Self-referenced mid-infrared frequency comb using a silicon-carbide nanophotonic waveguide

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Abstract: A dispersion-engineered SiC waveguide on a photonic chip simultaneously provides an f-2f interferometer and mid-infrared dispersive-wave frequency-comb generation at 120-pJ pulse energies. Accurate comb-assisted tunable-laser molecular spectroscopy is demonstrated at 3.6 µm.

1. Introduction

The mid-infrared spectral region features intense rovibrational transitions in most molecules and as a consequence, it is important for fundamental physics, including tests of quantum chemistry, and for applications such as environmental sensing. Although frequency comb techniques are available for precision spectroscopy in the mid-infrared, they often involve complex setups.

We demonstrate a new approach based on the 4H silicon carbide (SiC) on insulator platform [1,2], which dramatically simplifies mid-infrared comb-assisted spectroscopy. SiC is emerging as a powerful integrated-optics platform, which features a strong second- and third-order optical nonlinearity, a high refractive index, low losses, and a broad transparency range. Here, a dispersion-engineered SiC waveguide excited by a mode-locked laser at 1560 nm, simultaneously enables frequency comb self-referencing and mid-infrared frequency comb spectral broadening. Octave-spanning supercontinuum and second-harmonic generation simultaneously occur in the waveguide with a pulse energy of only 120 pJ. The optical part of an f-2f interferometer is therefore directly generated on chip and the carrier-envelope offset frequency beatnote f_{ceo} can be straightforwardly detected and controlled using a fast photodiode. The strong optical nonlinearity of SiC also enables to generate a broad dispersive-wave frequency comb centered in the 3-4 µm range, region of the fundamental CH, NH, OH stretches in molecules. By referencing f_{ceo} to an atomic clock, the mid-infrared comb can be used as a frequency ruler, which enables straightforwardly absolute frequency measurements at long wavelengths. Precision spectroscopy of methane at 3.6 µm is experimentally demonstrated.

2. Experiments and results

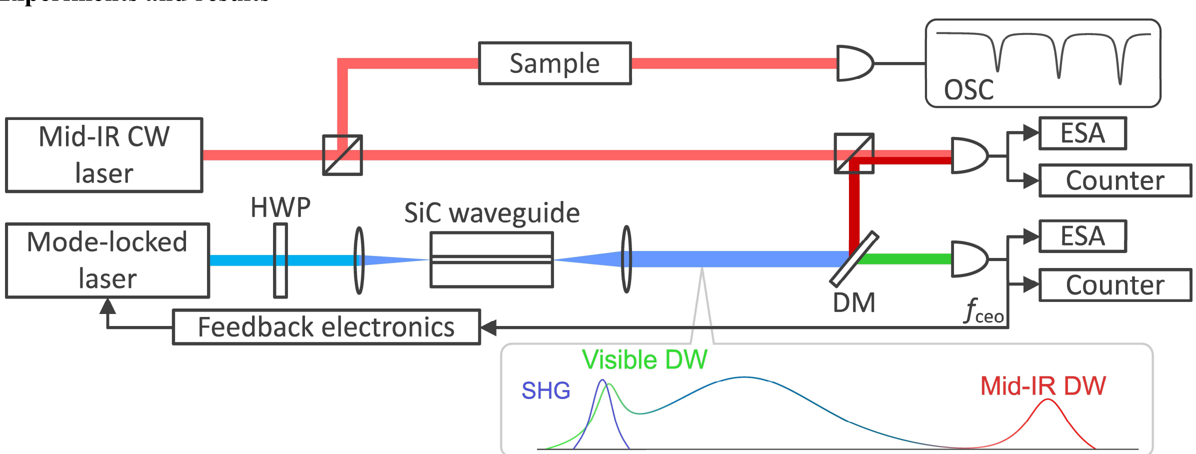

Figure 1. Experimental setup. SHG: second harmonics generation; DW: dispersive wave; CW: continuous wave; ESA: electrical spectrum analyzer; OSC: oscilloscope; HWP: half-wave plate.

An erbium-doped femtosecond mode-locked laser, centered at 1560 nm, is used to excite the SiC waveguide. The laser emits a train of pulses of 70-fs duration at a repetition frequency f_{rep} of 100 MHz, locked to a radio-frequency clock. The fundamental TE mode of the waveguide is excited. The dispersion of the waveguide is engineered for dispersive-wave generation in the visible and mid-infrared regions. The center wavelength of the mid-infrared dispersive wave ranges from 3000 nm to 3800 nm, depending on the waveguide width. The visible dispersive wave and second harmonic generation are designed to be centered at 800 nm for the waveguide with 500 nm height and 1617 nm width. The output spectrum of a 4-mm-length waveguide excited by pulses of an energy of 120 pJ, is shown in Fig. 2(a). The carrier-envelope offset frequency f_{ceo} is detected a silicon avalanche photo-detector Fig. 2(b) and used for locking the comb by retroaction on the current of the pumping diodes of the mode-locked laser. The required pulse energy is similar to that reported with other platforms such as lithium niobate [3].

The mid-infrared comb produced by the dispersive wave spans over 100 nm at a central wavelength of 3600 nm. Soliton-induced dispersive wave generation occurs in SiC at pulse energies as low as 120 pJ, whereas it has been reported, e.g. in silicon nitride at pulse energies on the order of 600 pJ [4]. Once the comb is self-referenced as described above, the absolute frequency of all mid-infrared comb lines is known. The mid-infrared comb can be used as a frequency ruler for calibrating a continuous-wave laser. Here, we use the idler beam of a tunable narrow-linewidth continuous-wave optical parametric oscillator (OPO). The beatnote between the OPO and one line of the mid-infrared comb is detected using a fast HgCdTe photodetector (Fig. 2(c)). The idler beam of the OPO is tuned across the mid-infrared rovibrational transitions of methane while its absolute frequency is measured against the frequency comb. Experimental spectra and prospects of the techniques will be discussed.

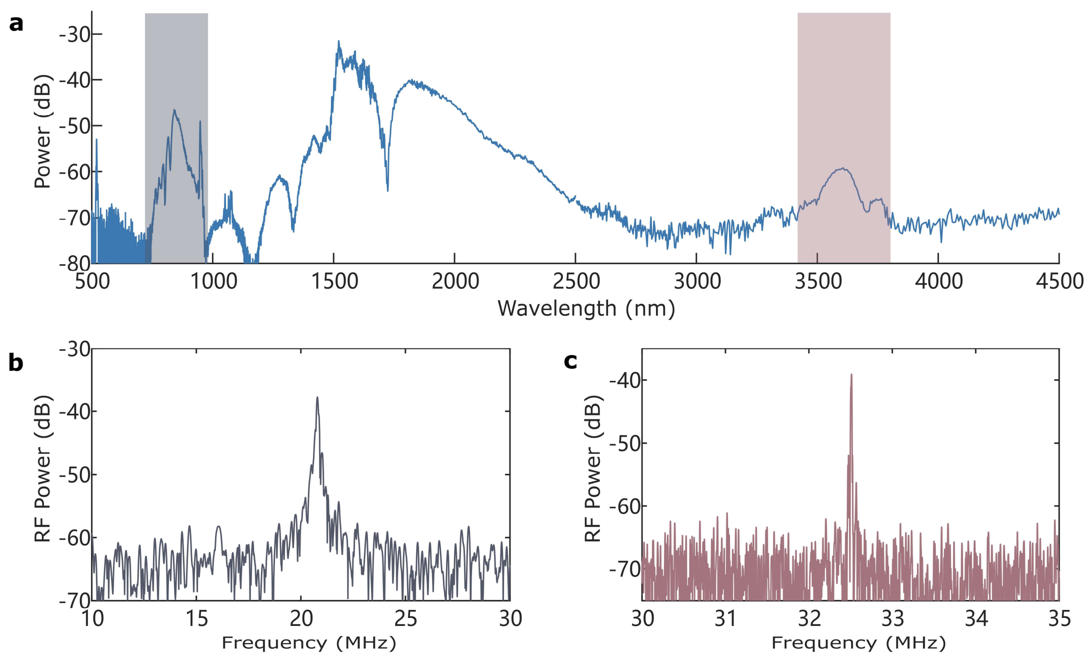

Figure 2 (a) Measured supercontinuum spectrum. The region centered at 800 nm is used for carrier-envelope offset frequency beat detection. The region centered at 3600 nm is used to detect the beatnote of one comb line with the idler beam of an OPO. (b) Measured radio-frequency (RF) spectrum of f_{ceo}. The resolution bandwidth (RBW) is 100 kHz. (c) Measured RF spectrum of the beatnote between one mid-infrared comb line and the idler of a narrow-linewidth continuous-wave OPO with 10-kHz RWB.

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3. References

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