RESEARCH STATEMENT[*]

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Abstract

This document contains a summary and a description of the main results of the research I carried on during the last five years of activity on semiconductor nanostructures and micro– and nanoelectronics. The results shown are obtained in collaboration with several research groups: Epitaxial Semiconductor Nanostructures Team (IM2NP Lab, Marseille, France), Measurement Science and Standards (NRC, Ottawa, Canada), ICFO (Institut de Ciences Fotoniques, Barcelona, Spain), LATSI Lab (Blida, Algeria), R&D Physics Department (Tescan Brno, s.r.o. Czech Republic) and Orsay Physics (Fuveau, France). The report is separated on different theoretical and experimental studies covering mainly the development, characterization and use of both focused ion beam (FIB) and molecular beam epitaxy (MBE). Several high technology techniques were used in this work, such as, elaboration methods: rapid thermal processing (RTP), plasma-enhanced chemical vapor deposition (PECVD), MBE, nanopatterning methods (e-beam, FIB) and analysis tools: electron microscopy (SEM and TEM), photoluminescence spectroscopy (PL), atomic force microscopy (AFM) ...etc.

Keywords: SiGe, nanostructures, focused ion beam (FIB), molecular beam epitaxy (MBE), nanowires, nanopatterning, photoluminescence

About the author

I am an Electronics Engineer graduate from the University of Blida, Algeria completed in July 2010 and a M.Sc. Nano-electronics Devices' graduate from Aix-Marseille University, Marseille, France completed in September 2012 after which I have been working as a Junior Research Physicist at the Epitaxial Semiconductor Nanostructures Team, in the IM2NP Lab from October 2012 to September 2015. Over these years I have also completed my Ph.D. in Condensed Matter Physics and Nanosciences from the Aix-Marseille University, which has helped me in acquiring deep knowledge in both experimental and theoretical physics as well as in the fabrication and the characterization of semiconductor nanostructures and has given me the confidence to explore my skills further down the career line.

My education and employment have laid a strong foundation for my excellence in physics, considering the fact that it has helped me acquire a great deal of knowledge in various sectors of physics such as semiconductor physics, charged particles physics, quantum mechanics, modern physics, thermodynamics, magnetism, optics, photovoltaics and condensed matter physics. During my stay in IM2NP Lab and TESCAN ORSAY HOLDING, a.s. I have been involved in the research of different phases of physical phenomena, developing theories based on physical experiment, and devising several methods to apply the laws of physics to different sectors of industries. I am also familiar with various equipment pertaining to the study and research of nanomaterials, such as molecular beam epitaxy, plasma-enhanced chemical vapor deposition, rapid thermal processing, focused ion beam, scanning and transmission electron microscopy, atomic force microscopy, photoluminescence, chemical analysis spectroscopy and I-V characterization.

1 Introduction

Due to their unique physical and chemical properties, semiconductor nanostructures (quantum wires and quantum dots) have been proposed as promising building blocks for novel nano- and optoelectronic devices. Several theoretical investigations predict that nanowires (NWs) could display extraordinary optical properties. Relevant macroscopic collective properties require perfect size homogeneity and ordering control.

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In the specific case of quantum-wires, various processes have been developed to obtain large density of ultra-small NWs and the most efficient and versatile approach is the preferential growth on AuSi catalysts.

2 Ph.D. thesis

In this context, my Ph.D. thesis is dedicated to the development of new processes for the selfassembly of silicon based nano-objects. My studies have been shared in four main activities:

2.1 Substrate Nanostructuring by Liquid Metal Alloy Source Focused Ion Beam

In this work we study the influence of the major focused ion beam operating parameters: ion chemical species, beam current, lens voltage and ion dose on the ultimate nanopatterning resolution. We propose a two-step process based on first ion milling of a SiO_2 sacrificial layer and second SiO_2 chemical etching for the fabrication of nanopatterns with ultimate size-density and ad-libitum shape. Examples of resulting patterns are presented. The morphological evolution of FIB patterns is quantitatively measured by AFM in air (non tapping mode)[1].

2.2 Fabrication of AuSi Catalysts Ordered Networks

$Au_{0.8}Si_{0.2}$ nanocatalysts (NCs) are synthesized via homogeneous dewetting of thin Au layers evaporated on Si(111) during thermal annealing in ultra-high vacuum. In a first part, the mechanism of dewetting is analysed as a function of the Au deposited thickness (h). We distinguish three different dewetting regimes: (I) for low thickness ($h \leq 0.4$ nm) a coverage by a submonolayer of Au is stable and there is no dewetting, (II) for intermediate thickness (0.4 nm $< h \leq 5$ nm) there is both dewetting and phase transformation into $Au_{0.8}Si_{0.2}$ clusters. The clusters size and density is directly related to h. When cooling down to room temperature, they decompose and reject the Si at the Si substrate / Au cluster interface; (III) high thickness ($h > 5$ nm) there is only dewetting without formation of AuSi clusters. In this regime, the dewetting is kinetically controlled by the self-diffusion of Au (activation energy ~ 0.43eV) without effect of Si-alloying. As a consequence, when relying solely on the kinetic dewetting to form the AuSi clusters, it is only in the regime II tha $Au_{0.8}Si_{0.2}$ clusters with a good size and density control can be produced.

We then develop a process for the pinning of $Au_{0.8}Si_{0.2}$ catalysts using Focused Ion Beam (FIB) assisted dewetting (heterogeneous dewetting). We show that whatever the FIB milling conditions and the Au nominal thickness are, the $Au_{0.8}Si_{0.2}$ droplets preferentially form on the patterned areas while in the same conditions, they are not observed on the unpatterned areas. Such behavior is attributed to the larger Au−Si interdiffusion in the patterned areas which results from the Si-bond breaking induced by the ion irradiation. A systematic analysis of the nanodroplets position evidences their preferential nucleation inside the patterns while a thicker almost pure Au dewetted layer is observed between the patterns[2].

2.3 Focused Ion Beam Assisted Heterogeneous Dewetting

In this work, we investigated complete and partial dewetting of thin Si films on silicon oxide (SOI substrates). By patterning the 2D silicon layer before dewetting (i.e. by E-Beam lithography and Reactive Ion Etching or by Focused Ion Beam), we demonstrate the control of final size, shape, density and spacing of the NCs. Patterning has a strong impact in determining the final shape and in-plane asymmetry of the dewetted 3D islands: etching long stripes oriented parallel or diagonal with respect to the crystallographic directions induces the formation of highly symmetric or largely asymmetric NCs. Finally, we show that the combined use of patterning and partial dewetting is a suitable method for controlling the exact position of individual dewetted 3D islands sitting on a partially dewetted 2D layer of crystalline silicon[3].

2.4 Physical Characterization of Nanostructures

In this work we develop a FIB based process for the insulation of nanostructures and their local electrical contact for I(V) measurements. We also perform photo-luminescence (PL) analysis of nanostructures depending on their size, geometry, density and chemical composition[4].

3 Marie Curie Initial Training Network Postdoc

The overall aim of the Marie Curie Initial Training Network was to establish a transnational research and training platform on energy beam (EB) processing methods “laser abrasive, water-jet machining and focused ion beam milling” which together represent a scientific field of critical importance for further advancement of high value-added manufacturing industry. Whilst these processes differ in nature, a set of key commonalities can be identified among them when considered as dwell-time dependent processes, this allows the approach of EB processes under a unitary technology umbrella. The key element that brings all the EB processing methods together is a unifying modeling platform of the footprints. I worked on the development of original methods to calibrate the generic footprint models for the ion beam milling and the validation of the modeling approach on FIB. I also participate on the implementation the beam path simulator on real workstations to generate micro, meso, macro and free-forms using the ion beam. A paper on these topics has been prepared and it will soon submitted to scientific journal.

3.1 Focused Ion Beam Development

In the second part of the Marie Curie Post Doc I spent a long secondment at the ORSAY PHYSICS, where I was working on the development of new commercial Ga liquid metal ion source for FIB instruments. The work was divided into two main topics, the first was to develop new strategies and procedure for starting and operating the Ga LMIS, while the second part was firstly to improve the old architecture of the sources and finally to develop a completely new LMIS design. These results represents leading edge research in fundamental physics and optics of charged particles.

Moreover, some of my works at TESCAN ORSAY HOLDING were also based on the development of emerging Xe plasma FIB systems which promise faster removal rates. We shown that the new Xe plasma FIB offers sputtering speed up to 50 times faster than the most powerful Ga FIBs. Compared to conventional Ga ion sources, the Xe plasma ion source reduces dramatically the time for cross-sectioning from tens of hours or even days to a matter of hours. Furthermore, combining this Plasma-FIB column with an UHR-SEM column expands even more the advantages for such a tool by opening possibilities of ultra-fast 3D tomography, large TEM lamella preparation, failure analysis and surface preparation. The UHR-SEM sample observations during the milling process offers imaging of the resulting cross-section and EDX or EBSD analysis, all being integrated in the same instrument, thus enabling the creation of complex automated tasks.

Finally, we performed new strategy for failure analysis on an integrated circuit using a rocking stage with 6-axes piezo movement capabilities together with the novel approach of the combined Xe-plasma ion source FIB and SEM system. Site-specific milling of copper with different milling strategies were tested to optimize time and homogeneity of the milling across the target surface and to overcome the channeling effect posed by polycrystalline copper. Only during the last few nanometers of copper layer the water vapor were used to protect the dielectric layer. The complete removal of copper was followed with XeF_2 assisted milling of the dielectric layer to observe the unharmed circuitry. Channeling effect was reduced by regulating the sputtering rates across different grains keeping the underlying dielectric layer safe. A paper on this topic has been submitted to Journal of Vacuum science & Technology B.

4 References

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