Optomechanical Networks for Neuromorphic Computing

Abstract
Von Neumann or Turing machines compute information implementing sequential algorithms that struggles with non-sequential and abstract problems such as image recognition, language translation, decision-making problems, and more. The human brain surpasses the computational power of standard computers when dealing with these tasks. The capacity to learn from examples defines human learning and inspires a radically novel way of information processing: artificial neural networks for neuromorphic computing. A potentially disruptive implementation of neuromorphic computing exploits photons as carriers of information and photonic meshes as an artificial neural network. In this project, we will explore the optomechanical coupling in silicon nanostructures that can be configured to perform neuromorphic computing. Our goal is to get familiar with an experimental setup to measure and readout the mechanical vibrations of the system with optical forces.

Motivation
Optical elements can perform the heavy matrix transformations needed for neuromorphic computing with almost no power consumption, e.g., an optical lens can do a Fourier transformation passively. Photonic meshes composed of many photonic nodes or neurons are very promising for neural networks. However, current integrated optics suffer from miniaturization and scalability issues but the real bottleneck of this approach emerges from the neuronal activation function implemented that typically relies on a material nonlinearities (e.g. electro-absorption modulation). This translates into very slow and lossy programmable hardware. In addition, human brain synapses are definitively complex and dynamic. Neural noise, initially thought to slow down and negatively affect the processing power, adds more sensitivity to a broader range of inputs in biological neurons.
In this project, we want to exploit an optomechanical network to process information. Our proposed biomimetic silicon neural networks attempt to capture the time- and space-dependent efficient nonlinear behaviour of biological neural networks. First, we will implement a strong elastic nonlinear activation function (the transmission of optical signal through the neuron) relying on optomechanical coupling [1,2]. This nonlinear interaction leads to the elastic amplification of mechanical modes by optical radiation pressure. Our main goal in this project is to get familiar with the experimental techniques used to characterize this coupling in a nanostructure [3]. We will get introduced in this research field, get hands on in a near-field experimental setup and explore the prospects of these systems and this interaction for neuromorphic computing.

Project description
The coupling of electromagnetic radiation (photons) to mechanical waves (phonons) is at the heart of solid-state quantum photonics while phonon transport at different frequencies governs crucial physical phenomena ranging from thermal conductivity to the sensitivity of nano-electromechanical

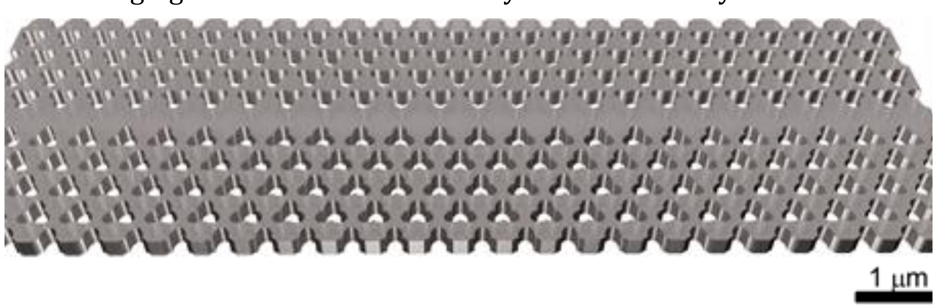

Figure: Optomechanical waveguide fabricated on silicon. This will be our basic geometry to study [3].

resonators. To engineer and control the overlap of light with the mechanical vibrations of matter in an efficient manner, we make use of very precisely fabricated nanometer-scale devices. The standard way of achieving this control is to use engineered defects in periodic structures - optomechanical crystals - where the electromagnetic field and the mechanical displacement are confined simultaneously within the same small volume thus enhancing their interaction. In the long-term, we want to exploit this interaction as the nonlinear neuron function to compute and process information in an optomechanical neural network

During this project, we will explore novel designs for optomechanical nanostructures and we will measure their mechanical and photonic properties in the lab. We already have the material and we are in the process to fabricate the structures. Our main goals are:

- To get introduced to optomechanics and neuromorphic computing.
- To characterize the mechanical and optical eigenmodes of the system and understand the basics of the experiment.

References

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