

Principles and applications of ultrafast terahertz spectroscopy

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In this lecture we will review the methods of generation and detection of ultrashort pulses of terahertz (THz) radiation using femtosecond laser pulses, and the basic principles of terahertz time-domain spectroscopy (THz TDS). The connection between the dielectric function, optical constants, and optical conductivity of materials will be reviewed, and examples will be provided of terahertz spectroscopy of electronic, lattice, and spin response in various materials. Different modalities of ultrafast THz spectroscopy, such as non-contact conductivity measurement, THz emission spectroscopy, pump-probe, and nonlinear THz spectroscopy will be introduced. As special highlights, we will discuss the ultrastrong electronic nonlinearity of graphene at THz frequencies, as well as THz spectroscopy of magnetic systems.

References:

- [1] Z. Mics, K.-J. Tielrooij, K. Parvez, S. A. Jensen, I. Ivanov, X. Feng, K. Müllen, M. Bonn, and D. Turchinovich, "Thermodynamic picture of ultrafast charge transport in graphene," *Nature Commun.* **6**, 7655 (2015).
- [2] Z. Jin, A. Tkach, F. Casper, V. Spetter, H. Grimm, A. Thomas, T. Kampfrath, M. Bonn, M. Kläui, and D. Turchinovich, "Accessing the fundamentals of magnetotransport in metals with terahertz probes," *Nature Phys.* **11**, 761–766 (2015).
- [3] H. A. Hafez, S. Kovalev, J.-C. Deinert, Z. Mics, B. Green, N. Awari, M. Chen, S. Germanskiy, U. Lehnert, J. Teichert, Z. Wang, K.-J. Tielrooij, Z. Liu, Z. Chen, A. Narita, K. Müllen, M. Bonn, M. Gensch, and D. Turchinovich, "Extremely efficient terahertz high-harmonic generation in graphene by hot Dirac fermions," *Nature* **561**, 507–511 (2018).
- [4] H. A. Hafez, S. Kovalev, K. Tielrooij, M. Bonn, M. Gensch, and D. Turchinovich, "Terahertz nonlinear optics of graphene: from saturable absorption to high-harmonics generation," *Adv. Opt. Mater.* **8**, 1900771 (2020).