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Project Name: ALLOPLASM

Tunable liquid-crystal long-range surface plasmon polariton components

Final Report

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Duration: 24 months

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FINAL PUBLISHABLE SUMMARY REPORT

Research in the scientific field of plasmonics is experiencing continuous expansion, as surface plasmon polaritons have emerged as a promising alternative for light-guidance in integrated optical devices and circuits. Compared with conventional optical dielectric waveguides, plasmonic waveguides allow the transmission of high-bandwidth optical signals with subwavelength confinement, leading to the miniaturization of the overall dimensions of the device. Moreover, plasmonic devices allow for their convenient integration with conventional silicon chips, where they may act as high-bandwidth interconnection freeways with limited use of precious die area. The need for broad communication bandwidth at all hierarchical system-levels, inter-rack, backplane, on-card and on-chip, has led to the accelerated penetration of optical technology solutions in such systems. To successfully exploit the high-bandwidth and throughput capacities of optical communication channels in integrated data centre architectures and routing platforms, one has to ensure small-footprint, low latency and, most importantly, low power consumption. Plasmonic optical interconnects constitute a promising solution, provided that adequate control in terms of their switching and data-routing efficiency is ensured.

In this context, the objective of the project was the development of novel plasmonic switching components electro-optically tuned by nematic liquid crystalline materials for use in integrated photonic circuitry. This involved the design, analysis, modeling and fabrication of plasmonic structures enhanced with liquid-crystal layers, capable of performing the target switching functions.

To this end, an extensive toolbox of numerical methods for both the electromagnetic analysis and the study of the liquid-crystal orientation was developed, comprising: i) a finite-element based fully-anisotropic eigensolver for the analysis of optical mode properties in liquid-crystal plasmonic waveguides, ii) an eigenmode expansion method for the rigorous analysis of lightwave propagation in longitudinal plasmonic switching components, iii) time-domain methods for the analysis of highly dispersive materials, in particular metals, which are the core element of any plasmonic device, iv) time-domain fully-anisotropic methods for the study of liquid-crystal photonics and plasmonic structures, and v) models for the investigation of liquid-crystal orientation and switching studies based on both the Frank-Oseen approach and the advanced Q-tensor/Landau-de Gennes formulation, which expands by far the capabilities of the former and accounts for complex structures in the presence of defects.

By exploiting this numerical arsenal, a variety of liquid-crystal based components for optical intra- and inter-connects was designed and studied, demonstrating advanced performance characteristics. These included: i) in-line long-range plasmonic variable attenuators, ii) in-line long-range plasmonic phase shifters, iii) directional coupler plasmonic switches for planar architectures, iv) directional coupler plasmonic switches for three-dimensional multi-level architectures, v) in-line dielectric-loaded plasmonic phase shifters, vi) coplanar dielectric-loaded directional coupler switches, and vii) metal-liquid-crystal-metal phase shifters and tunable filters and resonators. In all cases the switching properties are induced through the electro-optic control of properly designed liquid-crystal layers and cavities, leading to overall power consumption estimated several orders of magnitude below that of thermo-optic plasmonic switches.

During the whole project duration the fellow received extensive training in the premises of the host institution, which covered the following areas: i) clean-room fabrication processes and safety, ii) liquid-crystal alignment and infiltration in optical components, iii) investigation

techniques, including optical microscopy, surface profilometry, and scanning probe microscopy, iv) optical characterization of photonic devices, and v) sealing and packaging of liquid-crystal infiltrated components. Experimental samples have been fabricated and characterized. The demonstration of optimally performing prototypes is pending, following an extension of the fellow's contract with the same scientific objectives by the host institute. The end-components are expected to provide an ultra-low power consumption solution for inter-chip or on-chip optical interconnects.

No managerial problems were encountered overall during the implementation of the project. There have been no changes to the legal status of the beneficiaries involved in the project. No gender or ethical issues are relevant to the project. There was no subcontracting during the reporting period.

A website dedicated to the project was designed and published¹, in order to increase its visibility and facilitate the dissemination of the scientific results.

¹ <http://optol.artov.imm.cnr.it/alloplasm>