MA 21: Terahertz Spintronics

Time: Wednesday 9:30–12:15 Location: H43

MA 21.1 Wed 9:30 H43

Spintronic THz emitters for lightwave-driven scanning tunneling microscopy at MHz repetition rates — •Alkisti Vaitsi[1], Vivien Sleziona[1], Fabian Schulz[2], Luis Enrique Parra Lopez[1], Tom Sebastian Seifert[1,3], Martin Wolf[1], and Melanie Müller[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]CIC NanoGUNE BRTA, San Sebastian, Spain — [3]Freie Universität Berlin, Germany

Attaining simultaneous high temporal resolution and signal-to-noise ratio in THz lightwave-driven scanning tunneling microscopy (THz-STM) requires broadband single-cycle THz pulses at high repetition rates and electric field strength. In this context, we report on the operation of ultrabroadband spintronic THz emitters (STE) at MHz repetition rates and pump powers of several Watts. We discuss saturation mechanisms which can reduce THz emission efficiency, such as steady-state and transient heating, limiting the usable fluence at the STE. Furthermore, to maximize the THz field in the STM junction, we analyze and optimize THz propagation into the STM, which due to the ultrabroadband spectrum of the STE requires careful consideration of pump spot sizes in combination with the limitations arising from pump fluence and average pump power density. We present detailed experimental and theoretical analysis of the ideal excitation geometry, which allows STE operation up to 10 W average powers at 2 MHz repetition rate at optimized fluence and THz propagation into the STM.

MA 21.2 Wed 9:45 H43

Investigation of THz electromagnetic response in nanopatterned magnetic heterostructures by current confinement — •Bikash Das Mohapatra[1], Reza Rouzegar[3], Evangelos Papaioannou[1], Tobias Kampfrath[3], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, D-06120 Halle, Germany — [2]Interdisziplinäres Zentrum für Meterialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich-Damerow-Straße 4, D-06120 Halle, Germany — [3]Department of Physical Chemistry, Fritz Haber Institute, Faradayweg 4-6, 14195 Berlin, Germany

STEs (Spintronic Terahertz Emitters) are novel THz radiation sources. Many studies have demonstrated that the STEs when illuminated with fs-laser pulse, ultrafast spin current is produced which leads to ultrafast transverse charge current by Inverse Spin Hall Effect, resulting in THz electromagnetic pulses. We were able to fabricate THz emitters into arrays of various squares and rectangles of micron or sub-micron size, using Sputter deposition and e-beam lithography. These emitters generate a different emission spectrum than large area reference emitters when irradiated with a fs laser. We propose that the confinement due to small size induces local charge buildup, which leads to additional currents that counterbalance the original charge current due to the Inverse Spin Hall Effect.

MA 21.3 Wed 10:00 H43

Coupling of a local broadband THz emitter to a 2D microresonator — •Christopher Rathje[1], Rieke von Seggern[1], Leon Gräper[1], Jana Kredl[2], Jakob Walowski[2], Markus Münzenberg[2], and Sascha Schäfer[1] — [1]Institut für Physik, Universität Oldenburg — [2]Institut für Physik, Universität Greifswald

Recently, the advent of spintronic terahertz emitters (STE) has introduced a simple approach to generate broadband radiation in the terahertz (THz) spectral domain [1].

In this contribution, we utilize a resonator-grafted STE bilayer illuminated by a focused optical excitation pulse for the generation of a micrometer-scaled broadband THz emitter with a source size far below the THz diffraction limit [2]. The near-field of this localized transient electric dipole is coupled to a bow-tie antenna structure in direct proximity to the emitter. Depending on the position of the excitation focus, we detect the emitted THz time-domain signal in the far-field.

Our results show pronounced changes of the emission characteristics of the excited STE layer for a dipole positioned in the bow-tie gap, demonstrating the capability to tailor the emission spectrum including resonant enhancement of certain frequency components and increase of the overall bandwidth. We discuss the influence of different resonator designs and provide a model of the coupling process supported by numerical simulations. Further results for different isolated resonators and periodically structured metasurfaces are presented.

[1] Seifert et al., Nat. Photonics, 10, 483 (2016)
[2] Rathje et al., manuscript in preparation

MA 21.4 Wed 10:15 H43

Spin pumping in noncollinear antiferromagnets — •Mike Alexander Lund, Akshaykumar Salimath, and Kjetil Magne Dørheim Hals — University of Agder, Norway

The spin pumping and spin-transfer torque mechanisms in antiferromagnets have been theoretically and experimentally investigated in recent years. However, most of these works have concentrated on collinear antiferromagnets, leaving the spin dynamics of the more complex noncollinear antiferromagnets largely unexplored. Apart from a few works on spin-transfer torque, there has been no thorough investigation of the spin pumping process in noncollinear antiferromagnets.

In this talk, I will present our latest work on ac spin pumping in noncollinear antiferromagnets. Starting from an effective action description of the spin system, we derive the Onsager coefficients connecting the spin pumping and spin-transfer torque associated with the dynamics of the SO(3)-valued antiferromagnetic order parameter. Our theory is applied to a kagome antiferromagnet resonantly driven by a uniform external magnetic field. We demonstrate that the reactive (dissipative) spin-transfer torque parameter can be extracted from the pumped ac spin-current in phase (in quadrature) with the driving field. Furthermore, we find that the three spin-wave bands of the kagome antiferromagnet generate spin currents with mutually orthogonal polarization directions. This offers a unique way of controlling the spin orientation of the pumped spin current by exciting different spin-wave modes.

MA 21.5 Wed 10:30 H43

THz spin dynamics in antiferromagnetic Mn2Au — •Yannic Behovits[1,2], Alexander Chekhov[1,2], Stanislav Bodnar[3], Mathias Kläui[3], Martin Jourdan[3], and Tobias Kampfrath[1,2] — [1]Freie Universität Berlin, Insitut für Experimentalphysik, 14195 Berlin, Germany — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Abteilung Physikalische Chemie, 14195 Berlin, Germany — [3]Johannes-Gutenberg-Universität, Institut für Physik, 55122 Mainz, Germany

In metallic antiferromagnets, intrinsic terahertz (THz) magnons may allow high-speed spin information processing. For CuMnAs and Mn2Au, switching of the Néel vector has been demonstrated by using pulsed electrical currents and free-space THz pulses [1,2]. The switching was attributed to the current-induced Néel spin-orbit torque (NSOT)[3]. However, the underlying spin dynamics have not been observed on picosecond timescales. Here, we employ a THz-pump optical-probe setup to investigate dynamics of antiferromagnetic order induced by NSOT in Mn2Au. We observe a signal proportional to the driving THz field, which is consistent with NSOT-driven spin dynamics both in frequency and symmetry. Our results indicate a strongly damped magnon mode at 0.6 THz. By using a simple model, we can extract material properties and estimate the field strengths required for picosecond rotation of the antiferromagnetic order.

[1] K. Olejnik et al., Sci. Adv., 4(3): p. eaar3566 (2018) [2] S. Yu. Bodnar et al., Nat. Commun., 9(1): p. 348. (2018) [3] J. Zelezny et al., PRL, 113(15): p. 157201 (2014)

MA 21.6 Wed 10:45 H43

Spin-orbit interaction at terahertz rates — •Tom S. Seifert and Tobias Kampfrath — FU Berlin

Spintronics aims at implementing the spin degree of freedom into conventional electronics. To be compatible and competitive, spintronic functionalities thus need to keep pace with the ever-increasing speeds of electronic devices that are foreseen to enter the terahertz range eventually [1]. Therefore, one needs to study fundamental spintronic phenomena at terahertz frequencies. Following this approach, one might not only hope to reveal new physics but also to apply these novel insights in terms of innovative terahertz photonic applications. Here, I will discuss our recent experimental efforts to study a central spintronic effect, the anomalous Hall effect (AHE) [2] in metallic magnets from DC to 40 THz. We find a largely frequency-independent AHE in DyCo5, Gd27Fe73 and Co32Fe68, which we attribute to the large Drude scattering rate in metallic thin films. The gained knowledge could further enhance the efficiency of a novel ultrafast spintronic application, namely the spintronic terahertz source [3].

[1] Walowski, J., et al., J. Appl. Phys. 120 (2016). [2] Seifert, T. S., et al. Adv. Mat. 33 (2021). [3] Seifert, T. S., et al. Appl. Phys. Lett. 120 (2022).

MA 21.7 Wed 11:00 H43

Spin-orbit torque mediated coupling of terahertz light with magnon modes in heavy-metal/ferromagnet heterostructures — •Ruslan Salikhov[1], Igor Ilyakov[1], Lukas Körber[1], Attila Kákay[1], Kilian Lenz[1], Jürgen Fassbender[1], Stefano Bonetti[2,3], Olav Hellwig[1,4], Jürgen Lindner[1], and Sergey Kovalev[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Stockholm University, Stockholm, Sweden — [3]University of Venice, Venice, Italy — [4]Chemnitz University of Technology, Chemnitz, Germany

Nonvolatile and energy-efficient spin-based technologies call for new prospects to realize computation and communication devices that are able to operate at terahertz (THz) frequencies. In particular, the coupling of electro-magnetic radiation to a spin system is a general requirement for future communication units and sensors. Here we propose a layered metallic system, based on a ferromagnetic film sandwiched in between two heavy metals that allows a highly effective coupling of millimeter wavelength THz light to nanometer-wavelength magnon modes. Using single-cycle broadband THz radiation we are able to excite spin-wave modes with a frequency of up to 0.6 THz and a wavelength as short as 6 nm. Our experimental and theoretical studies demonstrate that the coupling originates solely from interfacial spin-orbit torques. These results are of general applicability to magnetic multilayered structures, and offer the perspective of coherent THz excitation of exchange-dominated nanoscopic magnon modes.

MA 21.8 Wed 11:15 H43

Laser-induced charge and spin photocurrents in $BiAg_2$ surface from first-principles — •Theodoros Adamantopoulos[1,2], Maximilian Merte[1,2,3], Frank Freimuth[1,3], Dongwook Go[1,3], Stefan Blügel[1], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

The physics of photo-induced effects in interfacial systems is intensively researched these days owing to numerous potential applications. Owing to the complexity of the problem, a comprehensive theoretical picture of photogalvanic effects is still lacking. Here we perform first-principles calculations of laser-induced currents in a $BiAg_2$ surface alloy, which is a well-known material realization of the Rashba model [1, 2]. Our results confirm the emergence of very large in-plane photocurrents as predicted by the Rashba model and establish a benchmark picture of photocurrents at Rashba-like surfaces and interfaces [3]. This work contributes to the study of the role of the interfacial Rashba spin-orbit interaction as a mechanism for the generation of in-plane photocurrents, which are of great interest in the field of ultrafast and terahertz spintronics.

[1] F. Freimuth et al., Phys. Rev. B **103**, 075428 (2021). [2] F. Freimuth et al., Phys. Rev. B **94**, 144432 (2016). [3] T. Adamantopoulos et al., arXiv:2201.07122 (2022).

MA 21.9 Wed 11:30 H43

Transition of laser-induced terahertz spin currents from torque- to conduction-electron-mediated transport — •Oliver Gueckstock[1], Pilar Jimenez-Cavero[1,2], Lukas Nadvornik[1], Irene Lucas[2], Tom S. Seifert[1], Luis Morellon[2], and Tobias Kampfrath[1] — [1]FU Berlin, Germany — [2]Universidad de Zaragoza, Spain

Transport of spin angular momentum is a fundamental operation required for future spin-electronic devices. To be competitive with other information carriers, it is required to push the bandwidth of spin transport to the terahertz (THz) frequency range [1]. Here, we use femtosecond laser pulses to excite prototypical F|N bilayers consisting of a ferrimagnetic metal F and a nonmagnetic metal N [2,3]. Following absorption of the pulse, a spin current in F is launched and converted into a transverse charge current in N, giving rise to the emission of a THz electromagnetic pulse [2]. Depending on the conductivity of F, two driving mechanisms of the spin current can occur: (i) the ultrafast spin Seebeck effect [3] generating magnons and (ii) a spin voltage, generating a spin current carried by conduction electrons [4]. Remarkably, in the half-metallic ferrimagnet Fe3O4, we observe the coexistence of these contributions and disentangle them based on their distinctly different ultrafast dynamics. Our results shed new light on the magnetic structure of this mature material. References: [1] Vedmedenko et al., J. Phys. D: Appl. Phys. 53 453001 (2020), [2] T. Seifert et al., Nat. Phot. 10, 483 (2016), [3] T. Seifert et al., Nat. Comm. 9, Article No: 2899 (2018), [4] R. Rouzegar et al., arXiv:2103.11710 (2021)

MA 21.10 Wed 11:45 H43

Ultrafast spintronic THz emission of thin CoFe/Pt films — •Jannis Bensmann[1], Robert Schneider[1], Mario Fix[2], Steffen Michaelis de Vasconcellos[1], Manfred Albrecht[2], and Rudolf Bratschitsch[1] — [1]University of Münster, Institute of Physics and Center for Nanotechnology, 48149 Münster, Germany — [2]University of Augsburg, Institute of Physics, 86159 Augsburg, Germany

THz radiation has great potential for spectroscopy, security and quality control applications. Recently, ultrafast spintronic THz emitters gained a lot of interest, as they are easy to handle and show high power and broadband emission. In these emitters, an ultrafast laser pulse launches a spin-polarized current from a nanometer-thin magnetic film into a non-magnetic metal layer. Due to the inverse spin Hall effect and the conversion to an ultrafast charge current, THz radiation is created. The THz emission of spintronic emitters can be tuned by the material compositions of the layers.

Here we present our recent results on THz emission spectroscopy of ultrathin Co_xFe_{1-x}/Pt bilayers with varying Co content x. The THz amplitude changes only slightly with x, leading to the conclusion that both Fe and Co have a similar contribution to the THz generation process [1]. Moreover, we were able to boost the THz emission by using multilayer stacks of the mentioned structure.

[1] R. Schneider et al., "Composition-dependent ultrafast THz emission of spintronic CoFe/Pt thin films", Appl. Phys. Lett. 120, 042404 (2022)

MA 21.11 Wed 12:00 H43

Ultrafast coherent THz lattice dynamics coupled to spins in a van der Waals antiferromagnetic flake — •Fabian Mertens[1], David Mönkebüscher[1], Eugenio Coronado[2], Samuel Mañas-Valero[2], Carla Boix-Constant[2], Alberta Bonanni[3], Margherita Matzer[3], Rajdeep Adhikari[3], Alexandra M. Kalashnikova[4], Umut Parlak[1], Davide Bossini[1,5], and Mirko Cinchetti[1] — [1]Department of Physics, TU Dortmund University, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Instituto de Ciencia Molecular (ICMol) Universidad de Valencia, Spain — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Austria — [4]alexandra.kalashnikova@gmail.com — [5]Department of Physics and Center for Applied Photonics, University of Konstanz, Germany

We used the setup described in [1] to study the laser driven lattice and spin dynamics of a 380 nm thick flake of the antiferromagnetic van der Waals semiconductor $FePS_3$ as a function of excitation photon energy and sample temperature. We found evidence of a coherent optical lattice mode at a frequency of 3.2 THz. The amplitude of the phononic signal vanishes as the phase transition to the paramagnetic phase occurs, revealing its close connection to the long-range magnetic order. These findings open a pathway towards the coherent manipulation of the magneto-crystalline anisotropy in a van der Waals antiferromagnet, scalable down to thinner flakes.

[1] F. Mertens et al., *Review of Scientific Instruments* **91** (2020)