CentraleSupélec within

LUMIN, UMR9024

LIGHT, MATTER AND INTERFACES LABORATORY

LuMIn is a research laboratory created in 2020 and devoted to light-matter interactions scaling from atoms to materials, devices and living systems at University Paris-Saclay. It aims at proposing novel and original synergies at the frontiers of optical and quantum physics, device technologies, along with the exploration *in vitro* and *in vivo* of fundamental biological processes for a better understanding of cancer and brain disorders pathogenesis.

The core activity of this structure is based on a wide spectrum of competences in optics (lasers, nonlinear optics, quantum physics, plasmonics), with applicative developments to the design and elaboration of micro- and nanophotonic devices (including microfluidic circuits) and to the investigation of biochemical phenomena in cells, tissues and living organisms.

LuMIn operates under the authority of four institutions: CNRS, ENS Paris-Saclay, Université Paris-Saclay and CentraleSupélec. It hosts the Equipex+ eDiamant and shares a common lab. with Thales R&T. It also belongs to the Institut d'Alembert in ENS Paris-Saclay.

Research topics

ULTRAFAST PLASMONICS AND NANOPHOTONICS

Metal nano-objects under light irradiation exhibit remarkable optical properties associated with the plasmon resonance phenomenon. We study, by carrying out dedicated experiments and simulations, the interaction of ultrashort light pulses with such plasmonic nanoparticles (NPs). This can lead to the formation of a hot electron gas, whose dynamics is accompanied by interesting phenomena which can be exploited in photonic, chemical or biomedical applications. Further, noble metal NPs are efficient converters of light into heat at small scales when lightened at their plasmon resonance. We study these fundamental mechanisms and exploit them for innovative functional materials and biomedical developments. In addition, we work on optomechanics, which designates the coupling of an electromagnetic wave with the motion or vibration of an object. This interaction is as strong as optical powers are important or as the objects are small. We investigate how optomechanical coupling can be magnified depending on the size of metal NPs and their environment. Besides, while piezoelectric materials change their dimensions when a voltage is applied, a similar effect called photostriction can occur under certain conditions when illuminated by an intense optical beam. We work with the SPMS lab. in CS to investigate this new optomechanical coupling.

DIAMOND-ENABLED MATERIALS AND SENSORS

Our research focuses on applying nitrogen-vacancy (NV) centers in diamond to sensitive magnetic measurements.

LASERS AND OPTICS

Our activities range from very fundamental studies in quantum information to the development of optoelectronic oscillators of high spectral purity, via the physics of lasers and nonlinear optics.

NANOPHOTONICS, MATERIALS AND SPECTROSCOPY

We fabricate and study different kind of nanomaterials and their interaction with light.

STRUCTURATION AND DEVICES

This research theme is focused on the elaboration, physical and technological studies of various kinds of photonic devices, mainly made of molecular and polymeric materials.

NEW OPTICAL METHODS FOR LIFE SCIENCE STUDIES

This theme aims at developing new methods for various applications in life sciences, with a focus on fundamental cellular processes: microscopy setups, optically active nanoprobes, optometry.

BIOPHOTONICS AND PHYSIOPATHOLOGY OF SYNAPSES

We study the synapse biology and circuit physiology in the healthy and diseased brain.

FLUIDIC AND ELECTRIC MICROSYSTEMS FOR LIFE SCIENCE STUDIES

We design and fabricate microfluidic devices for the characterization and treatment of living cells, for medical or environmental applications.

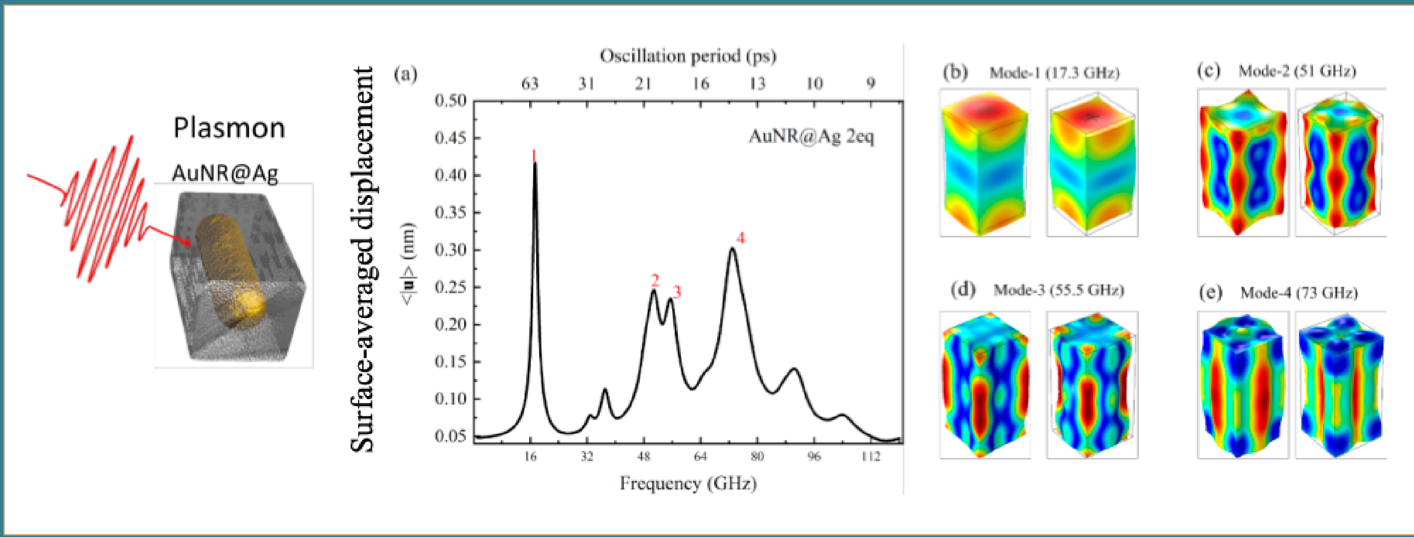
APPLICATION DOMAINS

- Optoelectronics,
- sensors,
- biomedical imaging,
- medical diagnosis and targeted therapies,
- photovoltaics,
- ultrafast optical processing,
- quantum information,
- new microscopies,
- materials for optics, sustainable energies and life science.

HIGHLIGHTS 2022

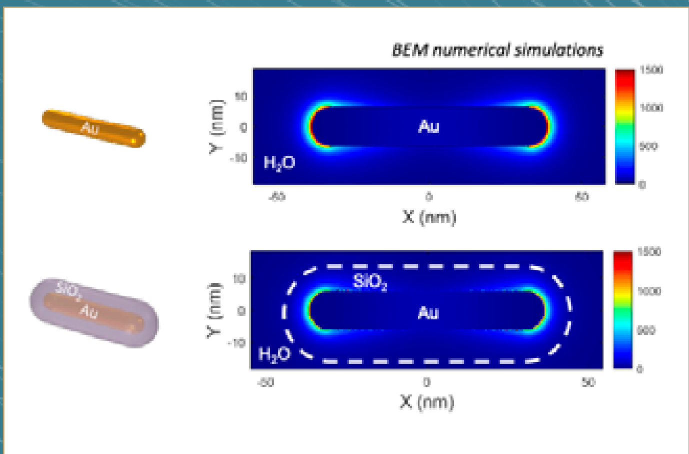
- Together with partners from **CEA NIMBE** (Paris-Saclay), we have demonstrated a novel benefit of coating plasmonic nano-objects with a thin silica shell for biomedical applications, as it dramatically reduces the production of reactive oxygen species under light irradiation. This work has been published in the review J. of Materials Chemistry B.
- A research agreement has been cosigned by CentraleSupélec and the Institut National de la Recherche Scientifique (**INRS**) in Québec, Canada, for facilitating joined research between LuMIn and one of the INRS labs. Prof. **M. Chaker** from INRS was invited in CS in 2022. A "cotutelle" PhD has started in September. **B. Palpant** has been nominated Associate Professor of INRS until 2026.

EXAMPLES OF STUDIES



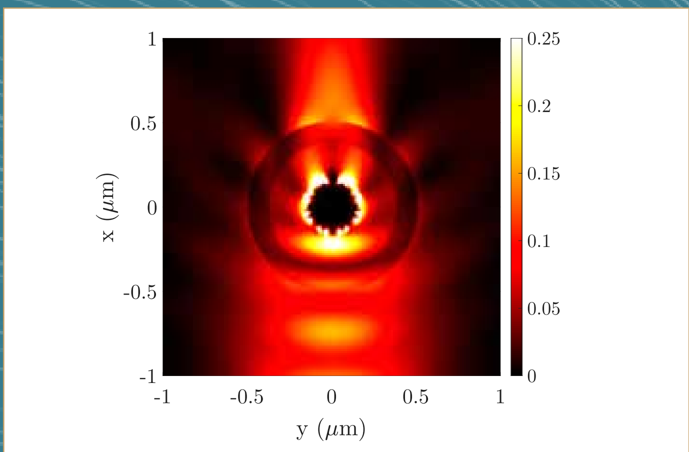
The vibrational landscape of nano-objects revealed by their ultrafast optical response

Bimetallic gold-silver core-shell nanoparticles: under pulsed laser illumination tuned to the plasmon resonance mode wavelength (left Fig.), the vibration properties of the nanoparticles can be analyzed by ultrafast transient optical absorption and modelling thanks to opto-mechanical coupling. The vibrational spectrum (middle) reveals different peaks in the sub-THz range, which correspond to specific vibration modes. The main ones are labelled and their origin revealed by acousto-plasmonic modeling (right; colors denote the relative induced displacement).
These results can be exploited for nano-sensing as both the optical and vibrational responses of the nanoparticles are very sensitive to their close environment. Collaboration: LPS, Orsay; ISM-CNR, Rome; IMMM, Le Mans. Published in: T. O. Otomalo et al., Chemosensors 10 (5), 193 (2022). DOI : https://doi.org/10.3390/chemosensors10050193.



Hindering the production of reactive oxygen species in biomedical applications of gold nanoparticles

Gold nanorods are extensively used for biomedical applications thanks to their tunable and effective optical properties. Under ultrashort laser pulses, they can generate reactive oxygen species (ROS) which, while useful for some targeted therapies, must be avoided in other developments like localized gene delivery. We have recently demonstrated that coating such nanoparticles with a thin layer of dense silica (SiO_2) enables us to hinder the production of ROS. This mainly stems from the confinement in the oxide layer of the electromagnetic near-field enhancement occurring at the nanoparticle tips, as illustrated on the figure (color levels: near-field intensity). Collaboration: NIMBE/CEA Saclay. Published in S. Mitiche et al., Journal of Materials Chemistry B 10, 589 - 597 (2022). DOI: https://doi.org/10.1039/D1TB02207E.



Mechanical properties of light at the nanoscale

Optomechanics refers to the coupling of electromagnetic radiation with one or more mechanical degrees of freedom. Indeed, although mass less, photons carry a mechanical momentum. It is intrinsically weak : the typical resulting force is 1nN for a 1W beam. Consequently these phenomena are negligible at the macroscopic scale, but at the nanometric scale objects are much lighter, and therefore much more sensitive to small forces. In addition, at such scales, surface effects are non-negligible since the surface to volume ration increases as the characteristic dimension decreases. In particular evanescent waves have a major contribution to the optical behavior and amplify the mechanical features of photons.

Industrial Partners

- Attocube R&D,
- Christex,
- Essilor,
- IMSTAR,
- Institut Photovoltaique d'Île-de-France,
- Orsay Physics,
- Photonscore GmbH,
- Thales TRT,
- United Visual Researchers.

Academic Partners

In France: PSL (ENS, ESPCI): LKB, RCP, LPENS, Gulliver, Institut Langevin, SIMM; SYRTE (Paris Observatory); U. de Paris: Centre des Saints-Pères, UMR_S942; Institut de la Vision, UMRS968; Institut du Cerveau; Institut Gustave Roussy: METSY; Institut National de la Transfusion Sanguine (INSERM, Paris); Sorbonne Paris Nord University: LPL, LSPM; Ecole Polytechnique: LPICM, LSI, LCM, Chaire Art&Science; Sorbonne U.: LRS, LKB, INSP, Centre de Recherche en Myologie (INSERM UMRS874); U. Gustave Eiffel, Paris-Est: ESYCOM; ISCR (Rennes), FOTON (Rennes), XLIM (Limoges), INL (Lyon), ENS Lyon, LCC (Montpellier), IMS (Bordeaux), LAAS (Toulouse), L2n (UTT, Troyes), LNCMI (Toulouse), CINaM (Marseille), CRC (Lyon), COMETE (Caen), Institut de Génétique Humaine (Montpellier), Institut Carnot de Bourgogne (Dijon).

In Europe: U. Leipzig, MPG-MPIP Mainz, U. Würzburg, Technical U. Munich, U. des Saarlandes, Heinrich Heine U. Düsseldorf (Germany); Wroclaw U. of Technology (Poland); CNR Rome, U. degli Studi dell'Insubria (Italy); Faculty of Applied Optics, ITMO University in St Petersburg (Russia); Hetman Petro Sahaidachnyi National Army Academy, Lviv, and Inst. of Radio-Physics and Electronics of the National Academy of Sciences of Ukraine, Kharkiv (Ukraine); CMN, U. de MONS (Belgique); U. of Nottingham, Cavendish Laboratory Cambridge, Oxford University (UK), Center for Physical Sciences and Technology (Lithuania); Vrije U. Amsterdam (The Netherlands); Institute of Organic and BioChemistry, Czech Academy of Sciences (Czech Republic).

Outside Europe: Tel-Aviv University, Bar-Ilan University and Weizmann Institute (Israel); University of South Florida, University of Georgia, Yale School of Medicine, Mount Sinai School of Medicine (USA); National Chung Cheng University, Academia Sinica, National Tsin Hua University (Taiwan); Assam University, RRI Bangalore, Indian Institute of Technology Ropar, State key laboratory of precision spectroscopy (India); Lanzhou University, Xi'an Institute of Optics and Precision Mechanics, Beijin institute of technology, Beihang University, Southeast University, HPStar Shanghai (China); Polytechnic University (Hong-Kong); Sfax, Monastir and Gafsa Universities (Tunisia); Faculty of physics, Hanoi National University of Education (Vietnam); Yonsei University (Korea); Pontificia Universidad Católica de Chile, Universidad de Chile (Chili); INRS, Montréal (Canada); Sharif U. of Technology (Iran); Univ. of Tokyo (Japan); Faculté des sciences et techniques de Tanger (Morocco).

Key figures*

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- Engineers & Administrative staff 2
- PhD Student 1
- Visiting Professor 1
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*CentraleSupélec only

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