Smallest micro house in the world, assembled on the facet of an optical fiber by Origami and welded in the µRobotex nano-factory.

Runing title: smallest micro house in the world
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Abstract:

In this study, we have demonstrated by the fabrication of the smallest micro-house, Fig. 1, that it is possible to realize several three-dimensional micro and nanostructures, with a dual beam SEM/FIB Auriga 60 from Zeiss, in which we have added a 6 Degree of Freedom (DoF) robot built with SmarAct components. In this new type of nano-lab, it is possible to cutting, etching, folding, assembling and then welding thin membranes of silica on top of a cleaved optical fiber SMF28, or produce micro and nanostructures, like the micro-house. We have experimentally shown that Focused Ion Beam (FIB) can be use, in this new generation of micro/nano factory in combination with Scanning Electron Microscope (SEM), and Gas Injection System (GIS), in order to fabricate three-dimensional microstructures: a micro-house in this study, with ultra-high accuracy assembly down to 10nm.

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By using the theory of sputtering we are able to propose a model of folding thin membranes of numerous materials such as metals, polymers or crystals ie, silica, silicon, potassium tantalate or lithium niobate…This method is usually described as Origami in the literature[1-3]. The experimental results indicates that the introduction of a micro robot inside the SEM vacuum chamber will provide the means to enlarge the scope of clean room facilities to build complex and smart 3D microsystems with heterogeneous materials, especially on the facet of an optical fiber in the Lab On Fiber (LOF) new field. We propose a new way to easily manufacture many kinds of optical functions for light trapping based on nanoantennas, nanophotonic crystal, axicon or lattice, 3D bio sensor with Origami, and nano patterning surfaces or Carbon Nano-Tubes…

I. INTRODUCTION

The micro and nano-factory in dual beam SEM/ FIB / GIS is a new way to increase the field of clean room processes especially with the introduction of several robots inside the chamber. By this new way, it is now possible to assemble several crystals as thin membranes in order to build new generations of real three-dimensional structures. The recent development of FIB process in three different types of action, is a powerful way to pattern the different elements before assembly. The first patterning mode is a high-powered membranes cutting mode with a high power of gallium beam, in etching mode. With the combination of high current, from 200pA to 20nA, and Xenon Fluor, XeF2, gas from the GIS, it is possible to etch very depth structures of more than hundreds micrometers. The second way to pattern structures leads to a process from 2003 by Origami [1-3]. With a medium power of the gallium beam, from 50 to 100pA, and with a specific process, it is possible to fold some crystals, metals or polymers and some membranes in order to obtain a self-folding of the membranes as patterning surfaces [4,5]. Membranes for 3D structures could be process in clean room by lithography or directly pattern by FIB in the same vacuum chamber as the assembly process. The third way to use the gallium beam correspond to the Ion Beam Assisted Deposition (IBAD)[6] process. In this process, with a low current of the FIB beam from 5 to 20pA, and in combination with one gas from the GIS, carbon, silica or platinum, injected just near the bombarded surface, it is possible to realize the growing of a thin film in order to link, stick or weld two different membranes or surfaces one with another. The step of assembly is carried out with the robotic 6DoF arm before welding. Origami or micro origami structures are also realized in atmospheric conditions in order to help robotic tasks as micro-assembly, clinical micro-surgery, cell manipulations, and biomedical engineering research[7,8].

We can find many papers related to Origami method, in SEM/FIB station, corresponding to the creation of three-dimensional microstructures[1-3]. The authors discussed the fold radius in function of ion implantation of Gallium on silicon nitride cantilever[1-4], the thickness of the cantilever, the stress resulting of the ion dose. Others[5] talk about tensile stress in case of self-folding chromium layers on silicon nitride cantilever. They also built a square nano-box of 800nm in Ti/Al/Cr, just by self-folding but without linking the different faces at the end of the process. All these papers aim to study the self-folding Origami process by Ga+ ion implantation. In the 2000s, many authors tried to build super structures by Electron Beam Lithography (EBL) of FIB milling in order to enhance properties of materials or metamaterials[5], but they were often limited by the manipulations or the characterizations at small scales under vacuum or in atmosphere Other authors[9] have fabricated nanobirds with plasmene nanoribbon of bimetallic gold and silver nanocubes (NCs). The thickness of their plasmene nanoribbons is in nanometer but the scale of the birds is in millimeter. They used Origami process by FIB milling to self-fold their 3D structures. Other Origami structures in SEM were realized in CMI EPFL, in order to produce a ‘silicon nano insect hotel’[10], or polyimide foils corset[11], but the structures were realized without robotic assembly. One of the most important and common properties of the process of Origami observed in bibliography is the end step of the self-folding process, when the cantilever is at 90°, it means parallel to the ion Gallium beam. In our study, we observe the same properties, when the walls are at 90° between the base of the house and the rest of the membrane, it blocks the ion beam and folding stops. However, in our study, we observe the same Origami and self-folding process, but it doesn’t depend on the ion implantation dose[1,2] or on the tensile stress of the membrane[3]. The recent development in nano-robotic, nano-optic, nano-probe or nano-antenna, combine the properties of optical fiber in interaction with another nano-system like bowtie nano-antenna[12,13] , campanile near-field probes on the facet of an optical fiber[14]. Electron Beam Lithography (EBL), Ultraviolet Nano-Imprint Lithography (UV-NIL) in dual SEM/FIB station, are often used to produce optical nano-system[12-14] but the authors, especially the optician researchers have difficulties to carried out the assembly of the two parts of a system with the right optical precision under vacuum because commercial solutions does not exist. The Lab on Fiber technologies (LOF)[15] is an emerging field, from 2013, with a lot of applications in multifunctional photonic devices, but the actual systems are produce in clean room with conventional facilities, EBL, UV-NIL, SEM, FIB, without robotic actuators and not under vacuum. The development of the new µRobotex station with robotic Smaract structure under vacuum will permit to have a reproducible solution to optical nano-assembly, because the Smaract actuators have a centimetric strokes with a nanometric accuracy, and because, we use the SEM/FIB parameters to pilot the robotic arm . The new generation of nano-factory like µRobotex will become a very important way to produce optical nano-system in the future, especially in the new Lab-on Fibers field[15]. In this study we show that the µRobotex nano-factory is able to assemble, each type of integrated components such as mirrors, filters, photonic crystal, hexagon of less than 1µm, on top of an optical stretched fiber, on the tip of an optical fiber or on the facet of a cleaved fiber. The assembly properties correspond to all the geometrics parameters, angle, distance between the two faces, positioning between the center of the optical fiber, with an accuracy from 2 to 10 nm. In the µRobotex nano-factory, it is also possible to realize geometric assembly with the Smaract robotic closed loop system with or without active optical way. Active optical way means that it is possible, under vacuum, to control the moving step of the robot in function of the properties of the transmitted light, losses, phases[16.]

The µrobotex station is a very powerful tool especially for the Lab-On-Fiber (LOF) technologies due to the very high accuracy of the assembly and to the robotic solutions which is necessary to control the position and the orientation of the center tool. The high accuracy of the robotic arm is necessary to set up the different components on the facet of the fiber, exactly at the optical center of the fiber, and exactly at the right position, or angle. Fig. 2 shows a mirror of 25*25µm pattern in a thin silica membrane of 1.2µm, assembly on top of an optical fiber. We also have realized the assembly of a hexagon of 760nm*40nm of an optical crystal on top of a tip, grown by opto-polymerization on the facet of an optical SMF28 fiber. The big vacuum chamber, the high stability of all the system, the low level of noise measured by infrared method[17] give exceptional conditions for all type of assembly, especially in all optical fields because the accuracy is well below the wavelength of 1550nm. The µRobotex station is a very powerful nano-factory for the LOF field. In this field, we often install the optical fiber on the arm of the robot, in order to place the z-axis of the fiber parallel to the z-axis of the FIB. In this position, it means that the facet of the fiber is exactly in the (x,y) plane of the FIB containing the eucentric point. Then we install the membrane, micro house, the mirror or the optical filter, Fig. 2, the pyramid[14], on the stage of the SEM, on a substrate holder with an angle of 54° so that to have the surface of the object to be assembled in the same (x,y) plane of the FIB.

II. EXPERIMENTAL

A. Folding thin layers or thin membranes by Origami

In this study, we have used silica as substrate membrane, for the building manufacture of the micro house: base, walls, roofs, we have used a specific process of self-folding of the silica membrane in order to change the orientation of the walls from 0 to 90°, and each side of the roof at 35°±2°. The most commonly used name for this process is Origami. The parameter of this process are describe in table 1 for several materials. In this study, the membrane is a silica membrane of 1.2µm thick covered on the upper face by a thin layer of 40-50nm of chromium. When we fold the wall, we begin by etching the thin chromium layer in order to remove it.

B. Theory of the self-folding process by Origami

Then with the ion gallium gun, we etch the silica of the membrane and after a short time, when the thickness of the etching area is thin enough, Fig. 3 (Color online), the self-folding process starts. In all our tests, in all conditions, we observe that the self-folding process always starts for the same thickness of the silica membrane, Fig 4a,b,c,d. If we change the materials to fold, then the thickness of the self-folding is different but always the same for the new material, as silicon, lithium niobate or alumina…. The specific volume of self-folding correspond to the etching area as a sputtering bulk. As it was explain in Fig. 3a, by the sputtering mechanism of ion beam[18-20], there is a transfer of momentum between the gallium ions and the atoms of the thinner etch membrane Fig. 3b. In fact, in the bulk of the last link between the two parts of the membrane, we can find two different areas: the upper value in white on Fig. 3b, c, d, the cold one, in which the gallium atoms pass across with high speed. We find also the rear part in which the gallium atoms are reflected, in red on Fig. 3b, c, d, the hottest. The temperature in the upper area is lower than the temperature in the bottom one because the path of the gallium ion is longer and they change there direction of propagation. The Gallium ions are reflected in the bottom part of the etching area. So, when the thickness of the membrane correspond to the maximum of the thermal dissipation of all the gallium ions, which were all reflected, it appears in this small bulk, or area in Fig. 3c,d, a bimetallic strip with the hottest zone in the down part and the coldest one in the upper.

The properties of the bimetallic strip with the differential dilatation coefficient between the hottest area and the coldest, give rise to the self-folding of the moving part of the membrane, always in the direction of the top part: Fig. 4a and 4b. It means that even if we want to cut a little part of the membrane, and remove it, it always finish with a small part at 90° from the base Fig. 4d. By this specific process of self-folding, we are able to produce real three dimensional micro and nano systems, with all type of material, crystal, metal, semiconductor, polymers, metamaterial or piezo-electric one…All the structures could be pattern before or after folding in function of the need. In the same vacuum chamber, we can, as in clean room but for smaller devices, in nanotechnologies use the µrobotex station as a new generation of micro and nano-factories or nano-Lab. Before the real assembly, we have simulate the result in order to prepare the assembly scene and the assembly tools. Fig. 5 represents the Conception Assisted by Computer (CAC) view of the conception step of the micro-house on top of the facet of an optical fiber.

III. Protocol for the assembly.

A. General description of the different components

The µRobotex station, the new powerful micro and nanofactory, is based on an Auriga 60 microscope produced by Zeiss. The Auriga 60 has a big vacuum chamber of 60*60*60cm^3, on the top of the chamber, a SEM FEG column is installed with two detectors for retro diffused electrons: In lens and ESB one. The third electron detector corresponds to the Secondary Electrons, SE2 detector. The Focused Ion Beam FIB column is produced by Orsay-Physics, this column is positioned at an angle of 54° from the z-axis of the SEM column. In this paper, we will always use the same Gas Injection System (GIS) with 3 gases: Xenon Fluor for etching processes and naphthalene and cyclopentadienyl-platinum for vapor deposition processes respectively carbon and platinum by Ion Beam Assisted Deposition (IBAD)[6]. The GIS is produce by Oxford Instrument and the type is OmniGis II, in the family of Omniprobe. We can also work in Electron Beam Assisted Deposition mode (EBAD) with a better uniformity but for thinner films

B. Robotic under vacuum

The robotic system is built with six individual actuators from SmarAct. The robotic structure is home assembled and all the robotic arms are controlled in order to obtain a very high accuracy on the object position. The moving steps are controlled with a Human / Machine / Interface (HMI) and the softwares are home made in order to combine high accuracy of positioning and synchronization of all axes in the assembly processes Fig. 6a (color online). The control of the robotic system is based on the Kinematic Model (KM) so as to calculate the value of position of the object of interest in function of the value of the position of each axes. The parameters of each axis are used to build a CAC representation of the assembly scene in order to control the position of the elements under vacuum because in the chamber it is impossible to see the elements, Fig. 6a. These structures are characterized by the possibility of decoupling the Kinematic Model in a complete geometric model calibrated in order to obtain informations about the position of the assembled elements. The solution of this model, depending on a solving solution by iteration, is given whatever the values of the geometric parameters, angles and distances between successive axes, that are not conditioning by the structure[21]. All the axes are synchronized every 500ms in position and in acceleration in order to pilot with a high accuracy the system. The axes are stick / slip type from SmarAct compagny. The combinaison of hight accuracy of the axis under vacuum and SEM parameters for pilots the geometric model offert a very important scientific result in this study. One of the most important things in this type of control in closed loop of the robot, correspond to the three ways to mouve the center tools of the robot. It is possible, by using the Kinematic Model, Fig. 6a, b to control the robot in three different repairs: the repair (x,y,z) of the SEM, the repair (x',y','z') of the FIB or the native repair of each axis of the robot.

C. Substrate preparation: the fiber

The substrate holder for the realization of the micro house is an optical fiber, SMF28, which is cleaved after stripping the sheath. The fiber is then installed on a special tool of acrylate realized by 3D printing. A PVD process of chromium layer coats all the system, tools and fiber. We sputter a thin film of less than 40 nm of chromium to pattern and observe the objet in the SEM conditions. After deposition, the acrylate tool and the fiber are installed on the robotic arm inside the SEM vacuum chamber. The axis of the optical fiber is installed in the same axis than the z-axis of the FIB. In this position, the top surface of the cleaved optical fiber is located in the (x,y) focalization plane of the FIB containing the eucentric point. The chromium layer is etch in the center of the fiber so as to let the optical signals lighting out of the fiber in working conditions. Four platinum plots of 1.4µm were deposited, on the as-patterned area, at the four corner of the following micro house, in the center of the fiber.

D. Substrate preparation: the membrane for patterning the micro house

The micro house comes from a silica membrane of 1.2µm thick, which is obtain by wet etching in KOH of a Silicon-On-Insulator (SOI) wafer in clean room. We etch a square area of 200*200µm, of silicon on both faces of the wafer, and then the silica membrane is coat with less than 50nm of chromium. After this step of preparation of the facet of the optical fiber, the fiber is retracted along the z-axis of the FIB in order to let the place to the mebrane. The membrane is then install inside the vacuum chamber on the stage of the microscope, at an angle of 54° in order to be pattern by FIB, in the (x,y) plane of the FIB, Fig. 7b. Before assembly, the first action is to install the membrane at the eucentric point of the machine in order to be able to image the assembly scene by both SEM and FIB, Fig. 7a, b. The gallium beam is used with high power and high beam current, 10 and 20nA, to draw cutting pattern by etching the membrane. We just keep a little link before folding the four walls and welding the base of the house on top of the optical fiber with both GIS, naphthalene gas, and FIB, Fig. 8a.

E. Origami process to raise the four walls

After cutting the pattern, etching the doors and the windows of the micro-house, the four walls of the house are in the plane of the membrane, Fig. 8a. We need to change the position of the walls by sefl-folding the membrane. Origami is often use for this action which consist to changing the angle of one part of the membrane [1,3]. In this paper we study and develop a self-folding way, Tab. 1, to install the four walls of the house at an angle of 90° from the original membrane plane Fig. 8b, c, d. Fig. 4a shows the different angles of folding in function of the different conditions of current of the FIB. Fig. 8b, c and Fig. 9a show the folding action of the first three walls and without the optical fiber, in the background, because the halls are dark. Fig. 9b shows the origami at 90° of the four walls, and the installation in the background, just behind the membrane, of the fiber. The robot, with a special end tool hold the fiber, and allows the z-axis of the FIB repair, to install the fiber in contact with the membrane, by learning and memorizing the position of the surface of the fiber before welding. This action required a very high accuracy, because if the fiber rises too far, the membrane explodes. The only way to control the position of the fiber relatively to the membrane is to observe through the dark windows whose appears after the self-folding of the four walls of the house as it can be observe on Fig0. 9a.

Figure 9b also shows the welding points with the FIB and naphthalene gas from the GIS, use to link or stick the base of the house in contact with the top cleaved surface of the fiber. The parameter for this process depends on the size and the thickness of the link to the plot. The first step consist of depositing a square of 5*5µm just near the membrane to increase the level of the surface of the plot, witch correspond to the thickness of the membrane, plus the thickness of the thin plots which were under the house, it means a thickness of 1.2+1.4µm=2.6µm. Then we deposit a new link of 7*4µm between the membrane and the plot of 2.6µm thick. After the last stick point, we expect that the base and the four walls of the micro house are definitively stick on the top of the fiber and then, we cut the last link between the membrane and the micro house Fig. 10a. By this process, we show that the house comes from the membrane, and after micro-assembly and stick process, is fixed on top of the optical fiber by robotic nano-assembly.

F. . Ultra-high accuracy assembly for tenon and mortise.

Then we pattern the two sides of the roof, Fig. 10c, d, the outer ribs and the mortise use for positioning the top of the walls before welding. Again, we use the Origami method to get each side of the roof to the right angle of 35°. This process depend on the control of the beam power of the FIB and the thickness of the etching line. As we can see on Fig. 10b, c, it is important to obtain the same angle for both sides of the roof. Again, we install the optical fiber with the base of the micro house just in front of one side of the roof, by the backside of the membrane without breaking the as-assembled micro house, linked on the fiber, and the first part of the roof, linked on the membrane. The ultra-high accuracy of the SmarAct robotic in HMI system is very useful for this assembly process, in all the (x,y,z) direction. We need from 4 to 10nm of accuracy in the plane of the roof, it means in the (x,y) plan of the FIB, for tenon and mortise integration, and less than 50 nm in the z-axis of the FIB. For this part of the process, we need a very high accuracy, a few nanometers in combination with a very high stability of all the robotic arms. After assembly, we deposit naphthalene between the top of the wall and the mortise of the roof, starting from the bottom of the roof like tiles. The properties of the naphthalene coating present the advantages to grow into two directions, planar and perpendicular, in order to link the space between the walls and the roof, and to fix the roof onto the walls. This process time vary from 3 to 10 min for each plot, and during this “long” time, we need a perfect stability of the SmarAct actuators. We use the same process for the second part of the roof, Fig. 10e, and then, after depositing all the tiles, the house is finished, the chimney can be built Fig. 10f and also Fig. 1 because Besançon is just near the mountain of Jura, it snows in winter and it's cold.

IV. SUMMARY AND CONCLUSIONS

In this study, we demonstrate the abilities of the new generation of micro and nano-factories or nano Labs, with a lot of peripheral equipment, as FIB, GIS, and micro-robotics structures inside the vacuum chamber, in our case SmarAct and Kleindiek. In the µRobotex station, we are able to set up others accessories as laser, ellipso-meter, and spectrometer, electrical and optical bulkhead crossing, in order to test, excite or align many samples in function of piezo answer or optical positioning. We are also able to introduce other gases for mechanical link and traction test under SEM. By the building of the smallest micro-house in the world, which is in fact, not even able to accommodate a mite[22], we demonstrate the high capability of the µRobotex station, the very high accuracy of the µrobot and the high flexibility of the station. It is not possible to realize all these actions in clean room with human accuracy but now with the new type of big SEM vacuum chamber, with the high accuracy of the new generation of µrobot installed under vacuum and other accessories installed inside the chamber, we can pattern, cut, fold, assemble, weld and stick many kinds of materials to produce real three dimensional micro and nano-systems, for many kind of new application. We also submit an original theory to understand the folding effect of thin membrane by the sputtering effect and the transfer of momentum. This new technology is an emergent one, which can be used for producing micro and nano-system for the future. In fact, it would have been impossible to realize such micro and nano-systems without the new µRobotex station. The LOF technologies could be developed in our new nano lab.

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Tables captions

materials	Etching line	Step 1	Step 2
Origami of Silica of 1.2µm thick	X=10 µm Y=1.7 µm	T=600 sec P=30kV 2 nA	T=60 sec P=30kV 200 pA
Origami of LiNbO3 of 1.0µm thick	X=20 µm Y=1.5 µm	T=480 sec P=30kV 2 nA	T=45 sec P=30kV 200 pA
Origami of silicon of 1.5 µm thick	X=25 µm Y=2.0 µm	T=360 sec P=30kV 2 nA	T=30 sec P=30kV 200 pA

Table 1 : Parameters of the Origami process for several materials such as silica, lithium niobate and silicon.

Figures captions

FIG. 1: The micro house is assembled by origami and welded on top of the facet of an optical fiber in a SEM .and FIB dual beam.

FIG. 2: A mirror of silica is assembled at the center of an optical SMF28 fiber. The space between the top of the optical fiber and the back face of the miror is controled by four small plots of 1.4µm thick. The size of the miror is 25*25*1.2µm.

FIG. 3: (color online) Theory of the Origami process: **a**: the first step of this process correspond to a sputtering with Gallium ions of the interesting area. B: When the bulk of the link between the membrane and the panel to fold correspond to a specific thickness, a bi-metallic strip appears **c**: The effect of sputtering produces a differential dilatation coefficient into the upper part in white and the down part in red of the link. **d**: the panel self-fold from 0 to 90°.

FIG. 4 : Origami of silica membrane of 1.2µm thick with the FIB process in different conditions. **a**: 6 succesives panel for testing the angles by using different widths of etching from 1µm to 1.7µm.The final angle depends on the initial width of etching. **b** test of the angle of a single wall of 15*15µm, with a width of etching of 1.7µm. In this case, we have test the elasticity of the origami link with a tip. **c**: 3 succesive panels with a width of 1.7µm. **d**: 4 walls without windows and doors processes by the Origami process in order to obtain the same structure than a house. The wall are at 90° from the base of the membrane.

FIG. 5 : (Color online) CAC modelisation of the final assembly. **a**: simulation view from the FIB when the top face of the fiber is located in the (x,y) plane of the SEM. **b**: cross section of the final assembly.

FIG. 6: (Color online) Representation of the Kinematic Model, (KM) in order to rebuilt the assembly scene on another control screen so that to be able to control the position of an object in function of the other inside the chamber. It is possible to zoom in this model and to change the repair of moving from the SEM one, to the FIB or Robot one.

FIG. 7: **a**: The top face of the SMF28 fiber, holding by the robot, is located in the (x,y) plane of the FIB, containing the eucentric point, and the z-axis of the fiber is paralleled to the z-axis of the FIB repair. The facet of the optical is installed in the (x,y) plane of the FIB containing the eucentric point, then memorized, and then retracted along the z-axis in order to let the place for the membrane patterning step. **b**: The membrane of silica, carried by the stage of the microscope, is also located in the (x,y) plane of the FIB containing the eucentric point for patterning the base and the walls of the micro house with door and windows.

FIG 8 : The scale was the same for all the pictures. **a** :Test of patterning of a membrane in silica without door and windows. **b**: Optimization of the origami process or self-folding with three walls of a box like a house, view from the SEM**. c**: the same optimization view by the FIB. **d**: Origami of the four walls views by the FIB.

FIG 9 **: a**: Origami process of the three walls of the final micro house. B: Origami process of the four walls and installation of the fiber in the background. We can see the diameter of the fiber, because the center of the house is installed in the center of the fiber in order to let the light throughout.

FIG. 10 : **a** : After the step of welding of the base of the micro house on the facet of the optical fiber, we must cut the thin last link between the base of the micro house and the membrane. During the assembly time and the welding time, the stability of the system is very important. In case of drift of the robot, the micro house could be broken. **b**: the link is cutting, we can extract the micro house by the background direction. **c and d**: After pattering and self-folding the first roof at 35°, we install the micro house from the background like ‘mortise and tenon’. This step requires a very high accuracy less than 10

nm. **e**: After welding the first roof, we install the second roof in the same conditions and we realize the welding step always with naphthalene gaz. This step requires also accuracy and stability. **f**: After welding the two roofs, we built the chimney .This picture was realized with the ESB detector. The other pictures were always realized with the SE2 detector.

Jean-Yves Rauch was born in Champagnole in 1969. He obtained a DEA degree of the university of Franche Comte in the field of chemistry and physics, surface and reactivity. After a first contract of 2 years with Rivex company on the PVD coatings layers, he began in 1997, a PhD degree with Surface Engineering in the field of mechanical protective layer such as TiN and DLC by PVD and PECVD. In 2001, he joined Photline technologie a joung start up for developing all the deposition process, evaporation layer such as Ti, insulator silica, Cr and gold and electroplating of thick gold layer. He joined the Femto institute in 2004, in the staff of clean room process, and especially in the vacuum technology of PVD, CVD and PECVD,. He is able to realized chemical and physical analysis of surfaces, by XPS, XRD, and spectrometric analysis of vacuum as mass spectroscopy and plasma diagnostics. Manager of the thin film department, he joined the µRobotex team in 2014 in order to develop the thin film processes by FIB+GIS. His scientific fields are every thin coatings layers, vacuum technology and surface analysis.

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Research: Development of characterization setups and methods (excitation, couplings) in near field specific for nanophotonics / plasmonics, biomedical applications
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2011 to 2013: Post-doc (Ecole Centrale de Lyon) at LTDS Laboratory (Ecully, France).
Research: Programming of the micro-indent setup for study of skin mechanical properties. Development of 3D imaging system for reconstruction of use marks into archeological samples of polished rock.
2009 to 2010: Post-doc (ENISE) at LTDS Laboratory (Saint-Etienne, France).
Research: Tailoring of interferometer microscope for mechanical surface study by Elastic–plastic contact measure.
2006-2008: Post-doc at University of Franche-Comté (Laboratory of Optics).

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Patrick ROUGEOT: :- Research Engineer at FEMTO-ST AS2M- was a senior technician in the development and control of robotic assembly equipment before receiving the graduate from the "Ecole Nationale Supérieure de Mécanique et des Microtechniques" (ENSMM), Besançon, France, in 1990. Then he is design engineer in 1996 in CNRS and is research engineer since 2000 in the department AS2M Femto-st. He works in the Micromanipulation, Micromechatronics and Microrobotic Research Group in the field of Micro/Nanoforce measurement (SPECIMeN), in the devlopment platform for biomedical (Minarob) and in the design platform for microassembly (Nanorobotics). His objectives are developments and exploitations of measurement chains at micro- and nanoscopic scales. His research interests are articulated around an atomic force microscope (AFM) and a *Scanning Electron Microscope (SEM)* for the characterization of the effects of surfaces and by the design and developments of tools and sequences of micromanipulations and microassembly. The major activities of his research concern the devlopment of pre-curved concentric tubes robots and the exploitation embedded actuatuors with smart materials (EAP, SMA, piezo,...). The aim is to combine these actuation techniques to benefit from their advantages. Thus, we are able to cover a better workspace and enhance the dexterity and manipulability for a biomedical application.

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