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UNIVERSITÉ DE LYON

ÉCOLE DOCTORALE 160

Sujet de thèse

École doctorale EEA de Lyon

Registration institution: Ecole Centrale de Lyon
Doctoral school : ED 160 EEA Lyon directed by Mr Delachartre Philippe
Speciality : Electronics, Nanotechnology, Optics and Laser
Thesis subject: Molecular beam epitaxy of oxide based metamaterials and in-situ control of their functional properties by real-time measurements
Laboratory : INL, directed by Bruno Masenelli
PhD director : Mr SAINT-GIRONS Guillaume

For more information on the host team, see the website:
https://inl.cnrs.fr/equipe-materiaux/

Scientific field and context:
Heterostructures based on functional oxides, and in particular superlattices combining dielectric oxides (typically $SrTiO_3$) and conductors (typically $(La,Sr)TiO_3$) nanostructured down to the atomic level present very interesting physical properties for applications in the field of optics, in particular (transparent conductors in the infrared, materials with highly anisotropic permittivity, etc.) [1, 2]. Moreover, these properties can be largely controlled by modifying the characteristics of the superlattices (thickness of the layers, period, level of doping). We have shown at INL that these superlattices could behave as metamaterials, whose response can be parameterized on demand [1]. This opens the way to a strong flexibility for the design of components, with a strong potential applicative impact.

Keywords: Molecular beam epitaxy, functional oxides, optical metamaterials, in-situ real-time characterizations.

Objectives:
Exploiting the potential of functional oxide heterostructures is only possible at the cost of controlling molecular beam epitaxy (ie, the technique used for their synthesis) beyond the state of art. Obtaining such control is the first of the two main objectives of this thesis. The aim will be to develop innovative strategies for in-situ and real-time growth control: elemental flux control by atomic absorption (OFM) [3], curvature measurement [4] and ellipsometry [5]. These measurements will enable to tune in real time the growth parameters to control and optimize the properties of the structures at the stage of their synthesis, which is much more efficient than the classical “error-trial” strategies based on post-growth characterizations. The combined analysis of these three techniques in situ and in real time would be very original at the international scale. The second main objective of this thesis is to develop a new family of metamaterials based on functional oxides for applications in the photonic field, based on the growth strategies mentioned above. We aim in particular to demonstrate a record and largely adjustable optical anisotropy in these structures, as well as the fabrication of transparent conductive materials and hyperbolic metamaterials with performances exceeding the state of the art. Such metamaterials would open up important prospects for applications in the field of data transmission and for the management of heat exchanges in optoelectronic components.

Scientific challenges:
The main challenges of the project are:

-Development of real-time measurements during growth: the proposed measurements are original or applied for the first time to the growth of oxides, and their implementation therefore constitutes a challenge that the thesis project proposes to take up. The real-time combined analysis of different structural and functional measurements to build a coherent overview of the functional properties of the growing materials is also a challenge.

-Optical measurements on anisotropic structures: the targeted superlattices generally have an anisotropic permittivity, the measurement of which, by ellipsometry in particular, is relatively non-standard and will therefore be the subject of specific efforts.

-Correlation between structural properties and functional properties: understanding the correlation between the structure of the metamaterials and their optical response is a challenge, especially since the optical properties of oxides are barely known compared to those of semiconductors, for instance. The tools and expertise available in the framework of this project will make it possible to take up this challenge.

Original contributions expected:

The PhD student will be at the heart of the project, and will be more particularly in charge of the following aspects:

-Growth of oxide-based structures by molecular beam epitaxy, and instrumental developments for the implementation of the in-situ and real-time characterization tools

-Structural and chemical characterizations of the epitaxial layers: X-ray diffraction, transmission electron microcopy, XPS, AFM, possible measurement campaigns at SOLEIL and ESRF synchrotrons

-Functional characterizations of the epitaxial layers, in particular by ellipsometry. Development of strategies for the optical characterization of anisotropic thin-films

For these activities, the doctoral student will of course take benefit of the expertise and resources available in the laboratory or within the dense collaborative network of the team.

Research program and proposed scientific approach:

The activities of the doctoral student will initially be focused on the development of the in-situ and real-time characterization techniques, and the associated analysis tools. When the first structures will available, the optimal experimental protocols for their structural characterization will be set up, and the appropriate optical characterization tools will be developed (for anisotropic materials in particular).

In a second step, activities will focus on evaluating the potential of metamaterials based on functional oxides for optics. This will generally involve understanding the correlation between structure and optical properties and implementing appropriate design strategies on this basis. The structures thus predicted will be fabricated and their properties will be measured, and compared to the state of the art.

External collaboration(s)/partnership(s)

-For transmission electron microscopy: access to the Lyon joint microscopy center (CLYME). Possible external collaborations, particularly with the SuperSTEM platform in England, to access to state-of-the-art measurements.

-Possible collaborations with the SOLEIL and ESRF synchrotrons for advanced in situ and real-time structural characterizations (photoemission and surface diffraction).

-Collaborations with the i-lum team at INL for optical characterizations and metamaterial design.

Scientific supervision
The thesis will take place in the functional materials and nanostructures team at INL

PhD director : Guillaume Saint-Girons, CNRS research director
Co-supervisor : Clarisse Furgeaud, CNRS researcher

Funding : EEA doctoral school, 2044€ brut/month (~1600€ net/month)

Profile of the candidate
We are looking for a holder of a Master 2 degree or equivalent, with skills in materials science and/or optics (optical properties of materials and/or optical systems for instrumentation), motivated by experimental work and able to synthesize results from various characterizations. The mission also requires skills for collaboration and teamwork, writing skills and a certain fluency in English.

Valorization objectives
The originality of the proposed research should lead to the publication of several articles in international journals, and to the participation of the doctoral student to conferences and workshops. The project currently developed at INL and aimed at creating a marketable OFM sensor could lead to the creation of a start-up, opening opportunities for the PhD student.

Skills that will be developed during the PhD:
This thesis project will provide solid training for the student: development of advanced skills in the field of thin film growth, in materials science, and use of advanced structural and optical characterization tools. After his/her PhD, the student will be familiar with the scientific approach and will have acquired the associated rigor and methods.

To apply:
Please send a motivation letter, a CV, as well as your available master marks and ranking to :
clarisse.furgeaud@ec-lyon.fr
guillaume.saint-girons@ec-lyon.fr

References:
[1] M. Bouras et al., Chem. Mater. 6, 1755, (2019)
[2] R. Ramesh et al., Nature Review Materials 4, 257, (2019)
[3] Y. Du et al., Appl. Phys. Lett. 104, 163110, (2014)
[4] A. Arnoult et al., Scientific Reports 11, 9393, (2021)
[5] M. Schubert et al., Optic Letters 27, 2073, (2002)