Sympsium Terahertz physics: toward probing and controlling of materials on the nanoscale (SYTH)

jointly organized by
the Semiconductor Physics Division (HL),
the Chemical and Polymer Physics Division (CPP),
the Magnetism Division (MA), and
the Surface Science Division (O)

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Electromagnetic radiation at terahertz (THz) frequencies is of central relevance for basic research and applications. Owing to its low photon energy (4.1 meV at 1 THz), ultrashort THz pulses are an excellent probe of the dynamics of many elementary excitations of solids, for instance phonons, conduction electrons, excitons and magnons. Highly intense THz pulses open up the fascinating possibility to not only probe solids but to even control these modes down to the nanoscale. The talks of this symposium will provide an overview over latest developments in the generation and detection of ultrashort THz pulses and their application in the probing and controlling of ultrafast motions of electrons, ions and spins in solids and at surfaces, with a spatial resolution down to the atomic scale.

Overview of Invited Talks and Sessions

(Lecture room H 0105)

Invited Talks

SYTH 1.1	Thu	9:30–10:00	H 0105	**Extracting the electrical properties of metal halide perovskite semiconductors using transient terahertz spectroscopy** — •Michael B. Johnston
SYTH 1.2	Thu	10:00–10:30	H 0105	**THz nanophotonics with 2D materials** — •Miriam SERENA Vitiello
SYTH 1.3	Thu	10:30–11:00	H 0105	**Nonlinear responses and 2D spectroscopy using THz electric and magnetic fields** — •Keith A Nelson
SYTH 1.4	Thu	11:15–11:45	H 0105	**Low energy electrodynamics of correlated spin systems.** — •N. Peter Armitage
SYTH 1.5	Thu	11:45–12:15	H 0105	**Lightwave scanning tunneling microscopy of single molecules** — Dominik Peller, Tyler L. Cocker, Ping Yu, Rupert Huber, •Jascha Repp

Sessions

SYTH 1.1–1.5	Thu	9:30–12:15	H 0105	**Terahertz Physics: Toward Probing and Controlling of Materials on the Nanoscale**

SYTH 1: Terahertz Physics: Toward Probing and Controlling of Materials on the Nanoscale

Time: Thursday 9:30–12:15 Location: H 0105

Invited Talk SYTH 1.1 Thu 9:30 H 0105

Extracting the electrical properties of metal halide perovskite semiconductors using transient terahertz spectroscopy — •Michael B. Johnston — Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, U.K.

Metal halide perovskite semiconductors are currently showing great promise for use in thin-film photovoltaic cells. These semiconductors may be deposited by a variety of methods including vapour deposition and solution processing, and the resulting films possess a high absorption coefficient and relatively benign defect chemistry. The prototypical metal halide perovskite is methyl ammonium lead triiodide with a 1.6eV bandgap at room temperature, however by altering the chemical composition it is possible to produce a large family of metal halide perovskite semiconductors with varying physical properties and bandgaps that span the full visible spectrum [1].

Time-resolved terahertz photoconductivity spectroscopy in an excellent non-contact probe of charge carrier dynamics in semiconductors. Using this technique, the fundamental charge recombination mechanisms in metal halide perovskite materials are revealed, allowing prediction of the electronics and optoelectronic properties of these novel semiconductors [2]. Using appropriate analysis, Shockley-Read-Hall, bimolecular and Auger recombination constants may be extracted [3] and exploited in the design of new solar cells and lasers.

[1] LM Herz, Annu. Rev. Phys. Chem. 67:65, 2016. [2] MB Johnston, LM Herz Accounts Chem. Res., 49:146, 2016. [3] TW Crothers, et al Nano Lett., 17:5782, 2017.

Invited Talk SYTH 1.2 Thu 10:00 H 0105

THz nanophotonics with 2D materials — •Miriam SERENA Vitiello — CNR-NANO and Scuola Normale Superiore, Piazza San Silvestro 12

Bi-dimensional nano-materials and related heterostructures are establishing themselves as a new material platform for a variety of photonic and electronic applications, ranging from saturable absorbers to optical modulators, from optical communication components to near field probes. Their peculiar band-structure and electron transport characteristics, which can be easily manipulated via layer thickness control, suggest they could also form the basis for a new generation of high-performance devices operating in the Terahertz frequency range (1-10 THz) of the electromagnetic spectrum. The talk will review our latest achievements in THz nanophotonic devices based on 2D materials and will discuss future perspectives of this rapidly developing research field.

Invited Talk SYTH 1.3 Thu 10:30 H 0105

Nonlinear responses and 2D spectroscopy using THz electric and magnetic fields — •Keith A Nelson — Department of Chemistry, MIT, Cambridge, MA, USA

Terahertz fields have been used to drive nonlinear responses of electronic, vibrational, molecular rotational, and spin degrees of freedom. In some cases far-from-equilibrium responses have been induced, including electronic/structural phase transitions in correlated electron materials and colossal Stark shifts and electroluminescence of quantum dots. These will be reviewed and two-dimensional THz spectroscopy of molecular rotations and collective spin waves (magnons) will be described. Linear spectroscopy of molecular and collective spin states will also be discussed, including THz electron paramagnetic resonance (EPR) measurements of high-spin transition metal zero-field splittings and measurements of magnon-phonon-polaritons in hybrid ferroelectric/antiferromagnetic waveguides and cavities. Prospects for new THz field-induced states of matter will be suggested.

15 min. break.

Invited Talk SYTH 1.4 Thu 11:15 H 0105

Low energy electrodynamics of correlated spin systems. — •N. Peter Armitage — The Johns Hopkins University

In condensed matter systems, the formation of long range order (LRO) with broken symmetry is often accompanied by new types of excitations. However, in many magnetic pyrochlore oxides, geometrical frustration suppresses conventional LRO while at the same time non-trivial spin correlations are observed. For such materials, a natural question to ask then is what is the nature of the excitations in this highly correlated state without broken symmetry? Frequently the application of a symmetry breaking field can stabilize excitations whose properties still reflect certain aspects of the anomalous state without long-range order. I will discuss our recent results on novel magnetic excitations in the quantum spin ice material Yb2Ti2O7, obtained from time-domain terahertz spectroscopy (TDTS). In large applied fields, both magnon and two-magnon-like excitations are observed illustrating the stabilization of a field induced LRO state. The g-factors of these excitations are dramatically enhanced in the low-field limit, showing a cross-over of these one- and two-magnon states into features consistent with quantum string-like excitations proposed to exist in quantum spin ice in a small <001> applied field. In zero magnetic field, we find that a form of the complex susceptibility is consistent with monopole motion. Using the unique phase sensitive capabilities of these techniques, we observe a sign change in the reactive part of the magnetic response. In generic models of monopole motion this is only possible through introducing inertial effects, e.g. a mass dependent term, to the equations of motion.

Invited Talk SYTH 1.5 Thu 11:45 H 0105

Lightwave scanning tunneling microscopy of single molecules — Dominik Peller, Tyler L. Cocker, Ping Yu, Rupert Huber, and •Jascha Repp — Department of Physics, University of Regensburg, 93040 Regensburg, Germany

Combining the concept of lightwave electronics [1] with scanning tunneling microscopy (STM) has enabled femtosecond temporal resolution in STM [2]. In lightwave STM, the electric field of a single-cycle laser pulse acts as a transient bias voltage across an STM junction. This way, the peak of an electric-field waveform could be used to induce tunneling of a single electron from an individual molecule's orbital [3] within a time window of $\simeq$100 fs – faster than an oscillation cycle of the terahertz laser pulse. This quantum process allows us to capture a microscopic real-space snapshot of the molecular orbital at a sub-Ångstrom spatial resolution and on a sub-cycle time scale. By correlating two successive state-selective tunneling events, we directly track coherent THz vibrations of a single molecule in the time domain [4]. References: [1] E. Goulielmakis et al., Science 317, 769 (2007); [2] T. L. Cocker et al., Nature Photon. 7, 620 (2013); [3] J. Repp et al., Phys. Rev. Lett. 94, 026803 (2005); [4] T. L. Cocker et al., Nature 539, 263 (2016).