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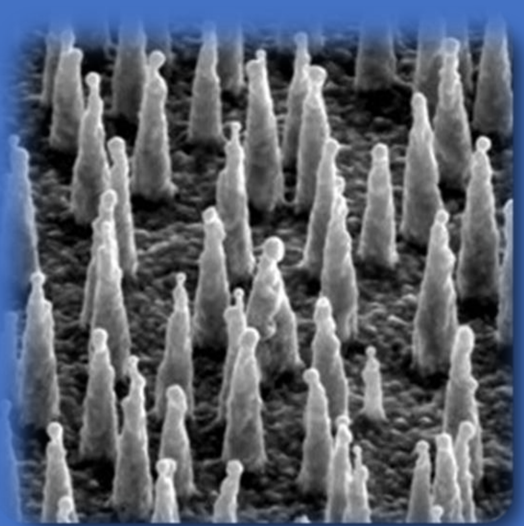
Jagiellonian University in Krakow Poland

The Nanostructures Group
Department of Solid State Physics



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MSc Elżbieta Trynkiewicz

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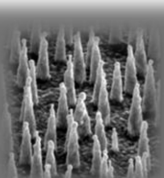

Au/Ge(001) system studies and Au hcp dynamics

The interaction of thin Au layer with Ge(001) surface, via thermally induced self-assembling process, leads to the formation of 1D, 2D and 3D structures. The atomic chains, which might exhibit 1D electronic state are formed together with subsurface Au enriched layer of 2D conductivity. Careful heat treatment leads to the appearance of 3D Au nanocrystalites made of unique and rare Au hcp phase.

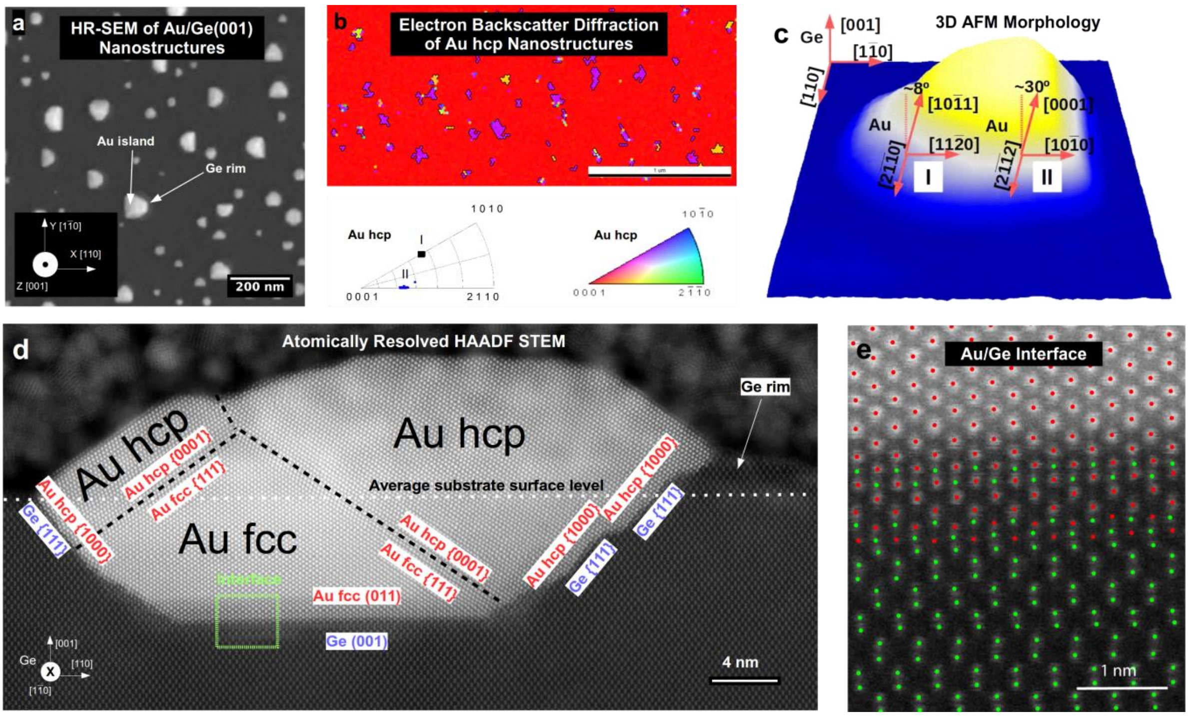

Figure 1: Self-assembled Au hcp nanostructures on Ge(001) surface. a) HR-SEM, b) EBSD IPF, c) 3D AFM, d) Atomically resolved HAADF STEM, e) Au/Ge interface (Au atoms – red, Ge atoms - green)

[1] F. Krok, M.R. Kaspers, A.M. Bernhart, M. Nikiel, B.R. Jany, P. Indyka, M. Wojtaszek, R. Möller, Ch.A. Bobisch, Beilstein journal of nanotechnology 5, 1 (2014)

[2] M. Nikiel, B.R. Jany, D. Wrana, K. Szajna, F. Krok, Surface and Coatings Technology 277, 165 (2015)

[3] M. Nikiel, B.R. Jany, K. Szajna, D. Wrana, A. Janas, R. Kozubski, F. Krok, CrystEngComm, 18, 5674 (2016)

[4] B.R. Jany, N. Gauquelin, T. Willhammar, M. Nikiel, K.H.W. van den Bos, A. Janas, K. Szajna, J. Verbeeck, S. Van Aert, G. Van Tendeloo, F. Krok, Scientific Reports 7, 42420 (2017)

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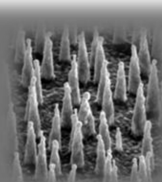
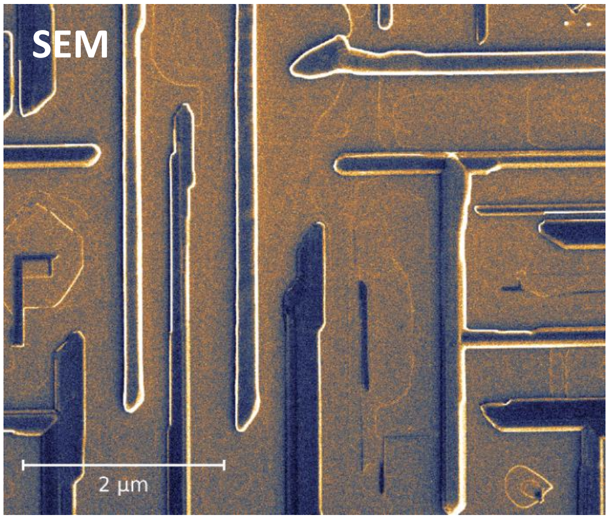


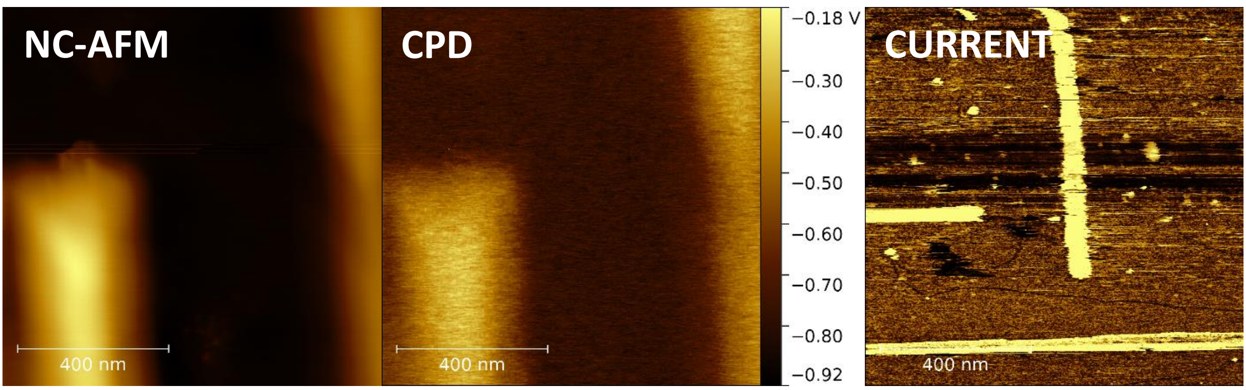
$SrTiO_3$: nanowires formation and redox reactions

Strontium titanate serves as a prototypical material for various nanotechnology applications. $SrTiO_3$ is a model band insulator, however its electronic properties can be easily controlled via doping or reduction. When the crystal is heated up, oxygen vacancies are formed but also diffusion of strontium and titanium are initiated. When a threshold temperature is reached, micrometers long nanowires of crystalline titanium oxide phases are formed on the surface. They are well oriented and metallic. Upon the crystal's oxidation, surface becomes insulating, yet nanowires are still conducting. Thus, surface redox reactions, diffusion and growth processes on $SrTiO_3$ result in array of nanoscale conductive 1D structures, which may be used as a wiring for optoelectronic applications.

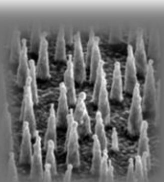


Figures:

Right: SEM secondary electrons image of the titanium oxide nanowires array on the surface of the reduced $SrTiO_3$(100).
Below: NC-AFM topography image, contact potential difference map and conductivity of a single nanowire. Increases of work function (0.6V) and current (4 orders of magnitude) are presented.



D. Wrana, C. Rodenbücher, B. R. Jany, K. Szot, F. Krok
Oriented crystalline nanowires formation on reduced SrTiO3(100) (2017)



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Electronic and structural properties of reduced doped TiO_2

One of the most studied and industrially relevant nanomaterial is titanium dioxide. We focus on ways of tune its key properties such as conductivity, electronic structure and crystallography, on the atomic scale. Thermoreduction of rutile TiO_2(110) single crystals, both Nb-doped and undoped reveals many interesting surface phenomena. After annealing the slightly doped crystal to temperatures as high as 800°C, the new (4x2) surface reconstruction is formed. The new periodicity and excellent conductivity makes it a perfect template for thin films growth and in memristive applications.

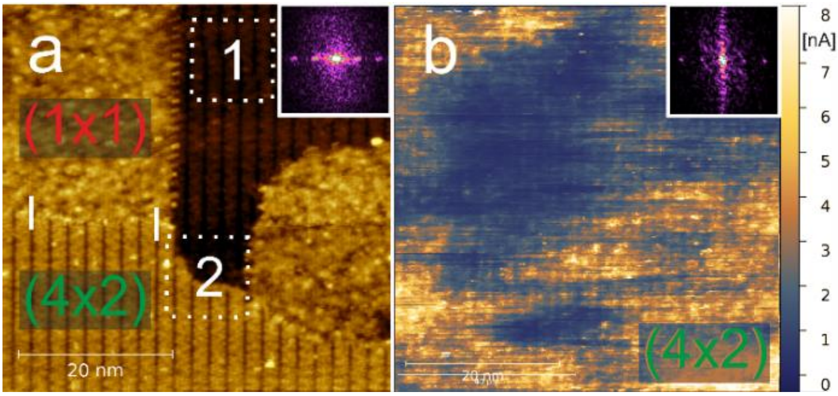
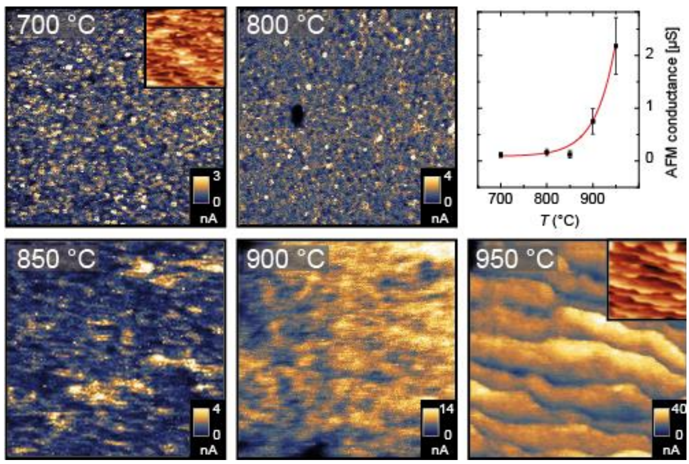
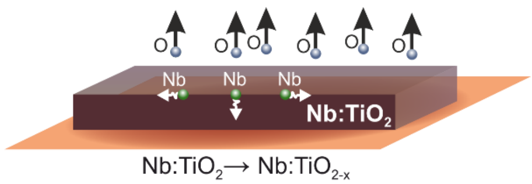


Figure 1:
a) STM image of new (4x2) reconstruction on reduced TiO_2:Nb surface (50x50 nm²),
b) LC-AFM atomic resolution of conductivity on TiO_2:Nb surface

Figure 2:
Series of conductivity maps (LC-AFM) of Nb-doped TiO_2(110) surface annealed to various temperatures. Transition from filamentary to homogenous conductivity is shown.





D. Wrana, C. Rodenbücher, B. R. Jany, J. Rysz, K. Szot, F. Krok, Tuning the surface structure and conductivity of niobium-doped rutile TiO 2 single crystals via thermal reduction (2017)

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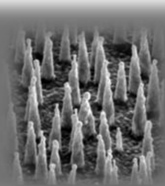


Titanium dioxide (110) surface preparation & modification

Experiments in the field of surface science usually require an atomically flat and clean surface which can be obtained e.g. for TiO_2(110) by subsequent cycles of ion beam sputtering and annealing. However, a highly anisotropic semiconducting substrate can be also needed. By exposing in particular conditions a TiO_2(110) surface to enough high fluence it is possible to produce in a controllable way a well-defined ripples structure consisting of densely packed atomic steps with high crystallographic order.

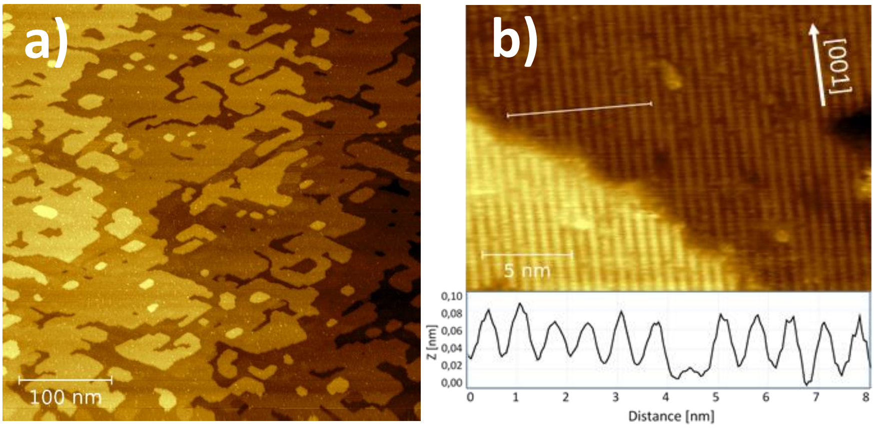
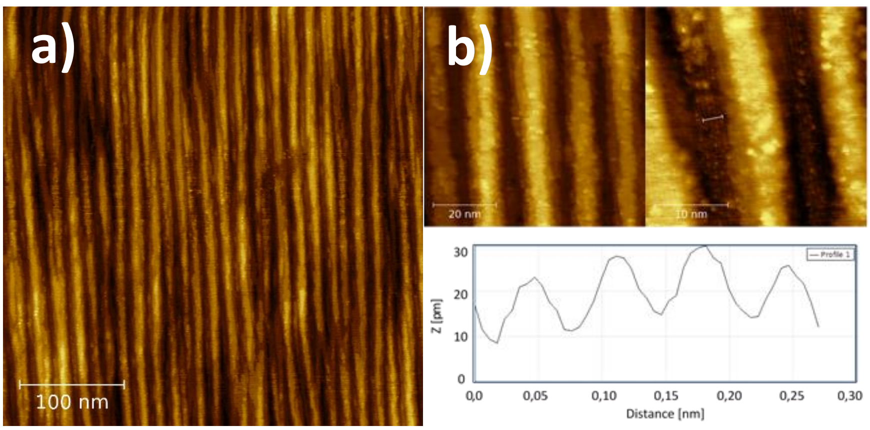


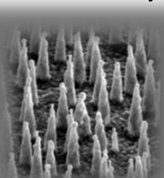
Figure 1:
a) STM image of atomically flat TiO_2(110) surface (500x500 nm),
b) atomic rows resolution of STM on TiO_2(110) surface with topography profile

Figure 2:
a) STM image of ripples on TiO_2(110) surface (500x500 nm),
b) atomic terraces and atomic rows resolution of STM on rippled TiO_2(110) surface with topography profile



[1] M. Kratzer, D. Wrana, K. Szajna, F. Krok, and C. Teichert, Phys. Chem. Chem. Phys. 16 (2014)

[2] K. Szajna, M. Kratzer, D. Wrana, C. Mennucci, B. R. Jany, F. Buatier de Mongeot, C. Teichert and F. Krok, J. Chem. Phys. 145, 144703 (2016)



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Thin organic films grown on modified $TiO_2(110)$ substrates

Controlling a thin film growth of small organic molecules, like *para-hexaphenyl* (6P) is a crucial issue in the field of organic electronics. Resulting morphology of 6P structures is strongly influenced by concentration of surface defects and can be easily changed by tuning the surface roughness from atomically flat, via slightly defected [1] to strongly modified, rippled templates formed by ion-beam sputtering. 6P structures changes, respectively, from needles consisted of lying type molecules to islands of up-right standing molecules in crystallographic order. Depending on surface roughness and anisotropy a 6P diffusion changes and induces different shape [2] and stability [3] of molecular islands.

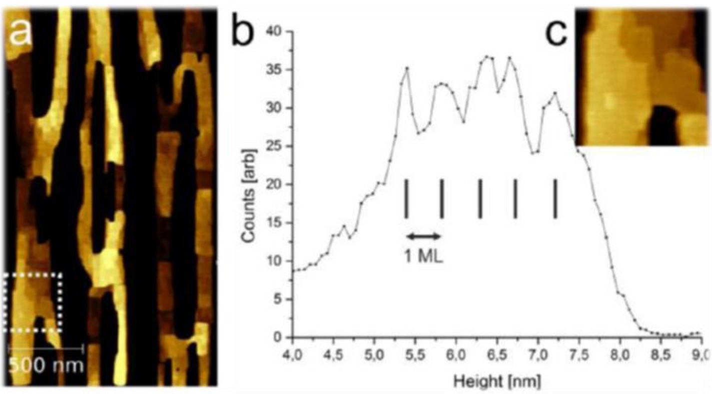


Figure 1: TM-AFM image of 0.25 ML coverage of 6P on TiO2(110): a) View on the top of the nanoneedles. b) Height histogram of nanoneedles. c) Monolayer terraces of the lying molecules imaged on top of the nanoneedles.

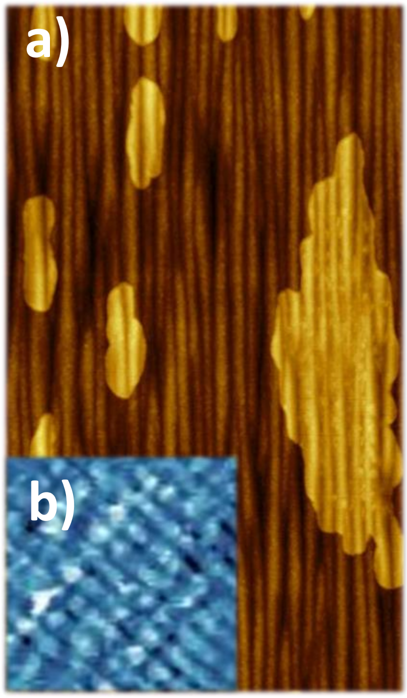
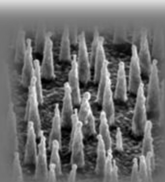


Figure 2: a) NC-AFM image of 0.5 ML coverage of 6P on rippled TiO2(110). b) View on the top of the islands with molecular resolution.

[1] D. Wrana, M. Kratzer, K. Szajna, M. Nikiel, B.R. Jany, M. Korzekwa, C. Teichert, F. Krok, J. Phys. Chem. C, 119 (2015)

[2] M. Kratzer, D. Wrana, K. Szajna, F. Krok, C. Teichert, Phys. Chem. Chem. Phys., 16 (2014)

[3] K. Szajna, M. Kratzer, D. Wrana, C. Mennucci, B.R. Jany, F. Buatier de Mongeot, C. Teichert, F. Krok, J. Chem. Phys. 145, 144703 (2016)



Self-assembly of Au nanostructures on AIII-BV surfaces

AIII-BV compound semiconductors are used in technology today as a base for many high-speed electronic and optoelectronic devices. Interaction of thin Au layer with different AIII-BV reconstructed semiconductor surfaces leads to the formation of various structures i.e. on GaSb(001) drop-like nanoisland are formed, while on InSb(001) substrate the elongated nanowires are synthesized.

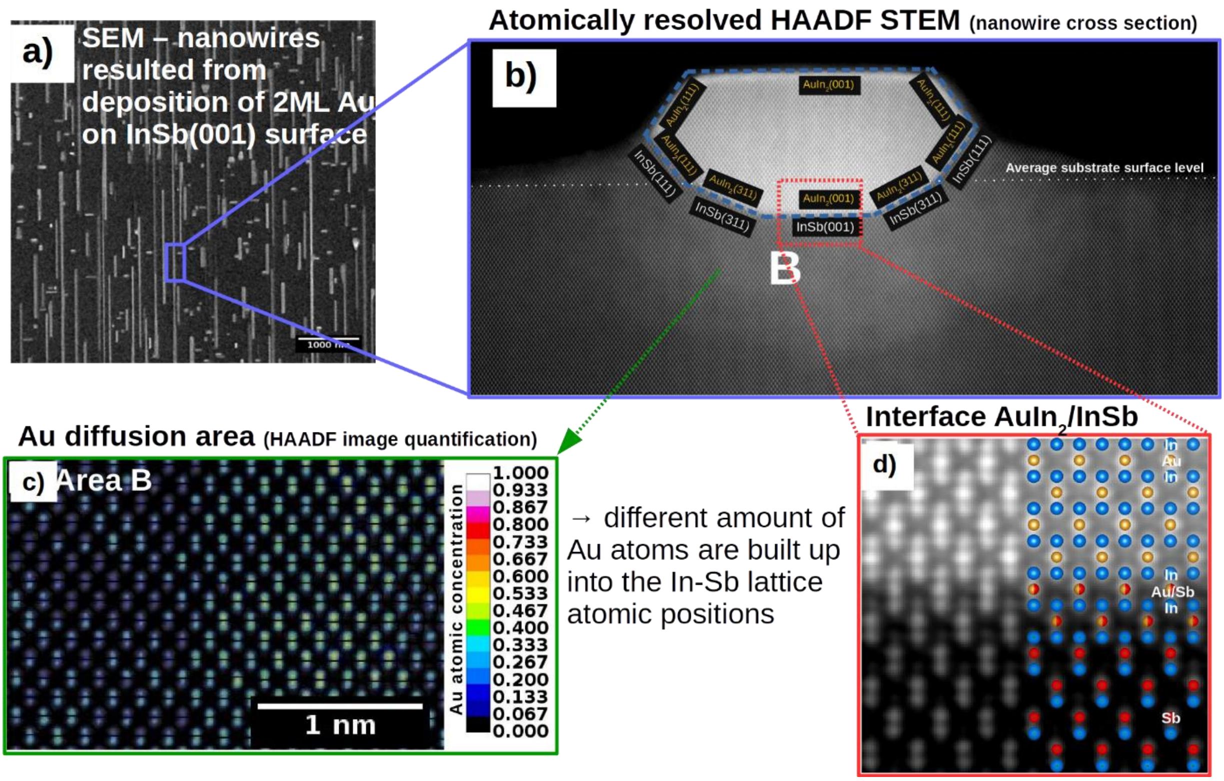
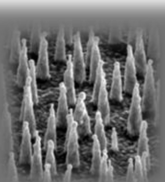


Figure: Nanonowires on InSb(001) substrate resulted from deposition of 2ML of Au at 330C. a) SEM image showing the wires, b-d) Atomically resolved HAADF STEM showing detailed atomic structure with chemical sensitivity (Au atomic columns appears brighter then In-Sb atomic columns).

B.R. Jany, A. Janas, K. Szajna, O. Kryshtal, G. Cempura, A. Kruk, A. Czyrska-Filemonowicz, F. Krok
Chemically driven growth of Au rich nanostructures on AIII-BV semiconductor surfaces (2017)



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AIII-BV semiconductors: ion-beam-induced nanostructures

Intensive research efforts have attracted widespread interest in the field of the synthesis, design and fabrication of regular semiconductor nanostructures with precisely defined size and shape over large areas. Depending on the material and the individual sputtering conditions it was observed that self-organized unique patterns, such as ripples, dots and pillars, can evolve after high fluence ion sputtering of AIII–BV semiconductor surfaces (e.g. InSb, InP, InAs, GaSb). These nanostructures obtained with length scales spanning from few to hundreds of nanometers can provide ideal elements in future nanoelectronic industry including, among others, FET transistors, interconnections with larger scale devices, as well as antireflective or hydrophobic coatings.

Figure 1

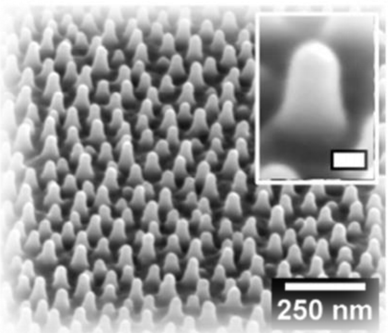


Figure 2

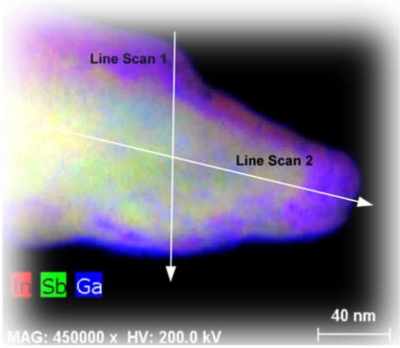


Figure 3

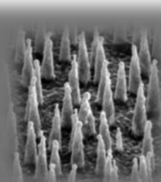
Fig. 1: SEM image of ion-beam-modified GaSb(001) surface bombarded with 3 keV Ar^+ ions. The inset represents the corresponding single structure with a scale bar of 25 nm.

Fig. 2: RGB EDX composition map of the fabricated single pillar.

Fig. 3: Photograph of irradiated phosphorus in MBE system equipped with broad-beam ion gun.

[1] B.R. Jany, K. Szajna, M. Nikiel, D. Wrana, E. Trynkiewicz, R. Pedrys, F. Krok, Appl. Surf. Scie., 327, 86 (2015)

[2] E. Trynkiewicz, B.R. Jany, A. Janas, F. Krok, Temperature controlled surface evolution of AIII-BV compound nanopillar arrays by Ar+ low-energy ion irradiation (2017)



Focused Ion Beam (FIB) nanofabrication

The Focused Ion Beam mounted on DualBeam FEI Quanta 3D FEG microscope is used for nanofabrication of various materials needed for different applications in science and technology. The nanopatterns in Au/Glass could be created for the atomic/optical physics applications as a Plasmonic Transmission Gratings. As well as patterns for X-ray capillary optics imaging. Also the FIB technique could be used for STM tip processing to produce sharp and repeatable tip radius.

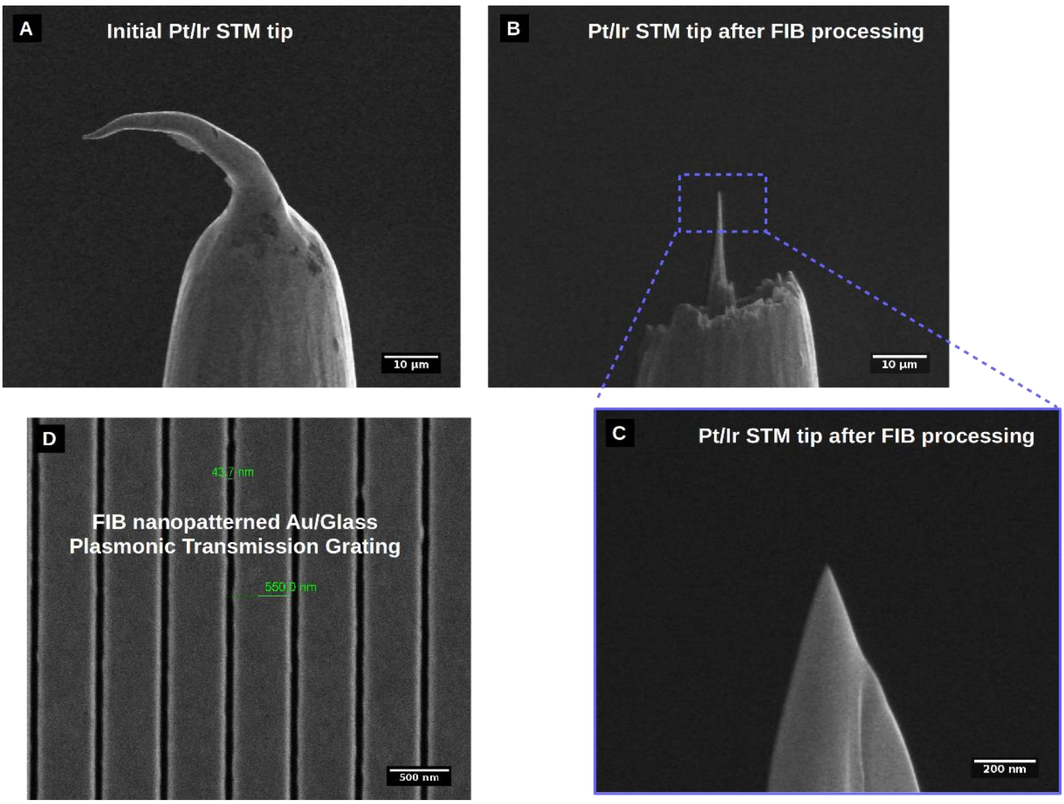


Figure 1: FIB sharpening of Pt/Ir STM tip a)-c), FIB nanopatterning of Au/Glass Plasmonic Transmission Grating

[1] B.R. Jany, K. Szajna, M. Nikiel, D. Wrana, E. Trynkiewicz, R. Pedrys, F. Krok, Appl. Surf. Scie., 327, 86 (2015)

[2] P. Korecki, K.M. Sowa, B.R. Jany, F. Krok, Physical Review Letters 116, 233902 (2016)

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Environmental Scanning Electron Microscopy for Life Sciences

The Environmental Scanning Electron Microscopy (ESEM) is used for Life Science Applications for the imaging and characterization of non conductive and biological specimens. The nanoporus drug carries could be directly characterize by the ESEM for pharmaceutical applications. The internal structure of melanoma cells was accessible by ESEM imaging. There is also a possibility to directly characterize the surface of Red Blood Cells (RBC) and try to link it to the specific disease entity.

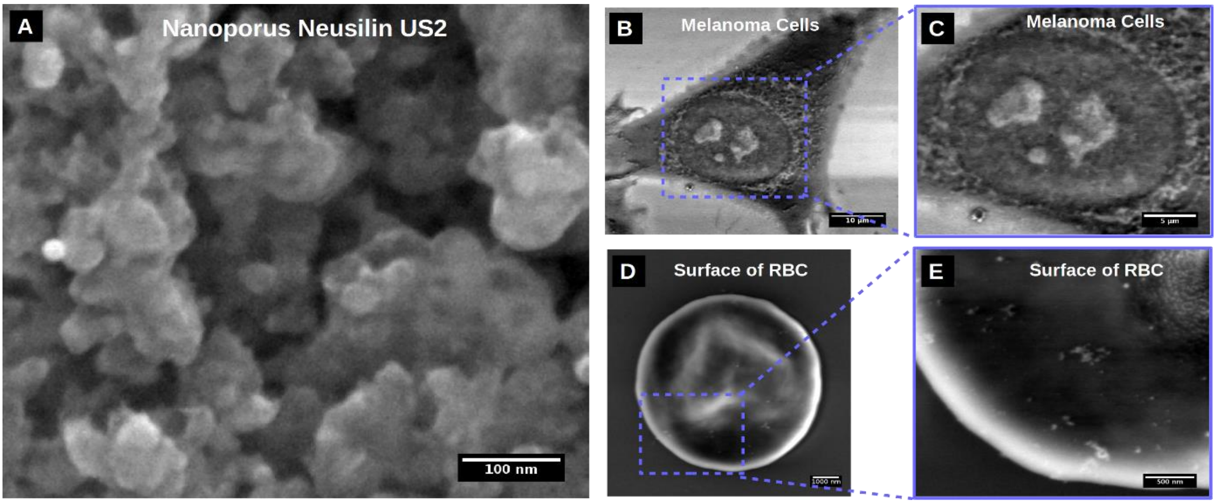

Figure 1: ESEM imaging of a) Nanoporus drug carrier Neusilin US2, b)-c) Details of Melanoma Cells internal Structure, d)-e) Surface of Red Blood Cells

[1] A. Krupa, J. Szlęk, B.R. Jany, R. Jachowicz, AAPS PharmSciTech, 16, 3 (2015)

[2] J. Bobrowska, J. Pabijan, J. Wiltowska-Zuber, B.R. Jany, F. Krok, K. Awsiuk, J. Rysz, A. Budkowski, M. Lekka, Analytical Biochemistry 511, 52 (2016)

[3] J. Bobrowska, J. Pabijan, J. Wiltowska-Zuber, B.R. Jany, F. Krok, K. Awsiuk, J. Rysz, A. Budkowski, M. Lekka, Data in Brief, 7, 1322 (2016)

[4] A. Kamińska, M. Platt, J. Kasprzyk, B. Kusnierz-Cabala, A. Gala-Bladzienska, O. Woźnicka, B.R. Jany, F. Krok, Journal of Diabetes Research, 2016, 5741518 (2016)

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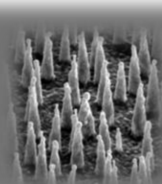

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