China Scholarship Council (CSC)
PhD Thesis Proposal Form
2021-2022

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FIELD
(Physics)

Thesis subject title: **Realization and applications of plasmonic nanostructures by optical method**

- Laboratory name: Laboratoire Lumière, Matière et Interfaces (LuMIn)
- PhD supervisor (contact person):
- Name: Ngoc Diep LAI
- Position: Associate Professor
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- Thesis proposal (max 1500 words):

Context: The physical phenomenon of surface plasmon resonance (SPR) is arisen by light/matter interaction at the interface of metallic and dielectric materials, especially in noble metals, e.g. silver and gold. This effect has attracted considerable interest in different domains: physics, chemistry, biology, etc. The plasmonic effect is distinguished into three categories: (i) surface plasmon polariton; (ii) localized surface plasmon resonance; and (iii) plasmonic nanostructures.

Localized surface plasmon resonance (LSPR) happens when collective oscillations of free electrons are confined to a finite volume, such as metal nanoparticles (NPs). Generally, the LSPR in visible range is obtained with noble NPs with dimensions below 100 nm. The plasmonic properties of metallic NPs vary with their shape and size, and are also affected by the refractive index of the surrounding medium. It is also demonstrated that the SPR effect becomes much stronger when two or multiple metallic nano-objects are arranged very close to form the so-called plasmonic nanostructure (PNS). A prominent example for coupled SPR is a nano-hole array (NHA). In such a system, the surface plasmon polariton can propagate throughout the NHA surface thanks to the coupling of multiple nano-holes perforated appropriately in a metallic thin film. The properties of plasmon resonance of NHAs can be tuned by characteristic length

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scales and types of arrays such as periodic, quasiperiodic, and aperiodic structures. Such PNSs have great promise for many interesting applications, such as tunable filter and color printer.

Recently, we demonstrated a robust technique based on the use of direct laser writing (DLW) method for realization on demand of plasmonic structures [1,2]. This allows obtaining plasmonic nanostructures in a single step without needing the preparation of polymeric template and lift-off process. By this direct fabrication technique, the nanoholes do not have circular shape as the laser focusing spot, due to the non-uniform heat transfer in a no-perfect flat Au film. It was theoretically and experimentally demonstrated that the properties of fabricated plasmonic nanoholes arrays are very close to those of ideal plasmonic nanostructures. Furthermore, it is theoretically demonstrated that the non-perfect circular shape of the Au hole allows amplifying the electromagnetic field of the resonant peak by several times as compared to the case of perfect circular shape. The direct fabrication method thus paves the way to many interesting applications, such as color nanoprinter [3,4], and the rough holes of plasmonic structures could be an advantage for application in laser and nonlinear optics domains.

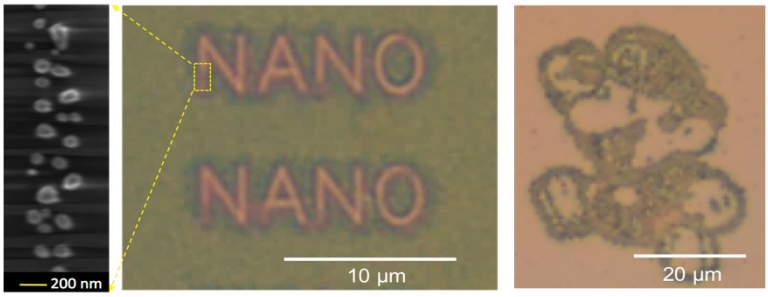

Figure 1: Optical microscope images of plasmonic patterns consist of Au NPs, realized by the optically induced thermal effect via DLW technique: "NANO" letter and "Mario" image. Left: a SEM image of the Au NPs.

Thesis proposal: We propose to exploit the use of fabricated PNSs for color nanoprinter application and the strong field of the rough PNSs for enhancement of nonlinear optical effects. The idea is shown in Figure 2.

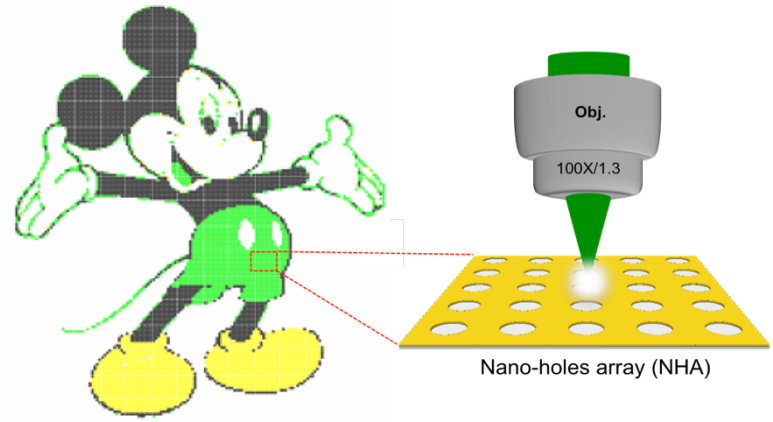

Figure 2: Optically induced local thermal effect in DLW system is used to realize desired plasmonic nanostructures on gold materials for application of color printer, tunable filter, and efficient nonlinear optics.

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In order to achieve our aim, the work should deal with different aspects, from theoretical calculation and experimental fabrication to applications demonstration. A PhD study of 3 to 4 years is required.

- **Publications of the laboratory in the field** (max 5):
  1. Q. C. Tong, M. H. Luong, J. Remmel, M. T. Do, D. T. T. Nguyen, N. D. Lai, "*Rapid direct laser writing of desired plasmonic nanostructures*", Opt. Lett. **42**, 2382- 2385 (2017).
  2. F. Mao, G. L. Ngo, C. T. Nguyen, I. Ledoux-Rak, and N. D. Lai, "*Direct fabrication and characterization of gold nanohole arrays*", Opt. Express **29**, 29841-29856 (2021).
  3. F. Mao, A. Davis, Q. C. Tong, M. H. Luong, C. T. Nguyen, I. Ledoux-Rak, N. D. Lai, "*Direct Laser Writing of Gold Nanostructures: Application to Data Storage and Color Nanoprinting*", Plasmonics **13**, 2285–2291 (2018).
  4. Q. C. Tong, F. Mao, M. H. Luong, M. T. Do, R. Ghasemi, Q. T. Tran, T. D. Nguyen and N. D. Lai, "*Arbitrary Form Plasmonic Structures: Optical Realization, Numerical Analysis and Demonstration Applications*", Chapter 5, book "Plasmonics", INTECH (2018).

- Joint Phd (cotutelle) : NO
- Co-directed PhD : NO

In case of a Co-directed or a Joint PhD, please detail:

- Partner University name
- Laboratory name and web site:
- PhD co-director (contact person):
- Name:
- Position:
- E-mail:
- Phone number:

- **Provisional duration and timetable of the PhD student stays at the ENS Paris-Saclay**

  - If the candidate has a master M2 in France or in Europe, the duration is 3 years.
  - If not, the duration is 4 years, full time at Ecole Normale Supérieure Paris-Saclay, in this case:
    - **First year**: Scientific courses (including summer school), papers work about the PhD subject, learning about simulation technique, and experimental setup for fabrication and characterization.

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- **Second year**: Simulation of optimum plasmonic structures and experimental validation, demonstration of various applications of plasmonic structures, such as color printers, bandpass filter, etc., writing scientific papers and attending conferences.
- **Third year**: Demonstration of nonlinear optical enhancement and laser effect by using rough plasmonic nanostructures, writing scientific papers and attending conference.
- **Fourth year**: writing scientific papers and attending conference, write the PhD thesis and defense.

- **If previous collaborations with the Chinese codirector/university, please detail:**

  - I have supervised several Chinese students in the frame of CSC scholarship and the results are quite satisfying.
  - Most of my Chinese students come from ECNU, and three of them already went back to China for working: Dingwei ZHENG (2007-2010); Xiao WU (2009-2012); Qinggele LI (2010-2014); Fei MAO (2015-2019). MAO Fei now continues his research work as a postdoc in my group.

- Interest of the Joint Phd for the French codirector, for his/her laboratory, for ENS Paris-Saclay

Date : 14 December 2021

Signature of the PhD director

Ngoc Diep LAI

Name and signature of the Laboratory director

Fabien Bretenaker

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