

INVITED

Femtosecond Fieldoscopy

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Field-resolved detection at near-petahertz frequencies [1] offers remarkable sensitivity, broad bandwidth, and high dynamic range, enabling both attosecond temporal and sub-diffraction spatial resolution. In a novel method termed **Femtosecond Fieldoscopy**, ultrashort excitation laser pulses impulsively stimulate the resonant molecular modes of a sample at near-petahertz frequencies. This excitation induces vibrational coherence at the trailing edge of the pulses, which decays exponentially according to the vibrational dephasing time. The transmitted electric field encodes not only the ultrashort excitation pulse but also the sample's delayed response over several picoseconds, along with a longer-lived signal from atmospheric gases persisting for hundreds of nanoseconds. By capturing the molecular response directly in the time domain and applying Fourier analysis to the decaying signal, one obtains spectroscopic information with exceptional sensitivity and dynamic range. This is made possible by temporally gating the molecular response from the excitation pulse. Thanks to recent advances in ytterbium laser technology [2–6], Femtosecond Fieldoscopy has successfully resolved overtone, Raman, and combination bands in liquid samples [7–9]. Furthermore, various approaches have accelerated the technique toward real-time sampling [10–12] and extended its scope to non-perturbative, label-free imaging [13, 14].

In this talk, I will present an overview of recent advancements in this field demonstrated by my group. If time permits, I will conclude with a brief outlook on our ongoing work developing solar lasers and their potential applications in space exploration [15].

References

- [1] Andreas Herbst, Kilian Scheffter, MM Bidhendi, M Kieker, Anchit Srivastava, and Hanieh Fattahi. Recent advances in petahertz electric field sampling. *Journal of Physics B: Atomic, Molecular and Optical Physics*, 55(17):172001, 2022.
- [2] Hanieh Fattahi, Helena G Barros, Martin Gorjan, Thomas Nubbemeyer, Bidoor Alsaif, Catherine Y Teisset, Marcel Schultze, Stephan Prinz, Matthias Haefner, Moritz Ueffing, et al. Third-generation femtosecond technology. *Optica*, 1(1):45–63, 2014.
- [3] A Alismail, H Wang, G Barbiero, N Altawajry, SA Hussain, V Pervak, W Schweinberger, AM Azzeer, F Krausz, and H Fattahi. Multi-octave, cep-stable source for high-energy field synthesis sci, 2020.
- [4] Tatiana Amotchkina, Hanieh Fattahi, Yuriy A Pervak, Michael Trubetskov, and Vladimir Pervak. Broadband beamsplitter for high intensity laser applications in the infra-red spectral range. *Optics express*, 24(15):16752–16759, 2016.
- [5] Hanieh Fattahi. Sub-cycle light transients for attosecond, x-ray, four-dimensional imaging. *Contemporary Physics*, 57(4):580–595, 2016.
- [6] Theresa Buberl, Ayman Alismail, Haochuan Wang, Nicholas Karpowicz, and Hanieh Fattahi. Self-compressed, spectral broadening of a yb:Yag thin-disk amplifier. *Optics express*, 24(10):10286–10294, 2016.
- [7] Anchit Srivastava, Andreas Herbst, Mahdi M Bidhendi, Max Kieker, Francesco Tani, and Hanieh Fattahi. Near-petahertz fieldoscopy of liquid. *Nature Photonics*, pages 1–7, 2024.
- [8] K Scheffter, A Srivastava, A Herbst, S Jun, and H Fattahi. Field-resolved stimulated raman spectroscopy. In 2024 IEEE Photonics Conference (IPC), pages 1–2. IEEE, 2024.
- [9] A Srivastava, A Herbst, and H Fattahi. Field-resolved, far-field characterization of air bubbles in liquid water. In 2024 IEEE Photonics Conference (IPC), pages 1–2. IEEE, 2024.
- [10] S Gommel, M Lippl, K Scheffter, A Srivastava, A Herbst, NY Joly, and H Fattahi. Towards field-resolved photonic time stretch at near-petahertz frequencies. In 2024 IEEE Photonics Conference (IPC), pages 1–2. IEEE, 2024.
- [11] Kilian Scheffter, Jonathan Will, Claudius Riek, Herve Joussetin, S'ebastien Coudeureau, Nicolas Forget, and Hanieh Fattahi. Compressed sensing of field-resolved molecular fingerprints beyond the nyquist frequency. *Ultrafast Science*, 4:0062, 2024.
- [12] Anni Li, Mehran Bahri, Robert M Gray, Seowon Choi, Sajjad Hoseinkhani, Anchit Srivastava, Alireza Marandi, and Hanieh Fattahi. 0.7 mw yb: Yag pumped degenerate optical parametric oscillator at 2.06 μm . *APL Photonics*, 9(10), 2024.

- [13] Soyeon Jun, Andreas Herbst, Kilian Scheffter, Nora John, Julia Kolb, Daniel Wehner, and Hanieh Fattahi. Nonlinear dynamics of femtosecond laser interaction with the central nervous system in zebrafish. *Communications Physics*, 7(1):161, 2024.
- [14] A Herbst, A Srivastava, K Scheffter, S Jun, N Petrini, A Rubino, I Kriegel, and H Fattahi. Label-free hyperspectral microscopy with attosecond precision. In *2024 IEEE Photonics Conference (IPC)*, pages 1–2. IEEE, 2024.
- [15] Michael Küblböck, Jonathan Will, and Hanieh Fattahi. Solar lasers: Why not? *APL Photonics*,9(5):050903, 05 2024.