

SLS Symposium on

Magnetism and photoluminescence

Tuesday, July 10, 2018

10:00 to 11:45, WBGB 019

10:00 Lanthanide-based Single-Molecule Magnets on an Oxide Surface: Understanding Slow Magnetization Relaxation Dynamics

Michal Studniarek, A. Singha, R. Baltic, C. Wäckerlin, K. Diller, F. Donati, Y. Lan, S. Klyatskaya, M. Ruben, S. Rusponi, H. Brune, M. Muntwiler, Ari P. Seitsonen, J. Dreiser

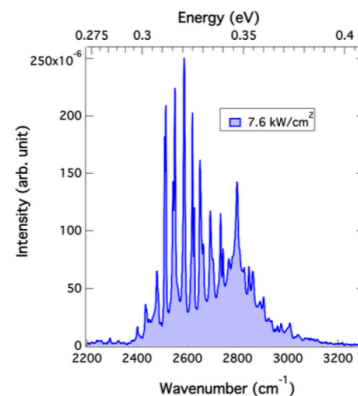
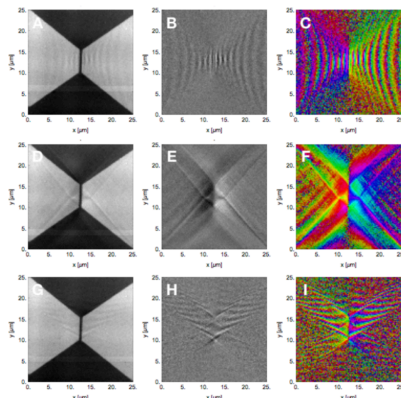
10:30 X-ray imaging of a magnon dynamics in the magnetic insulator yttrium iron garnet

Joe Bailey, S. Wintz, J. Förster, S. Finizio, K. Baumgärtl, J. Raabe, D. Grundler, G. Schütz, G. Aeppli

11:00 Coffee break

11:15 Emerging optical gain in highly strained Germanium

Francesco Armand Pilon, T. Zabel, C. Bonzon, A. Gassenq, N. Pauc, J. Widiez, V. Reboud, V. Calvo, J.M. Hartmann, A. Chelnokov, J. Faist and H. Sigg



Lanthanide-based Single-Molecule Magnets on an Oxide Surface: Understanding Slow Magnetization Relaxation Dynamics

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Single-molecule magnets (SMMs)¹ including a single trivalent lanthanide ion² are attracting much attention due to their large energy barrier for magnetization reversal, opening a path toward potential applications in spintronic devices and high-density data storage³. The obstacle towards these applications is lack of understanding of the interaction between the molecules and their environment, especially with a surface, which often leads to the vanishing of the SMM's remanence and closing of their hysteresis. Despite considerable effort to study SMMs on various surfaces⁴ knowledge about this interaction mechanisms remains scarce. A new light is shed by our study employing the use of an oxide surface as a substrate for SMMs. Its outcome deepens the understanding of the SMM-surface interaction and brings us closer towards finding a universal substrate preserving or improving the intrinsic magnetic properties of SMMs.

We evidenced by x-ray magnetic circular dichroism that the sub-ML of TbPc₂ on the MgO surface exhibits an extraordinary three-Tesla wide hysteresis opening with very large remanence at 3 K, outperforming the bulk properties of these molecules and the ones of any other surface adsorbed SMMs.⁵ A similar experiment which we performed with DyPc₂ molecules, known of their significantly faster intrinsic relaxation dynamics than TbPc₂, revealed additionally interesting result, namely a large butterfly-shaped hysteresis of DyPc₂ with an opening up to 1 T and no remanence, yet with significant increase of DyPc₂ blocking temperature.

The studied cases reveal sizable openings of the SMMs' magnetic hystereses and rise of a blocking temperature suggesting a desirable slowdown of magnetization relaxation dynamics induced by the oxide film. During the talk I will discuss the possible mechanisms by which the oxide surface impacts the magnetization relaxation pathways of an SMM and by using the empirical model I will demonstrate this influence on the SMM's magnetization dynamics.

¹ R. Sessoli, D. Gatteschi, A. Caneschi, and M.A. Novak, *Nature* **365**, 141 (1993).

² J. Dreiser, *J. Phys. Condens. Matter* **27**, 183203 (2015).

³ L. Bogani and W. Wernsdorfer, *Nat. Mater.* **7**, 179 (2008).

⁴ A. Cornia and M. Mannini, in *Mol. Nanomagnets Relat. Phenom.*, edited by S. Gao (Springer Berlin Heidelberg, 2014), pp. 293–330.

⁵ C. Wäckerlin, F. Donati, A. Singha, R. Baltic, S. Rusponi, K. Diller, F. Patthey, M. Pivetta, Y. Lan, S. Klyatskaya, M. Ruben, H. Brune, and J. Dreiser, *Adv. Mater.* **28**, 5142 (2016).

X-ray imaging of a magnon dynamics in the magnetic insulator yttrium iron garnet

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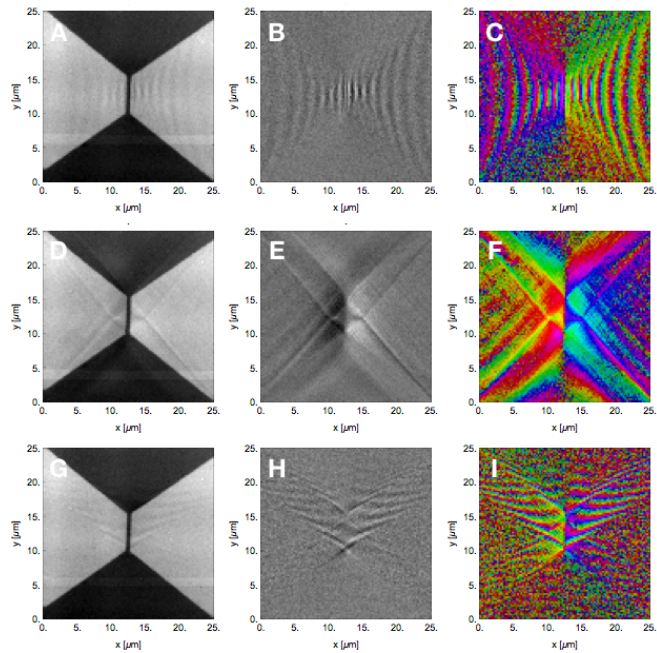
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The study of magnons, the quasiparticle description of collective spin excitations, and magnonics, the development of devices utilizing magnons to perform information processing tasks, are rapidly growing fields covering many important fundamental and technological topics. Yttrium iron garnet (YIG), a ferrimagnetic insulating oxide, has long been appreciated in the context of high-Q microwave filters that make use of its sharp ferromagnetic resonance. The long magnon lifetime, with damping values up to three orders of magnitude lower than conventional metallic magnetic materials, along with advances in thin film growth and processing capabilities has resulted in a resurgence of interest in YIG from the magnonics community.

A phenomenon closely linked to the extremely long lifetimes of magnons in YIG is their reported Bose-Einstein condensation (BEC) at room temperature. A finding that has raised many questions about the nature of a quasiparticle BEC in quasi-equilibrium, its relation to traditional BECs familiar from cold atom physics, and other types of macroscopic coherent phenomena. From an applications perspective the incorporation of condensate related phenomena to the magnonics toolbox would open the door to supercurrents of magnons and quantum information processing.

Here I report on the first time resolved scanning-transmission x-ray microscopy (TR-STXM) of magnon dynamics in yttrium iron garnet. We demonstrate the ability to excite and observe both linear and non-linear magnon dynamics and discuss the steps we have taken towards imaging the magnon condensate.

Figure 1. TR-STXM measurement of magnon dynamics in YIG. Frames show snapshots of time resolved measurements with different applied magnetic fields. The first column (A, D & G) shows transmission snapshot in which the stripline is visible as the vertical dark strip, and the spin waves are visible as the slight fluctuations in intensity. The second column (B, E & H) shows the dynamics, with each pixel normalised by its time averaged value. The third (C, F & I) column shows a phase/amplitude image extracted with Fourier analysis of the time series. The different rows correspond to external fields (horizontal in-plane) of 75 mT (top) 65 mT (middle) and 55 mT (bottom) all with an excitation frequency of 3.5 GHz.



Emerging optical gain in highly strained Germanium

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Germanium (Ge) is considered as a silicon compatible light source, thanks to the possibility of becoming a direct bandgap material and its CMOS compatibility. In alternative to alloying Ge with Sn [1], a direct bandgap configuration can be reached by protracting Ge in specific crystallographic directions [2]. We present cavity mode analysis of photoluminescence (PL) spectra of uniaxial tensile stressed (along $\langle 100 \rangle$) suspended GeOI micro-bridges and their dependence on the excitation wavelength.

The highly strained Ge is obtained by patterning and under-etching a SmartCutTM GeOI layer with a built-in biaxial tensile pre-strain of 0.16% [3]. Through e-beam lithography and dry etching step, we define two stressor pads, connected by an 8 μm long and 1 μm wide micro-bridge and two parabolically shaped corner cube mirrors, which integrate the central constriction into an optical cavity. The subsequent selective etching of the underlying silicon oxide by vapor HF releases the germanium structure which enables the pads to elastically relax. As a result, the micro-bridge is uniaxially stretched to an amount uniquely defined by the geometrical dimensions of the pattern [4]. Thanks to the high quality of the GeOI substrate, we were able to achieve tensile strain values up to 4.9 % at room temperature [5].

The integration of a direct bandgap germanium structure inside an optical cavity represents a powerful tool to access the optical gain and loss, via the Fabry-Perot cavity mode analysis, as first shown by J. Petykiewicz *et al* [6]. Here, we used an excitation laser at 2100 nm wavelength to carry out power dependent photoluminescence experiments, from 0.5 to 30 kW/cm^2 . The temperature was reduced down to 20 K, allowing a further increase of the tensile strain in the micro-bridge, which reached approximately 6 %, shrinking the direct bandgap down to almost 0.3 eV. From the cavity modes analysis, we found an onset in the mode intensity at 1 kW/cm^2 , as well a narrowing up to a factor 3 of the linewidth. Due to the absence of a clear proof of threshold in the intensity, lasing can still not be claimed. Coherence measurement and comparison with group IV lasing system, namely GeSn, will be further discussed.

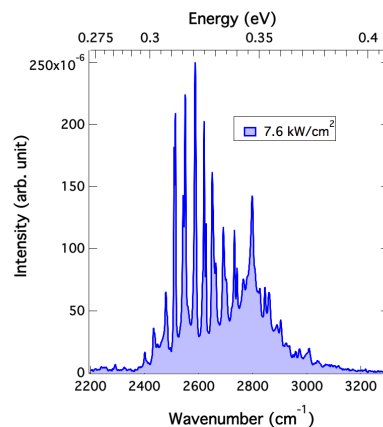


Fig. 1 Photoluminescence measurement at 20 K excited with 2100 nm wavelength laser in CW configuration.

[1] S. Wirths *et al.*, *Nature Photonics* **9**, 2015

[2] R. Geiger *et al.*, *Frontiers in Materials* **2(52)**, 2015

[3] V. Reboud *et al.*, *Proceedings of SPIE* **9367**, 2015

[4] M. J. Süess *et al.*, *Nature Photonics* **7**, 2013

[5] A. Gassenq. *et al.*, *APL* **108**, 2016

[6] J. Petykiewicz *et al.*, *Nano Letters* **16**, 2016