# Functional oxides for infrared plasmonics

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**Keywords :**
Plasmonics, functional oxides, metamaterials, epitaxy

**Context** :
The subject aims to develop new nanostructured materials for infrared (IR) plasmonics, integrated on substrates compatible with nanoelectronics standards. A plasmon is a resonant collective oscillation of an electron gas. It is accompanied by an exaltation and a confinement of the resonating electromagnetic field in its proximity. These properties can be exploited to enhance any interaction phenomenon between light and matter (absorption, light emission, etc.) as well as for the design of hyperbolic metamaterials, the highly anisotropic permittivity of which is of great applicative (hyperlenses, design of high finesse optical cavities, more generally development of new strategies for density of states engineering).

**Objectives :**
Plasmon resonance typically occurs in metallic materials and is directly controlled by the concentration of the electron gas. However, it is not tunable and restricted to visible wavelengths in common metals. All the infrared (IR) radiation/matter interaction phenomena are therefore inaccessible for plasmonic exaltation. However, IR is the preferred range for probing molecular vibration modes, for a number of applications in the field of datacoms, or to control the emission and propagation of heat in energy recovery devices.
In recent years, alternative materials[1] (Ga- or Al-doped ZnO[2], ITO[3], etc.) opening the field of plasmonics to IR have been studied. In pioneering studies, INL has demonstrated the interest of epitaxial functional oxides in this field, highlighting their unparalleled performance, tunability and integrability with standard technologies of nanoelectronics (silicon substrate).[5]
The present subject therefore proposes to develop new materials based on functional oxides (based in particular on titanates such as $SrTiO_3$ and associated solid solutions) for IR plasmonics. The aim is to fabricate these materials (by molecular beam epitaxy), to study their structural, electrical and optical properties using various advanced characterization techniques, to combine them together in the form of heterostructures and nanostructures controlled at the atomic scale to design new metamaterials with improved or new optical and plasmonic properties, and to exploit these properties by producing demonstrator devices. The work will focus on :
1-Controling and enhancing the plasmonic response in functional oxides, and in particular in doped titanates, by understanding the correlation between structure and functional properties
2-Designing the optical and plasmonic properties of epitaxial metamaterials based on oxides structured at the nanometric scale
3-Designing and fabricating demonstrator devices. The first aim will be the design of nanometric radiative coolers integrated on silicon, possibly combined with thermal energy

recovery devices. Other devices, such as ultra-sensitive sensors or high-performance IR emitters based on high-Q optical cavities embedding hyperbolic metamaterials could be considered.

**Challenges :**
Regarding material issues, the main challenge is to understand the correlation between the structural properties of oxides and their plasmonic properties, and to control these functional properties with the required accuracy. The design of metamaterials based on these oxides, in particular structured at the atomic scale, is also a notable innovation. Finally, the technological aspects related to the realization of demonstrator devices with these materials are not mature and will also have to be developed.

**Research program**
The work will first be focused on two types of epitaxial structures, namely thin $(La_x, Sr_{1-x})TiO_3$ layers and heterostructures/metamaterials associating these thin layers with each other, and Ruddlesden-Popper type structures based on $SrTiO_3$,[6] that we have shown as behaving as strongly anisotropic metamaterials structured at the monolayer scale.
We will develop the growth of these materials, with the concern of controlling their structure to control their electrical, plasmonic and optical properties. The materials will be synthesized by molecular beam epitaxy, based on INL's know-how, which is unique and internationally recognized. The structural properties of the materials will be studied using X-ray diffraction, photoemission spectroscopy, AFM, TEM microscopy (collaboration with CLYME, in particular), and synchrotron radiation if necessary (collaborations with the ESRF-BM32 and SOLEIL TEMPO beamlines). The optical properties of the materials will be measured by spectroscopic ellipsometry, FTIR, and using various more specialized optical benches, which may need to be adapted or even designed.
We will also develop methods to design metamaterials based on structures, superlattices and nanostructures combining the materials studied in the first point. The thus designed metamaterials will be fabricated, and their structural and functional properties studied using the tools described above.
Finally, demonstrator devices will be designed and fabricated, relyong on the resources and expertise of the Nanolyon technology platform.

**Grant :** doctoral contract, Ecole Centrale de Lyon

**Start date :** october 1st, 2021

**Request profile**
Candidates should have solid skills in solid-state physics, solid-state optics and materials. Knowledge of nanosciences and nanotechnologies is a serious asset. Candidates should have a strong interest and skills in experimental physics while having a good theoretical foundation to interact and collaborate with theorists when necessary. Ability to interact in a strongly collaborative framework is also necessary.

**Contact**
Please send a CV and a motivation letter to guillaume.saint-girons@ec-lyon.fr

**References**

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