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Nonlinear Optical Down- and Up-Conversion in PPLN Waveguides for Mid-Infrared Spectroscopy

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Middle-infrared (MIR) spectroscopy in the 2 to 4 µm spectral range is a powerful tool in particular for environmental analysis and monitoring. However, this method suffers from missing compact, tuneable, coherent light sources and sensitive detectors. To overcome these problems to a certain extent we demonstrate consecutive nonlinear wavelength down- and up-conversion in Ti-indiffused periodically poled lithium niobate (Ti:PPLN) waveguides to generate and to detect MIR radiation [1]. In detail, nonlinear difference frequency generation (DFG) using pump and signal sources in the near infrared (NIR) is used in the transmitter. On the receiver side, we apply sum-frequency generation (SFG) to reconvert the MIR signal to the NIR.

The experimental scheme is shown in Fig 1. We use a 40-mW, 1.064-µm fiber Bragg grating (FBG)-stabilized diode laser as pump and a 5-mW, 1.55-µm external cavity laser (ECL), followed by a 50:50-fiber-coupler, as tunable signal source. The pump and the signal (from one arm of the 50:50-coupler) are combined by a fiber WDM coupler and butt-coupled to the 80 mm long, 18-µm-wide Ti:PPLN waveguide of the transmitter (Fig. 2). Due to the domain periodicity of 26 µm, MIR-radiation of ~ 3.4 µm wavelength is generated by quasi phase-matched DFG.

After coupling to free-space, residual NIR radiation is blocked by a Ge-filter and the MIR radiation is coupled to the receiver waveguide. CaF_2 lenses (f=8.3 mm) are used both for collimating the MIR beam from the transmitter and for coupling into the receiver. Using the second 50:50-output, followed by an erbium doped fiber amplifier (EDFA) as pump, the MIR-radiation is converted back to 1.064 µm by means of SFG. The radiation is then detected with a Si-photodiode. The receiver module is nearly identical to the transmitter. To realize co-propagation of pump (1550 nm) and signal radiation (3.4 µm) in the receiver, a dielectric mirror of high reflectivity at 1550 nm and 1064 nm, and high transmission at 3.4 µm, is deposited on end-face of the receiver waveguide.

Experimentally, at a fixed sample temperature, MIR radiation can be tuned by about 5 nm within the phase-matching bandwidth. 1.7 µW of MIR radiation were determined in the free-space beam, at 10 mW of pump, and 1.7 mW of signal, respectively, coupled to the transmitter waveguide. In the receiver module, 0.8 nW of 1.064-µm radiation were generated at 52 mW pump power coupled to the receiver waveguide.

The MIR free-space transmission line (see Fig. 1) has been used to demonstrate absorption spectroscopy of methane. A 39.5 cm long cuvette, filled by CH_4 at a partial pressure of 70 mbar in ambient air, was inserted between transmitter and receiver. The measured NIR-power is plotted in Fig. 3 as function of the signal wavelength of the transmitter, which determines – together with the pump – the wavelength of the MIR-radiation. The tuning range is limited by the phase-matched bandwidth of here about 1.3 nm in the NIR, corresponding to about 5 nm in the MIR. Some methane absorption lines can be clearly identified, especially by a comparison with a calculated spectrum [2].

Several possibilities exist to improve experimental setup and measurement. In principle, power scales linearly with coupled power levels in both modules. Moreover, the pump wavelength in the receiver module can be chosen in a way that the MIR radiation is converted to the wavelength of optimum responsivity of the detector. Also, a DFG – DFG scheme can be realized, which would in principle allow even parametric gain in the receiver module.

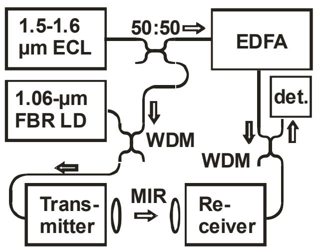

Fig. 1 Schematic experimental set up for consecutive down- and up-conversion by DFG and SFG.

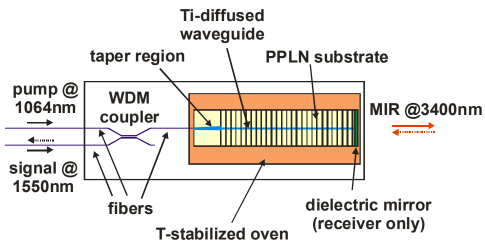

Fig. 2 Design of nonlinear down- and up-converter modules with Ti:PPLN waveguides

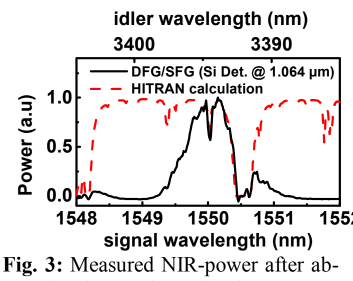

Fig. 3: Measured NIR-power after absorption by methane in the MIR as function of the signal wavelength of the transmitter together with a corresponding HITRAN calculation [2]

References

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