Proposal for a doctoral project 2018-2019

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Plasmonic-enhanced graphene-based modulator neuron for neuromorphic nanophotonic applications

Scientific and technologic objectives

Neuromorphic photonics is an emerging field that uses photonic devices to overcome the limits of electronic devices such as processing speed, information density, and energy consumption. It uses thus, the advantages of photonics such as the interconnectivity through photonic waveguides and information density through wavelength division multiplexing. To decrease energy consumption, photonic devices need to scale down size down to the nanometer scale. Plasmonic-enhanced graphene-based optical modulator have the potential to increase energy efficiency. In this doctoral project, we aim at exploring and developing subwavelength-scale optical modulator based on graphene integrated on silicon photonic waveguides as building block for future modulator neurons in neuromorphic nanophotonic networks. The subwavelength-scale modulator will be designed to consume less than 1 femtoJoule of energy per bit of information, which allow photonic neural networks to to consume less energy per operation.

The technological objective is to establish and to identify solutions for the efficient integration of 2D materials into integrated photonic structures with surface plasmon polaritons (SPPs). SPPs are the excellent candidates to enhance the light-matter interaction as they present light confinements compatibles with 2D materials. The high propagation loss of SPPs is one of the major problem that limits the development of plasmonic circuitry, we propose to overcome such losses with the use of ultra-short novel structures with lengths typically less than that of the propagation length of SPPs and the integration with photonic waveguides. The transfer of 2D materials into large surfaces is still a blocking problem that we will challenge with the use of a dry transfer technique. In such nanophotonic devices, the in- and out-coupling of light is done through passive components such as photonic low loss waveguides whereas plasmonic structures are used to enhance and to actively control the light interaction with 2D materials at subwavelength-scale dimensions. The solution of the challenges describes above could lead to major breakthroughs in the integration of 2D materials into integrated plasmonic structures for the development of integrated active nanophotonic devices.

Within the main objective of doctoral project, we aim at particular objectives such as the theoretically study and understanding of the interaction of SPPs and 2D materials, the design and numerical simulations of efficient resonant and nonresonant plasmonic structures for a strong interaction by 3D FDTD method. The fabrication of test samples and the exploration of efficient fabrication and transfer techniques of nanomaterials onto photonic waveguides will be challenged. We propose the use of appropriate characterization techniques such as near-field scanning optical microscopy (NSOM). This technique allows the imaging and analysis of the propagation characteristics of light along the nanostructures with high spatial resolution. L2n team at UTT has all the necessary numerical tools and nanofabrication facilities (nano'mat http://www.nanomat.eu/fr/index.html), as well as the expertise to conduct the doctoral project.

Organization of the project and resources granted

In order to reach the ambitious and innovative research objectives described above, the proposal requires the knowledge and expertise in integrated photonics, 2D materials fabrication and characterization, nanofabrication and near field characterization of integrated plasmonic devices. The 2D materials expertise is included through the role of the quantum device physics group of the Department of Energy Science, CINAP of the Sungkyunkwan University, South Korea. They have been working on 2D materials for many years. Its unique expertise includes the realization of large area single crystalline graphene and graphene-silicon junctions [1, 2], the understanding of the boundary stitching mechanisms of graphene [3], and the fabrication of ohmic contacts with MoTe2 materials [4, 5]. They also offer dry transfer technique of 2D materials on a targeted area of a substrate. This unique feature is fundamental for a precise alignment of nanomaterials relative to the plasmonic structures. CINAP's knowledge on the theory, fabrication, and transfer of single-crystalline 2D materials onto large-scale areas are unique and thus, not easily found elsewhere. Among its everyday activities, they use Raman spectroscopy. This collaboration offers huge opportunities towards the development of integrated nanophotonic devices based on 2D materials.

Impact of the doctoral project

Neuromorphic nanophotonic processing has the potential to manage a vast volume of data. It can perform computationally intense operations with low-energy consumption. Current and future Data Centers rely on such operations and require low energy consumption. Although integrated nanophotonic devices based on graphene have been demonstrated, there are few developments in the literature of integrated plasmonics based on other 2D materials. Innovative optoelectronic nanophotonic devices are expected to impact tremendously nanoscience and engineering fields. The integration of graphene and 2D materials will increase optical functionalities at subwavelength-scale length and will allow light propagation at longer propagation lengths with the use of the nearby photonic waveguides and therefore, a plethora of devices are foreseen.

References

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