RAPPORTO FINALE SUI RISULTATI DEL PROGETTO COMUNE DI RICERCA
FINAL REPORT ON RESULTS OF JOINT RESEARCH PROJECT

1. Accordo /Agreement

CNR / ...ANAS.....

anni/ years …2016-2017…..

2. Titolo del progetto

2. Title of the project
Germanium on silicon tunable sensors for visible and near infrared bands and explosive detectors based on germanium and carbon nanostructures

Parole chiave (massimo 3)

Key words (max. 3)
Germaniun infrared sensors, nanostructure based sensors for explosives

(solo per parte italiana)
Area scientifica / Scientific area (tabella 1/ table1)
Dipartimento Information Technology, Energia and Trasporti (DIITET)

3. Responsabili del progetto
Project leaders

Responsabile italiano **Claudio Ferrari**	**Project leader** **Sevda Abdullayeva**
istituto di appartenenza Istituto IMEM indirizzo Parco Area delle Scienze 37/A 43124 Parma Italy	affiliation Institute of Physics, Azerbaijan National Academy of Sciences address AZ-1143, H.Javid ave., 131 Baku (Azerbaijan)

4. Obiettivi del progetto

1)

2)

3)

4)

4. Aims of the project

1) A silicon/Germanium (Si/Ge) sensor for operation in both the visible and the near-infrared

2) Doped Germanium nanowires for the preparation of field effect transistors (FET) for ultra-high sensitive explosive detectors using gold as catalyst

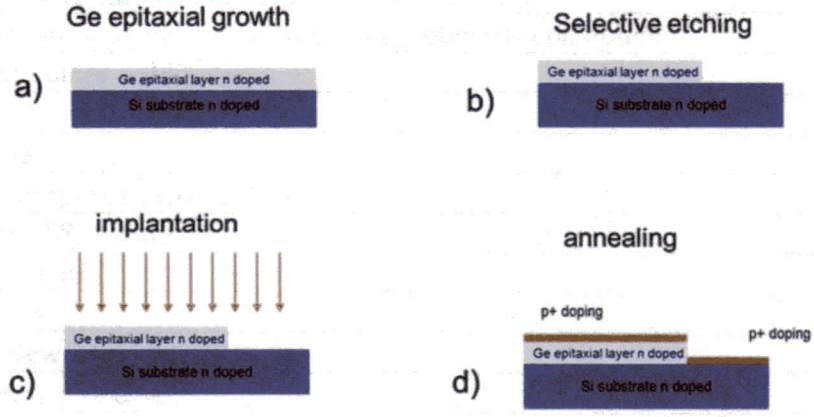
3) Carbon nanotubes (CNT) will be grown by the Aerosol CVD technique (ACVD) to obtain single walled and monodispersed nanotubes to be used as explosive detector device

5. Risultati ottenuti per obiettivo (1 pagina)

5. Achieved results (one page)

1- **Germanium on silicon tunable sensors for visible and near infrared bands**

The first goal of this project is to develop a semiconductor voltage-tunable sensor for visible and near-infrared bands integrated on the same chip, fabricated using Germanium on Silicon technology with a novel design of light detecting. The scheme of the proposed device is the following, in which two p+n junctions are obtained by implantation on silicon and germanium.



We proposed a new approach based on dopant implantation, specifically by boron implantation on n doped Ge epilayer and silicon substrate.

To study the effect of implantation (a process that was proposed only very recently) the implantation has been performed at IMM Institute of CNR of Bologna on a germanium substrate. A germanium wafer n doped $1x10^{17}cm^3$, was split in two samples. The implantation dose has been chosen in order to obtain a 200 nm thick p+ doped zone. The implantation specie was boron.

The implanted samples have been used to realize diodes and infrared sensors by means of contact deposition and selective etching. The test is progress.

2-Explosive detectors based on germanium and carbon nanostructures

Semiconducting nanowires can detect TNT down to a detection limit of $\sim 1x10^{-6}$ ppt by surface functionalization with an electron-rich amino-silane which binds the electron-deficient explosive molecules of TNT through charge-transfer donor-acceptor interactions thus causing sharp changes in the conductance of the electrical-sensing nanoelements.

Functionalized single-walled carbon nanotubes (SWNT) are highly responsive to their physical and chemical environment. SWNT are unique among nanoscale sensor platforms in their ability to detect the adsorption of as few as a single molecule of an analyte. Single-walled carbon nanotubes (SWNT) may be covalently functionalized with urea, thiourea, and squaramide. Carbon nanotube (CNT) based chemiresistors display promising performance in explosive sensing. CNT chemiresistors can be deposited between electrodes by evaporation or dispersions, or can be effectively drawn from compressed CNT solids.

Germanium nanowires and single and multiple walled nanotubes have been obtained at IMEM Institute and Institute of Physics in Baku respectively.

In this part of the project we concentrated to the techniques to be used to functionalize the nanowires and the carbon nanotubes. From literature we have found the method of functionalization of Si and Ge nanowires by 3-aminopropyltriethoxy silane (APTES).

Sensors based on carbon nanotubes

The carbon nanotubes were grown by aerosol CVD technique facility at the Institute of Physics in Baku and were subsequently characterized by x-ray diffraction and transmission electron microscopy at IMEM institute in Parma. First, amino groups were attached to the sidewall of single-walled CNTs (SWCNTs) via thermal aziridination. The resulting NH 2 –SWCNTs are then allowed to react with a second reagent containing the desired selector.

Simple sensors will be obtained by depositing the functionalized carbon nanotubes on a contact pad.

6. Prodotti del progetto / Results obtained

	n./no.
Pubblicaz. scient. su riviste internaz./ scientific publications on international reviews con IF-----**3**----- senza IF	3
Pubblicaz. in atti congressi internaz./ publications in international congress proceedings	
Pubblicazioni in atti congressi nazionali / publications in national congress proceedings	
Pubblicazione libri nazionali / Publication of national books	
Pubblicazione libri internazionali / Publication of international books	
Altre pubblicazioni / other publications	
Brevetti / Patents	
Prototipi / Prototypes **2**	2
Strumentazione / Equipment and /or Devices	
Programmi software / Software	
Banche dati / Data bases	
Protocolli / Protocols	
Nuovi Materiali / New Materials	2
Nuovi processi / New processes	2
Cataloghi/inventari/repertori / Catalogues/Inventories	
Atlanti/Carte/Mappe / Atlases/Charts/Maps	
Progetti di ricerca / Research projects **1**	1
Trasferimento innovazioni / Knowledge transfer	
Laboratori congiunti / Joint laboratories	
Alta formazione / Training	
Altro / Other **3 seminars**	3

7. Informazioni dettagliate sui risultati indicati sub 6

7. Detailed information on results indicated under point 6

Publications:

1. S.Abdullayeva, N.N.Musayeva, C.Frigeri, A.B.Huseynov, R.B.Jabbarov, R. B.Abdullayev, Ch.A.Sultanov,R. F.Hasanov "Characterization of high quality carbon nanotubes synthesized via Aerosol –CVD". Journal of Advances in Physics, 2015, Vol. 11, No. 4, pp.3229-3240
2. S.H.Abdullayeva, N.N.Musayeva, C.Frigeri, A.B.Huseynov, R.B.Jabbarov, R.F.Hasanov. Optimization of synthesis condition for high quality carbon nanotubes.Azerbaijan Journal of Physics, Volume XXII, No 1. Section: En 2016, p. 11-14
3. S. H. Abdullayeva, A.B. Huseynov, N. N. Musayeva, R.B. Jabbarov, A.D.Guliyev, Ch.A. Sultanov, R.F. Hasanov. Carbon nanotubes dispersion in polymers by two-factor mechanical method/ Advances in Materials Physics and Chemistry, v.7 number 11, 2016, pp.291-304
4. S. H. Abdullayeva, N. N. Musayeva, R.B. Jabbarov, C.Frigeri, C.Ferrari, G.Attolini, C.A. Sultanov, G.Gahramanova. Electrochemical Sensing of Explosives by functionalized CNTs. *(submitted to* World Journal of Nano Science and Engineering, June, 2017)

Seminars during the 2016-2017 period

- seminar at Institute of Physics, Baku on 30 October 2016, "Sensors for explosives based on germanium nanowires and carbon nanotubes"
- seminar at IMEM Institute on 22nd of June 2016 "Sensori per esplosivi basati su nanofili di germanio e nano tubi di carbonio"
- seminar at IMEM Institute 24th of May 2017 "Preparation of the NATO project "Portable sensors for unmanned explosive detection"

Reports

Relazione scientifica primo anno del progetto bilaterale tra Istituto IMEM-CNR e Accademia Azera delle Scienze (ANAS) "Germanium on silicon tunable sensors for visible and near infrared bands and explosive detectors based on germanium and carbon nanostructures", C. Ferrari, Nahida Musayeva
15th of January 2017

Prototypes

Samples of doped germanium nanowires
Samples of multi-walled carbon nanotubes

New processes

Method for the growth of p-doped germanium nanowires
Method for the growth of carbon nanotube (several grams per run)

Projects

Proposal to the NATO call "Science for Peace and Security Programme".

Title of the project "portable sensors for unmanned explosive detection".
Abstract
The projects aims to the preparation of portable sensors for explosives based on semiconductor nanowires or carbon nanotubes. Nanostructures permit the preparation of sensitive, very compact and lightweight chemical sensors that can be carried by unmanned vehicles such as drones to be used to explore dangerous sites without the direct human intervention. Devices based on functionalised nanostructures have the advantage of very low electrical consumption, high chemical sensitivity, simple technology

8. Formazione di giovani ricercatori
Training of young researchers

Dr. Matteo Bosi
Seminar at Institute of Physics, 26 October 2016
Optimization of germanium on silicon heterostructures MOCVD grown by using iBuGe as a precursor

9. Motivazione degli sviluppi della collaborazione negli anni successivi
(eventuali estensione ad altri paesi, collaborazioni multilaterali, contratti nazionali o internazionali)

9. Reasons for cooperative project developments in the following years, if any
(extension to other countries, multilateral collaboration, national or international contracts

A new NATO project has been submitted aimed at the development of sensors for explosives to be proposed to NATO program "Science for Peace and Security Programme" (http://www.nato.int/cps/en/natolive/78209.htm).

Even in case of successful presentation the bilateral agreement will permit to keep alive a successful scientific cooperation until the start of the program.

Claudio Ferrari

(firma del responsabile italiano del progetto)

(signature of the … project leader)
(anche fax)

IL DIRETTORE IMEM - CNR
Dr. Salvatore Iannotta

(firma del direttore)

date: 28/06/2017