Advanced Textbooks in Physics

AN INTRODUCTION TO PLASMONICS

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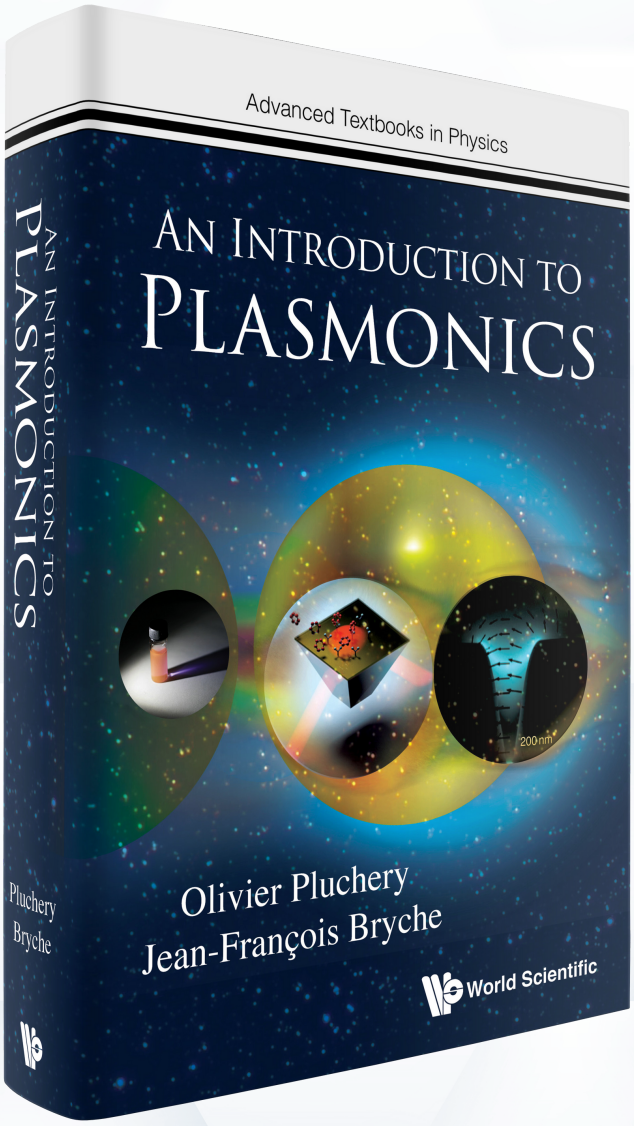

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What is a plasmon? Is it a particle, like a photon or a wave? Plasmonics stands at the frontier of condensed matter physics, which is the world of electrons, optics and of photons. Plasmonics is one of the most active fields in nanophotonics. This book begins by exploring the concepts behind waves, and the electromagnetic description of light when it interacts with metals; it dedicates every chapter thereafter to all aspects of plasmonics. In particular, the surface plasmon polariton wave is explained in full detail, as well as the localized surface plasmon resonance of metallic nanoparticles. The active research area opened by plasmonics, as well as its applications, are also briefly explained, such as advanced biosensing, subwavelength waveguiding, quantum plasmonics, nanoparticle-based cancer therapies, optical nano-antenna and high-efficiency photovoltaic cells.

The book is adapted for graduate students and places a special emphasis on providing complete explanations of the fundamental concepts of plasmonics. Further, each of these concepts is illustrated with examples drawn from the most recent scientific literature. Each chapter ends with a set of exercises that will help the reader revise the concepts and go deeper into the world of plasmonics. More than 70 exercises are included.

Contents

Readership

The book is intended for academia: university, college and engineering schools. Specially suited for graduate students in physics, materials science or chemistry. Also useful for PhD students and researchers entering the field of plasmonics as well as undergraduate courses in physics and electromagnetism.

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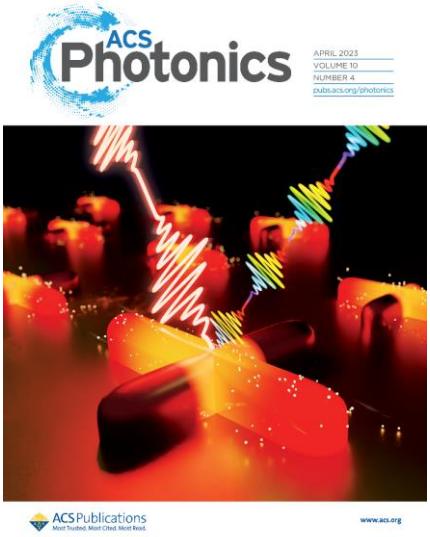
List of recent articles by

O. Pluchery and J-F Bryche

Abstract: Thermoplasmonics has benefited from increasing attention in recent years by exploiting the photothermal effects within plasmonic nanoparticles to generate nanoscale heat sources. Recently, it has been demonstrated that exciting gold nanoparticles with ultrashort light pulses could be used to achieve high-speed light management and nanoscale heat-sensitive chemical reaction control. In this work, we study non-uniform thermal energy transient distribution inside cross-shaped nanostructures with femtosecond transient spectroscopy coupled to a thermo-optical numerical model, free of fitting parameters. We show experimentally and numerically that the polarization of the excitation light can control the heat distribution in the nanostructures. We also demonstrate the necessity of considering nonthermal electron ballistic displacement in fast transient heat dynamics models.



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J-F. Bryche[†], M. Vega[†], J. Moreau, P-L. Karsenti, P. Bresson, M. Besbes, P. Gogol, D.Morris, P.G. Charette, M. Canva « *Ultrafast Heat Transfer at the Nanoscale: Controlling Heat Anisotropy*», **ACS Photonics**, Mar. 11, 2023 - https://doi.org/10.1021/acsphotonics.2c01968
https://hal-iogs.archives-ouvertes.fr/hal-04059607

[†]1st shared co-authorship

Abstract: This work demonstrates the enhancement in plasmonic sensing efficacy resulting from spatially-localized functionalization on nanostructured surfaces, whereby probe molecules are concentrated in areas of high field concentration. Comparison between SERS measurements on nanostructured surfaces (arrays of nanodisks 110 and 220 nm in diameter) with homogeneous and spatially-localized functionalization with thiophenol demonstrates that the Raman signal originates mainly from areas with high field concentration. TERS measurements with 10 nm spatial resolution confirm the field distribution profiles predicted by the numerical modeling. Though this enhancement in plasmonic sensing efficacy is demonstrated with SERS, results apply equally well to any type of optical/plasmonic sensing on functionalized surfaces with nanostructuring.

J-F. Bryche, M. Vega, A. Tempez, T. Brulé, T. Carlier, J. Moreau, M. Chaigneau, PG. Charette, M. Canva, « *Spatially-Localized Functionalization on Nanostructured Surfaces for Enhanced Plasmonic Sensing Efficacy* », **Nanomaterials**, 2022, 12(20). https://hal.science/hal-03815795
https://doi.org/10.3390/nano12203586.

Abstract: Self-assembled monolayers composed of various long-chain aliphatic molecules and different tail functional groups have been synthesized on the Au(111) surface and characterized by Kelvin Probe Force Microscopy and Ultraviolet Photoelectron Spectroscopy. Carboxy, amino, thio and methyl terminal groups have been considered in the design of self-assembled monolayers with different aliphatic chain lengths (from C6 to C16). The work function measurements by Kelvin Probe Force Microscopy have been carried out under controled and room atmosphere. Remarkably, a reduction of the relative humidity from 40 % to 3 % has induced a work function shift up to 0.3 eV. As expected, the changes of the chain length of the aliphatic moiety and of the tail group have a significant impact on the tuning of the measured work function (3.90 eV for dodecanethiol versus 4.57 eV for mercaptohexadecylamine). Surprisingly, the change of the net dipole moment of the tail group (sign and amplitude) does not dominate the work function variations. In contrast, the change of the chain length and the possibility of the tail group to form a complex hydrogen-bond network between molecules, lead to significant modulations of the work function. In order to interpret these original findings, density functional theory models of equivalent self-assembled monolayers adsorbed on the Au(111) surface have been developed at an unprecedented level of description with large supercells including simultaneously 27 coadsorbed molecules and weak van der Waals interactions between them. Such large systems have allowed the theoretical modeling of complex hydrogen-bond networks between molecules when possible (carboxy tail group). The comparison between computed and measured work functions shows a striking agreement, thus allowing the disentanglement of the previously mentioned competing effects. This consistency between experiment and theory will help designing the electronic properties of self-assembled monolayers in the context of molecular electronics and organic transistors.

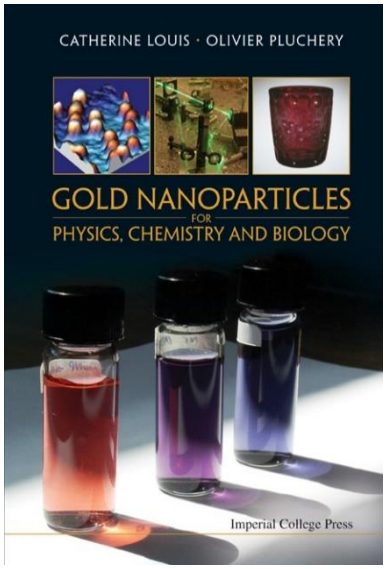
L. Bossard-Giannesini, L. Cardenas, H. Cruguel, A. Demessence, D. Loffreda, and O. Pluchery, “How far the Chemistry of the Self-Assembly Monolayers on Gold Surfaces Affects their Work Function?,” Nanoscale. Royal Society of Chemistry (RSC), 2023. https://doi.org/10.1039/D3NR03172A

Abstract: We report on the performance and inherent artifacts of *k*-space optical microscopy for the study of periodic arrays of nanoparticles under the various illumination configurations available on an inverted optical microscope. We focus on the origin of these artifacts and the ways to overcome or even benefit from them. In particular, a recently reported artifact, called the “condenser effect,” is demonstrated here in a new way. The consequences of this artifact (which is due to spurious reflections in the objective) on Fourier-space imaging and spectroscopic measurements are analyzed in detail. The advantages of using *k*-space optical microscopy to determine the optical band structure of plasmonic arrays and to perform surface plasmon resonance experiments are demonstrated. Potential applications of *k*-space imaging for the accurate lateral and axial positioning of the sample in optical microscopy are investigated.

J-F. Bryche, G. Barbillon, B. Bartenlian, G. Dujardin, E. Boer-Duchemin, E. Le Moal, *« k-space optical microscopy of nanostructure arrays: opportunities and Artifacts »*, **Journal of Applied Physics**, 2018, 124(4), 43102. - https://doi.org/10.1063/1.5029976
https://hal.science/hal-01848629

Abstract: The fascination with gold is a story which spans millennia, however scientists have recently found a new interest for gold when it is divided into miniscule grains, such as gold nanoparticles. This scientific enthusiasm started in various fields of science in the middle of the 1980s and the present book offers a panorama of the major scientific achievements obtained with gold nanoparticles.

Various topics are reviewed such as: gold nanoparticle preparation methods, their plasmon resonance and thermo-optical properties, their catalytic properties, their use in biology and medicine as well as their possible toxicity and, finally, their future technological applications. The book also contains an in-depth study of the use of gold nanoparticles throughout the ages, starting from times where the concept of nanoparticles was beyond the realm of human imagination. All these topics are presented by world-class scientists within a set of self-contained chapters.



This book may be used as an advanced textbook by graduate students and scientists who need an introduction to gold nanoparticles. It is also suitable for experts in the related areas of chemistry, biology, material science, optics and physics, who are interested in broadening their knowledge and who wish to have an overview of the subject. Each chapter gradually leads the reader from the basics of a topic towards some of the current scientific challenges in the area. The necessary background material to achieve a solid understanding of each topic and the scientific literature to go further in the field is provided.

C. Louis and O. Pluchery, "Gold Nanoparticles for Physics, Chemistry and Biology." IMPERIAL COLLEGE PRESS, Oct. 24, 2011. https://doi.org/10.1142/p815

Free chapter 1 from World Scientific:
https://www.worldscientific.com/doi/suppl/10.1142/p815/suppl_file/p815_chap01.pdf

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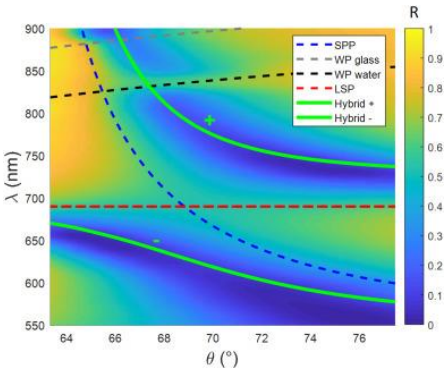
Abstract: This paper compares plasmonic substrates manufactured by three lithography methods: E-beam, soft and hard UV NanoImprint Lithography. The different plasmonic modes existing in samples made of an array of gold nanostructures on gold film are investigated for biochemical detections taking advantage of Surface Plasmon Resonance Imaging (SPRI) and Surface-Enhanced Raman Scattering (SERS). Recently, it has been shown that this geometry of substrate is of great interest for both SPRI and SERS measurements. A comparison of their performances obtained by the different lithographic methods is provided. In particular, due to limitations in NanoImprint Lithographic techniques, the impact of sidewall geometry of nanostructures is investigated in regard to plasmonic properties. Thus, experimental optical characterization analyses have been carried out on samples and compared with the numerical simulations.



Normalized angulo-spectral SPR reflectivity map showing the different plasmonics modes (D = 50 nm – P = 300 nm) Reproduced from the citation below.

J-F. Bryche, F. Hamouda, M. Besbes, P. Gogol, J. Moreau, M. Lamy de la Chapelle, M. Canva, *B. Bartenlian, « Experimental and numerical investigation of biosensors plasmonic substrates induced differences by e-beam, soft and hard UV-NIL fabrication techniques »*, **Micro Nano Engineering**, 2019, 2, 122–130. https://doi.org/10.1016/j.mne.2018.11.003
https://hal.science/hal-02184340

Abstract: The assemblies of cross-linked gold nanoparticles (AuNP) attract lot of scientific attention due to feasible perspectives of their use for development of scaled contact electrodes. Here, we developed and tested method of solid-state formation of dimers created from small AuNP (~18 nm) cross-linked with 1.9-nonadithiol (NDT) molecules. The morphology of created coating of a glass surface and its optical-polarization properties have been studied in detail by combination of scanning electron microscopy, atomic force microscopy, UV-visible spectroscopy, and modulation-polarization spectroscopy. The modification of localized surface plasmon resonance (LSPR) of single AuNP and their assemblies were studied by measuring of the spectral characteristics of polarization difference at all stages of synthesis. The radiative and nonradiative modes of LSPR have been analyzed in detail at different angles of incidence light. This allowed establishing relation between surface morphology of the coating and its optical properties.

M. O. Stetsenko, S. P. Rudenko, L. S. Maksimenko, B. K. Serdega, O. Pluchery, and S. V. Snegir, “Optical Properties of Gold Nanoparticle Assemblies on a Glass Surface,” Nanoscale Research Letters, vol. 12, no. 1. Springer Science and Business Media LLC, May 12, 2017. https://doi.org/10.1186/s11671-017-2107-8
https://hal.science/hal-01534721v1