Exploiting resonance effects in ferromagnetic nanoresonators towards magnonic spacetime metasurfaces

Modern information processing and transmission technologies are almost entirely based on electronics, i.e., using electrical charges as information carriers. Although electronics has many advantages, it is also burdened with many disadvantages that severely limit the further development of this technology. These drawbacks include, e.g., the limits of miniaturisation of electronic circuits and the Joule heat generation during the transmission of electrical charges in conductors. Therefore, it is essential to develop alternative technologies to electronics, which could support the currently used technologies or even replace them. One of the fields of physics currently being developed in this regard is magnonics, the science of spin-wave propagation.

One of the properties of elementary particles, like mass or charge, is a spin. Spin is the momentum of a particle that has its origin in quantum physics, and it is spin that is responsible for the magnetic properties of matter. In ferromagnetic materials, the spins are aligned so that the system simultaneously attains a state of minimum energy, i.e., reaches an equilibrium state and has a non-zero magnetic moment without the presence of an external magnetic field. Suppose that one of the spins in the magnetic material is thrown out of its equilibrium position by some external factor (e.g. a change in the magnetic field). In that case, it begins to precess around its equilibrium position. As the spins interact, among others, through dipole and exchange interactions, one of the precessing spins transfers its motion to the neighbouring spins. In this way, a propagating disturbance in the magnetic material called a spin wave is created.

Spin waves have unusual properties, unattainable by electromagnetic waves used in photonics and broader microwave technologies. They are characterised by much shorter wavelengths than their electromagnetic counterparts at the same frequencies. In addition, spin waves do not carry any charge or mass. Therefore significantly less energy is required to transmit information when spin waves are used, than when electric charges are used. The same quantities describe spin waves as other waves, i.e., amplitude, wavelength, and phase. Therefore, using spin waves in functional magnonic devices involves finding means to operate their parameters similarly to other known wave devices.

Our project will focus on investigating the resonance effects of spin waves incident on magnonic Gires-Tournois type interferometers. These interferometers modulate the phase and amplitude of the waves reflected from them and are ideal for manipulating spin waves. We will begin our study by describing the reflection of spin waves from a uniformly magnetised interferometer. We will then study the phenomenon of inelastic scattering of spin waves on mode located in a uniformly magnetised resonator of a Gires-Tournois interferometer, which belongs to the group of nonlinear phenomena. We will then study non-uniformly magnetised resonators in the form of alternating magnetic domains with different magnetisation directions and their influence on spin-wave propagation in the interferometer environment. In the last phase of the project, we will gather all the knowledge from the previous work stages to design a stable magnonic spacetime meta-surface. A meta-surface is a system component with dimensions much smaller than the wavelength, which modulates the wave parameters in a strictly man-made way. This project will propose a spacetime version of a magnonic meta-surface that is characterised by a continuous change of magnetisation direction in both time and space. The final goal of this project is to describe the possibility of using such a meta-surface as a magnetic resonator texture in an interferometer to modulate the parameters of spin waves reflected from a Gires-Tournois interferometer.

Our project is the first step toward designing a new type of magnonic devices based on spin-wave modulation using resonant effects and spacetime meta-surfaces. These devices may become the basis for more complex information transmission and processing systems, which will be characterised by significantly lower energy consumption than currently used electronic systems. Thus, our project may contribute to the development of new technologies reducing energy consumption in information technologies.