M2 Internship and PhD position

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Magneto-plasmonic nanoscale imaging

Context: Planar optical circulator based on magneto-optical materials

Si, InP or GaAs integrated photonics is explored for a wide range of applications like integrated optical communication for datacom and telecom, bio- or gas sensing for environment, or quantum cryptography. In order to minimize and to densify photonic circuits, numerous optical devices must be integrated together efficiently and without crosstalk. o successfully achieve this integration, light propagation direction must be fully controlled: performing *integrated isolators or circulators* , which both require non-reciprocal light transmission, are required but not yet available. Indeed, their realization remains a major challenge.

The most efficient non-reciprocal transmission in planar waveguides[1] is based on Transverse Magneto-Optical Kerr effect (TMOKE) at the interface between a MO material layer and the waveguide. However MO effect often remains perturbative and insufficient. Several hybrid integration in photonic platform approaches aim at enhancing the non-reciprocal MO properties[2]. A particularly promising device structure has been proposed and numerically demonstrated in Cimphonie Team (C2N) in 2021[3]. The principle, called magneto-biplasmonic, explores the TMOKE enhanced by both the surface plasmon polaritons and coupled modes system in a slot waveguide (see Fig. 1, from S. Abadian PhD manuscript, 2021). Here TMOKE induces asymmetrization of the coupled modes profiles, which depends on the propagation direction: the optical energy carried by these modes doesn't follow the same path in the forward and backward directions. This property is used to realize non-reciprocal optical transmission.

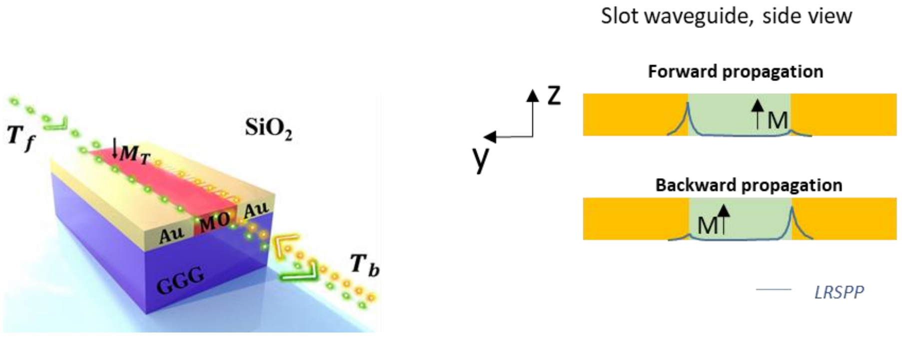

Fig. 1. Scheme of magneto-biplasmonic isolator[3] (left), and basic operation principle illustrated with side and top views (right). BIG represents the MO material, with magnetisation M_T. L(S)RSPP=Long (Short) Range Surface Plasmon Polariton.

This new principle brings a breakthrough in this research field: yet, it has been only theoretically described and the first experimental demonstration is still lacking. This concept will be developed **within the Horizon Europe PathfinderOpen project CIRCULIGHT** started in 2024 in order to demonstrate a magneto-biplasmonic circulator as shown in Fig. 2.

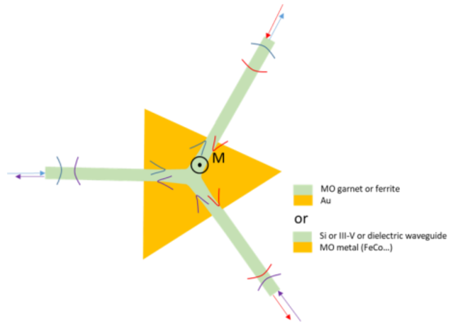

Fig. 2. Scheme of the optical circulator based on magneto-biplasmonic effect

Internship and PhD topic

In this global context we propose a **four to six months M2 internship** and a **PhD position**.

The main objective is to **experimentally demonstrate the magneto-biplasmonic effect**, using and adapting a Scanning-Near-Field Microscope (SNOM, Fig. 3). A commercial SNOM is available in the host team, and the setup will be further developed in order to characterize MO and plasmonic guided devices.

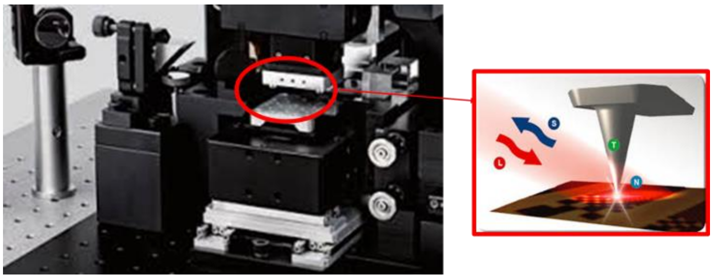

Fig. 3. Scheme of the SNOM apparatus and principle

The **internship topic** will include:

- bibliography report on SNOM (Scanning Near-field Optical Microscope) characterization for plasmonics

- characterization of plasmonic devices (already available) on SNOM apparatus, at 1.55µm: design and realization of fiber injection system compatible with SNOM.

The specific **objectives of the PhD** with respect to previous work are as follows:

- to contribute to the design of low-losses interface of MO slot waveguide with monomode semiconductor (GaAs or InP membranes) waveguides, and of the full integrated circulator, in collaboration with CIRCULIGHT partners. This includes the understanding of the physical mechanism, which induces modes asymmetrization during propagation.

- to adapt the SNOM apparatus (Scanning Near-field Optical Microscope) to directly observe the asymmetrization of the modes during propagation and their non-reciprocal behaviour.

- to realize the experimental demonstration of magneto-biplasmonic structures, by measuring non-reciprocal transmission in a fibered bench. The MO material will be made of cobalt-ferrite nanoparticles embedded in silica matrix, deposited by sol-gel process.

The candidate will be fully involved in the optical simulation work and the characterization using optical benches. The research activity will include:

- **Theoretical study and optical simulations** (using commercial and home-made software) to evaluate the key metrics for optimising the non-reciprocal optical properties of the MO slot waveguide modes and the interface with usual silicon waveguides.

- **Experimental characterizations** of integrated devices using optical integrated benches.

VALUED QUALITIES IN THE STUDENT

- Curiosity for novel research experiences and fields.
- Ability to work in a multipartner project, in english
- Creativity and pro-activity in the search for innovative solutions and approaches.
- Attractivity in experiments and simulations.
- Capability to communicate and share results in a multidisciplinary and multi-nationality environment.

1. D. Jalas, A. Petrov, M. Eich, W. Freude, S. Fan, Z. Yu, R. Baets, M. Popović, A. Melloni, J. D. Joannopoulos, M. Vanwolleghem, C. R. Doerr, and H. Renner, "What is-and what is not-an optical isolator," Nature Photonics 7, 579–582 (2013).

2. B. J. H. Stadler and T. Mizumoto, "Integrated magneto-optical materials and isolators: A review," IEEE Photonics Journal 6, (2014).

3. Sevag Abadian, Giovanni Magno, Vy Yam, and Beatrice Dagens, "Broad-band plasmonic isolator compatible with low-gyrotropy magneto-optical material," Opt. Express 29(3), 4091-4104 (2021). https://doi.org/10.1364/OE.415969