Programme for Research-Development-Innovation for
Space Technology and Advanced Research - STAR

Thin film photodetectors - new concepts and studies for aerospace applications CONDAS

Project Coordinator: Dr. Dana Cristea

Speaker: Dr. Dana Cristea

National Institute for R&D in Microtechnologies
IMT-Bucharest

Romanian Space Week , 12-16 May 2014, Bucharest, Romania

- **Coordinating organization**:

  National Institute for R&D in Microtechnologies, IMT-Bucharest

- **Project manager:**

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- **Participating teams**:
  - **Laboratory of Micro/Nano Photonics,** member of the ***European Centre of Excellence in Microwave, Millimetre Wave and Optical Devices***, (funded by FP7 programme "Capacities"). The lab *relevant expertise* includes: *modelling and simulation* of micro and nano photonic structures*; new materials* for micro-nanophotonics; *soft lithography* for photonics; development of *photodetectors on different semiconductors*, *optical and electrical characterization* of materials and devices.
  - **Laboratory for Micro- and Nanostructuring and Characterization** with expertise in *characterization and structuring methods for materials and processes* at micro and nanometre scale (AFM, SEM, Nano indentation, electron beam lithography).
  - **Reliability Laboratory** - aimed to provide tools and expertise to improve the design & technology of sensors, actuators, microsystems, nanostructures and microelectronic components by assessing and building the quality & reliability in a Concurrent Engineering approach.

Short description of the project

- **The aim** of the proposal is to *design and experiment new type of photodetectors*, with increased *photoresponse over a wide wavelength range (UV-VIS-IR)*, based on thin film semiconducting materials/composites and *to investigate the applicability of these device for space applications.*
- We will ***focus on solution processable materials*** based on graphene and/or QDs that can be easily deposed using spin coating and can readily be integrated with many substrates including as a post-process on top CMOS silicon and flexible electronics.
- ***The main challenges*** in developing commercial devices based on graphene are:
  - production of graphene-based layers in large scale
  - understanding of the photodetection mechanisms and the influence on the device lay-out and structure on the operation
  - improved and tunable absorption.
- Our ***innovative solutions*** consist in :
  - using *solution processable graphene-based materials* (reduced graphene oxide in particular, functionalized to achieve the desired optical and electrical properties) to allow the obtaining a good quality and reproducible thin layers for photodetection,
  - combining these materials with metallic nanoparticles or quantum dots to improve the light absorption and the response tunability.

Objectives

1. Concept development

- theoretical and experimental investigation of detection principles in graphene-based devices using the test structures and advanced characterization techniques
- theoretical and experimental investigation of techniques for the improvement of detection; we will apply in parallel alternative methodologies (2 approaches):
    - *plasmonic enhancement*
    - *quantum-dot photodetectors*

The concept development will be supplemented by rigorous modelling and device analysis for component optimisation and exploitation purposes.

2. Process development, including

- ***material investigation, development of new synthesis routes*** for obtaining solution processable graphene based functionalized materials with controllable optical and electrical properties (i.e. carrier mobility, opened and tunable band-gap,
- ***process flow design*** and development of individual process steps (*nano-patterning, functionalization, layer assembly and packaging)*

3.Realization of demonstrative structures

4. Characterization and demonstration of the functionality

- microphysical characterization of materials, thin layers (during the technology process) and devices
- functional characterization
    - *optoelectrical characterization* to obtain spectral responsivity, dark current, linearity, variation of the opto-electrical parameters with the temperature.

Estimated results:

- *new detector concepts*, *new material systems* that can operate well under the harsh conditions found in space applications
- *an optimised and low cost technology* that allow the fabrication of detectors and arrays of detectors.
- *new or improved characterization* techniques for *testing* photodetectors in conditions simulating the aerospace environment

Human resources involved

three complementary teams with expertise in:

1. research and development activity in the field optoelectronic devices,
2. in micro-nanotechnology and material development,
3. characterization techniques and reliability testing.

65 pm/36 months **(less than 2 persons /month full time)**

8 senior researchers+3 PhD students

(medium working time: 28 hours/month/person)

Start date of the project: November 19th 2012

End date of the project: November 18th 2015

Project Work Plan

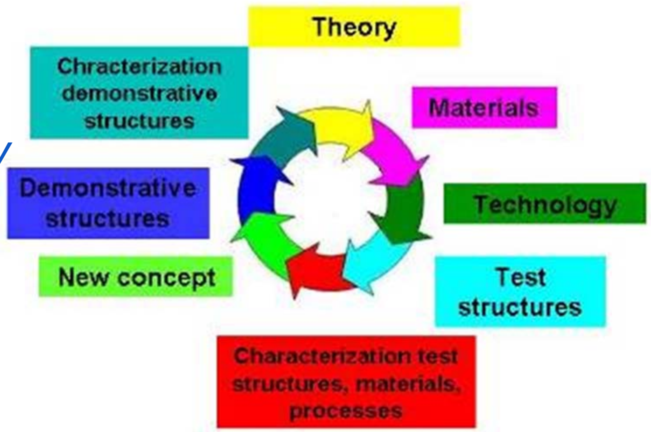
- **Phase/WP 1- Preliminary studies** (12.5 months 2012- 2013)
  - Task 1.1.Preliminary studies regarding aerospace application requirements for photodetector; Acquisition of components for up-grading the charqcterization set-up (15 days-2012)
  - Task 1.2. Experimental investigation of deposition of graphene and QDs based semiconducting layers
  - Task 1.3. Design and realization of test layers and preliminary devices
  - Task 1.4. Device studies for concept development
  - Task 1.5. Characterization-of materials, thin layers and first set of structures
  - Task 1.6. Dissemination

- **Phase /WP 2 Device optimization and nanotechnology** (12 months- 2014)
  - Task 2 .1. Process flow design and optimization
  - Task 2.2. Characterization for process and device improvements
  - Task 2.3. Optimization of the device structure and definition of the demonstrator
  - Task 2.4. Experimental realization of the demonstrative structures.
  - Task 2.5. Dissemination

Based on the characterization results (obtained in both phase 1 and 2), *the optimum structure(s) for the final demonstrator will be selected*, and the devices will be *fabricated* using the process chain already developed.

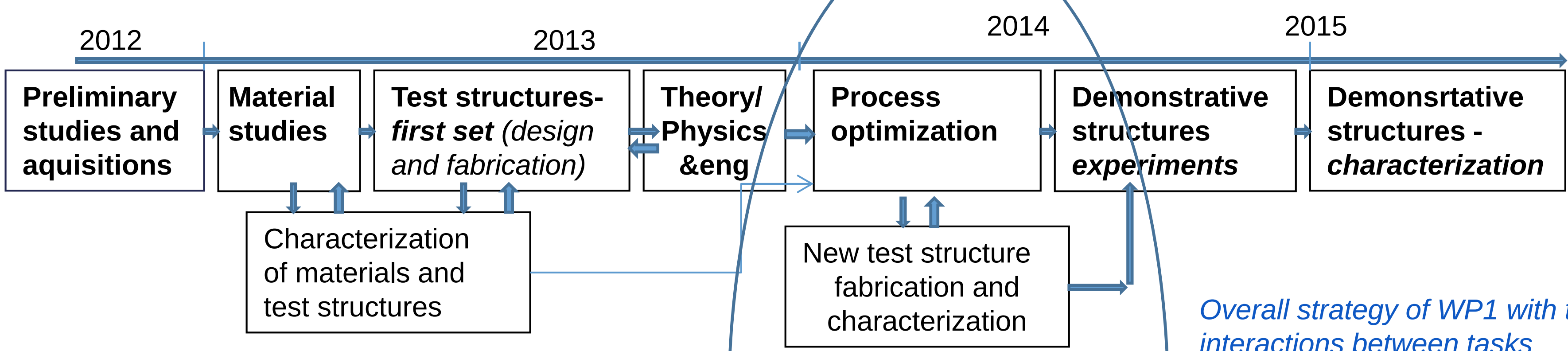
- **Phase /WP 3 Demonstration (**11 months-2015**)**
  - Task 3.1. Characterization of the demonstrative structures
  - Task 3.2. Dissemination

Project strategy



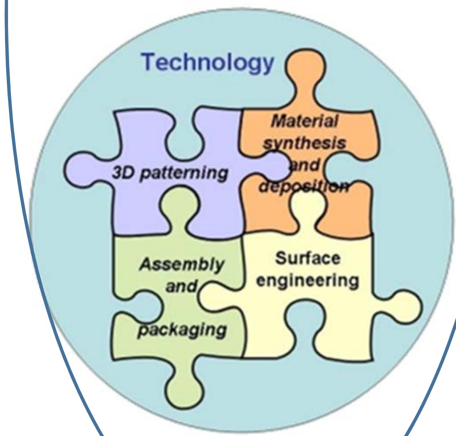
The work plan has a complex structure, including theoretical investigations, ***material development, process development and integration, characterization activities.***

Implementation status of the project



Overall strategy of WP1 with the interactions between tasks

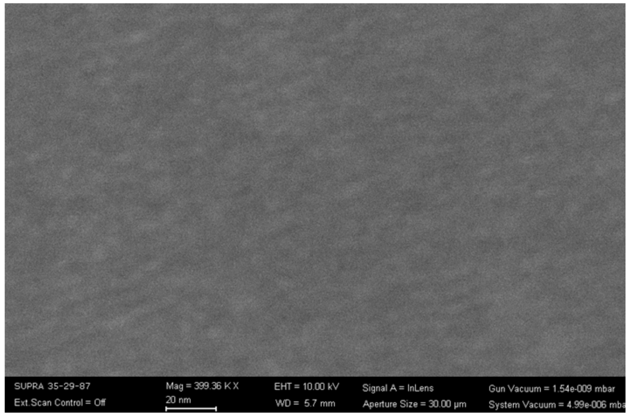
The main components of the process chain to be developed and integrated in WP2



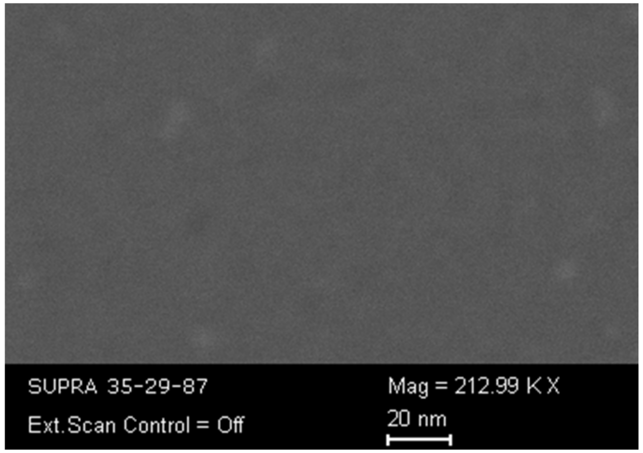
To optimize the technology process, *characterization of materials, surfaces, test devices are carried* out

Materials

Deposition of thin films of semiconducting nanoparticles and QDs (exchange of ligand)

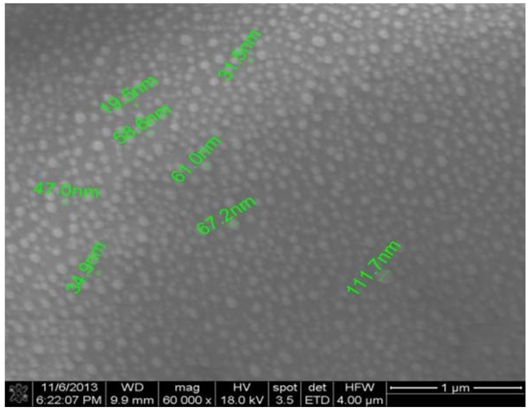


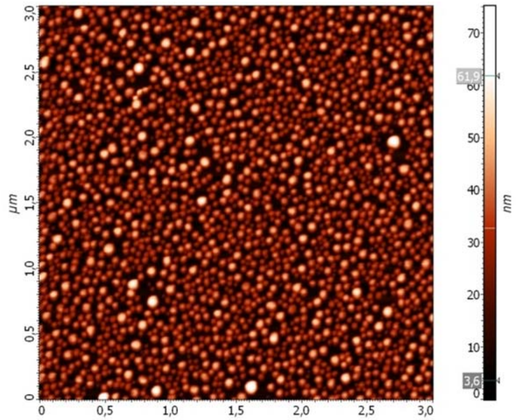
SEM image of PbS QDs with long ligand (oleic acid) (spining - monolayer)



SEM image of 6 layers of PbS QDs with short ligand (TG)

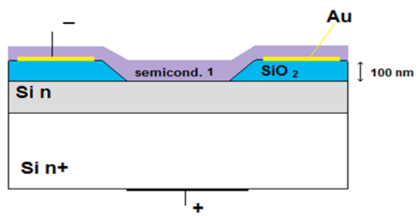
Metal nanoparticles for plasmonic structures



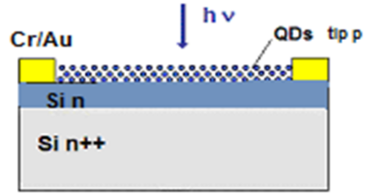


SEM and AFM image of a nanostructured Ag layer- for light trapping in the active layer of the photodetectors

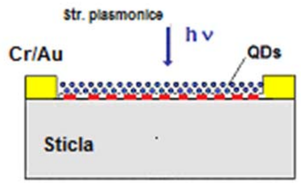
Test structures: design and fabrication (1)

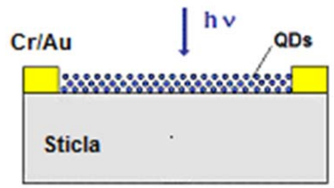


- Heterojunctions *compozite semiconductor/silicon*
  compozite: P3HT- PbS QDS, P3HT-graphene or coloidal QDs;
  Role of semicond.1- to increase sensitivity in IR
- Schottky silicon photodetector with a layer of PbS-QDs with ligand organic ligand (fig. 13.b)



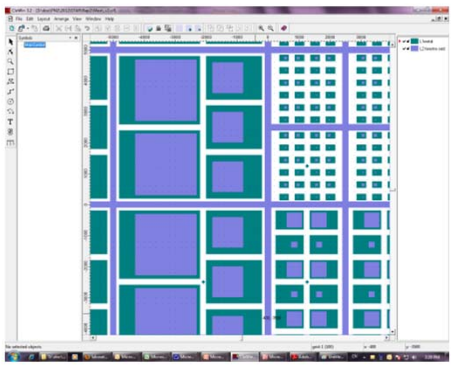
- Photoconductor based on PbS-QDs on glass



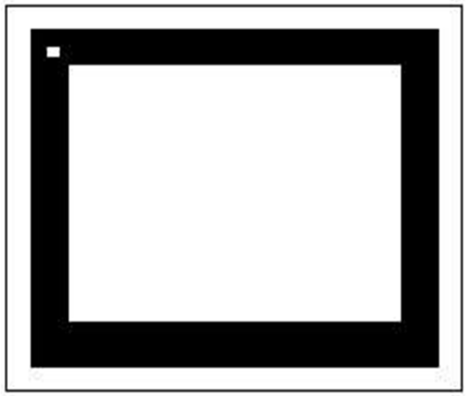


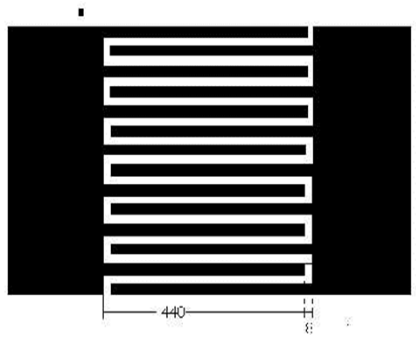
Mask lay-out

Square geometry



Detectors with interdigitated electrodes

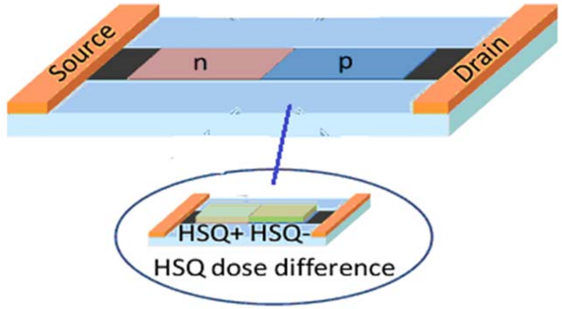


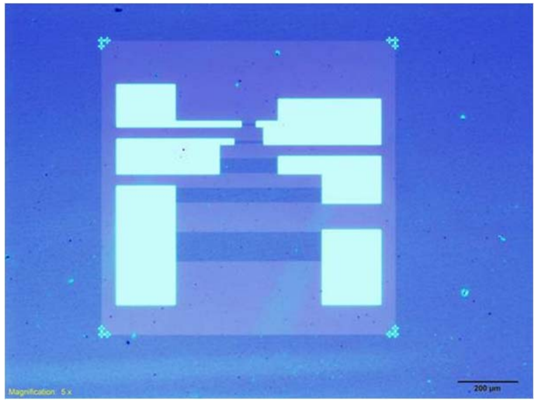


Test structures-design and fabrication (2)

Test structures for studies on the doping effect of HSQ on graphene

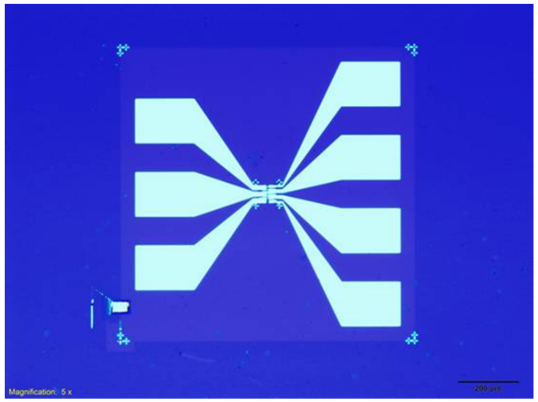
(Graphene FETs with different W and L)





Chip A

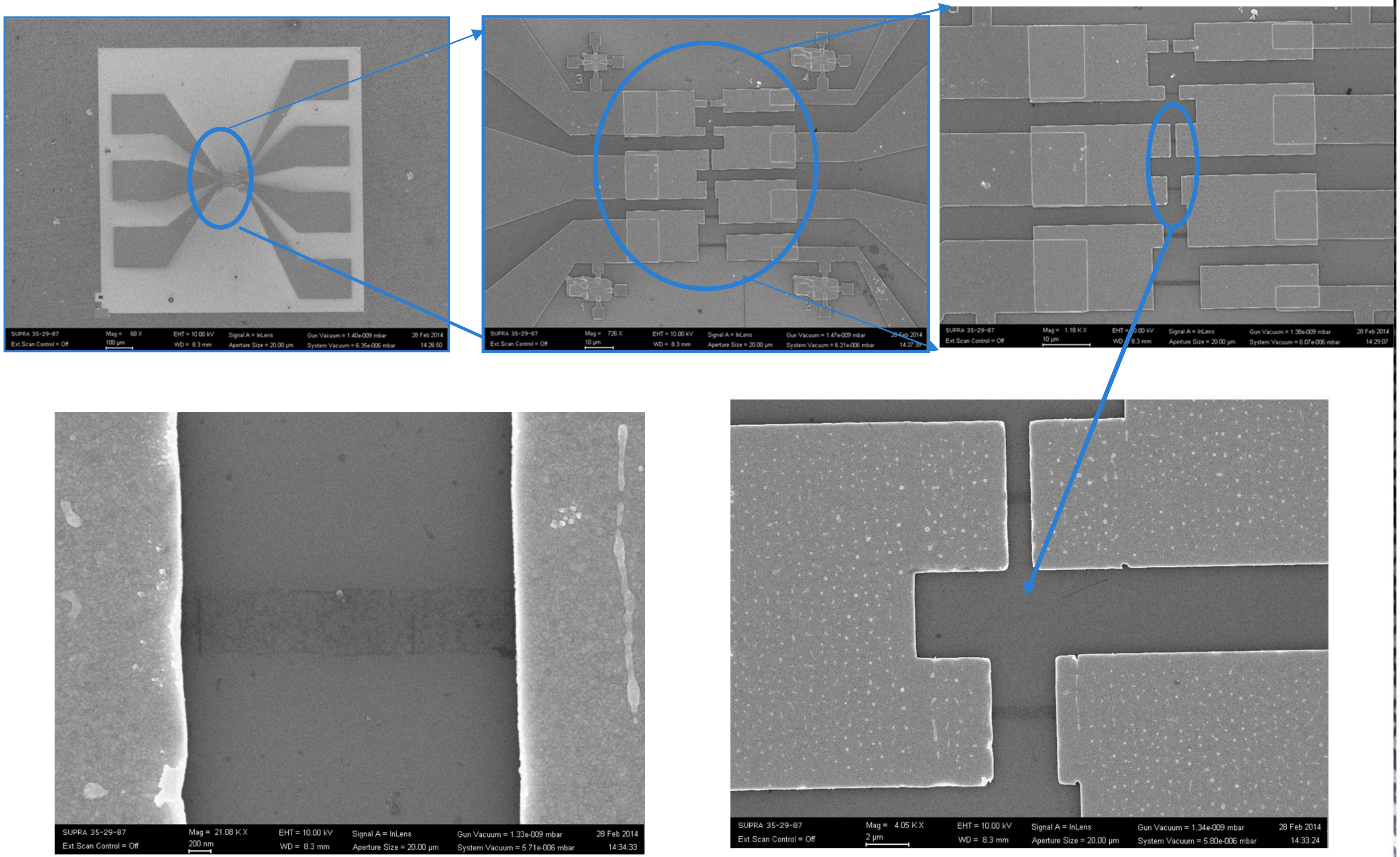
L	W
50, 100 µm	10µm
200, 500 µm	50
500 µm	100



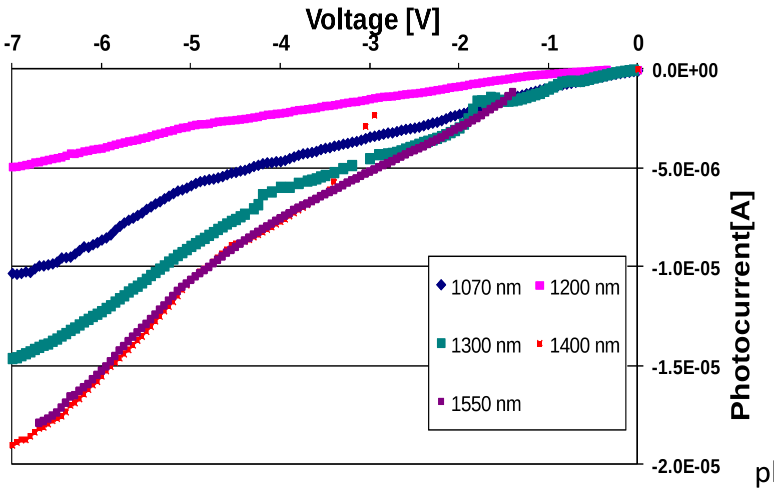
Chip B

L	W
1 µm, 3 µm	300 nm
1 µm, 5 µm	500 nm
5 µm, 10 µm	1 µm

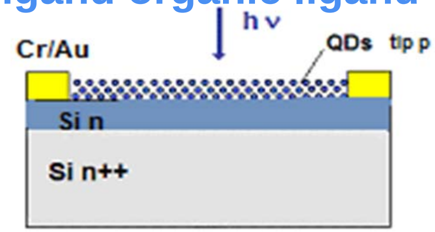
SEM images of graphene FETs (chip B) after the first step



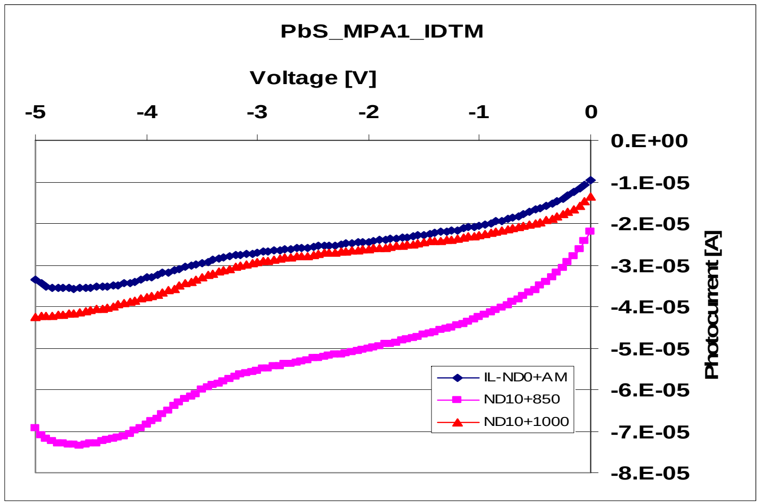
Test structures- experimental realization and characterization

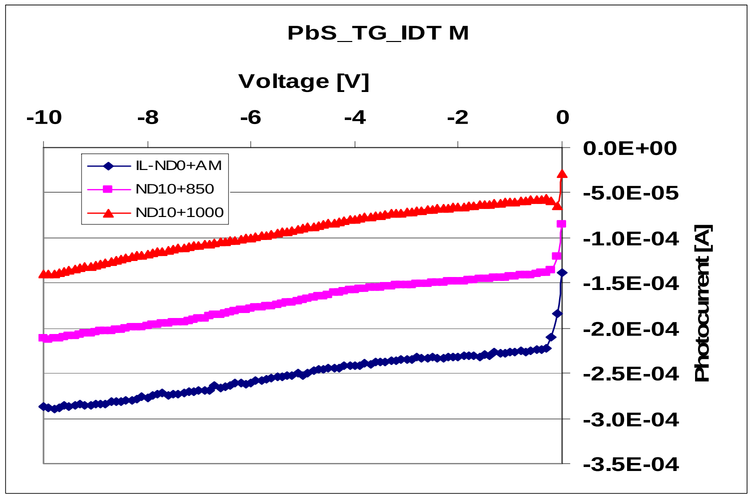


Schottky silicon photodetector with a layer of PbS-QDs with ligand organic ligand



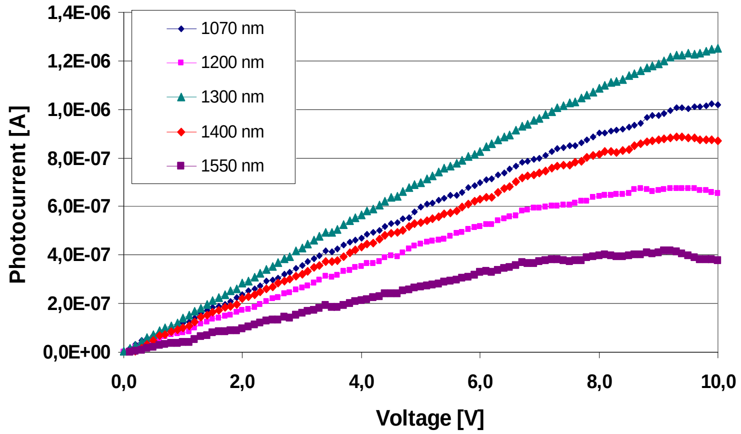
Photocurrent under IR illumination for Si Schottky photodetector with PbS-QDs (MPA Ligand) ; IDT electrodes



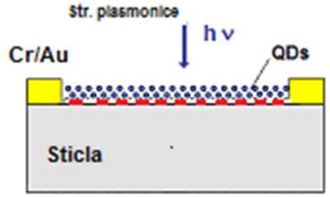


Photocurrent under IR illumination (Xenon lamp with filters) for Si Schottky photodetector with PbS-QDs (ligand MPA and TG)

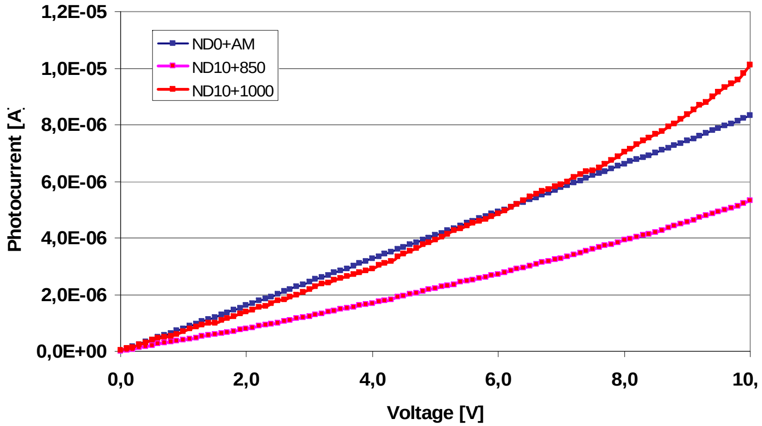
Test structures- experimental realization and characterization



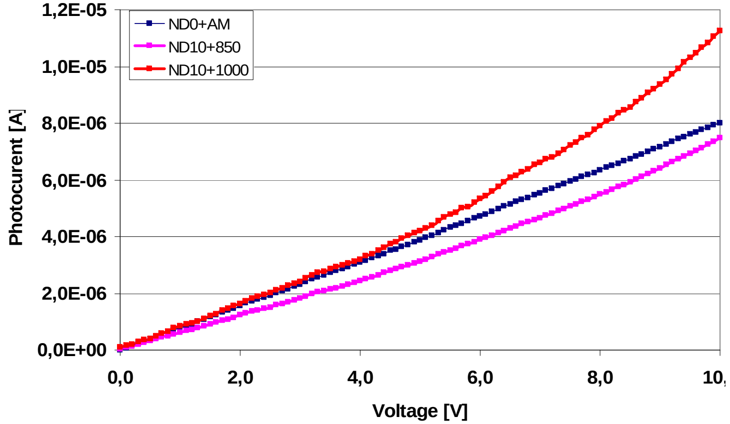
Photoconductors PbS-QDs /glass



Photocurrent under IR illumination – 1070nm, 1200 nm, 1300 nm, 1400 nm, 1550 nm) for the detector PbS-QDs (ligand MPA)/glass with Ag nanoparticles



a)



b)

Photocurrent under Vis and IR illumination (xenon lamp with different filters) for the photodetectors a) PbS-QDs (ligand MPA)/glass b) for the detector PbS-QDs (ligand MPA)/glass with Ag nanoparticles Ag.

Next steps in process/device development and optimization

- PbS/graphene/HSQ (new processe for PbS sinthesys for broad-band absorption
- Combination PbS-ZnO
- Characterization set-up improvement for IR

Contingency plan

Different types of materials and structures are developed in parallel to minimize the risks

Project's contribution to the goal of the STAR and ESA Programmes

- The aim of the proposal is demonstrate ***the proof-of-concept*** of new types of photodetectors based on thin film semiconductors, with broad spectral sensitivity (from UV to SWIR and even MWIR) for astronomy and space applications such as **hyperspectral observation, earth observations for meteorological or scientific purpose and science experiments** → the proposal is aligned with **ESA Basic Technology Research Programme (TRP)** and will allow later the participation in the **ESA's General Support Technology Programme (GSTP)**

- After we achieve TRL 2 we can apply for proposal under calls under the **Romanian Industry Incentive Scheme**

- The project is relevant also for the **ESA Science Program**, the detectors for UV to be developed being useful for the telescopes for the future science missions, i.e. Euclid and **Solar Orbiter**.

- UV-VIS IR detectors are also useful for the **Earth Observation Envelope Programme (EOEP) for sensors and imaging systems (SENTINEL 2…5)**

- Development of state-of the art photodetectors will increase the visibility of our institution in EU and will become a credible partner in ESA s and H2020 projects (i.e. European Research infrastructures)

Dissemination activities

- **Web-site**: http://www.imt.ro/condas/
- **Oral presentation** **in** ***E-MRS Spring Meeting 2013***, Strasbourg, France 27-31 May, Symposium J ***Semiconductor nanostructures towards electronic and optoelectronic device applications – IV***
  - ***Solution-processable graphene-based nanocomposites for UV-Vis-IR photodetectors***
    Authors: Dana Cristea, Cosmin Obreja, Paula Obreja, Iuliana Mihalache, Raluca Gavrila
- ***Poster prezentation in*** **Consultation Workshop on Micro-Nano-Bio Convergence Systems,** MNBS 2013, 24th-25th September 2013, in Cork, Ireland

  Research results on nanocomposite materials and processing technologies for integration of photonic components with MEMS

  Authors: D.Cristea, P.Obreja, A.Dinescu, C. Obreja, R.Gavrila, M.Purica
- Oral presentation - ***5th EOS Topical Meeting on Optical Microsystems (OμS'13)***, 12-14 September 2013, Italy

  Graphene-P3HT nanocomposite/n-type silicon photodetectors

  Authors: Dana Cristea, Cosmin Obreja, Paula Obreja, Raluca Gavrila

Planned:

- Poster to be presented at ***ESA industry Space Days-*** June 3rd-4th , 201, 4ESTEC Noordwijk, The Netherlands
- Participation in conference (nanotechnology)

Conclusions

- A new set of ***nanocomposites, thin layers,*** *and* ***devices*** have been obtained and characterized
- Different types of materials and structures are developed in paralel to minimize the risks
- The devices based on heterojunction Si/hybrid nanocompozite based on PbS QDs and/or graphene show good photosensitivity in the spectral domain 400-1500 nm
- The experiment results will be used for the selection, optimum design and fabrication of the demonstrative structures