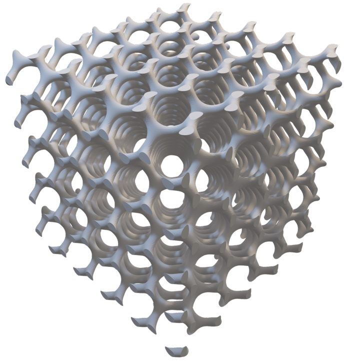
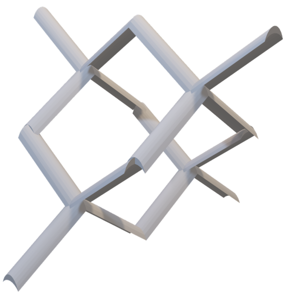
More efficient methods of information processing offered by the spin-wave domain can solve today's nanotechnology problems. Efficient and effective control, induction, and detection of these perturbations are the basis of modern research, known as magnonics, which seeks their application in industry. Such a signal propagates in magnetic materials without charge transfer and thus without thermal loss. This, combined with a wider range of frequencies available than in electronics and the ability to encode information in both amplitude and phase, makes spin waves a technological milestone. A similar proposal to move from the electron's charge domain to its spin as an information carrier is offered by a branch of electronics called spintronics. Here, however, the charge will still play an active role in the effects or functionalities to be analyzed, thus offering a different range of applications. Combining magnonic and spintronic phenomena in 3D nanostructures is therefore the basis of this project.



Advanced research in the design and numerical simulation of 3D structures using Comsol Multiphysics software, and collaboration with leading experimental groups in the field, allows us to comprehensively analyze complex 3D systems such as gyroid networks (right image) or diamond bond-like lattices (left image). These systems offer unique geometrical properties for the study of interesting physical phenomena with different origins. Gyroid networks consist of twisted nanowires with triple junctions, which are excellent carriers of chiral effects. This could lead to exciting properties of these materials, such as an asymmetric spin-wave dispersion relation and current-direction dependent electrical conductivity. Thus, three-dimensional gyroidal structures could have a high application potential, since the dynamic control of the spin-wave frequency or the amplitude of propagating electric current could lead to the design of various magnonic and spintronic devices based on them. On the other hand, diamond bond networks are characterized by tetrapod connections of nanowires with non-trivial cross sections. In their case, our research will focus on the spin-wave bonding properties of these junctions and, analogous to gyroids, their complex effects on electrical conductivity. In addition, we will conduct separate analyses of crescent-shaped nanowires, which are the building blocks of these nanostructures.



Within the project framework, we intend to carry out a comprehensive study of the interaction of magnetization dynamics with electric current flowing in inhomogeneous 3D structures, which is a very promising starting point for the study of phenomena such as anisotropic magnetoresistance or dynamic magnetization switching. In addition, systems that combine electronic and magnonic phenomena are particularly desirable because of the search for so-called technological bridges between the currently dominant charge-based devices and next-generation spin-wave solutions. These are concepts now widely developed by researchers for future spintronic and magnonic devices. A complete analysis of these interactions by means of theoretical calculations and numerical simulations in 3D structures is therefore the most general picture of our project plan. Special attention will be given to the modeling of magnetic systems, where non-trivial geometry and the use of the third spatial dimension can significantly increase the efficiency and likelihood of their future industrial application. Mastering and understanding the nature of magnetization dynamics, the binding of spin waves at edges, surfaces or in the volume of three-dimensional magnetic systems, will allow the exploration of new phenomena in magnetism physics and the creation of previously unknown functionalities in magnonic and spintronic devices. An additional advantage and benefit of this research is our access to and ability to interpret experimental measurements of the described 3D ferromagnetic nanostructures based on our theoretical analyses. All physical parameters in numerical simulations will therefore remain within the limits of technical feasibility.

The scientific project "Three-dimensional complex-geometry ferromagnetic nanostructures in magnonics and spintronics" aims to make significant contributions to condensed matter physics in terms of their magnetic properties, spin waves and spin-charge coupling. Currently, magnonics and spintronics are dominated by planar systems, which limits their further miniaturization and development. With this project, we intend to extend this paradigm to the third spatial dimension and prove that this is the right and promising direction for the development of these fields.