PULSE SUMMER SCHOOL on EPITAXY BASES AND PROMISES

2-8 July 2021
Porquerolles (France)

ORGANIZERS:

Jean-Noël Aqua, Institut des NanoSciences de Paris (INSP), Sorbonne Université, Paris
Isabelle Berbezier, l'Institut Matériaux Microélectronique Nanoscience de Provence (IM2NP), CNRS, Marseille
Michele Amato, Laboratoire de Physique des Solides (LPS), Université Paris Saclay, Orsay
Noëlle Gogneau, Centre de Nanosciences et de Nanotechnologies (C2N), CNRS, Palaiseau

INVITED SPEAKERS

Peter Voorhees (Northwestern University, Evanston)

Alberto Pimpinelli (Rice University, Houston)

Eli Kapon (EPFL, Lausanne)

Bernard Gil (CNRS, Montpellier)

Monica Bollani (L-NESS, Como)

Lorenzo Rigutti (U. Rouen)

Guylaine Poulin-Vittrant (CNRS, Tours)

Julien Brault (CRHEA, Valbonne)

Dan Buca Mihai (PGI, Julich)

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Clément Merckling (IMEC, Leuven)

Valerio Pasquali (XFAB)

Noëlle Gogneau (C2N, Palaiseau)

Michele Amato (U. Paris Sud, Orsay)

Jean-Noël Aqua (Sorbonne U, Paris)

Paola Castrucci (Università Roma Tor Vergata)

Fabien Deprat (ST Microelectronics)

Jean Decobert (III-V lab)

POSTERS

Quentin Hochart
MBE-grown Be-doped InP and related materials behavior after high temperature annealing

Ramiro Zapata
Silver thin film growth on glass substrates: microstructural control using magnetron sputtering deposition process parameters

Sumit Kumar
Highlights of 15R crystal phase in Au-catalyzed ZnS nanowires

Nesrine Shaiek
Two dimensional Metal-organic Frameworks at a metal surface

Q. Guillet
Molecular Beam Epitaxy of van der Waals Cr1+xTe2 with perpendicular magnetic anisotropy

Alexandre Llopez
In situ growth of 1T'-WTe 2 thin films

Bastien Marguet
Interface collisions with diffusive mass transport

Virginia Falcone
Graphene suspended on Ge micro-crystals for photodetection applications

Ismaila Kounta
Epitaxy growth and structural and magnetic characterizations of the antiferromagnetic compound Mn_5Si_3

Giulio Gentile
Fe_xGeTe_2 van der Waals Ferromagnets grown by Molecular Beam Epitaxy

Arup K. Kunti
Development of flexible InGaN white LEDs based on nano-phosphors

T. Sodhi
Electrical characterization of PA-MBE grown GaN nanowires via conductive probe AFM - Effect of load and generator resistances

R. S. Joshya
Chiral photodetector based on GaAsN

R. S. Joshya
InGaAsP quantum-well active regions for telecom devices: design, growth and optical characterization

Zouhour Ben Jabra
Hydrogen-Mediated CVD Epitaxy of Graphene on SiC: Implications for Microelectronic Applications

I. Madaci
Integration of oxide ferromagnets with high spin polarization onto ZnO-based 2D, 1D nanostructures: growth, structure, properties of Fe3O4 onto ZnO(0001) substrates

SCIENTIFIC PROGRAM

Day 1 – Friday July 2, 2021

Registration and welcome

- 18:00 to 20:00 – Registration and welcome

Day 2 – Saturday July 3, 2021

- 9:00 to 10:45 – **Alberto Pimpinelli**
  Crystal in and out of equilibrium

- 11:15 to 13:00 - **Noëlle Gogneau**
  Instrumental epitaxy

- 13:00 to 17:00 – **Lunch and Break**

- 17:15 to 19:00 - **Jean-Noël Aqua**
  Growth on a stepped surface and stochastic equations

Day 3 - Sunday July 4, 2021

- 9:00 to 10:45 – **Michele Amato** (on-line)
  Physical properties of semiconductors nanostructures: theory and simulations

- 11:15 to 13:00 - **Dan Buca Mihai**
  Optical applications

- 13:00 to 17:00 – **Lunch and break**

- 17:15 to 19:00 - **Alberto Pimpinelli**
  Growth modes

Day 4 - Monday July 5, 2021

- 9:00 to 10:45 - **Clément Merckling** (on-line)
  New challenges in applications

- 11:15 to 13:00 - **Eli Kapon** (on-line)
  Epitaxial growth of quantum nanostructures

- 13:00 to 17:00 - **Lunch and break**

- 17:15 to 19:00 - **Peter Voorhees** (on-line)
  Nucleation and coarsening

Day 5 - Tuesday July 6, 2021

- 9:00 to 10:45 - **Bernard Gil** (on-line)
  Physical properties of nanostructures and their characterization

- 11:15 to 13:00 - **Noëlle Gogneau**
  Self-organization and surface structuration

- 13:00 to 17:00 - **Lunch and break**

- 17:15 to 19:00 - **POSTER SESSION**

Day 6 - Wednesday July 7, 2021

- 9:00 to 10:45 - **Julien Brault**
  Electronic applications

- 11:15 to 12:15 – **Lorenzo Rigutti** (on-line)
  Atom Probe Tomography and Semiconductor Nanostructures: Principles, Applications, and Correlative Techniques

- 12:15 to 13:10 – **Guylaine Poulin-Vittrant** (on-line)
  Piezo-semiconducting nanowires integration into flexible nanogenerators for mechanical energy harvesting

- 13:00 to 17:00 - **Lunch and break**

- 17:15 to 19:00 - **Paola Castrucci** (on-line)
  Epitaxial growth of 2D materials

Day 7 – Thursday July 8, 2021

- 9:00 to 10:45 – **Monica Bollani**
  Solid state dewetting in semiconductor thin films

- 11:15 to 13:00 - **Round table: From fundamental research to industrial sector: what opportunities?** (on-line)

  11:15 to 11:30 **Valerio Pasquali**, XFAB
  11:30 to 11:00 **Clement Merckling**, IMEC
  11:45 to 12:00 **Fabien Deprat**, ST Microelectronics
  12:00 to 12:15 **Jean-Decobert**, III-V Lab
  12:15 to 13:00 Discussion

- 13:00 - **Closing words**

MBE-grown Be-doped InP and related materialsbehavior after high temperature annealing

Q.Hochart[1&2], A.Elias[1], O.Delorme[1], H.Carrère[2], A.Wilk[1]

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This work focus on the effect of Be-dopant diffusion in GaInAsP-based materials - typically used in MBE -grown on InP substrate, following a high temperature annealing of InP at various steps of the epitaxial process.A MOCVD reactor has been used to perform annealing on MBE-grown epilayers. Studies have been carried-out on various types of structure: bulk and more complex stacks such as multi-QW structures.

In comparison with MBE, MOCVD is a high temperature process that can eventually modify underlying layers' properties.By means of E-CV (figure 1, exhibiting active doping) and SIMS (figure 2, displaying total amount of Be contained in the structure) characterizations, we show how Be is behaving depending on annealing conditions (temperature and gaseous species involved) and the type of epilayers (alloys, stacks and interfaces). It has been observed diffusion and dopant deactivation. Diffusion from substitutional to interstitial sites and hydrogen passivation are the main mechanisms observed.We will also showin which conditions we can reactivateBe,at least partially.

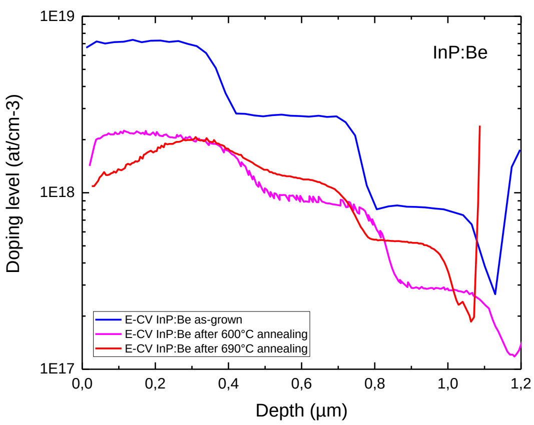

Figure 1: E-CV Be-Profile after MOCVD annealing

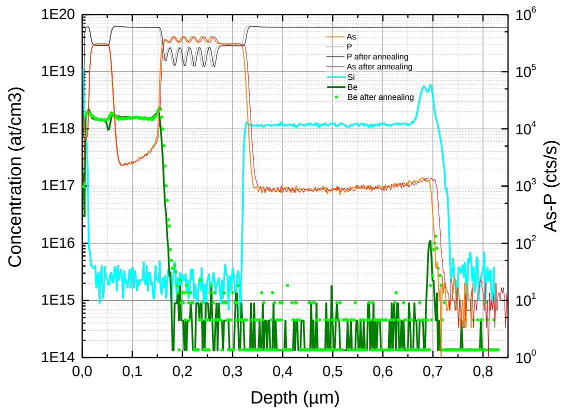

Figure 2: SIMS Profile of GaInAsP-based MQW

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- M. B. Panish, R. A. Hamm, D. Ritter, H. S. Luftman, and C. M. Cotell, "Redistribution of beryllium in InP and Ga0.47In0.53as grown by hydride source molecular beam epitaxy and metalorganic molecular beam epitaxy",*J. Cryst. Growth*, vol. 112, no. 2–3, pp. 343–353, 1991, doi: 10.1016/0022-0248(91)90309-S.
- Y. J. Ma et al., "Behaviors of beryllium compensation doping in InGaAsP grown by gas source molecular beam epitaxy", AIP Adv., vol. 7, no. 7, 2017, doi: 10.1063/1.4989884.
- L. Ji et al., "The striking influence of rapid thermal annealing on InGaAsP grown by MBE: material and photovoltaic device", J. Cryst. Growth, vol. 458, pp. 110–114, 2017, doi: 10.1016/j.jcrysgro.2016.11.003.

Silver thin film growth on glass substrates: microstructural control using magnetron sputtering deposition process parameters

*Authors : ZAPATA Ramiro[1,2], MONTIGAUD Hervé[1], BALESTRIERI Matteo[1], GOZHYK Iryna[1], CREPET Jean-François[1], LAZZARI Rémi[*2]*

1 : Laboratoire SVI Surface du verre et interfaces (CNRS – Saint-Gobain Recherche Paris) – UMR 125
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In the context of low-emissivity (low-E) glazing production, silver thin films (approximately 10 nm thick) are deposited on glass substrates. Current research efforts aim at optimizinglow-E performance by producing silver films with the lowest possible thickness and electrical resistance. The aim of this thesis is thus to explore the effectson the resulting silver thin film, of different changes in process parameters for magnetron sputtering deposition. Both *in situ*and real-time measurements are carried out in order to monitor film growth and to assess the effect of different process parameter changes on the resulting film microstructure, composition and properties. First results are shown for the effect of different O2/Ar gas mixtures in the deposition chamber, on the film thickness threshold value for film percolation (a growth stage characterized by a sharp decrease in film electrical resistance),using real-time electric resistance measurements for Ag films deposited on Si wafers. A reduction in said threshold is observed with increasing oxygen flux(*Figure below*).

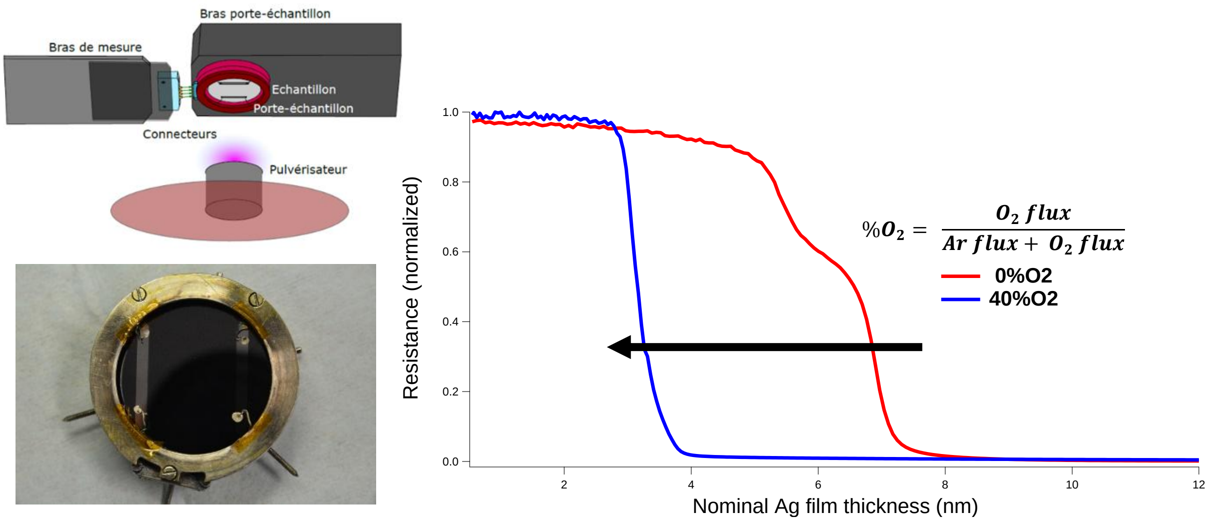

Figure: Real time measurement of the Ag film electrical resistance during deposition. Percolation threshold thickness shift with oxygen addition.

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Pliatsikas, N.; Jamnig, A.; Konpan, M.; Delimitis, A.; Abadias, G.; Sarakinos, K. Manipulation of Thin Silver Film Growth on Weakly Interacting Silicon Dioxide Substrates Using Oxygen as a Surfactant. *J Vac Sci Technol A J Vac Sci Technol A***2020**, *38* (4).

Minicolloque n° MMPS22

Highlights of 15R crystal phase in Au-catalyzed ZnS nanowires

Sumit Kumar[a*], Frédéric Fossard[b], Gaëlle Amiri[a], Jean-Michel Chauveau[a] and Vincent Sallet[a]

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Unique growth mechanisms involved in semiconductor nanowires (NWs) pave the way to the achievement of new crystallographic phases and remarkable material properties. Interestingly, in the case of 1D nanostructures, polytypism can arise due to the particular growth mode below a catalyst droplet, that may induce stacking faults along the length of the NWs. Moreover, these stacking faults can be correlated and form ordered arrays, until giving rise to new phases (polytypes) with distinct properties [1,2]. Hence, 4H, 6H, 8H, and 10H (so-called high order polytypes) can been observed in NWs [3]. Hence, studying polytypism in semiconductor NWs arouses a strong interest for the next generation of electronic and photonic applications. In this framework, ZnS is an important II-VI semiconductor which has a wide range of optoelectronic applications including luminescent devices, infrared windows, and UV-photodetectors.

In this work, Au-assisted ZnS NWs were grown by MOCVD, directly on GaAs (111B) substrate (VLS, vapor-liquid-solid mode), and on ZnS (buffer)/GaAs (111B) (VSS, vapor-solid-solid mode). The idea is to provide a change in the growth mechanism *via* the physical state of catalyst droplet (liquid or solid) and hence, study the induced polytypism in ZnS NWs. ZnS NWs with length up to 1.4 µm and diameter in the range 10–34 nm was successfully achieved. The obtained morphologies and densities of the NWs has been systematically inspected by scanning electron microscopy (SEM) directly on the substrate. Transmission Electron Microscopy has been also used to investigate the crystallographic structures and compositions of both catalysts and NWs. NWs grown directly on GaAs (VLS mode) induced periodic stacking faults, and the resulting structure was accurately identified as 3 sequences of 5 planes ABCBA-BCACB-CABAC (refer Figure 1), giving rise to an astonishing 15R crystal structure [4]. This structure is highlighted for the first time in ZnS nanowires. Additional conventional TEM has been performed to identify the signature of the 15R phase and its peculiar pattern (*i.e.* a 5th order superstructure). Additionally, we modeled this 15R structure and plotted its formation probability in the framework of the classical nucleation theory and axial-next-nearest-neighbour-Ising model (ANNNI).

Interestingly, in contrast with the VLS case, in nanowires grown on ZnS buffer (i.e. VSS mode, with solid catalyst), a different crystal structure made of pure ZB and WZ phases was observed.

[1] G. Priante *et al.* Phys Rev B. 89 (2014) 241301
[2] F.J. Lopez *et al.* Nano Lett. 9 (2009) 2774–2779.
[3] Y. Jiang *et al.* Adv. Mater. 15 (2003) 1195–1198.
[4] S. Kumar *et al.* Nano Res. (2021). https://doi.org/10.1007/s12274-021-3487-8

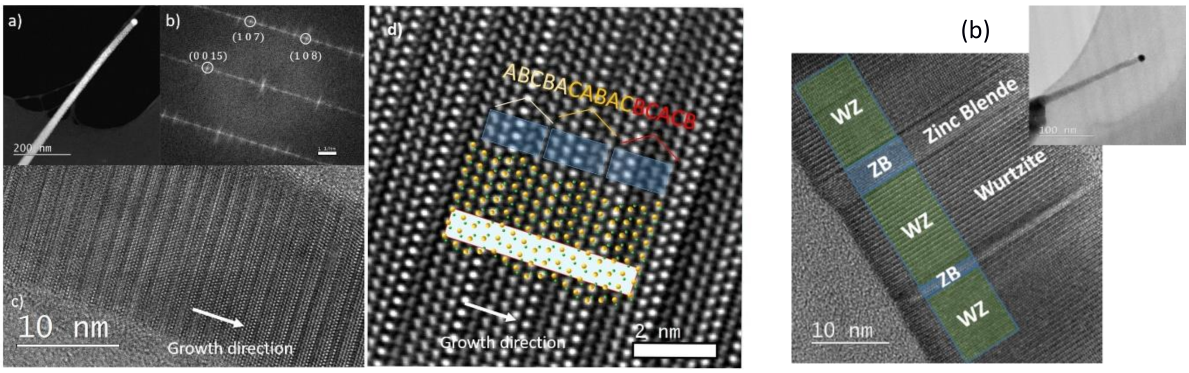

Figure 1: HRTEM image of ZnS nanowires grown by a) VLS process, HRTEM image of NW with 15R stacking sequence, and b) VSS process, pure ZB/WZ phases.

Two dimensional Metal-organic Frameworks at a metal surface

Nesrine Shaiek [a,b], *Mathieu Koudia* [a], *Chokri Lamine* [b], *Akremi Abdelwaheb* [b], *Mathieu Abel* [a]*

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Abstract:

Two-dimensional materials (2D) are the favored appropriate material, which has attracted a great scientific interest, due to their several important and excellent electronical properties. In a similar way to the transition metal dichalcogenide materials, the combination of metal and organic species (preserving the pi-delocalization) allows to obtain not only a particular electronic structure of 2D materials but also unique magnetic properties. In this context, the new class of conductive 2D -MOF has emerged in 2009 [1] and are particularly attractive because of their ability to form stable 2D materials for application in spintronic (spinvalve ferrimagnet), superconductivity, or electrochemistry.

Herein the growth of 2D conductive MOF composed of Tetrahydroxy-1,4-benzoquinone (THBQ) and metal atoms of manganese and copper have been studied under UHV on Ag(111) substrate. The surface is studied by complementary methods of Scanning tunneling microscopy (STM), low energy electron diffraction (LEED) and X-ray photoelectron spectroscopy (XPS) to optimized the growth conditions (fluxes, temperatures…).

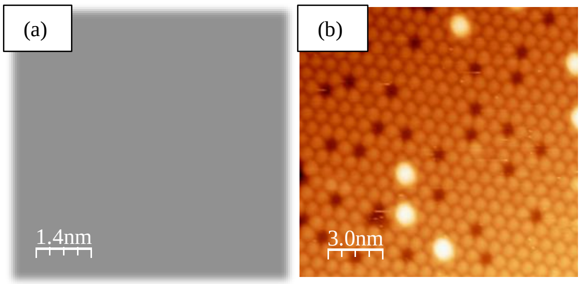

Figure 1:STM images acquired after Co-depositing (a) (THBQ-Cu) (b) (THBQ-Mn) molecules on a Ag(111) substrate.

[1] Crystal Growth & Design, Vol. 9, No. 12, 2009

Molecular Beam Epitaxy of van der Waals $Cr_{1+x}Te_2$ with perpendicular magnetic anisotropy

Q. Guillet, H. Boukari, A. Marty, F. Bonell, C. Vergnaud, J.F. Jacquotand M. Jamet

Achieving the large-scale growth of 2D ferromagnetic materials with above room temperature Curie temperature and perpendicular magnetic anisotropy is highly desirable for the development of future magnetic sensors or magnetic memories based on van der Waals heterostructures. In this context, $Cr_{1+x}Te_2$ appears as a promising candidate [1].

In this poster, I present large-scale (1x1 cm^2) deposition by molecular beam epitaxy of $Cr_{1+x}Te_2$on graphene/SiC substrates.

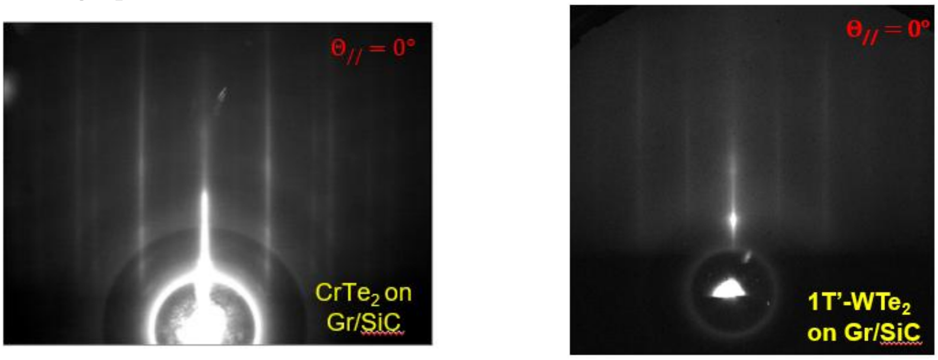

Figure 1: RHEED images of the layers grown by MBE

The crystalline quality was verified in-situ by RHEED (see Fig. 1), post-growth x-ray diffraction and Raman spectroscopy. The samples were capped with amorphous Te to prevent any oxidation in air.

The magnetic properties of the $Cr_{1+x}Te_2$ layers were measured by SQUID magnetometry in out-of-plane and in-plane geometries and normalized in units of Bohr magneton per Cr atom. We obtained a perpendicular magnetic anisotropy with a Curie temperature of 180K down to a thickness of 2 nm corresponding to 1-2 monolayers.

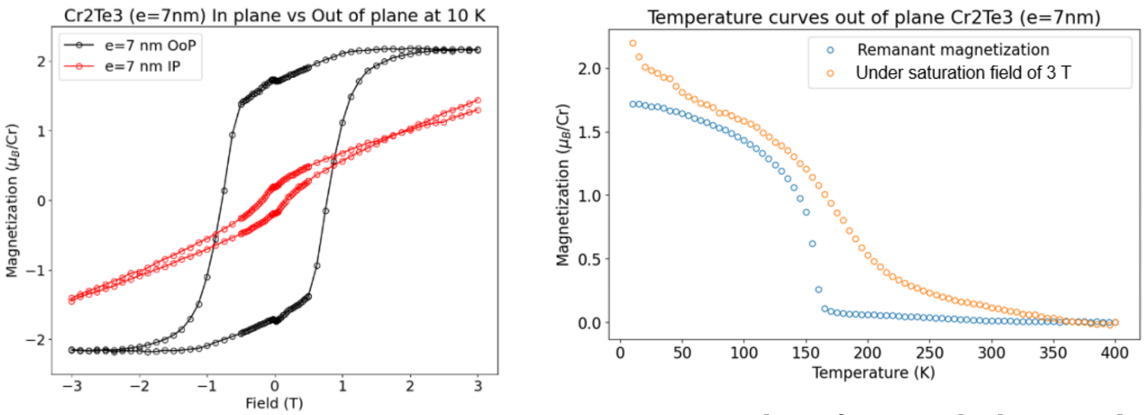

Figure 2: SQUID data of a 7 nm-thick Cr_2Te_3 layer grown on graphene in out-of-plane and in-plane geometries.

I also present preliminary data on the epitaxial growth of 1T'-WTe_2 on graphene by MBE. For its exotic spin texture and strong spin-orbit coupling, this material is a good candidate togenerate spin currents from charge currents to switch the magnetization of an adjacent 2D ferromagnet like Cr1+xTe2.

[1] Purbawati et al. ACS Appl. Mater. Interfaces **12**, 30702−30710 (2020)

In situ growth of 1T’-WTe_2 thin films

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[2]CRHEA, Université Côte d’Azur & CNRS, Valbonne, France

Original works of Geim and Novoselov on graphene in 2004 highlighted the exceptional properties of two-dimensional materials (2D) [1]. A considerable research effort is now focused on 2D materials such as transition metal dichalcogenides (TMDCs). TMDCs can be elaborated in different crystal structure called polytypes. Among those, 1T’-polytype was predicted to exhibit Quantum spin Hall (QSH) effect [2]. This makes 1T’-TMDCs promising materials for spintronic or quantum computation. Among TMDCs, WTe_2 favorably exhibits a 1T’ polytype under ambient conditions [3] and was predicted to be a semimetallic QSH material at the monolayer [4].

In order to obtain 1T’-WTe_2 monolayer at large-scale (~ 1cm²), WTe_2 growth has been realized by molecular beam epitaxy on a graphene substrate on 4H-SiC(0001). The temperature of the substrate during the growth is around 275°C and the W:Te-flux ratio is maintained between 1:200 and 1:800. The growth conditions are monitored *in situ* by RHEED and confirm the crystalline quality of the deposited films (Fig. 1). Post-growth characterizations include STM and LEED/LEEM along with *ex situ* Raman spectroscopy.

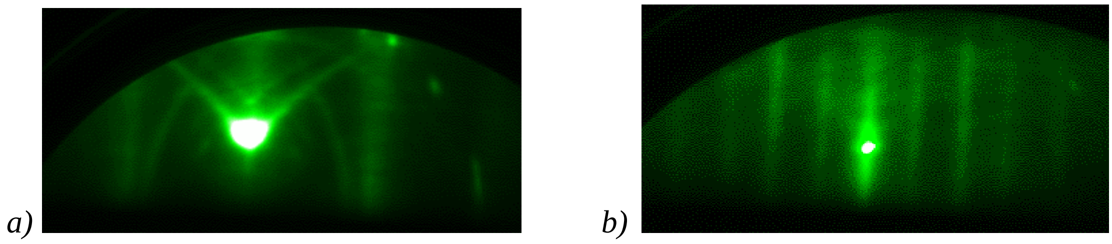

Figure 1: RHEED pattern of a) graphene on 4H-SiC(0001) substrate b) as grown WTe_2 thin film.

Preliminary STM characterizations have been carried out on sub-monolayer WTe_2 films (≈0.25 ML). For a W:Te-flux ratio of 1:200, undesired clusters remain on WTe_2 islands (Fig.2.a). By annealing the sample around 350°C-400°C, we can eliminate the majority of those clusters (Fig.2.b). Growth with a lower W:Te flux ratio (1:800) also seems to give films with an improved quality (Fig.2.c).

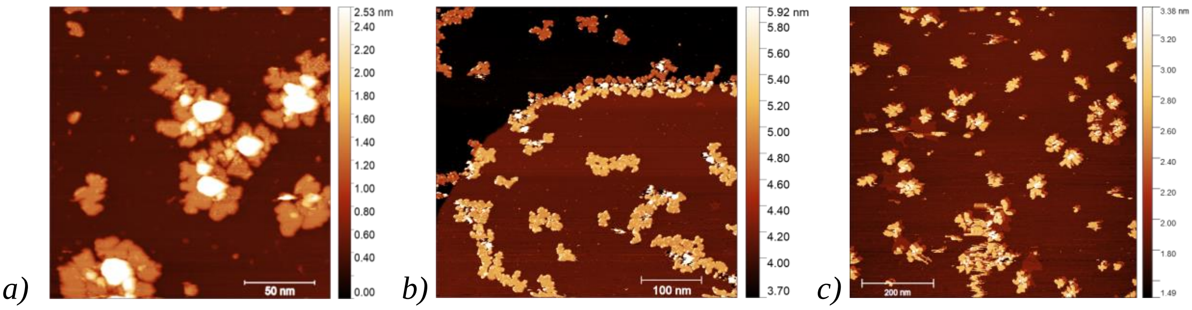

Figure 2 : STM images of sub monolayer WTe_2 sampels. Growth with a W :Te flux ratio of 1 :200, a) before annealing, b) after annealing. c) Growth with a flux ratio of 1 :800 without annealing.

[1] K. S. Novoselov et al. Science **306** (2004) 666
[2] X. Qian et al., Science **346** (2014) 1344
[3] K.A. N. Duerloo et al. Nat Commun **5** (2014) 4214
[4] F. Zheng et al. Advanced Materials **28** (2016) 4845-4851

Interface collisions with diffusive mass transport

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In manygrowthprocesses, two-dimensionaldomains are nucleated, grow, and finallymerge. This scenario canbefound in diverse non-equilibriumprocesses, such as the quenching of magneticsystems[1], epitaxialgrowth of molecular or atomicmonolayers[2], or growth of bacterial colonies[3]. Whilenucleation and growth have been studiedextensively, lessisknown about the mergingprocess. In order to investigatethisprocess, westudy in details the collision of two straight interfaces movingtowardseachother and colliding. When the interfaces interactonly with short-range interactions[4], the interface whichisformed by the collision wasrecentlyfound to beasymptoticallyindependent on the collision details (type of interaction, fluctuations during the collision, etc...). As a consequence, despite the complexnonlinearcharacter of the collision process, simple universalityemerges.

We focus on the case where interactions are induced by diffusingspecies, such as during the growth of two-dimensionalmaterials (such as graphene), or during the growth of bacterial colonies competing for food. We use on-latticeKinetic Monte Carlo Simulations and findthat a linear Langevin model canreproduce the main results. As opposed to the intuitive expectations, wefindthat the roughness of the newlyformed interface canbesmallerwhengrowthisfaster. Theseresultscould help to minimize the roughness of grain boundaries of grown 2D materials, which have a strong influence on the thermal and electronic transport properties of thesematerials.

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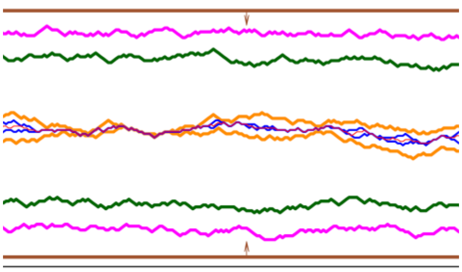

Figure 1: Collision of lines

Graphene suspended on Ge micro-crystals for photodetection applications

Virginia Falcone[a], Andrea Ballabio[a], Andrea Barzaghi[a], Carlo Zucchetti[a] , Luca Anzi[a], Jacopo Frigerio[a], Federico Bottegoni[a], Roman Sordan[a], Paolo Biagioni[a] and Giovanni Isella[a]
[a]Politecnico di Milano

The epitaxial growth of germanium on silicon enables the microfabrication of Si-based photodetectors with near-infrared (NIR) sensitivity. In this work we report on a new type of detector, obtained from Ge micro-crystals epitaxially grown on a patterned Si substrate. The faceted morphology and relatively high aspect ratio of the micro-crystals was found to enhance the detector responsivity in the wavelength region comprised between the direct (λ≈1550 nm) and indirect gap(λ≈1800 nm) as compared to conventional planar devices. The epitaxial growthwasperformedby Low-EnergyPlasma-EnhancedCVD (LEPECVD). Micro-crystal formation is based on theself-assemblyofGecrystalsonaSisubstrate, deeply patterned byoptical lithography and reactive ion etching. Three-dimensional micro-crystals, several micrometer tall andwith alimitedlateralexpansion are obtained by using optimized growthparameters. Modeling of the near-IR absorption properties of the Ge/Si micro-crystalswas done by finite difference time domain simulations (FDTD). The absorptance ratio is always larger than one, with a relevant increase in the indirect gap wavelength range. The main challenge in realizing vertically illuminated photodiodes based on Ge-on-Si micro-crystals is the fabrication of a top transparent contact that can adapt to the 3D-morphology of the sample and bridge the 100-200 nm gap between adjacent microcrystals. Graphene can be used as a suspended continuous top contact, with an absorption that does not exceed 2.4%. After the wet transfer of a single graphene layer, characterization bythe scanning electron microscope (SEM) revealed the presence of cracks and discontinuitiesin the graphene layer placed over the patterned area,generating a "spider web" effect.This was caused by the capillary forces that play an important role for this type of structures in which the distance between the micro-crystals is the order of hundred nanometers.Different strategies were attempted to solve this problem. Eventually, the number of suspended graphene layers was increased and a graphene bilayer was used by modifying the transfer process. The absorption due to the graphene bilayer, was estimated to be ~ 5% which did not significantly affect the efficiency of the optoelectronic device. The fabricated devices werecharacterized by electrical and optical measurements that confirmed the NIR photoresponse. Responsivity measurements, by a confocal microscope and a supercontinuum laser, proved the enhancement of absorption of this type of structure close to the Ge indirect gap. Fixing the reverse bias V_b = -2V the responsivity of the micro-crystals was almost ten times that ofa reference Ge epitaxial layer in the 1650-1800 nm wavelength range.This effect is linked to the light-trapping effects that take place in this structure.Their dependence on the pattern geometry and the micro-crystal morphology, isstill under investigation.

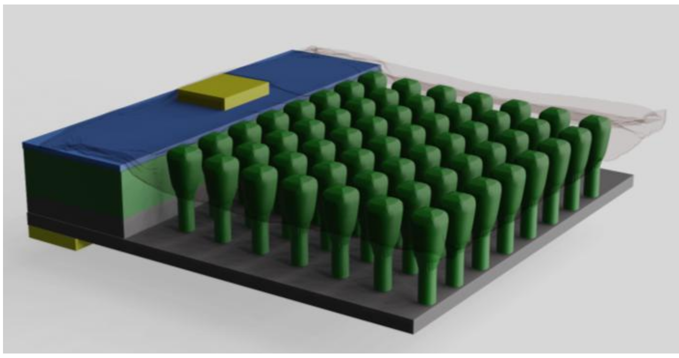

Figure 1: Graphene suspended on Ge self-assembly micro-crystals

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Title :Epitaxy growth and structural and magnetic characterizations of the antiferromagnetic compound Mn_5Si_3

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Summary of the poster:

The development of innovative energy-efficient solutions becomes crucial to overcome the ultimate scaling limit and reduce power consumption of the electronic devices. This is one of the main challenges of spintronic, which is based on mutual dependence of electron transport and magnetization dynamics. This field, in which ferromagnetic (FM) materials play so far a major role, has stimulated numerous applications especially in engineering, information science and nanotechnology. It has recently been established that antiferromagnetic material (AFM) can also play an active role [1, 2].

Besides their attractive spin-dependent transport properties, their robustness against magnetic fields perturbation, the absence of stray fields, their fast dynamics open new routes in spintronic for devices with better energy-efficiency and better compactness. In this context, the material Mn5Si3 is particularly attractive, hence the interest of the study.

Its non-trivial temperature-dependent spin arrangement (non-collinear antiferromagnetic (AF) phase at T <66K and collinear AF order for 66K <T <99K) can be used to study a collinear effect. A topological Hall effect was observed on the non-collinear AF phase on polycrystalline samples [3].

Moreover, its isostructural ferromagnetic (FM), Mn5Si3Cx by carbon doping, makes possible the complete epitaxial growth of an FM / AF structure and thus the study of the effect of FM / AF heterosturcture.

So for the growth of Mn5Si3, we opt to codeposition of Mn and Si on Si(111)-7x7 reconstruction surface and (√3x√3)R30° reconstruction (by Sn deposition on Si(111)-7x7 substrate).

We were able to observe the spontaneous Hall effect for the first time in antiferromagnetic materials, for samples of Mn5Si3 with high crystal quality (https://arxiv.org/abs/2012.15651).

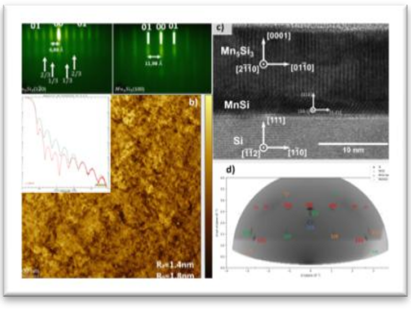

FIG. 5. Growth characterization of the epitaxial Mn_5Si_3 films.

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Fe_xGeTe_2 van der Waals Ferromagnets grown by Molecular Beam Epitaxy

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Since the discovery in 2017 of ferromagnetism in single layer CrI3[1], 2D van der Waals (VdW) magnetic materials havebeen regardedby the scientific community as promising for spintronics[2,3].Among these, Fe_xGeTe_2(x=3,5)compounds are of interest for their itinerant ferromagnetism and Curie temperature Tc close to room temperature[4,5].Due to their VdW nature they can be micro-mechanically exfoliated, but only small micrometer sized-films are obtained.

In this work,molecular beam epitaxy (MBE) allows us to growlarge cm-scale area Fe_xGeTe_2(x=3,5)on Al_2O_3 (111), controlling both the thickness and the composition.The crystal structure was characterized by RHEED, x-ray diffraction and scanning transmission electron microscopy,and the magnetic properties were measured by SQUID magnetometry and anomalous Hall effect.

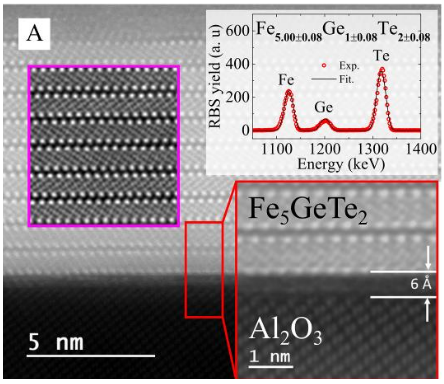

Figure A: HAADF-STEM cross section of $\boldsymbol{Fe_5GeTe_2}$van der Waals ferromagnet. Inset: composition determined by Rutherford backscattering.

We show that thin films of Fe_xGeTe_2grown by MBE display a very high crystalline quality (Fig.A). SQUID magnetometry and transport measurements show magnetic properties consistent withthose of bulk crystals grown with other techniques[4,5].The obtained films feature long rangeferromagnetic ordering. 11-nm-thickFe_3GeTe_2has a $Tc \approx 240K$ and perpendicular magnetic anisotropy, while 12-nm-thick Fe_5GeTe_2has $Tc \approx 293K$ and in-plane magnetization.Ultrathin films of Fe_5GeTe_2 (2 nm) retain a large $Tc \approx 240K$.

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Development of flexible InGaN white LEDs based on nano-phosphors

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White light emitting diodes (LEDs) have enormous applications in lighting and display devices. Commonly, a blue emitting InGaN LED chip with yellow emitting $Y_3Al_5O_{12}:Ce^{3+}$ phosphors are used to fabricate commercially available white LEDs. However, this technology suffers lower color rendering index (CRI) and high value color correlated temperature for the lack of the red component in the emission spectrum.Now a days, technology demands flexible LEDs to design foldable displays,wearable optoelectronic device, bio-medical devices... Commercially, available flexible LEDs are made of active organic medium. However, organic LEDs are not stable over the long period and are characterized by low brightness. These problems can be solved by developing mechanically flexible LEDs using InGaN nanowires (NWs), where the lack of red component can be overcome by introducing red phosphors with yellow emitting phosphors.
In this project, investigations focused on the optimization of indium concentration within InGaNNWs, grown either by MOVPE or by MBE, to achieve proper blue emission to excite yellow and red phosphors and then to fabricate flexible white LEDs. We demonstrate a successful fabrication process of flexible InGaN NWs/phosphorus basedLEDs and the corresponding electro-luminescence emission spectra highlighting the performance of the device.

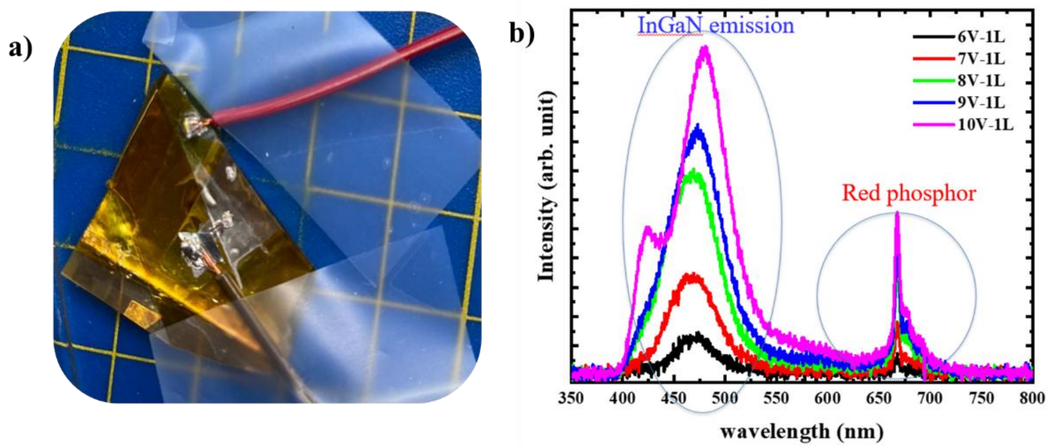

Figure 1:(a)Image of a laboratory protype flexible LED device and (b) electroluminescence performance of the device.

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Electrical characterization of PA-MBE grown GaN nanowires via conductive probe AFM - Effect of load and generator resistances

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Today, the miniaturization of the electronic devices has led to a decrease on their energy consumption (mW-µW) and opened new ways for renewable energy harvesting solutions to power them. We focus on energy sources like mechanical deformations and vibrations, which are present at all times. Our goal is to develop a new generation of piezoelectric generators, which are easily integratable, ultra-compact and generate sufficient power to supply the micro-devices, without increasing their size or weight. Due to their superior mechanical properties, higher piezo-electric coefficients (6 times higher than bulk GaN) and sensitivity to smaller forces (nN-pN range), GaN nanowires (NWs) appear as promising nanostructures to convert efficiently the mechanical energy, found in the direct environment of the micro-device, into electrical energy.

Here, we study the piezo-electric response of single GaN NWs via an atomic force microscope (AFM) equipped with a home-made modified Resiscope that permits to measure simultaneously the topographic and piezo-generation signals in contact mode. The efficiency of the modified Resiscope module to collect the piezo-charges is maximum for an R_{Load} of 1 Gohm and asymptotic values of O.V. are obtained (Figure 1). However, the corresponding P_i, are negligible (Figure 2) which indicates a low efficiency. For the first time in the nanoscale regime, we investigate the influence of R_{load} (varying from 1 Mohm to 1 Gohm) of the system's electronics on the output voltage (O.V.) and power (P_i) generated by intrinsically doped GaN NWs. Based on this study, we emphasize the importance of optimization of R_{load}. We also demonstrate that the resistance of the nano-generator, R_{gen}, (convolution of contact resistance and NW resistance), which is often neglected in literature, cannot be ignored to optimize the electronic system associated to the piézo-generator (Figure 2).

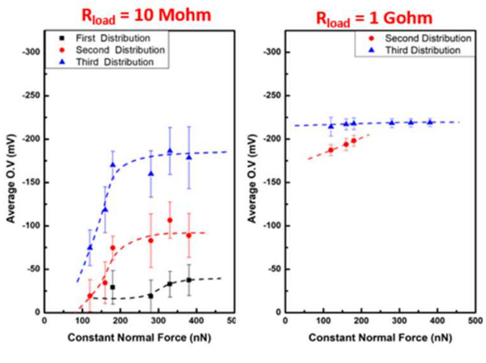

Figure 1 : Effect of R_{load} on output voltage

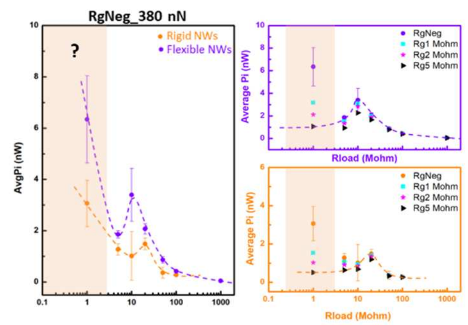

Figure 2 : Optimisation of R_{load} without R_{gen} (left) and with R_{gen} (right)

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CHIRAL PHOTODETECTOR BASED ON GaAsN

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Direct detection of circularly polarized light plays a vital role in various fields, from drug production to optical communication. However, conventional photodetectors are inherently difficult due to the lack of intrinsic chirality in traditional semiconductors. In this work, we propose a novel scheme for a chiral detector based on GaAsN, allowing for the simultaneous detection of the intensity and degree of circular polarization of incident light at room temperature. It relies on the engineering of deep paramagnetic defects (Ga^{2+}) displaying giant spin-dependent recombination. The device's operating spectral range can be extended from visible to infra-red using (InGaAl)AsN alloys.

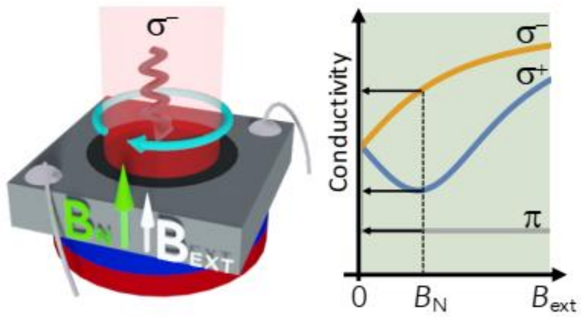

Figure 1: A novel scheme for a chiral detector based on GaAsN

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InGaAsP quantum-well active regions for telecom devices: design, growth and optical characterization

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In order to cope with the growing increase in telecommunications needs, recent years have seen the emergence of very high speed optical networks to connect the major metropolitan centers, and the development of optical access network such as Fiber-to-the-home (FFTH). Low cost, optoelectronic devices are key elements to the achievement of dense and ultra-dense wavelength-division multiplexing (WDM) networks. In this study, we investigate InGaAsP quantum wells as gain material for optoelectronic devices emitting in the O, C and L bands, the transmission windows of silica fibers. First, we present the heretostructure design in terms of composition and widths with the view of reaching the appropriate wavelengths, namely 1,3 µm, 1,55µm and 1,625µm. The band structure and transition energies are calculated by solving a 6-band Luttinger-Kohn k.p Hamiltonian includeing strain and confinement. The eigenvalue problem is solved by the transfer-matrix method, taking into account the interfacial discontinuity condition. The heterostructures were grown by MBE on n-doped InP substrates and consist of…. Finally, we perform photoluminescence characterization and discuss the matching with the quantum well design.

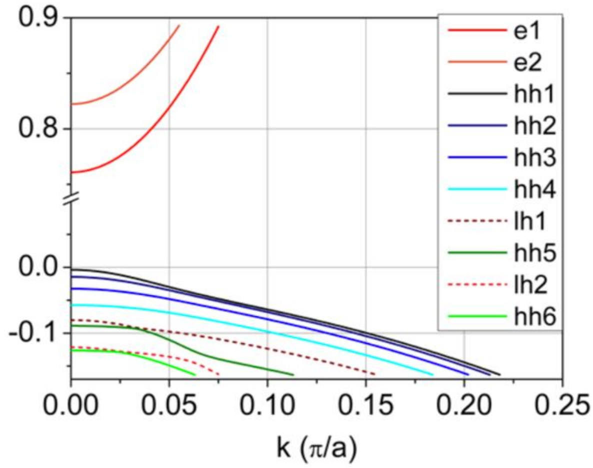

Figure 1: band structure of InGaAsP/InGaAsP quantum well

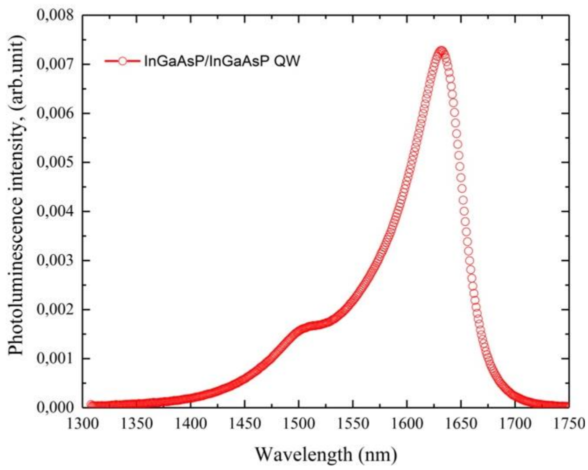

Figure 2: room temperature photoluminescence spectrum of InGaAsP/InGaAsP quantum well

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Hydrogen-Mediated CVD Epitaxy of Graphene on SiC: Implications for Microelectronic Applications

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Abstract

Despite the large body of literature reporting on the growth of graphene (Gr) on 6H−SiC(0001) by chemical vapor deposition (CVD) [1-3], some important issues have not yet been solved, and full-wafer-scale epitaxy of Gr remains challenging, hampering applications in microelectronics. With this study, we shed light on the generic mechanism which produces the coexistence of two different types of Gr domains: Gr on hydrogen (H-Gr) and Gr on buffer layer ((6 × 6) Gr), whose proportion can be carefully controlled by tuning the H_2 flow rate. We show for the first time that the growth of Gr by CVD under a H_2/Ar flow rate proceeds in two stages [4]. First, the nucleation of free-standing epitaxial Gr on hydrogen (H-Gr) occurs; then, H-atoms eventually desorb from either step edges or defects. This gives rise, for a H_2 flow rate below a critical value, to the formation of (6 × 6) Gr domains. The front of H-desorption progresses proportionally to the reduction of H_2. Using the robust and generic X-ray photoelectron spectroscopy (XPS) analysis, we realistically quantify the proportions of H-Gr and (6 × 6) Gr domains of a Gr film synthesized under any experimental conditions. Scanning tunneling microscopy supports the XPS measurements. From these results, we can deduce that the H-assisted CVD growth of Gr developed here is a unique method to grow fully free-standing H-Gr in contrast to the method consisting of H-intercalation below (6 × 6) Gr epitaxial layer. Further description will be highlighted in the poster. These results are of crucial importance for future applications of Gr/SiC(0001) in nano- and microelectronics and in particular for field-effect transistors, for which maximization of mobility is mandatory. We achieve thus a precise identification of new Gr surface structures which provide the groundwork for the use of Gr as an optimal template layer for Van der Waals homo- and heteroepitaxy for optoelectronic applications.

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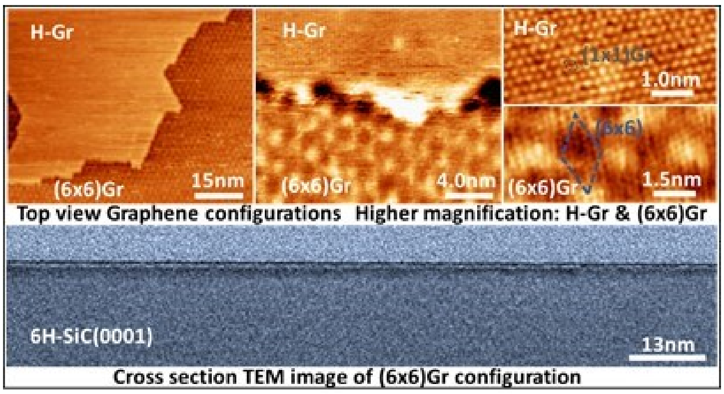

Figure 1: STM images showing the interface between H-Gr and (6×6)Gr domains existing on the same surface layer and their atomic structures. Large scale TEM image showing the continuity and homogeneity of (6×6)Gr configuration

Integration of oxide ferromagnets with high spin polarization onto ZnO-based 2D, 1D nanostructures: growth, structure, properties of Fe_3O_4 onto ZnO(0001) substrates

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Summary of the poster:

Spintronics is the field of physics where we exploit the spin of electron instead of, or coupled with its electrical charge which give another degree of freedom. It offers a new range of applications with lower heating generation, smaller packaging, less energy consumption and higher processing speed [1]. The main idea of my PhD project is to pair a magnetic material which controls (manipulates) the spin of electrons with a semiconductor where we exploit these spin polarized charges. Several systems of metallicferromagnet(FM)/semiconductor(SC) have been investigated by researchers, but always defects and interdiffusion at the interface FM/SC are the major obstacle to an efficient spin injection and detection.

In order to reduce the spin depolarization at the interface FM/SC, we have focusedour study on all-oxide structures. The Fe_3O_4 as a ferrimagnetic oxide with a high Curie temperature (Tc ~ 850K) and an expected ~ 100% spin polarization (80% already measured [2]), and the ZnO as a wide bandgap semiconductor with a long spin lifetime [3] and conduction band that can be aligned with the Fermi level of the Fe_3O_4 [4], present a promising combination for opto-spintronics applications.

In this work we present the Pulsed Laser Deposition (PLD)growth of thin Fe_3O_4 films onto (0001)-oriented ZnO substrates. The Fe_3O_4 has an inverse-spinel structure, while the ZnO has a wurtzite structure with lattice parameters of a=8.396Å, a=3.249 Å respectively. This difference of lattice parameters gives rise to a large lattice mismatch (8,6%) from which comes down the complexity of this growth, beside the possibility of formation of other iron oxide phases (FeO, αFe_2O_3, γ- αFe_2O_3). We targeted lower growth temperatures to limit the interdiffusion at the interface FM/SC. Samples have been studied by structural, morphological, and magnetic characterizations (RHEED, X-ray diffraction XRD, Raman spectroscopy, Atomic Force Microscopy AFM, High Resolution Transmission Electron Microscopy HR-TEM, Vibrating Sample Magnetometry VSM).

We show that we achieved an efficient stoichiometry control by adjusting the PLD growth parameters at relatively low growth temperatures (substrate surface temperature ~ 260°C). Thus, the growth conditions of three stable iron oxide phases were established, most interestingly for epitaxial Fe_3O_4. The magnetic measurements show a sharp Verwey transition at the expected temperature but magnetization of the grown Fe_3O_4films is slightly lower than the bulk value, probably due to the antiphase boundaries.

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