Title:

Compact ultrafast mid-infrared fiber laser – Pulse delivery and compression using antiresonant hollow-core fiber

Abstract:

The ultrafast pulse itself has enabled time-resolved studies of fast molecular and atomic-scale dynamics leading to a Nobel prize for groundbreaking work in femtochemistry. Molecules exhibit bond stretching, vibrations and rotations; the characteristic energy associated with many of these excitations correspond to mid-infrared photon energies. Coherent broadband mid-infrared light useful for molecular spectroscopy can be generated using infrared pulses through a nonlinear process - supercontinuum generation. The high peak power accorded by ultrafast pulses with sufficient pulse energies makes it possible to drive nonlinear processes.

A compact thulium-based fiber laser system was developed to produce high-energy ultrafast 2 µm pulses. The high energy output was achieved using the chirped pulse amplification technique, through a multi-pass chirped volume Bragg grating compressor. Fiber lasers are particularly attractive as 2 µm sources as they offer excellent beam quality. Furthermore, their efficient heat dissipation along long fiber lengths allows high pulse repetition rates and consequently high output powers. High-power 2 µm lasers are also useful for material processing of semiconductors and clear polymers, and for interactions with water-rich biological tissues and biomaterials. Hence, remote delivery of the high-power 2 µm pulses is desirable and is demonstrated using antiresonant hollow-core fibers (HCFs). The antiresonant HCF was designed to have a wide transmission band around the 2 µm wavelengths, with a flat and slightly anomalous dispersion profile, which makes it suitable for the transmission of ultrashort pulses. To compress the 2 µm pulses beyond the transform-limited pulse width, the spectral bandwidth has to be broadened, typically through the self-phase modulation (SPM) effect. The new frequency components generated are red-shifted near the pulse leading edge and are blue-shifted near the pulse trailing edge. As the pulse propagates in a gas-filled antiresonant fiber, the SPM-induced chirp is compensated by the antiresonant HCF's anomalous dispersion. The interplay between nonlinearity and dispersion effects in a gas-filled HCF can thus be exploited for nonlinear pulse compression. Future work involves peak power scaling of the compact ultrafast 2 µm fiber laser system, to overcome the nonlinearity and improve the pulse temporal profile to achieve higher peak powers after compression. Interesting nonlinear phenomena such as dispersive wave generation and supercontinuum generation in gas-filled antiresonant HCF can be explored as well.