Tailored on-chip mid-IR light generation and application for gas spectroscopy

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Abstract: In this contribution, we present how coherent supercontinuum generation in Si_3N_4 waveguides enabled by fiber laser pumping can be tailored to cover part of the mid-IR spectrum and the use of such sources in spectroscopy. © 2021 The Author(s)

Supercontinuum generation is the extreme broadening of the spectrum of a pulse upon propagation in a nonlinear medium [1]. The development of supercontinuum sources is an active research field, quickly evolving together with new technological developments. They find applications if various fields such as optical coherence tomography [2], device testing [3], metrology or spectroscopy [4]. While the first supercontinua were observed as early as in 1970's, and optical fibers have been the main nonlinear medium used, integrated photonic structures have become an extremely attractive alternative for the generation of such sources. Chip scale platforms offer the promise of compact, mass producible and energy efficient devices. In addition, the rapid maturing of fabrication, the wide range of nonlinear materials available and the nano-meter scale control of the waveguide's dimensions offer undeniable opportunities in the tailoring of the source, in terms of reach or bandwidth. Supercontinua spanning various spectral regions such as visible, near infrared and mid-IR have been successfully demonstrated [5-7]. The practicality of the such source can however be often hindered by the required pumping source, both in terms of wavelength and power, and work has been focused on targeting this engineering aspect.

We show here our work on soliton-induced dispersive-wave (DW) emission in silicon nitride (Si_3N_4) waveguides. Improvements in fabrication process allow for large cross-section high quality Si_3N_4 waveguides with an anomalous dispersion window extended towards long wavelength and decrease losses in the mid-IR. This opens the possibility for pumping using 2-micron fiber lasers while maintaining the desired phase matching conditions, necessary to obtained a conversion efficiency compatible with spectroscopic applications. The combination of dispersion engineering of the waveguide and optimization of pumping wavelength enables the efficient and targeted transfer of light from 2-micron near-infrared input laser up to the 4-micron wavelength range [4]. The central wavelength of the mid-IR light can be controlled through waveguide cross-section dimensions while fine tuning can be reached by slight adjustments of the pumping source wavelength (Figure 1a). The bandwidth of the mid-IR light reaches up to 1000 nm at the highest coupled pump power, following to the emission of several DWs at these coupled powers [8] (Figure 1b). The milliwatt power level of mid-IR light, generated with close to 30 % of efficiency, is used in a proof-of-principle absorption spectroscopy experiment, confirming that the generated mid-IR DW can be used for the parallel detection of several gas species (Figure 1c). Such light generation, based on soliton dynamics initiated from femtosecond pulses and relatively low soliton numbers, maintains the coherence of the input signal such that the scheme can be extended to perform dual-comb spectroscopy [9]. Fully coherent broadening can also be obtained relying on propagation in a purely normal dispersion regime, where self-phase modulation is the dominating mechanism, offering the possibility for ultrashort pulse generation through recompression re-compression. Exploiting different dispersion regimes in a single design, relying on the extreme polarization sensitivity of integrated waveguides, thus offers an additional degree of freedom for the tailoring of such sources (Figure 2).

The presented approach, leading to efficient, compact and easy to use devices for the generation of coherent light in the mid-IR, takes benefits from advances in photonic integration. It bridges the wavelength gap between fiber sources and quantum cascade lasers. It also provides an alternative to microresonator for the generation of frequency combs with sub-gigahertz teeth spacing and to the generation of ultrashort pulses.

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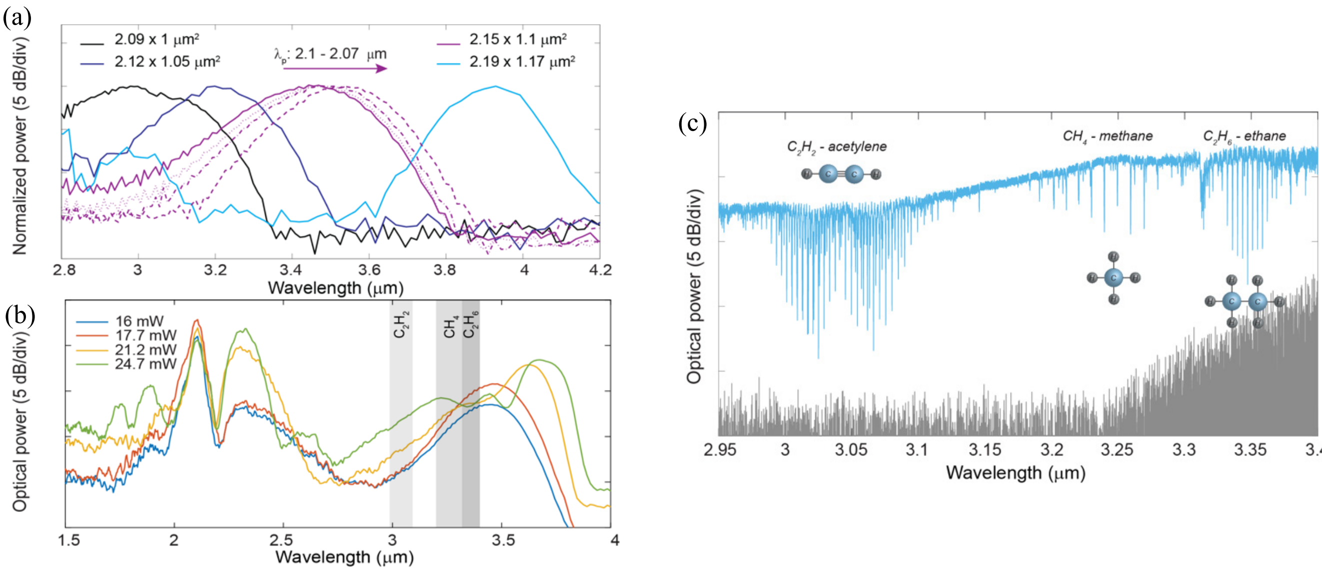

Figure 1: a) Experimental spectra at the output of 5 mm long Si_3N_4 chips of different dimensions pumped at 2.09 μm. A clear DW is generated between 3 and 4 μm depending on the cross-section. Slight adjustments to the pump wavelength enable blue or red shift of the DW. b) Spectra at the output of the 2.15 x 11 μm^2 chip pumped at 2.1 μm for different pump powers. We see the generation of the DW which initially grows in power then in bandwidth for a coverage extending from 3 to 3.8 μm. c) Spectrum of the mid-IR light generated on chip as in b) with maximum power after a 5 cm gas cell containing CH_4, C_2H_6 and C_2H_2, showing clear absoprtion lines.

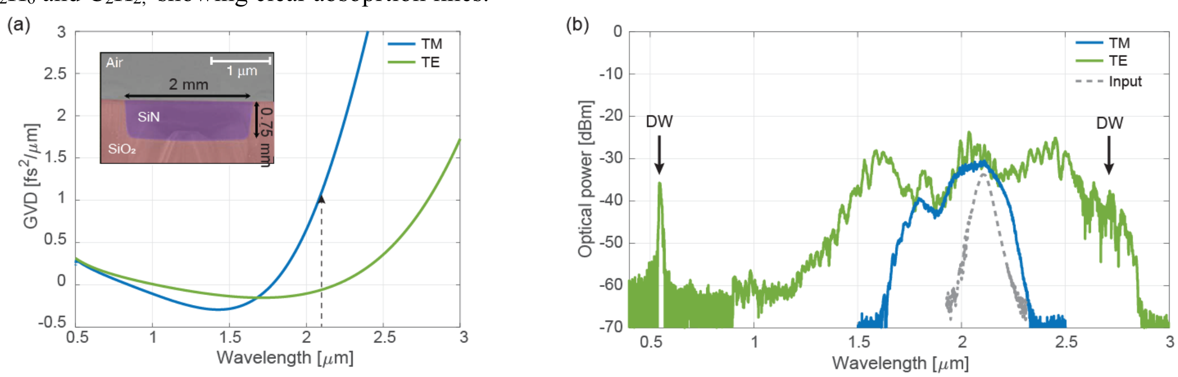

Figure 2: a) Dispersion engineering of a Si_3N_4 waveguide as to enable both soliton-dynamics and self-phase modulation by leveraging polarization properties. b) Output spectra of a 4.5 cm long waveguide with dispersion depicted in a) and showing two different broadening mechanisms for either spectroscopy or pulse recompression.

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