Center For Energy Efficient Magnonics (CEEMag)
EFRC Director: Yuri Suzuki
Lead Institution: SLAC
Class: 2024 – 2028

Mission Statement*: To advance the basic scientific understanding of magnon excitation, propagation, transduction, and control that is motivated by an end use of magnon-based interconnects and their integration into microelectronics.*

Magnons provide the promise for microelectronics with low-loss information and energy transfer at the nanoscale using propagating excitations with wavelengths that are orders of magnitude smaller than microwave or photonic interconnects. Fundamental innovations in materials, theory, and structures for magnonic systems in a co-design approach will enable new THz-frequency, low-loss interconnects based on spin wave excitations that can also deliver active control including switching, modulation, and amplification. Not only can information be encoded in both amplitude and phase of magnons, but also nonlinearity and non-reciprocity can provide additional functionality, making magnons far more versatile than electrons in future interconnects. We will exploit THz frequencies characteristic of strong exchange interactions in ferrimagnets (FiM) and antiferromagnets (AFM), focusing on low-damping semiconducting and insulating FiMs and AFMs to minimize charge current dissipation. Low-loss oxides will be integrated into silicon-based platforms via co-design of interconnect characterization, nanofabrication, and theory. CEEMag will build on previous scientific and commercial success in spin-based microelectronics, including spin torque phenomena for memory applications pioneered by several team members.

In order to develop a comprehensive understanding of magnon excitation, propagation, transduction and control for realizing magnon interconnects (*Figure 1*), we will:

- manufacture resilient FiM and AFM materials with record low damping
- demonstrate *robust* tunability of FiM and AFM materials to functionalize magnon interconnects
- enhance magnon transmission within and among FiM and AFM materials as well as at interfaces which can dominate insertion losses
- generate and detect coherent and incoherent magnons efficiently from GHz to THz frequencies and identify tradeoffs in interconnect usage
- develop a framework for nonlinear magnon behavior permitting *robust* magnon control

To meet these four-year integrated scientific goals of CEEMag, we have assembled an EFRC team with experience in materials synthesis, local and element-specific characterization of spin phenomena, THz and GHz spectroscopy, device design and nanofabrication, along with theoretical expertise in materials design, spin transport, and device architecture. The materials growth experts, who bring a range of techniques for complex oxides and 2D materials, will work in tandem with theorists in materials design and with characterization experts to achieve low damping and enhanced magnon transmission in *manufacturing-*

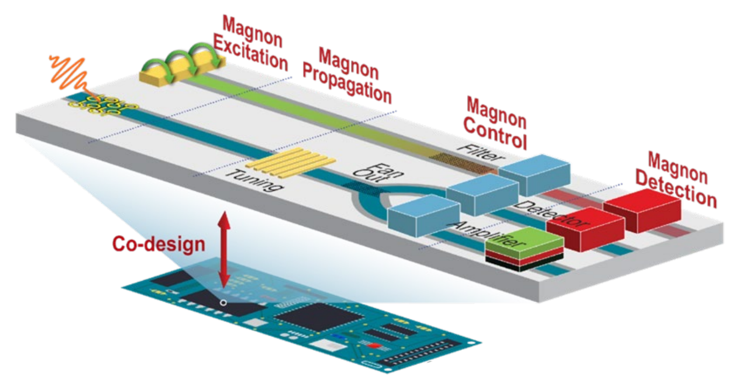

Figure 1. EFRC Conceptualization. Magnon interconnects will be realized by addressing fundamental questions concerning magnon excitation, propagation, control and detection within three research thrusts.

resilient FiM and AFM materials. We will realize interconnect structures to enhance magnon transmission within FiM and AFM materials as well as at interfaces which can dominate insertion losses. Team members will demonstrate energy-efficient magnon detection from GHz to THz frequencies and mechanisms for *robust* tunability to enable switches, modulators, and amplifiers. Theoretical simulations will be integrated with experiments in all of these efforts. Theoretical efforts will also develop a framework for beneficial utilization of magnon nonlinearities and to identify tradeoffs affecting performance.

To tackle the multi-disciplinary scientific challenges of understanding magnon behavior and making useful interconnects, we have organized CEEMag into three interconnected research thrusts:

THRUST 1: ADVANCED MATERIALS FOR MAGNON INTERCONNECTS identifies promising magnon materials and how best to excite and visualize magnons

THRUST 2: ENERGY EFFICIENT MAGNON DETECTION addresses the challenges associated with transducing GHz-THz magnons to electrical signals

THRUST 3: FUNCTIONALITY IN MAGNON INTERCONNECTS addresses the fundamental limits associated with control of magnon amplitude, propagation path, and interference between their excitation and detection

Our scientific discoveries related to magnon interconnects will enable critical elements such as sources, waveguides, amplifiers, mixers, and devices based on non-reciprocity. By examining new materials, magnon phenomena (e.g., excitation, detection, frequency conversion, nonlinearities) and their practical implementation, we will not only address the challenges associated with magnon excitation, transmission, detection and control but also develop magnonic interconnects with functionality beyond simple transduction. Throughout the EFRC, the projects will adopt a co-design approach of theory, materials, and characterization.

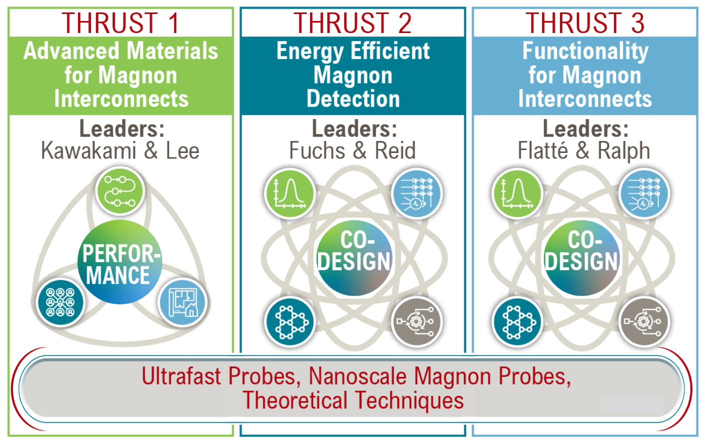

Figure 2. CEEMag organization. Each of the three research thrusts are comprised of a co-design approach to achieve the goal of realizing magnon interconnects along with cross-cutting themes of ultrafast probes, nanoscale magnon probes and theoretical techniques.

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