

# Photochromic control of Surface Lattice Modes

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## Overview of the project

The [Light, nanomaterials and nanotechnologies laboratory \(L2n\)](#) is a Research Unit of the University of Technology of Troyes, which is also labeled by the CNRS as a Joint Research Team (EMR). This laboratory is composed of around 100 people, researchers, engineers, post-docs, doctoral students and interns. Its research themes are declined in 4 axes: light-matter interactions at the nanometric scale (axis 1), photonic devices (axis 2), biophotonics and bio-sensors (axis 3) and nanofabrication and synthesis (axis 4). The present rather fundamental project is part of axis 1. It benefits from the technological support of the Nano'Mat Platform, consisting of more than 1000 m<sup>2</sup> laboratory space with 700 m<sup>2</sup> of clean rooms.

A localized surface plasmon is a resonance (LSPR) sustained by a metallic nanoparticle smaller than the wavelength of the illumination light. These resonances, known since the middle age, are responsible of the specific colors of stained glasses (Fig. 1a). It corresponds to the collective oscillation of the conduction electrons of the metallic nano-object, which occurs at fixed frequencies (Fig. 1b). These resonances are sensitive to several factors such as size, shape, morphology, the surrounding environment or the material chosen. They are clearly visible in the extinction and diffusion spectra of a nanoparticle, in particular the dipole mode which presents a high amplitude, and which easily couples to a propagating plane wave (Fig. 1c).

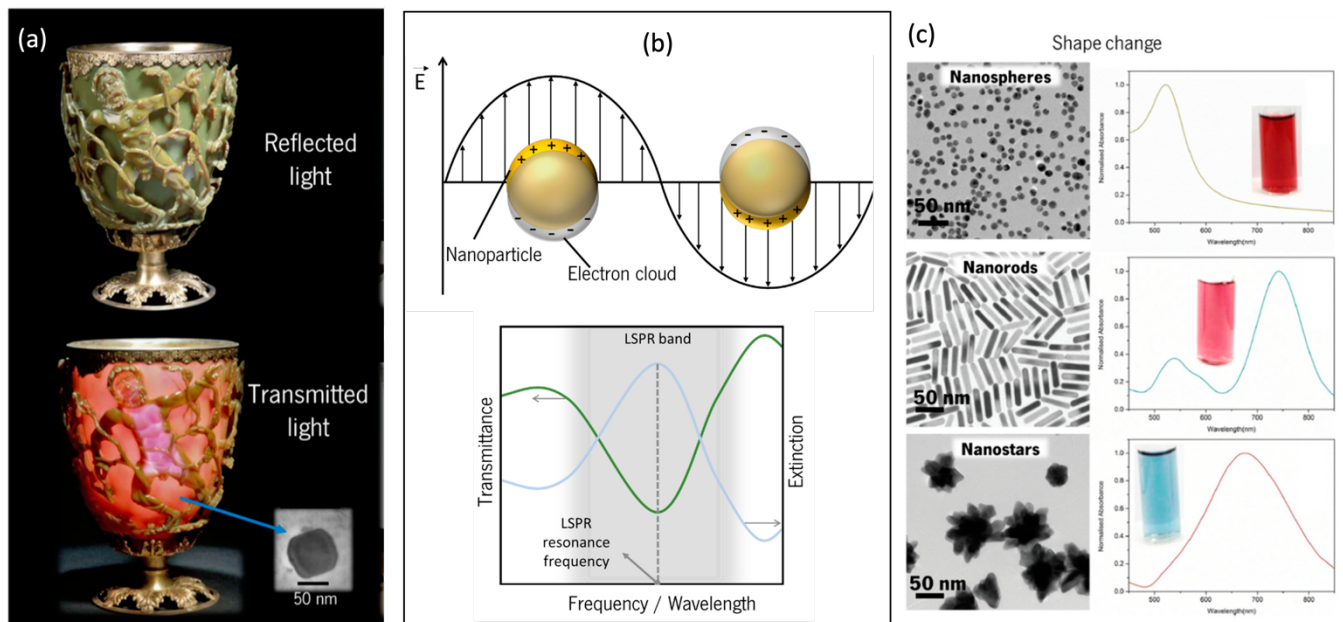


Figure 1: (a) Lycurgus Cup, a Roman glass from the fourth century AD, whose color change is due to Au-Ag alloy nanoparticles. (b) Schematics of localized surface plasmons of a metal sphere, leading to a typical LSPR band, measured in transmittance and extinction spectra. (c) TEM images of Au nanospheres, nanorods, and nanostars, with the corresponding LSPR observed by UV-Vis spectroscopy and color (adapted from Rodrigues et al. [1])

However, plasmon resonances have rather low-quality factors (defined as the ratio between the central wavelength and the width at half-height of the resonance), mainly because of their large scattering cross section and losses due to metal absorption. Moreover, the techniques of nanofabrication do not make it possible to obtain completely identical nanoparticles and the

influence of the geometrical deviation on the optical properties is colossal for certain optical phenomena. Therefore, studying large surfaces of periodically arranged metallic nanoparticles allows to significantly increase the signal levels collected, to average the signals thus smoothing the local geometric deviations, and also to benefit from the interaction of nanoparticles via lattice modes allowing a drastic reduction of losses.

The diffraction phenomenon appears when each element of the grating diffuses the incident light in a coherent way. However, during the first observations of reflection or transmission spectra of a periodically corrugated surface, anomalies in the form of sudden intensity variations in these spectra appeared, at zero order, at wavelengths and angles of incidence defined. These changes, called Rayleigh anomalies, correspond to the appearance (or disappearance) of diffracted orders and are associated with a grazing wave propagating in the grating plane [2]. This wave oscillates spatially with the same periodicity as the lattice and when the lattice elements are metallic nanoparticles, this wave can couple with the LSPR of each particle. This coupling produces two hybrid states presenting the properties of its components. The lattice plasmonic mode, called SLR (for Surface Lattice Resonance) is one of these hybrid states. It allows a long-distance coupling of the LSPR dipole modes of each nanoparticle and presents a high-quality factor [3,4]. Moreover, this phenomenon of strong coupling is very sensitive to the environment of the nanoparticles since the slightest asymmetry of the system, at a given wavelength, breaks the coherence of the response and drastically reduces the quality factors [5]. The idea of this project is to optically modify the refractive index of the dielectric medium covering the grating to control the SLR modes. For this, we will use photochromic molecules which present a transparent molecular state and another colored state. The passage from one to the other takes place by absorption of UV radiation in one direction and visible or thermal radiation in the other. These molecules are well known to eyewear manufacturers since they are used in progressive tinting lenses.

- [1] Rodrigues M.S., Borges J., Lopes C., Pereira R.M.S., Vasilevskiy M.I., Vaz F., Gas Sensors Based on Localized Surface Plasmon Resonances: Synthesis of Oxide Films with Embedded Metal Nanoparticles, Theory and Simulation, and Sensitivity Enhancement Strategies. Appl. Sci. 2021, 11, 5388.
- [2] James E. Harvey and Richard N. Pfisterer, Understanding diffraction grating behavior: including conical diffraction and Rayleigh anomalies from transmission gratings, Optical Engineering 58(8), 087105 (2019)
- [3] Vasil G. Kravets, Fredrik Schedin, and Alexander N. Grigorenko, Extremely Narrow Plasmon Resonances Based on Diffraction Coupling of Localized Plasmons in Arrays of Metallic Nanoparticles, Phys. Rev. Lett. 101, 087403 (2008)
- [4] Vasil G. Kravets, Andrei V. Kabashin, William L. Barnes, and Alexander N. Grigorenko, Plasmonic Surface Lattice Resonances: A Review of Properties and Applications, Chem. Rev., 118, 5912–5951 (2018).
- [5] Dmitry Khlopin, Frédéric Laux, William P. Wardley, Jérôme Martin, Grégory A. Wurtz, Jérôme Plain, Nicolas Bonod, Anatoly V. Zayats, Wayne Dickson and Davy Gérard, Lattice modes and plasmonic linewidth engineering in gold and aluminum nanoparticle arrays, J. Opt. Soc. Am. B 34, 691-700 (2017)

## INTERNSHIP DESCRIPTION

The intern must first follow the online or face-to-face training allowing him to have access to the L2n clean rooms.

She/He will then start working on square arrays of gold nanocylinders with different periods, fabricated on a glass substrate by an engineer from the Nano'Mat platform. She/He will cover the sample using the spin-coating technique of photochromic molecules, diluted in a liquid polymer matrix.

She/He will then measure the extinction spectrum of the nanoparticle arrays via an upright microscope equipped with a spectrophotometer, before and after the photochromic transition. She/He will quantify the influence of the index variation on the appearance or disappearance of SLR modes and we will compare these results to simulations carried out using the FDTD (Finite Difference Time Domain) method.

The results of this internship can be promoted through the writing of a publication.

## REQUIRED BACKGROUND

The required student currently follows an engineer or master degree in Materials, Optics or Nano-photonics. She/He must have in-depth knowledge of electro-magnetism and basic knowledge of Plasmonics would be preferable. She/He must have a strong taste for experimental research and not be reluctant to do bibliographical research. A first appetite for numerical simulations would be a bonus.

## ADMINISTRATION

<b>Application deadline :</b>	30/06/2023
<b>Start :</b>	02/10/2023
<b>Duration :</b>	6 months
<b>Location :</b>	L2n, UTT, Troyes, France
<b>Degree:</b>	Engineer last internship or M2 internship
<b>Research key-words:</b>	Nanomaterials, Nano-Optics