SORBONNE UNIVERSITÉ

CHINA SCHOLARSHIP COUNCIL

Appel à projets
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Title of the research project :

Infrared sensor based on nanocrystals with optimized light matter coupling

Thesis supervisor (HDR) :

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Research Unit

Name : Institute for nanosciences of Paris (INSP)

Code *(ex. UMR xxxx)* : UMR 7588

Doctorate School

Thesis supervisor's doctorate school (candidate's futur doctoral school) : ED397 physic and chemistry of material

PhD student currently supervised by the thesis supervisor (number, year of the first inscription) :

1.5

Description of the research project

Context

Nanocrystals are promising building block for optoelectronics. They are one of the few nanotechnologies to have reached a mass market with their use as light source for display. Nanocrystals appears equally promissing for the design of infrared sensor. This field has started with solar cell. Thanks to quantum confinement it is possible to tune the band gap of nanocrystals around the optimal value for single junction solar cell. In this case, the band gap enables to harvest the infrared part of the solar spectrum. At even longer wavelength, nanocrystals also appear appealing because they offer a cost effective alternative to existing narrow band gap nanocrystals

Over the past decade, significant progresses have been achieved for the field of IR sensing based on nanocrystals. 10 years ago the chalenge was at the material level with the growth of particles absorbing and emitting light at wavelength above 1.5 µm [1]. Since that, key demonstrations include (i) demonstration of intraband photoconduction, (ii) growth of THz absorbing particles, (iii) demonstration of focale plane array based nanocrystal as active material (figure d), (iv) design of light matter coupling with in mind the enhancement of the light absorption (figure c) [2,3,6].

With times, devices have become far more complex that the initial thin film deposited onto interdigitated electrodes. While many concept have been demonstrated independently, a key chalenge is their combination. This PhD project will tackle two chalenges. On one side, we target to combine gate control of the carrier density with enhanced absorption obtained by light trapping. A second aspect aims to adress the design of effective diodes which structure can be transfered to the design of focal plane array. To date, many diodes structure proposed in the litterature are not compatible with the presence of a read out circuit, asking to revisit the full diode design.

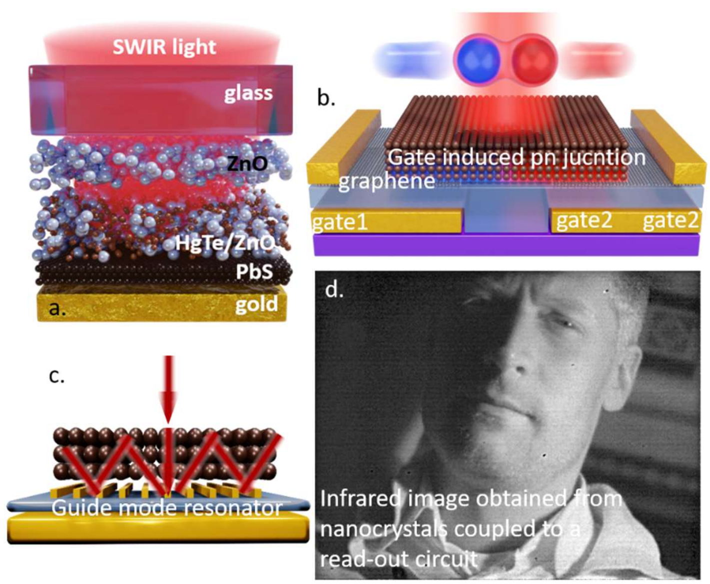

Figure a Scheme of an infrared LED based on HgTe nanocrystals. b. Scheme of dual gate device used to enhance charge dissociation. c Scheme of a guided mode resonator used to enhanced light absorption. d. infrared image obtained using nanocrystals as active material.

The PhD project will take place at institute for nanosciences of Paris (INSP) and more specifically in the optoeletronic of confined material group. The activity of the team is dedicated to device design based on low dimentional materials and in particular on narrow band gap materials being optically active in the infrared range. The group works on all aspects of the project from material growth to device characeterization [1-6] including electronic transport [4] and investigation of the electronic structure.

Methodology

The thesis will be organized along two main projects which general objective will be the design and fabrication of a short wave infrared sensor based on HgTe nanocrystals [1]

- **Design of focal plane array compatible photodiode**

Current best diodes based on HgTe nanocrystals rely on the following stack of layer ITO/HgTe/Ag_2Te/Au, where the HgTe layer is used as absorber and Ag_2Te as hole extractor. In the current stack the transparent conductive oxide is at the bottom of the stack on a transparent substrate. However, when using a read-out circuit, the substrate is no longer transparent and the transparent contact has to be deposited as top layer. This obviously requires to invert the whole stack. Furthermore, gold is generally not apperaciated by solicon fundery since gold acts as a deep trap for Si. Thus, even the metal used to extract the charges has to be updated. The goal of this part is to design a diode stack that can later be transfered to a read out circuit, while keeping the HgTe NC as asborbing layer.

We thus aim to design a diode stack where a metal will be used as bottom electrode and will be possibly coupled to an electron transport layer. To conduct a rational design of the device we will conduct photoemission measurements (at french synchrotron Soleil). The goal of this experiement will be, not only to unveil the band alignement, but also the presence of interfacial band bending. To do so, we will used pump probe photoemission.

The PhD candidate will have in charge the whole fabrication and characterization of the device. This includes spectral response, time reponse, calibrated response and noise measurements.

- **Combining gate control and enhanced absorption**

The mots basic geometry to achieve photodetection is the photoconductive geometry. This structure is in particular robust toward the quality of the nanocrystal film, however the dark current is larger than in the diode mode. A strategy to improve the device is to add gate(s). Gate enable carrier density control [3,5] and the device can be operated in a condition where the material is close to intrinsic. When multiple gates (figure b) are introduced the control of the carrier density can be pushed further and pn juntion can be optained. This enables planar diode. A key benefit of the planar diode compared to their vertical geometry counter part is its faster response. The group of INSP has develloped skills to build such type of device based on narrow band gap nanocrystals. Now, we aim to tackle the weak light absorption of this device around 10 % of the incident light. Coupling of infrared nanocrystals to light resonator have become a hot topic over the recent years [2,3,6], see figure c. The concept behind is to focus the light on a thin slab of semiconductor, which thickness is compatible with the carrier diffusion length. Our group has made some contribution to this field and design guided mode resonator applied to various geometries such as photoconductor and diode. The next chalenge will be to combine simultaneously, in the same device, two gates and a light resonator. Ideally, we aim to design a resonator with broad band enhancement of the absorption

PhD project outline

Year 1: proper training to nanocrystal synthesis, device fabrication and device characterization.
Follow one master class on nanoelectronic and possibly a summer school on nanocrystal

Year 2 design of diode with geometry compatible with focal plane array. Participation to a synchrotron beamtime

Year 3 design and fabrication of device combining gate+light resonator. Participation to a second synchrotron beamtime

Year 4 finalize poublications anw write PhD these

Required background for this PhD project

A strong background in semiconductor physics is required. The PhD project takes place in an international team (1/3 of student are non french speaking) and thus being fluent in english is a must. French is a plus for interaction with engineer but not requested. Other appreciated skills include : clean room experience, nanocrystal synthesis, solution processable device fabrication, electronic transport, electromagnetic simulation. Because it is unlikely that a young reseracher gets all these talents, applicant has to be eager to learn new skills and be hard working.

Skills to be develloped

Scientific skill : clean room and glove box fabrication, nanocrystal synthesis, measurement on large scale facility mostly photoemission on synchrotron, Electronic transport in cryogenic condition, infrared device characterization.

Soft skills : work in an international team, manage project and deliver results, build a collaborative network.

A few references from the group

[1] Mercury Chalcogenides Quantum Dots: a Material Perspective for Device Integration, C. Gréboval, A. Chu, N. Goubet, C. Livache, S. Ithurria, E. Lhuillier, Chem Rev 121, 3627 (2021).

[2] Bias Tunable Spectral Response of Nanocrystal Array in a Plasmonic Cavity, T.Dang, A. Vasanelli, Y. Todorov, C. Sirtori, Y. Prado, A. Chu, C. Gréboval, A. Khalili, H. Cruguel, C. Delerue, G. Vincent, E. Lhuillier, Nano Lett 21, 6671 (2021)

[3] Ferroelectric Gating of Narrow Band-Gap Nanocrystal Arrays with Enhanced Light Matter Coupling, C. Gréboval, A. Chu, D. Vale Magalhaes, J. Ramade, J. Qu, P. Rastogi, A. Khalili, S.-S. Chee, H. Aubin, G. Vincent, S. Bals, C. Delerue, E. Lhuillier, ACS Phot 8, 259 (2021)

[4] Infrared Photoconduction at the Diffusion Length Limit in HgTe Nanocrystal Array, A. Chu, C. Gréboval, Y. Prado, H. Majjad, C. Delerue, J. F. Dayen, G. Vincent, E. Lhuillier, Nature commun 12, 1794 (2021)

[5] Reconfigurable 2D/0D p-n Graphene/HgTe nanocrystal heterostructure for Infrared detection, U. N. Noumbé, C. Gréboval, C. Livache, A. Chu, H. Majjad, L. E. Parra López, L. D. Notemgnou Mouafo, B. Doudin, S. Berciaud, J. Chaste, A. Ouerghi, E. Lhuillier, J.-F. Dayen, ACS Nano 14, 4567 (2020)

[6] Near Unity Absorption in Nanocrystal Based Short Wave infrared Photodetector using Guided Mode Resonator, A. Chu, C. Gréboval, N. Goubet, B. Martinez, C. Livache, P. Rastogi, F. Bresciani, Y. Prado, S. Suffit, S. Ithurria, G. Vincent, E. Lhuillier, ACS Photonics 6, 10, 2553-2561 (2019)