Hyperspectral imaging using sub-cycle mid-infrared pulses generated through two-color filamentation

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Abstract: We have demonstrated hyperspectral imaging using sub-cycle mid-infrared pulses generated through two-color filamentation. Up-conversion of the MIR pulse transmitted through the sample at the image plane significantly improve the performance of the spectral imaging.

Hyperspectral imaging integrates imaging and spectroscopy to characterize chemical distributions. The resulting spectral image, a "data cube," combines two spatial dimensions with one spectral dimension, offering full-spectrum insights from each pixel. The power of mid-infrared (MIR) hyperspectral technique lies in its ability to perform "chemical imaging" or "chemical mapping," capturing the molecular composition of objects through molecular vibration. However, the efficacy of the MIR hyperspectral imaging is hampered by limited pixels and the low signal-to-noise ratio of MIR detectors.

To overcome these challenges, the concept of up-conversion emerges as a promising strategy. By converting MIR ultrashort pulses into visible or near-infrared light, detection using Si-based detectors becomes feasible, greatly enhancing performance. Prior approaches focused the MIR beam into a nonlinear crystal to generate intense visible light through wavelength conversion at the Fourier plane [1]. However, this method necessitates wavelength-dependent image calibration based on phase matching conditions, hindering efficiency.

In this invited talk, a novel MIR hyperspectral imaging technique based on sub-cycle MIR pulses [2] is introduced. With broad bandwidth spanning functional group (1500–3000 cm^{-1}) and fingerprint (500–1500 cm^{-1}) regions, and intense intensity facilitating wavelength conversion at the image plane, this configuration eliminates wavelength dependency in image size. Figure 1(a) illustrates the two imaging types with up-conversion.

Generating sub-cycle MIR pulses (13.4 fs) utilizes four-wave mixing through two-color filamentation [3]. A ~4.4 μm thick GaSe crystal positioned on the sample's image plane interacts with the MIR pulse passing through the sample and a chirped 800 nm pulse (1.8 ps). This interaction generates a sum frequency signal subsequently captured by a silicon-based hyperspectral camera, producing hyperspectral images for analysis.

Our analytical prowess is validated through imaging and mapping of *A. cepa* bulb leaf epidermal cells. Cells affixed to 200 μm CaF_2 substrates reveal intricate structures illuminated by visible light (Fig. 1(b)), while hyperspectral imaging (Fig. 1(c)) maps cell wall (red), cytoplasm (cyan), and nuclei (green) through MIR spectral analysis. Significantly, nuclei distribution is exclusively visible in the MIR hyperspectral image, underscoring the method's potential for precise cell analysis. This innovative approach broadens horizons for advanced hyperspectral imaging, particularly in the realm of cellular exploration and characterization.

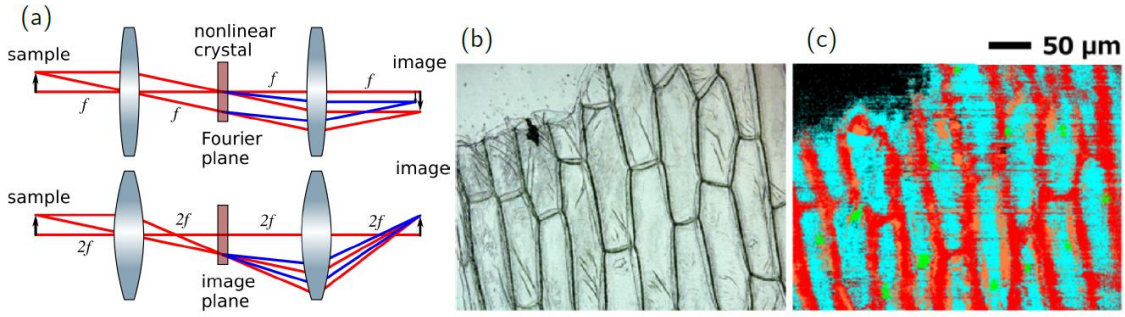

Fig. 1(a) Schematic of the two types of the imaging with upconversion. (b) Microscopy image illuminated by visible light. (c) Mapped hyperspectral images of the onion (*A. cepa*) bulb leaves epidermal cells.

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