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

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

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National Institute for R&D in Microtechnologies
IMT-Bucharest

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- 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-NIR-SWIR*), 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*
    - *graphene/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, NEP, variation of the opto-electrical parameters with the temperature.
    - *reliability tests* to verify the behaviour in aerospace applications of photodetectors based on new thin film semiconductors

Estimated results:

- *new detector concepts*, *new material systems* that can operate well under the harsh conditions found in space applications and
- *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

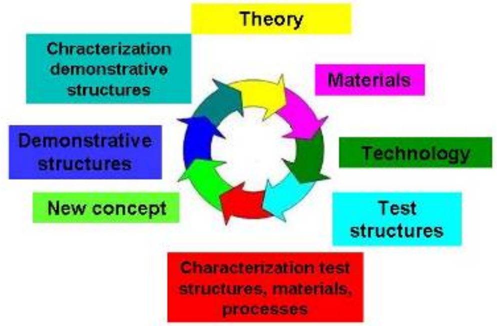
(medium working time: 28 hours/month/person)

Start date of the project: November 19th 2012

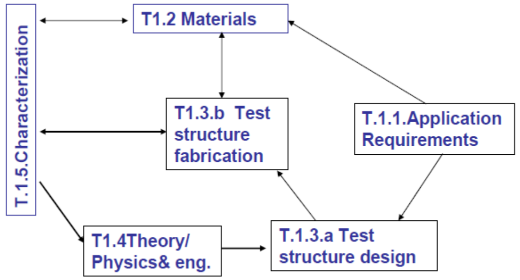
End date of the project: November 18th 2015

Project Work plan

Project strategy



- **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 and doping of graphene 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**



Overall strategy of WP1 with the interactions between tasks

- **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.

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

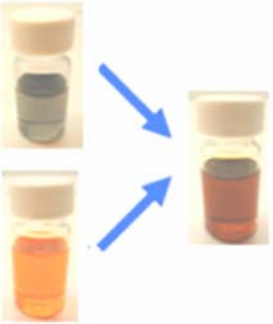
- **Phase /WP 3 Demonstration (11 months-2015)**
  - **Task 3.1. Characterization of the demonstrative structures**
  - **Task 3.2. Dissemination**

Implementation status of the project (1)

- 2012 (15 days) - preliminary studies and acquisition of components (IR light sources, calibrated detectors for IR, optical components(filters, gratings) to extend the capabilities of the set-up for photodetectors characterization in IR)
- 2013
  - **Task 1.2. Experimental investigation of deposition and doping of graphene 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**

Results (1)

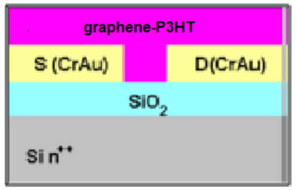
- optimization of the process for obtaining preparation of the composite films from *functionalized graphene and poly (3-hexylthiophene)*
- preliminary test devices



Organic field effect transistors (OFET)

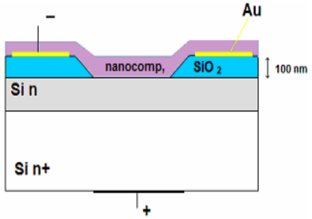
on silicon substrate- for testing the nanocomposite

- *Substrate (gate):* high conductivity Si
- *Gate dielectric:* SiO_2 300nm-thick or Si_3N_4 240 nm thick
- *Interdigitated gold electrodes* for drain and source (bottom contact configuration).
- *Active layer* : spin-coating lof nanocomposite solution in chloroform/ DCB in glove box under N2 atmosphere + annealing (160°C for 15 minutes in the oven under nitrogen)- thickness ~ 10-20 nm



Photodetectors nanocomposite/siliconSilicon

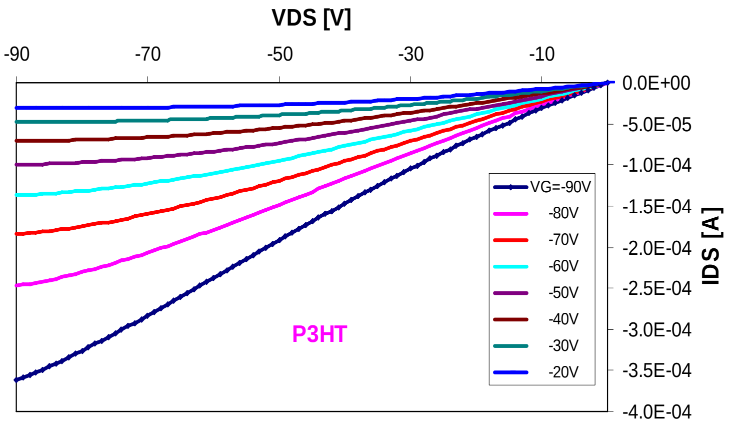
- *n/n+ Si substrate*
- *P-type layer* : spin-coated IRGO-P3HT solution in chloroform/ DCB in glove box under N2 atmosphere + annealing (160°C for 15 minutes in the oven under nitrogen).
- *Field dielectric- SiO2 100 nm thick*
- *Electrodes- Au*

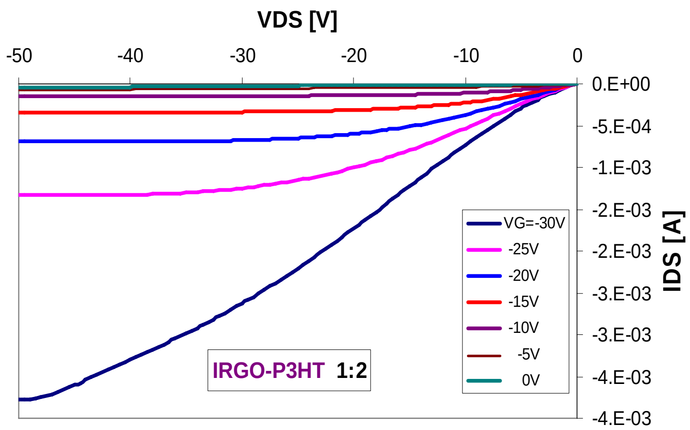


Implementation status of the project(2) - *Materials and device characterization*

Characterization of FET with graphene-P3HT nanocomposite as active layer

I-V characteristics in dark





The composite shows p-type behaviour

Characterisation under illumination

R~ 2 mA/W / λ= 404....435 nm

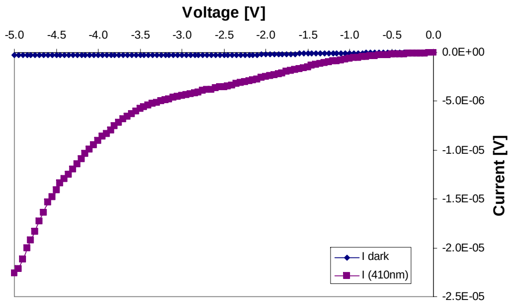
R -10 mA/V / / λ= 600-900 nm

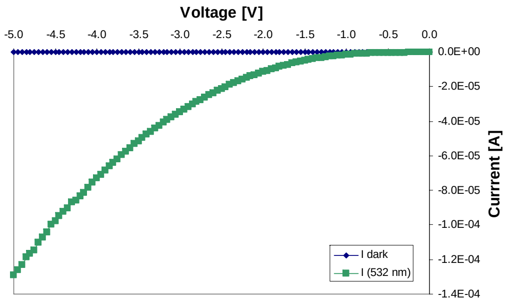
R~1 mA/W / λ= 1550 nm

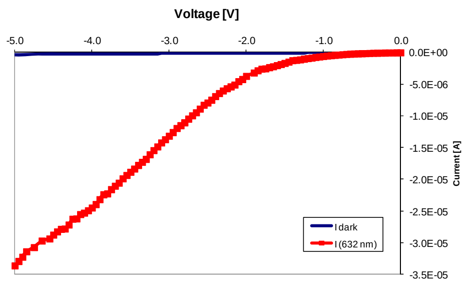
Implementation status of the project(3) - *Materials and device characterization*

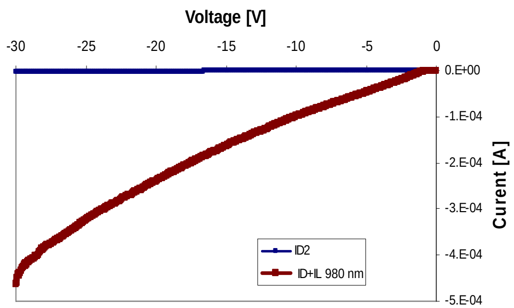
Characterization of the photodetectors
graphene nanocomposite /silicon

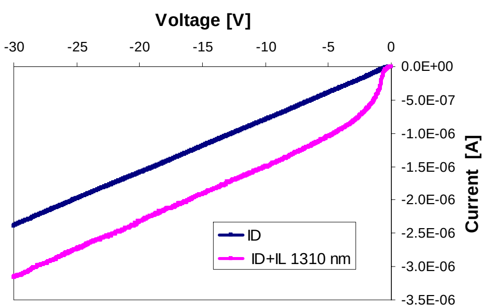
Examples of I-V characteristics (in dark and under illumination at different wavelengths

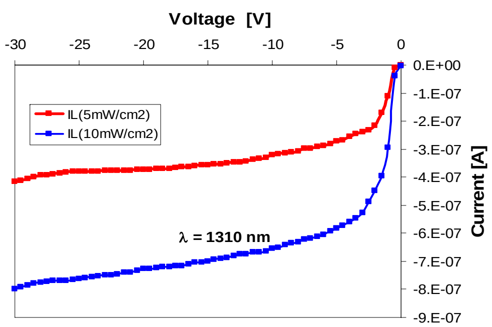












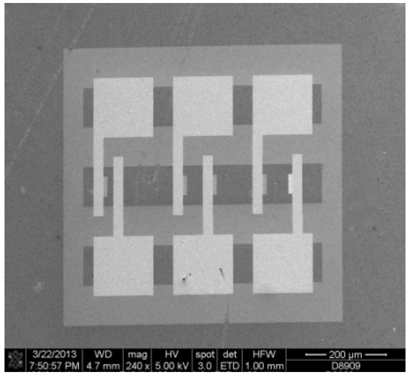
Responsivities

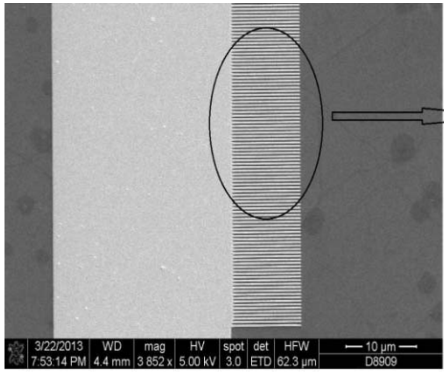
λ[nm]	R[A/W]
410	~8
532	~6
632	~25
980	17….22
1200-1550	0.01…0.03

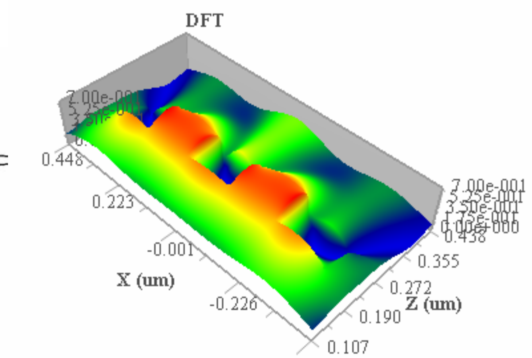
Transistor (npn) –like operation (possible n-doping of IRGO under metal contact)

Implementation status of the project(3) – *Alternative test devices*

A. Grephene-based device with plasmonic enhanchment



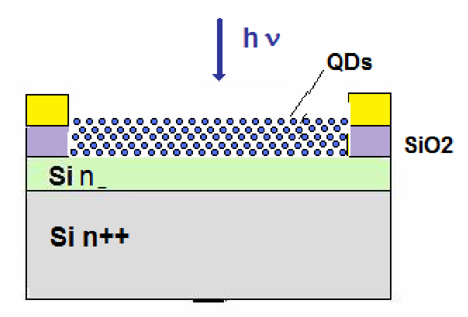




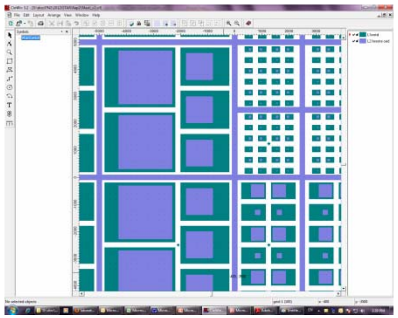
SEM images of the test structures

Simulation results indicating the plasmonic effect that offers an enhancement in the radiation intensity that is coupling in graphene under the nanostrucured metallic layer

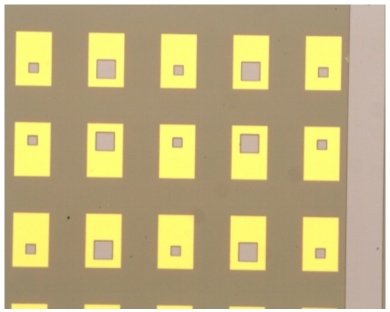
B. **Quantum-dot based devices**



Proposed test structure



Masks lay-out



Optivcal image of the device before QDs deposition

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- Risk analysis and contingency plan (lessons learned)

  - After only 5 months it is difficult to present the lessons we have learned
  - To minimize the risks we develop in parallel several types of structures- as presented before

- Project’s contribution to the goal of the STAR Programme

  - 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 projects

- Dissemination activities

  - Web-site under construction
  - 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

  - Planed activities-
    - participation in 1st EOS Topical Meeting on Optics at the Nanoscale- Italy-Sept. 2013
    - Journal paper

- Conclusions

  - All the activities planed for 2013 have been started
  - A first set of nanocomposites, thin layers and devices have been obtained and characterized
  - Promising results have been obtained- detectors with good response over a large spectral domain 400-1500 nm
  - New test structures are under development