MAGNON-PHONON COUPLING IN MAGNETIC 2D HETEROSTRUCTURES IN PRESENCE AND ABSENCE OF SKYRMION LATTICE

Abstract for general public

In electronic devices, data are carried by electric charges, which creates undesirable Joule heating and limits integration density. As an alternative, wave-based information or computation technology is in high demand. The ferromagnetic materials possess permanent magnetic moments as the neighboring electronic spins are aligned parallel to each other. Perturbing one spin can set off a wave, known as spin wave (SW), in ferromagnetic thin film due to the collective precessional motion of spins. Likewise, solid crystalline materials consist of periodical arrays of atoms. Perturbing a group of atoms can create a vibration in the solid which can propagate inside the solid like a wave known as acoustic wave. For thin films the acoustic waves propagate along the surface known as surface acoustic waves (SAWs). The quasiparticles associated with SWs and SAWs are known as magnons and phonons, respectively. Like electromagnetic waves, the SWs, SAWs can be employed to carry an information encoded in its amplitude, phase, wavelength, frequency. The SWs can propagate through the magnetic media without moving any charge particles, which eliminates unwanted heating and offers for the development of an alternative wave-based technology at low energy cost. Typical frequencies of SWs lay in the range from few GHz to hundreds of GHz with their respective wavelengths in the range from hundreds down to tens of nanometers. This makes SWs suitable for design of miniaturized devices for processing information operating at high microwave frequencies. To eliminate some disadvantages of magnons, they should be coupled with phonons. One of the major challenges is to enhance the coupling coefficient to ensure back and forth information exchange with high efficiency. At the same time diode like effects, i.e., unidirectional propagation of SWs and SAWs are required. Another crucial point is to select suitable material system so that SW and SAW properties can be manipulated efficiently and device size can be reduced down to nanometer size. In this regarding a single atomic layer of magnetic films, known as magnetic 2D materials (M2DMs) and their heterostructures (M2DHs) have recently become very popular. However, the properties of magnons, phonons in M2DHs has not been explored so far. Another interesting spin texture is known as skyrmions, a type of spiral spin orientation in magnetic thin film heterostructures. As the skyrmion size can be down to tens of nanometer, it has huge potential for high density data storage devices. In addition to that the presence of skyrmions can add more ingredients to control magnon, phonon characters and magnon-phonon coupling. Here we take the challenge to investigate, control, optimize magnon, phonon and skyrmion properties to enhance the magnon-phonon coupling, nonreciprocity in M2DHs in the absence and presence of skyrmions with an aim to develop hybrid magnonic devices which will eventually surpass the speed, efficiency, functionality and integration density of the present CMOS technology.

We would like to address four key questions in this proposal: (1) Can we efficiently tune the properties of magnons and phonons by playing with the properties of M2DHs? (2) Can we achieve strong coupling between magnons and phonons? If yes, what is the route and what are the key ingredients? (3) Is it possible to achieve very high non-reciprocity in magnons, phonons and hence magnon-phonon coupling? If yes, then how? (4) What are the advantages of skrymion lattices as a magnonic crystals and whether magnon-phonon coupling can be improved in presence of skyrmions or not?

The main objective of the proposal is the investigate magnon-phonon coupling in M2DHs. The M2DMs will be made by mechanical exfoliation and chemical vapor deposition method and the devices afterwards will be fabricated by conventional nanolithography techniques. M2DHs will be prepared by hybridizing M2DMs with various magnetic, nonmagnetic 2D materials and non-2D thin films. The magnons and phonons will be excited either thermally at room temperature or electrically by microwave transducers. The magnons, phonons and magnon-phonon coupling phenomena will be investigated by Brillouin light spectroscopy or all-electrical SW spectroscopy techniques. We will investigate how the properties of M2DHs can influence the properties of on magnons, phonons, skyrmion and magnon-phonon coupling. Skyrmions will be observed by electron microscope or optical Kerr microscope. The analytical and computational approaches will be employed to analyze properties of M2DHs and the properties of magnons, phonons, skyrmions and their coupling phenomena.

The proposal will have multidisciplinary impact on the development of research fields and future technology. The study and control of the interfacial properties as a function of various parameters will surely improve the general understanding of the interfacial phenomena in M2DHs including the underlying physical mechanisms. The study of the magnon, phonons, skyrmions and controlling their properties will also help to increase general knowledge on the characteristics of various quasiparticles in M2DMs. This project will demonstrate the creation of skyrmion lattice in various ways and the control of magnon-phonon coupling in absence and presence of skyrmions. The investigation and manipulation of magnon, phonon nonreciprocity and its impact on the magnon-phonon coupling will be related to the real device applications such as diodes, circulators.