GÖTEBORGS UNIVERSITET

A Play of Light and Spins: Excitation and Detection of Non-linear Magnetization Dynamics using Light

Shreyas Muralidhar
Institutionen för fysik
Naturvetenskapliga fakulteten

Prodekan har vidare beslutat **att som fakultetsopponent utse:**
Prof. Dr. Stéphane Mangin, Université de Lorraine – Nancy (France)
Och

att som ledamöter i betygsnämnden utse:
Dr. Magnus P. Jonsson, Department of Science and Technology, Linköping University, Norrköping, Sweden.
Dr. Petra Jönsson, Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden.
Prof. Fredrik Höök, institutionen för fysik, Chalmers tekniska högskola, Göteborg, Sweden
Och

att som ersättare i samma nämnd utse:
Dr. Mats Granath, institutionen för fysik, Göteborgs universitet, Sweden

att som ordförande vid disputationen utse:
Prof. Måns Henningson, Göteborgs universitet, Sweden

Akademisk avhandling för filosofie doktorsexamen i Fysik som med tillstånd från Naturvetenskapliga fakulteten kommer att offentligt försvaras onsdag den 30 september 2020 kl. 9:00 i PJ-salen, institutionen för fysik, Fysikgården 2 (chalmersområdet), Göteborg.

ISBN: 978-91-8009-006-3 (PRINT)
ISBN: 978-91-8009-007-0 (PDF)
Tillgänglig via http://hdl.handle.net/2077/65625

GÖTEBORGS UNIVERSITET

A Play of Light and Spins: Excitation and Detection of Non-linear Magnetization Dynamics using Light

ABSTRACT

The excitation and detection of magnetization dynamics play key roles in thefield of spintronics and magnonics. In this thesis, we investigate a contactless method of exciting non-linear magnetization dynamics using a femtosecond pulsed laser, and study the same with a Brillouin Light Scattering (BLS) microscope. Further, we explore the synchronization characteristics of spin-Hallnano-oscillator (SHNO) arrays and their applicability to neuromorphics and Ising machines, using electrical measurement as well as optical measurements utilizing a phase-resolved BLS microscope.

After a brief introduction to the basic phenomena and techniques, the optical setup unique to this work is described in detail in Chapter 1. By using a frequency comb to pump the system, a strong enhancement of the weak scattering amplitude of the selected spin wave (SW) modes is observed. Additionally, the pump laser can be focused down to the diffraction limit and scanned along the focal plane to study the propagation characteristics of elementary excitations.

Frequency-comb-enhanced BLS microscopy was used to excite SWs in NiFe thin films (20 nm) and to study their characteristics. As the duration between consecutive pump pulses is shorter than the decay time of the magnons, sustained coherent emission of selected SW modes was observed. The BLS counts versus laser power follows a stronger than square dependence. This is in accordance with the Bloch $T^{3/2}$ law. The spatial map of the SW amplitude depicts strong unidirectional propagation of the main SW mode, whose direction of propagation can be controlled by changing the angle of the in-plane component of the applied field. An in-depth analysis of SW propagation at different fields showed a caustic X-pattern for high *k*-vector SWs, which has potential applications in the field of magnonics.

Chapter 3 lays the emphasis on two-dimensional SHNO arrays that show robust mutual synchronization up to arrays of 64 oscillators. Well-resolved BLS maps of the magnetization dynamics in the 2D arrays show that the oscillators in line with the direction of current synchronize first, which is followed by the four chains synchronizing together at higher currents. The applicability of 2D SHNO arrays in neuromorphics is demonstrated by injecting two external microwave signals, creating a synchronization map, like the one used for neuromorphic vowel recognition using vortex oscillators. Additionally, at higher powers of the injected signal, we demonstrate phase binarization of the microwave output using a phase-resolved BLS microscope. A direct application for solving combinatorial optimization (CO) problems using a SHNO array-based Ising machine is shown.

Keywords: Spin waves, laser-induced magnetization dynamics, Brillouin light scattering, spin Hall nano-oscillators, neuromorphic computing, Ising machine.