Imaging and Spectroscopy with Sub-Cycle Mid-Infrared Pulses

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Mid-infrared (MIR) hyperspectral imaging, a powerful technique for identifying and mapping chemical constituents through their unique molecular vibrations, faces limitations due to detector sensitivity and pixel count. To overcome these challenges, up-conversion of MIR light to the higher-performing visible or near-infrared spectral range has emerged as a promising strategy. However, existing up-conversion-based methods, where wavelength conversion typically occurs at the Fourier plane, suffer from wavelength-dependent image scaling, necessitating complex calibration procedures.

Here, we introduce a novel MIR hyperspectral imaging approach based on broadband sub-cycle MIR pulses. These ultrashort pulses, spanning both the functional group (1500–3000 cm^{-1}) and fingerprint(500–1500 cm^{-1}) regions with sufficient intensity, enable efficient wavelength conversion directly at the image plane. This image-plane up-conversion eliminates wavelength-dependent image size variations, paving the way for snapshot hyperspectral imaging.

We generate 13.4 fs sub-half-cycle MIR pulses via four-wave mixing through two-color filamentation. In our setup, the MIR pulse transmitted through a sample is focused onto a ∼4.4 µm thick GaSe crystal positioned at the image plane. Simultaneously, a 1.8 ps chirped 800 nm pulse interacts with the MIR pulse in the crystal, generating a sum-frequency signal. This visible/near-infrared signal, carrying the spectral information of the MIR interaction with the sample, is then directly captured by a high-performance silicon-based hyperspectral camera, enabling rapid acquisition of chemically specific images.

In this talk, we will also introduce background-free MIR spectroscopy with sub-cycle pulses.