2D-NANOLATTICES

FP7-ICT-2009-C (FET Open)

Highly anisotropic graphite-like semiconductor/dielectric 2D nanolattices

Deliverable D5.1

Dissemination and Use Plan

Report

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Contributors: All

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Project Coordinator: NCSR- D (*Dr. A. Dimoulas*)

Contractors: IMEC, KULeuven, CNR, CNRS, U. de Provence

Project funded by the European Community under the "Future and Emerging Technologies" Programme

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This deliverable will be updated periodically as described in the Gantt chart in ANNEX I/DoW. Due to the short time elapsed from the start of the project, the first version of D5.1 contains very few actual dissemination actions, while most of the material presented here concerns plans for dissemination and use targeting the first 18 months.

Part A: Dissemination

A.1 Publications in International Journals

We give below 2D-NANOLATTICES member publications or articles in preparation which are relevant to the 2D-NANOLATTICES research topics.

a) First reporting period

i) Planned/in preparation

Patrick Vogt, Paola de Padova, Claudio Quaresima, José Avila, Emmanouil Franzeskakis, Maria Carmen Asensio, **Andrea Resta**, **Bénédicte Ealet** and **Guy Le Lay**, "Silicene: The discovery of graphene-like 2-Dimensional silicon", *should be submitted before Nov. 30, 2011*

ii) Already published/accepted

1) **M. Houssa**, E. Scalise, K. Sankaran, G. Pourtois, V.V. Afanas'ev, and A. Stesmans, "Electronic properties of hydrogenated silicene and germanene", Appl. Phys. Lett. 98, 223107 (2011).

2) E. Scalise, **M. Houssa**, V.V. Afanas'ev and A. Stesmans, "Strain-induced metal-semiconductor transition in monolayer and bilayer MoS2", to be published in Nano Res. (2011).

b) Second reporting period
To be completed in due time, at the end of second period

c) Third reporting period
To be completed in due time, at the end of third period

A.2 Conferences and Invited Presentations

1) First reporting period

i) Already given

Guy Le Lay: Invited presentation Japan-UK workshop on Graphene Synthesis and Characterisation for Applications Workshop , Windermere lake, UK, Nov. 15-18, www.lancs.ac.uk/depts/esqn/WindermereWorkshop/ "Silicene: Dirac fermions in atom-thin epitaxial honeycomb silicon Sheets"

Guy Le Lay: Oral presentation " Silicene epitaxial sheets" with P. Vogt, P. De Padova, C. Quaresima, J. Avila, E. Frantzeskakis, M.C. Asensio,B. Ealet AVS 58th Int. Symposium, Nashville, Tn, USA, Oct. 30 – Nov. 4, 2011

Guy Le Lay, Oral presentation "Epitaxial silicene sheets" with P. Vogt, P. De Padova, C. Quaresima, J. Avila, E. Frantzeskakis, M.C. Asensio, NANOSMAT, Krakow, Poland, October 17-20, 2011

Patrick Vogt, oral presentation "Formation of 2D hexagonal silicon monolayers on Ag(111): a graphene-like structure" with P. De Padova, M. E. Davila, M. Cei, A. Pietsch, F. Hennies and **G. Le Lay** at the Int. Conf. on the Formation of Semiconductor Interfaces (ICFSI-13), Prague, Czech Republic, July 3-8, 2011

Patrick Vogt, oral presentation "Formation of 2D hexagonal silicon monolayers on Ag(111): a graphene-like structure" with P. De Padova, M. E. Davila, M. Cei, A. Pietsch, F. Hennies and **G. Le Lay** at the European Conference On Surface Science (ECOSS-28) Wroclaw, Poland Aug. 28-Sept. 2, 2011

Guy Le Lay, invited talk "Silicene and prospects for other graphene-like nano-lattices" at the Int. Conf. on the Formation of Semiconductor Interfaces (ICFSI-13), Prague, Czech Republic, July 3-8, 2011

Paola De Padova oral presentation "Electronic structure of honeycomb silicon sheets on silver (111)" with P. Vogt, C. Quaresima, B. Olivieri and **G. Le Lay** at the 11th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures October 3-7, 2011 St. Petersburg, Russia

Patrick Vogt invited talk "Honeycomb 2D silicon monolayers on Ag(111): a possible formation of silicene" with P. De Padova and **G. Le Lay** at Optics of Surfaces and Interfaces (OSI-9) Akumal, Mexico, Sept. 19-23, 2011

M. Houssa, E. Scalise, K. Sankaran, G. Pourtois, V.V. Afanas'ev, and A. Stesmans, "Hydrogenated silicene and germanene: A first-principles study", presented at the 7th International Conference on Si Epitaxy and Heterostructures (Leuven, September 2011).

1) Second reporting period

To be completed in due time, at the end of second period

2) Third reporting period
To be completed in due time, at the end of third period

A.3 Workshop Conferences organization

Planned: Following a proposal by Alessandro Molle of CNR, a symposium proposal for the EMRS 2013 in Strasbourg has been submitted. The symposium titled "*The route to post-Si CMOS devices: from high mobility channels to graphene-like 2D nanosheets*" will emphasize 2D lattice structures like $MoSe_2$, hexagonal BN, hexagonal Si and Ge, layered structures like Bi_2Se_3 and Bi_2Te_3 all with electronic structure and physical properties similar to graphene. The latter will also be included as one of the subtopics. As such, the symposium will be relevant to the 2D-NANOLATTICES themes and it will provide an opportunity to disseminate project results and enhance its visibility. 2D NANOLATTICES members, A. Molle (CNR), leading organizer, G. Le Lay (U.de Provence/CNRS) and A. Dimoulas (NCSRD) are in the organizing committee. Prof. Max Lemme (KTH) from the graphene community has been invited (and accepted) to participate in the committee. 2D-NANOLATTICES will sponsor the symposium from the coordinator's management funds.

A.4 Press release

We have published two press releases:

- Press Release #1: *Nanotechweb*

http://nanotechweb.org/cws/article/yournews/46230

YOUR NEWS

Jun 9, 2011

Silicene: a new "fabric" for nanoelectronics made of the same raw material, silicon

Silicon is the basic semiconductor material from which modern electronics is built. However, as nanoelectronic integrated circuits become smaller and denser for economic reasons, the devices made from silicon do not run as fast and consume excess power.

To overcome the problem, researchers in Europe want to use the same raw material, silicon (Si), to make a totally new "fabric" called silicene which is essentially a twodimensional (2D) lattice made of a single layer of Si atoms in an hexagonal arrangement looking like a honeycomb (Fig. 1). The term silicene is inspired from the famous graphene, the 2010 Nobel Prize winner material, which forms the equivalent 2D honeycomb lattice made out of carbon atoms. Leaders in silicene-like materials research from CNRS-CINaM and Université de Provence, Marseille and KU, Leuven have come together with MOS device experts from IMEC, Leuven, CNR-IMM/MDM, Milano, and NCSR DEMOKRITOS, Athens to explore silicene as one of the many options for the post-CMOS devices of the future.

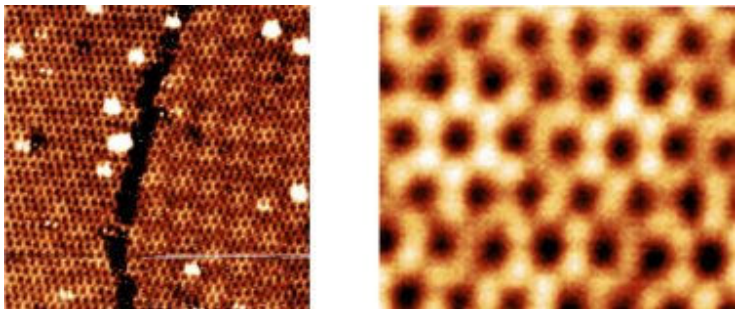

Fig. 1.

The consortium has put together a project named 2D-NANOLATTICES which started on 1st June 2011 and is funded by the EU 7th Framework Program in Future and Emerging Technologies (FET). Coordinated by NCSR DEMOKRITOS, the team aims at showing in three years from now that it is possible to engineer silicene and that this new 2D Si allotrope has better properties than conventional bulk Si for field effect electronic devices.

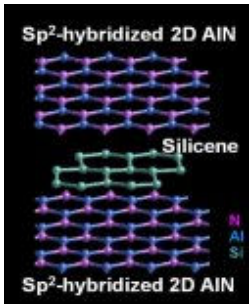

Fig. 2.

The task is difficult because silicene, which does not exist in Nature, is not as easy to form as graphene for reasons which may be related to the larger Si atom size and the specifics of its electronic structure. However, it seems that silicene-like material can be engineered if suitable metal substrates are used. As many of us, humans, silicene has an intimate relation with silver (Ag). Professor Guy Le Lay, a 2DNANOLATTICES consortium member and his coworkers, have obtained strong evidence of silicene-like monolayer sheets grown on single crystalline Ag (see Fig. 1), although it is not certain yet whether these layers form true silicene equivalent to graphene. One of the goals of the project is to unambiguously prove the existence of silicene and understand why Ag and possibly other metals are so “friendly” to it. On the other hand, metal substrates are not suitable for devices because they screen the electric fields and nullify field effects which are at the heart of the operation of present day electronic devices. Therefore, in 2DNANOLATTICES we will look for alternative substrates and capping layers with insulating properties to encapsulate silicene (Fig. 2). These insulating materials made for example from aluminum nitride are designed to be very similar to silicene in the way atoms bond to each other to form layered structures. Moreover, they will be bonded to silicene with weak van der Waals forces so that they can offer a “safe shelter” to silicene (Fig. 2) allowing electric charge to flow fast and undistracted in the plane as in the case of graphene.

The consortium members believe that the work in 2D-NANOLATTICES is not merely a replication of graphene properties with silicon instead of carbon atoms. The project goes beyond that exploring a number of other potential 2D nanolattices and their combinations to show that 2D materials beyond

graphene can be created with potentially new properties for useful devices. The 2D world of nanolattices offers not only high speed but also a natural confinement of electronic transport in just one monolayer of lattice atoms, facilitating its manipulation in a very efficient way. This could make 2D nanolattices the ideal materials base for the future electronic devices offering high speed and low power /energy operation at the same time, the "holy grail" of nanoelectronics.

Source:
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- Press release #2: *EE Times Europe*
  http://www.electronics-eetimes.com/en/search.html?query=2D-NANOLATTICES

Technology News

2D Nanolattices project to explore Silicene as a new "fabric" for nanoelectronics

June 10, 2011 | Julien Happich | 222907789

Silicon is the basic semiconductor material from which modern electronics is built. However, the same raw material could be used to build a totally new "fabric" called silicene, essentially a two-dimensional lattice made of a single layer of Si atoms arranged in a hexagonal pattern very much like the atoms of carbon in graphene.

At a research stage, a two-dimensional, atom-thin silicon layer on a dense silver surface Ag(111) has been demonstrated at PCSI 2011, San Diego. The silicene layer exhibited a honeycomb arrangement like in graphene from which the new fabric's name has been inspired. Leaders in silicene-like materials research from CNRS-CINaM and Université de Provence, Marseille and KU Leuven have come together with MOS device experts from IMEC, Leuven, CNR-IMM/MDM, Agrate near Milano, and NCSR Demokritos, Athens to explore silicene as one of the future materials of electronics beyond CMOS devices.

The consortium has put together a project named 2D-Nanolattices, which started on the 1st of June 2011, funded by the EU 7th Framework Program in Future and Emerging Technologies (FET). Coordinated by NCSR Demokritos, the initial goal of this project is to examine the electronic properties of 2D Si lattices for field effect electronic devices and demonstrate the feasibility of silicene-based devices.

From the current state of research, it seems that silicene-like material can be engineered if suitable metal substrates are used such as silver. Yet, it is not sure whether these layers form a true silicene equivalent to graphene. One of the goals of the project is to unambiguously prove the existence of silicene and understand why Ag and possibly other metals are so "friendly" to it.

To circumvent the screening properties of metal substrates which nullify field effects, the 2D-Nanolattices project will look at alternative substrates and capping layers with insulating properties to encapsulate silicene. These insulating materials made for example from aluminum nitride are designed to be very similar to silicene in the way atoms bond to each other to form layered structures. Moreover, they will be bonded to silicene with weak van der Waals forces so that they can offer a "safe shelter" to silicone allowing electric charge to flow fast and undistracted in the plane as in the case of graphene.

The consortium members believe that the work in 2D-Nanolattices is not merely a replication of graphene properties with silicon instead of carbon atoms. The project goes beyond that exploring a number of other potential 2D nanolattices and their combinations to show that 2D materials beyond graphene can be created with potentially new properties for useful devices.

The 2D world of nanolattices offers not only high speed but also a natural confinement of electronic transport in just one monolayer of lattice atoms, facilitating its manipulation in a very efficient way. This could make 2D nanolattices the ideal materials base for the future electronic devices offering high speed and low power /energy operation at the same time.

A.5 Networking in the European Research Area

1) FET Flagship initiatives

Our intentions have been sketched already in ANNEX I / PART B section 3.1.2, p. 47. Two FET Flagship consortia which have been approved for the preparatory phase, namely Guardian Angels and Graphene are of interest to our 2D-NANOLATTICES consortium. Definite and detailed plans cannot be made at this stage because these FET Flagships will not get final approval (if successful) until after the launching of the FP8 program. However at this point 2D-NANOLATTICES members could contribute to the success of these projects by proposing research topics which could be of mutual interests. This way, 2D-NANOLATTICES will have the chance in three years from now to channel research results into a bigger platform for more effective dissemination, better visibility and better exploitation opportunities.

The coordinator has also established contacts with the coordinator of the Graphene Flagship. The initial consortium is in the finalization stage. Expansion of this Flagship consortium at this stage is not foreseen but a budget will be reserved so that potential expansion through competitive calls after the 1st project year becomes possible. Nevertheless, we are free to suggest to the Flagship management that topics relevant to our project could also be included to the Flagship workplan. We will decide about that in our first management meeting of 2D NANOLATTICES which will be held in Marseille in January 2011.

2) Other projects: ERC /IDEAS

The project coordinator, Dr. Dimoulas has been awarded an ERC/IDEAS 2011 AdG SMARTGATE in PE7-Systems and Communication Engineering, which is relevant to the 2D-NANOLATTICES research topics. The project titled "*Smart gates for the 'green' transistor*" will start 1st January 2012 and will investigate graphene and a class of layered materials (Bi_2Se_3, Bi_2Te_3) known as topological insulators with surface electronic properties similar to those of graphene. We believe that the two projects have no overlap, rather they are complementary and as such they will benefit one from the other, adding value to the research of new layered 2D materials. Dr. Dimoulas will make any effort to link the two projects.

A.6 Web

The 2D-NANOLATTICES website http://www.2dnanolattices.eu has been completed (D5.4). The site was prepared by professionals in order to have an attractive design and user friendly dynamic webpages for easy maintenance and updates. The projects fact sheets presented in the CORDIS official site and the ICT-FET webpage are linked to the 2D-NANOLATTICES website.

The website is divided in two main areas, namely the public area and the restricted access area. In the first, the R&D community is informed about the summary, the objectives of the project, which may change in the course of time as a result of the moving state of the art and the progress made worldwide. In addition, the results highlights in the form of publications, conference presentations, public (non-confidential) deliverable reports and press releases will inform the interested parties about the progress of 2D-NANOLATTICES. The first batch of information, regarding mainly conferences, has been posted. A first (home) page is designed to attract interested readers showing the project *at-a-glance*, presenting a brief statement about the vision, showing the news and events and finally informing the reader about networking activities in FET research area.

In the restricted access area, only the members of 2D-NANOLATTICES have the privilege to enter using a password. They will be able to exchange data in an interactive way using a standard protocol (FTP). Each one of the partners is able to upload, download, edit, save and remove files by an easy-to-use- copy and paste procedure. A pre-print depository for the publication in process will be formed. It is proposed that the project officer will also have access to this restricted area.

Part B: Use of results

B.1. Identification of exploitable results

There are no results yet considered as exploitable.

B.2 Plan for exploitation

For most of the academic partners, the main route for exploitation is the filing of patents on the generated foreground according to the consortium agreement and the general rules of the EC. However, partners who have tighter links with industry such as IMEC and CNR may develop in due time more concrete and well-defined exploitation plans depending on the progress in the project and the exploitable results. At present, the plans for use are based on the description already found in ANNEX I/PART B section 3.2.2., p. 49-51.