spanning from 1500 nm up to 3300 nm when the photonic wire is pumped with by 70 long pulses having an energy of 16 pJ and centered at 2290 nm. By beating the generated supercontinuum on a photodetector with a narrow line width light source the phase coherence of the supercontinuum is verified.

1. Introduction

The mid-infrared (mid-IR) spectrum, spanning wavelengths from approximately 2-14 µm, is a highly relevant spectral range for many research field, in particular for spectroscopy. This stems from the fact that the fundamental rovibrational absorption lines of many molecules of practical interest fall within this spectral band. This optical spectrum is often referred to as the "molecular fingerprinting" spectrum, since the specific absorption features of these molecules act as a fingerprint. Mid-IR spectroscopic sensors may be used to monitor the presence and concentration of chemical and/or biological molecular species within via their distinct rovibrational resonances [1]. Spectroscopy within the mid-IR is superior from a sensitivity standpoint, as the fundamental absorption lines can be 100-1000 times stronger than the higher-order overtone and combination lines present in the near-IR. Silicon photonics circuits have originally developed for the telecom wavelength for telecommunication and data communication applications. However the superior performance of the platform, which it leverages from the high volume, high yield CMOS compatible fabrication technology can also put to use for sensing applications. Expanding the platform beyond the telecom window around 1550 nm into the mid-infrared could enhance the selectivity and the sensitivity of these sensors a lot.

A broadband light source generated on the silicon photonic chip would be a viable alternative to the integration of a single laser on a chip which has only a limited tunability [2]. Here we demonstrate a supercontinuum extending from the telecom band deep into the mid-infared. Furthermore we show that the supercontinuum is phase coherent and as such is a frequency comb. The linewidth of the individual lines of the comb spaced by 100 MHz is measured to be less than 50 kHz.

2. Experimental results

The 1 cm-long silicon nanophotonic wire used in the experiment is fabricated in imec's CMOS pilot line, on a 200 mm silicon-on-insulator (SOI) wafer consisting of a 390 nm silicon waveguide layer on a 2 µm buried oxide with no top cladding. The dimensions of the photonic wire are shown in the inset of Figure 1 a). The waveguide is slightly over etched by 10 nm. The inset of Figure 1 shows a schematic cross section of the waveguide. Using a cutback method, the propagation loss in the 2200-2400 nm band is estimated to be < 0.2 dB/cm. The geometrical cross section of the waveguides is designed such that the group velocity dispersion is anomalous in the mid-infrared. As shown on figure 1, the zero dispersion wavelength is 2180 nm. At longer wavelength the group velocity dispersion becomes anomalous. A small anomalous group velocity allows for broadband supercontinuum generation [3]

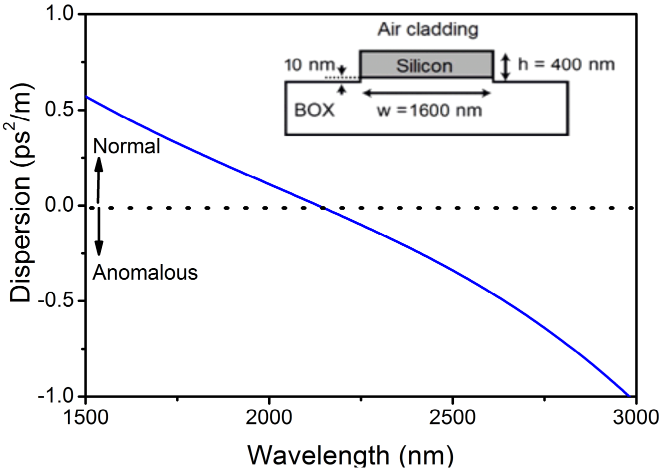

Figure 1: The simulated dispersion of the quasi TE-mode of the photonic wire waveguide. The zero dispersion wavelength is at 2180 nm. The dispersion is normal at shorter wavelengths and anomalous at longer wavelengths. The waveguide cross-section is shown in the inset.

For the experiment the quasi TE mode of the waveguide is excited by a home-made femtosecond optical parametric oscillator (OPO) with a repetition frequency of 100 MHz. When the center wavelength of the output pulses of the optical parametric oscillator is tuned to a center wavelength of 2290 nm, about 70-fs long pulses are produced. The pulses are coupled to the chip using a high numerical aperture (NA) chalcogenide lens. The energy of the coupled pulses measures at maximum power 16 pJ. The output of the photonic chip is coupled via a high NA lens to a Fourier transform infrared spectrometer (FTIR). The output spectrum as a function of coupled energy on the chip is Figure 2. At the maximum pulse energy the spectrum spans from 1550 nm up to 3300 nm.

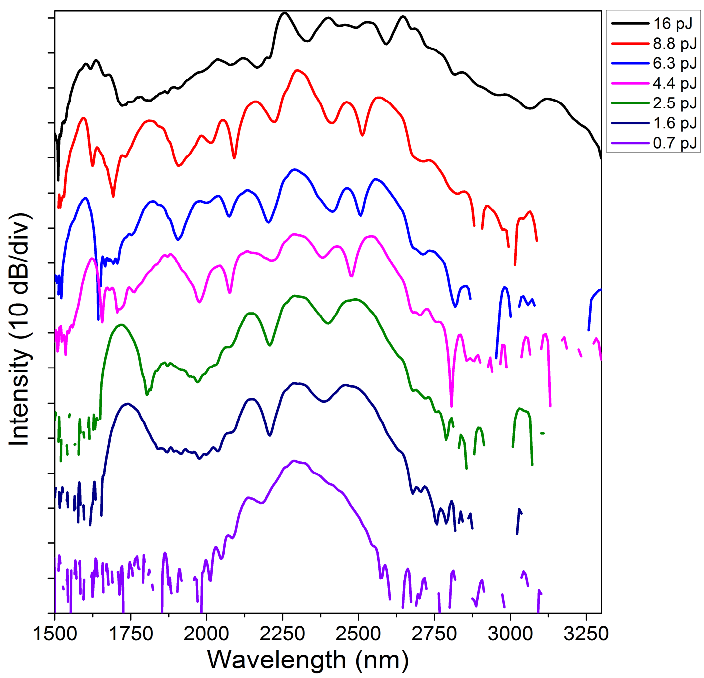

Figure 2: The superconintuum as a function of the input energy of the pulses. At the maximum energy of the input pulses (black line) the spectrum of the output pulses spans from 1500 nm up to 3300 nm.

3. Phase coherence of the generated supercontinuum

By spectrally broadening a pulse in a nonlinear medium coherence can get lost by noise generated in the process by competing effects as Raman amplification, but also by the amplification of noise by the process of modulation instability. To verify the coherence of the supercontinuum we beat the supercontinuum with a narrow linewidth fiber laser. The laser (Koheras Adjustics E15, line-width ~ 1 kHz at 120 µs) and the supercontinuum were combined and send to a fast InGaAs photodetector. A portion of the resulting radiofrequency (RF) spectrum of the output of the photodetector is shown in Figure 3. A resolution bandwidth of 10 kHz is chosen to limit the spread in beat-note frequency due to variation in the unlocked optical sources. The linewidth of the free running beatnote did not broaden as compared to the input light. The results demonstrate good phase coherence of the broadened spectrum generated by the Si chip. Additonal measurements were done to verify the coherence in the mid-infared. These suggest that the supercontinuum is coherent over its whole bandwidth. These results will be discussed at the conference

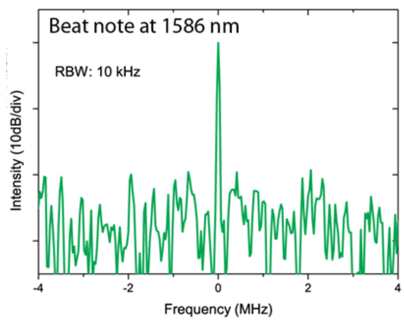

Figure 3: The RF spectrum of a photodetector measuring the beat note of the supercontinuum comb and a cw narrow linewidth laser at 1586 nm, No other lines are observed in the measurement with a frequency span equal to half the repetition frequency. The free-running beat note is measured with a resolution bandwidth (RBW) of 10 kHz.

4. Acknowledgements

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5. References

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