MA 22: Terahertz spintronics

Time: Tuesday 14:00–15:45 Location: H52

MA 22.1 Tue 14:00 H52

Roadmap for THz Generation from Metallic Spintronic Emitter — •Laura Scheuer[1], Dennis Nenno[1], Garik Torosyan[2], Sascha Keller[1], Alexander Brodyanski[3], Rolf Binder[4], Hans Christian Schneider[1], René Beigang[1], and Evangelos Papaioannou[1] — [1]Fachbereich Physik der TU Kaiserslautern und Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany — [2]Photonic Center Kaiserslautern, 67663 Kaiserslautern, Germany — [3]Institut für Oberächen- und Schichtanalytik (IFOS) and Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany — [4]College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Spintronic ferromagnetic/nonmagnetic heterostructures are novel and easily fabricated sources for the generation of THz radiation with large bandwith.

The key technological and scientific challenge of THz spintronic emitters is to understand and engineer their THz emission amplitude and bandwidth. Here, we pave the way to define and manipulate both.

We correlate the THz signal amplitude and its bandwidth with the electron-defect scattering lifetime and the interface transmission for spin-polarized, non-equilibrium electrons.

We experimentally and theoretically prove that epitaxial heterostructures contribute to a significant enhancement of signal amplitude. The results of our study define a roadmap for the properties of the emitted and detected THz pulse shapes and spectra that is essential for future applications of metallic spintronic THz emitters.

MA 22.2 Tue 14:15 H52

Broadband THz time-domain spectrometer at 300 kHz repetition rate using spintronic emitter — •Sergei Sobolev, Gerhard Jakob, Mathias Kläui, and Jure Demsar — Institute of Physics, University of Mainz, Germany

The linear and time-resolved terahertz (0.1-20 THz) time-domain spectroscopies are powerful tools to study low frequency optical conductivities and their dynamics with the sub-picosecond time resolution. To achieve high sensitivity in both configurations, a system with high repetition rate, yet high enough pulse energy for photoexcitation, is required. Heterostructures composed of ferromagnetic and nonferromagnetic metal films - so called spintronic emitters - have been recently demonstrated as efficient broadband THz emitters when driven by both, low pulse energy high repetition rate femtosecond oscillators [1][2] and by a 1 kHz repetition rate mJ-level femtosecond laser amplifiers [3][4]. Here we report on a development and characterization of a spintronic emitter based broadband time-domain THz spectrometer built around a 300 kHz μJ-level laser system. The parameters of the generated THz electric field pulses, the bandwidth and the sensitivity of the time-domain set-up are benchmarked to the system using photoconductive interdigitated finger emitters [5].

[1] T. Seifert et al., Nat. Photonics 10, 483*488 (2016) [2] G. Torosyan et al., Scientific Reports 8, 1311 (2018) [3] T. Seifert et al., Appl. Phys. Lett. 110, 252402 (2017) [4] D. Yang et al., Adv. Opt. Mater. 4, 1906-1914 (2016) [5] M. Beck et al., Opt. Express 18, 9251-9257 (2010)

MA 22.3 Tue 14:30 H52

Simulation of Terahertz Radiation and Ultrafast Spin-Currents in Optically-Excited Magnetic Multilayers — •Dennis Nenno[1], Rolf Binder[2], and Hans Christian Schneider[1] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern — [2]College of Optical Sciences, University of Arizona

Thin metallic bilayers have been shown to emit strong terahertz pulses due to the interplay of optically excited spin currents in ferromagnets and the Spin-Hall effect in heavy metals [1]. We present a novel theoretical scheme that allows us to determine both spectrum and temporal shape of the emitted pulses. We use structural details and the laser pulse parameters as an input. Our model itself relies only on *ab initio* material data and does not use any fit parameters. Optical effects are calculated from the nanometer to the micrometer scale for absorption and emission. The electron dynamics after laser excitation is simulated using the Boltzmann transport equation and solved numerically combining Particle-In-Cell approach and operator splitting technique [2]. Our model reliably reproduces experimental findings studying the variation of layer thickness [3] and excitation wavelength. We show how the terahertz generation efficiency can be improved and optimized using stacked layers in conjunction with terahertz anti-reflection coatings.

[1] T. Seifert *et al.*, Nat. Photonics **10**, 483 (2016)

[2] D. M. Nenno, B. Rethfeld, and H. C. Schneider, Phys. Rev. B (in press, 2018); arXiv:1807.04733

[3] G. Torosyan *et al.*, Sci. Rep. **8**, 1311 (2018)

MA 22.4 Tue 14:45 H52

On-chip generation of unipolar THz current pulses by the inverse spin-Hall effect — •Wolfgang Hoppe[1], Jonathan Weber[2], Tobias Kampfrath[2], and Georg Woltersdorf[1] — [1]Martin Luther University Halle-Wittenberg, Physics, Halle, Germany, — [2]Free University of Berlin, Physics, Berlin, Germany

We use optical pump pulses to generate current pulses using the spin-dependent Seebeck effect and the inverse spin-Hall effect (ISHE) in heavy metal/ferromagnet bilayers. In our on-chip approach the bilayer structures are used to terminate coplanar waveguides. The optical excitation from an ultrafast amplified laser system injects ultrashort spin current pulses from the ferromagnet into the heavy metal layer via the spin-dependent Seebeck effect [1]. Subsequently, this spin current pulse is converted into a charge current pulse inside the heavy metal layer via the ISHE [2]. The direct measurement of the electric signal using a fast sampling oscilloscope with a bandwidth of 50 GHz provides already picoseconds time resolution but suppresses most of the THz signal. Subpicosecond time resolution is achieved by electro-optic sampling on the chip. Here we measure the change of polarization of linear polarized light induced by the electric pulse and observe a unipolar signal. We determine optical pulse to THz pulse energy conversion efficiency for both methods and compare them.

[1] A. Melnikov. et. al.: arXiv:1606.03614[physics.optics] (2016)

[2] T. Seifert, T. Kampfrath, et. al.: doi:10.1038/nphoton.2016.91

MA 22.5 Tue 15:00 H52

Terahertz spin dynamics with a field-derivative torque — •Ritwik Mondal[1], Andreas Donges[1], Ulrike Ritzmann[2], Peter M. Oppeneer[2], and Ulrich Nowak[1] — [1]Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany — [2]Department of Physics and Astronomy, Uppsala University, P. O. Box 516, Uppsala, SE-75120, Sweden

Efficient manipulation of magnetization at the ultrashort timescales is of particular interest for future technology. In a previous work, we developed a relativistic Dirac theory to derive the Landau-Lifshitz-Gilbert equation of motion that showed an additional contribution, the "field-derivative torque" (FDT) that is frequency and damping dependent [1]. Our analytical results show that the FDT effects can become important for pulses at terahertz frequencies or higher. In this work, we numerically investigate the contribution of field-derivative torques to the magnetization dynamics. We propose that only considering the THz field underestimates the spin excitation in antiferromagnetic oxide systems (NiO, CoO etc.), however, accounting for both, the THz and the FDT, the theory can quantitatively explain earlier experiments [2]. We also study the damping dependence of FDT effects for spin excitation in these systems.

[1] R. Mondal, M. Berritta and P. M. Oppeneer Phys. Rev. B **94**, 144419 (2016) [2] Kamfrath *et al.*, Nature Photonics **5**, 31 (2011)

MA 22.6 Tue 15:15 H52

Magnetic-Field-Dependent THz Emission of Ferrimagnetic Rare Earth Transition Metal Alloys Combined with Pt — •Mario Fix[1], Robert Schneider[2], Richard Heming[2], Steffen Michaelis de Vasconcellos[2], Rudolf Bratschitsch[2], and Manfred Albrecht[1] — [1]Institute of Physics, University of Augsburg, Universitätsstr. 1 Nord, 86159 Augsburg, Germany — [2]Institute of Physics and Center for Nanotechnology, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Bi-/multilayer structures of ferro-/ferrimagnetic (FM) and nonmagnetic (NM) metals have been shown to be THz emitters when excited by femtosecond laser pulses.[1-3] Amplitude and frequency of the emitted THz radiation depend on the film thickness, the electric and magnetic properties of the FM layer, and the spin-Hall conductivity of the NM layer and can therefore be tuned by changing the composition of the used layer stack.[4]

Here we report on the THz emission of ferrimagnetic rare earth transition metal alloys combined with Pt. All films were magnetron sputter deposited at room temperature. The dependence of the THz radiation on the sample magnetization has been investigated with respect to the composition of the ferrimagnetic layers.

References:
[1] T. Kampfrath *et al.*, Nature Nanotechnology 8, 256-260 (2013).
[2] R. Schneider *et al.*, ACS Photonics 5, 3936-3942 (2018).
[3] D. Yang *et al.*, Advanced Optical Materials 4, 1944-1949 (2016).
[4] T. Seifert *et al.*, Nature Photonics 10, 483-488 (2016).

MA 22.7 Tue 15:30 H52

Exchange stiffness of terahertz spin waves in iron — •Liane Brandt[1], Niklas Liebing[1], Ilya Razdolski[2], Georg Woltersdorf[1], and Alexey Melnikov[1] — [1]Martin Luther University Halle-Wittenberg, Institute of Physics — [2]Fritz Haber Institute of the Max Planck Society, Department of Physical Chemistry

Recently, we have demonstrated the excitation of perpendicular standing spin waves (PSSW) in Fe/Au/Fe tri-layers studied by the time-resolved magneto-optical Kerr effect in a back pump-front probe scheme [1]. This high-frequency spin dynamic is driven by interface-confined spin transfer torque (STT) exerted by 250 fs-short spin current pulses generated in the optically excited emitter Fe layer [2]. The frequency of the PSSWs is tuned up to 2 THz by continuously reducing the thickness of collector Fe layer from 17 to 1 nm. By analyzing the exchange stiffness of the first five PSSW modes we observe its decrease with decreasing collector thickness down to 50% for the thinnest collector, compared to the literature value of Fe. To model this stiffness behavior in Fe, we introduce modifications of the exchange interaction in the vicinity of the interfaces, and obtain important insights into the physics of itinerant ferromagnets by means of micromagnetic simulations using mumax3.

[1] I. Razdolski et al., Nature Commun. 8, 15007 (2017)
[2] A. Alekhin et al., PRL 119, 017202 (2017)