Selective Growth of GaN Nanodots on Ion Beam Induced Nucleation Centers on Si(111) 7x7

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Abstract

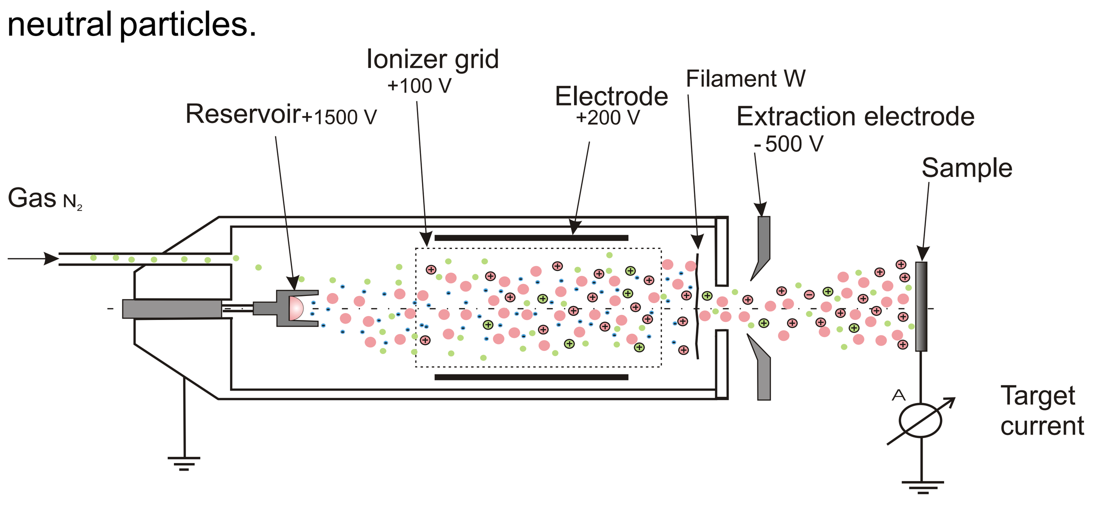
The growth of gallium nitride nanodroplets on Si substrates by physical vapor deposition assisted by a low energy (50 eV) N_2^+ ions is reported. The changes of morphology and composition of these structures with substrate temperature (RT - 400 °C) were studied by atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS). In addition, we present a simple hybrid method for fabrication of ordered structures of these GaN nanodroplets on a Si(111) 7x7 substrate. First, the focus ion beam (FIB) was used to pre-pattern the substrate with milled sites in the a Si(111) substrate covered withthe native SiO_2. Further, this substrate was thermally flashed to remove the native oxide (Si(111) 7x7 reconstruction formed) and then the selected growth of GaN droplets at 350 °C was performed at the milled sites. The local conductivity of these nanostructures was measured ex situ by atomic force microscopy (C-AFM).

Introduction

GaN has become an attractive material for semiconductor industry. This material has a wide range of applications, for instance in light emitting devices operating in the blue- and ultraviolet (UV) spectral regions and in solar cells because of the direct tunable bend gaps of these material providing a wide spectral range, including the visible and ultraviolet.

Ion-Atom Beam Source

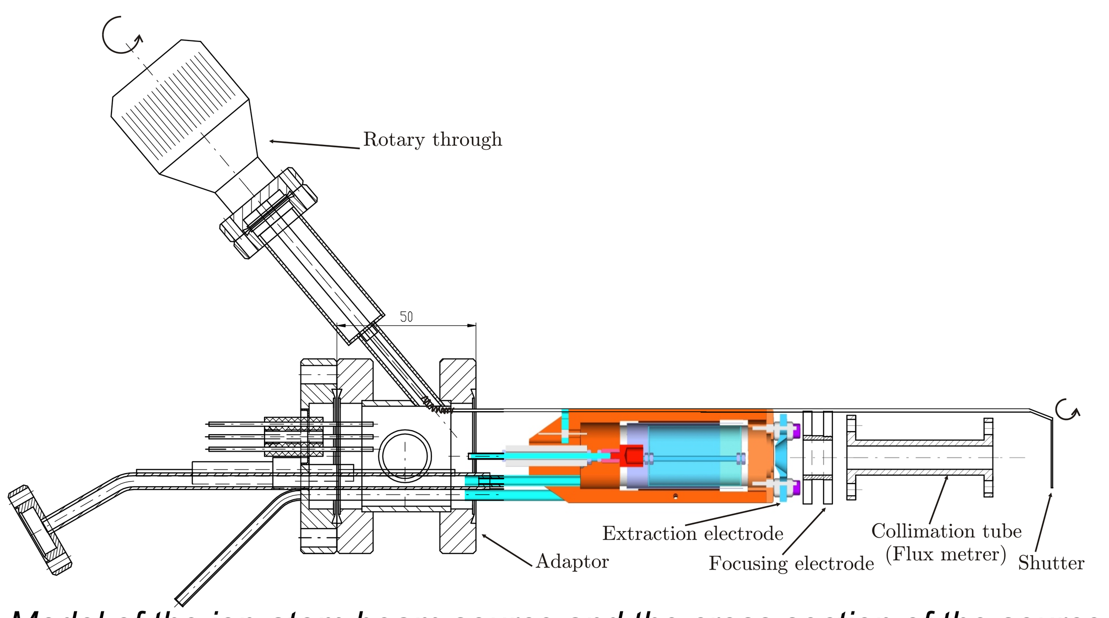
The ion-atom beam source designed at IPE BUT is capable to modify surfaces and also to deposit ultrathin films. Surface modification is carried out by hyperthermal (< 120 eV) energy ion beams. The source produces a mixture of atoms and ions. The ions are generated in an ionisation chamber by electron collisions with neutral particles.



Schematic of the ion-atom beam source generating hyperthermal ions (30 - 200 eV).

Principles of Ion-Atom Beam Bource

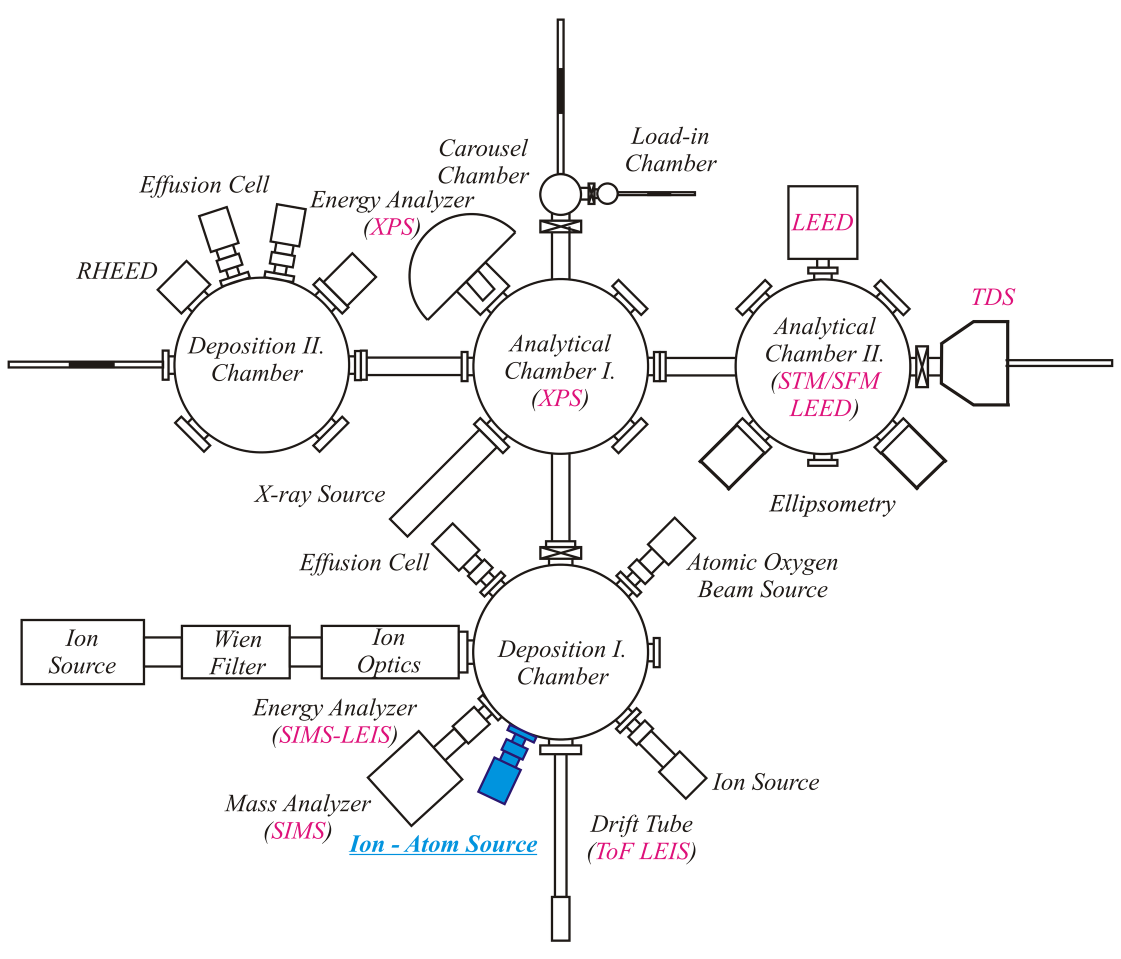
Electrons having energies (0,1 - 1) eV are emitted from a heated tungsten filament and accelerated by a voltage of approximately 100 V towards a grid forming walls of a cylindrical ionization chamber and consequently enter the ionization area. In this way electrons can collide with neutral atoms inside the ionization chamber at a well defined energy optimized to the most effective ionization (i.e. the highest ionization cross section). Other electrons not interacting with atoms go through the grids of the ionization chamber and are post-accelerated towards the crucible being at the typical potential U_c= 1500 V. In this way the crucible is heated by electron bombardment to a temperature sufficient for the evaporation of a material inside. Evaporated atoms flow towards the target. The gas is introduced into the source through an UHV valve. The positive ions are extracted from the ionization chamber by an extraction electrode being at a negative potential with respect to earth.



Model of the ion-atom beam source and the cross section of the source body.

UHV Deposition Chamber

The properties of surfaces and growing films can be monitored in situ in an UHV experimental chamber by a series of analytical techniques such as XPS, SIMS, ToF-LEIS, AES/LEED, ellipsometry and STM/AFM.



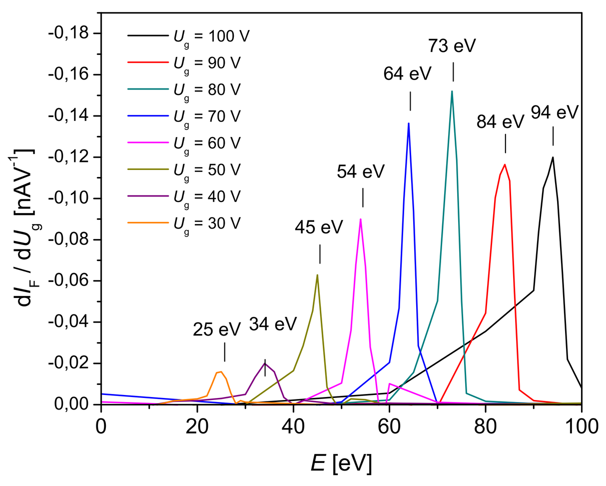
Apparatus for deposition and analysis of ultrathin films

Properties of Ion-Atom Beam Source

Available Deposition Modes :

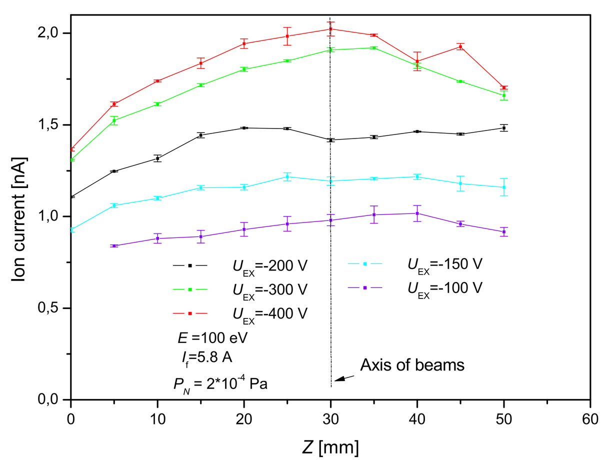
- Effusion cell
- Electron impact source
- Ion-atom beam source
- Pulsed ion source

Nitrogen ion beam
Minimum ion beam energy: 30 eV,
Ion current density: 500 - 800 nA/cm²
Gallium atomic beam:
Flux ions Ga: 10 nA



(a)

Ion energy distribution for various grid potentials.

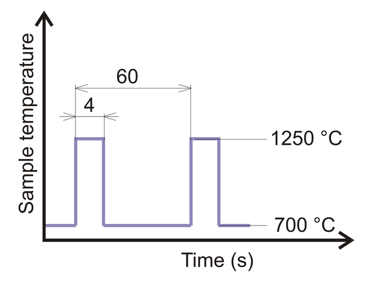


(b)

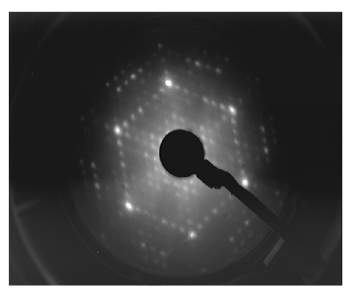
Ion beam profiles for various extraction potential.

Substrate preparation

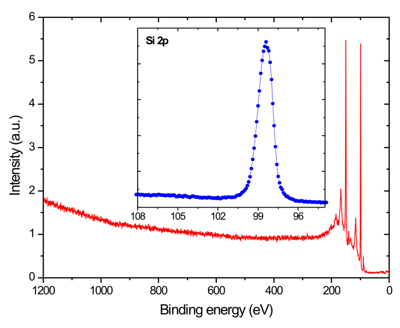
P-doped Si(111)
annealed overnight at 650 °C
thermally flashed for 120 s at 1250 °C
pressure kept bellow 1×10⁻⁶ Pa
after flash annealing:
structure Si(111) 7×7 checked by LEED and XPS (see figures below)



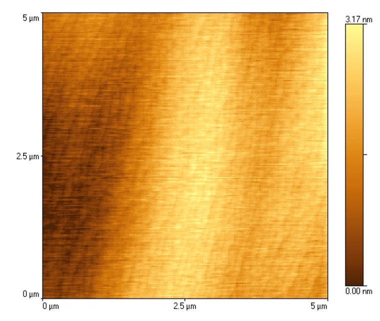
Flash annealing procedure



LEED pattern of Si(111) 7×7 structure after flash annealing



XPS spectra of Si(111) 7x7 structure after flash annealing



AFM ex-situ analysis of Si(111)7x7 structure after flash annealing

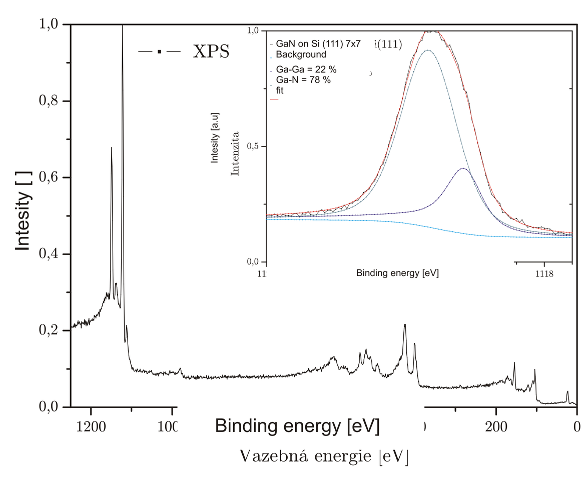
Application Areas

- Ultrathin films (~ 100 nm)
- Adhesion improvement
- Enhancement of thin film density
- Formation of metastable phases

Synthesis of GaN Nanodots

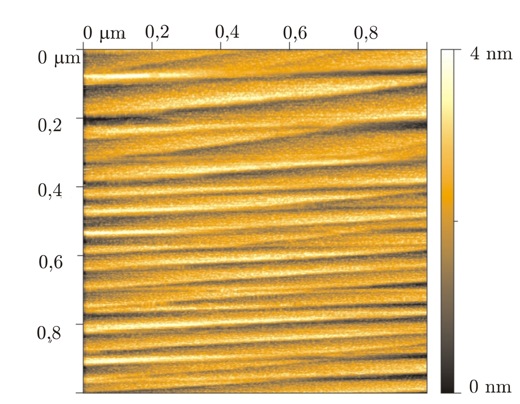
Deposition of GaN at Room Temperature

Conditions:
Ion beam energy 50 eV, Current: 800 nA, Ga flux: 10 nA,
Deposition time 30 min, Substrate temperature RT.



(a)

XPS spectra of a GaN film (the inset shows the Ga 2p peak fit with the parameters listed in the table below)

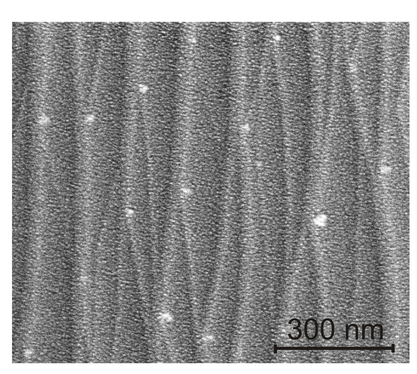


(b)

AFM ex-situ analysis (scan area 1x1 m²)

Parametrs	Ga-Ga	Ga-N *	Ga-O *
Gauss width	0,79	2,4	1,8
Energy	1120,7	1,33	2
Lorentz width	1,07	0,8	1
Asymmetry	0,089	0	0

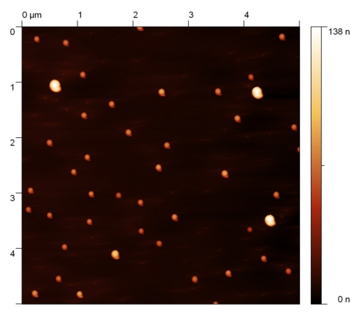
**Fit parameters are relative*



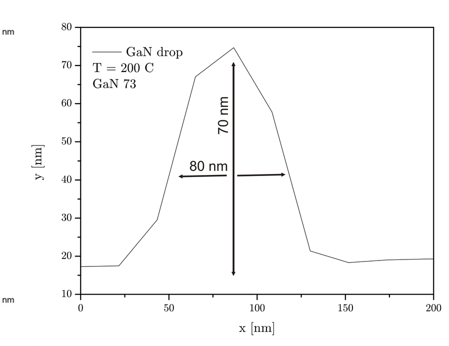
The detail of GaN droplets growing at room temperature on Si(111) 7x7 measured by SEM (FEI company)

Deposition of GaN at enhanced temperature (200 °C)

Conditions:
Ion beam energy 50 eV, Current: 800 nA, Ga flux: 10 nA,
Deposition time 120 min, Substrate temperature 200 °C.



AFM ex-situ analysis (scan area 5x5 m²)

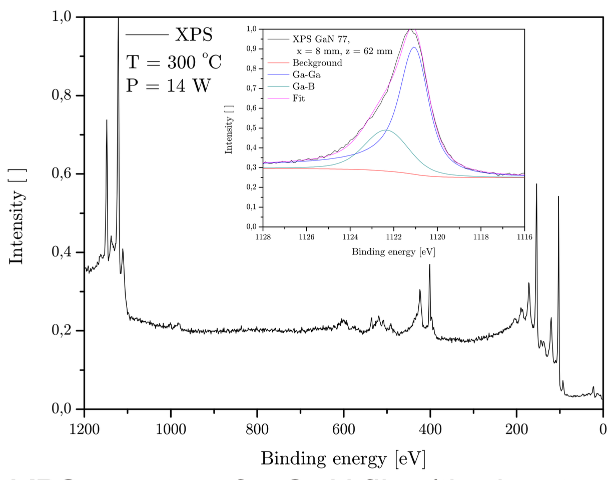


Profile of a GaN droplet

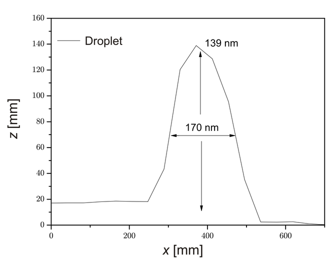
Local conductivity

Increasing atom flux of Ga while keeping nitrogen ion beam current constant leads to the growth of two kinds of droplets.

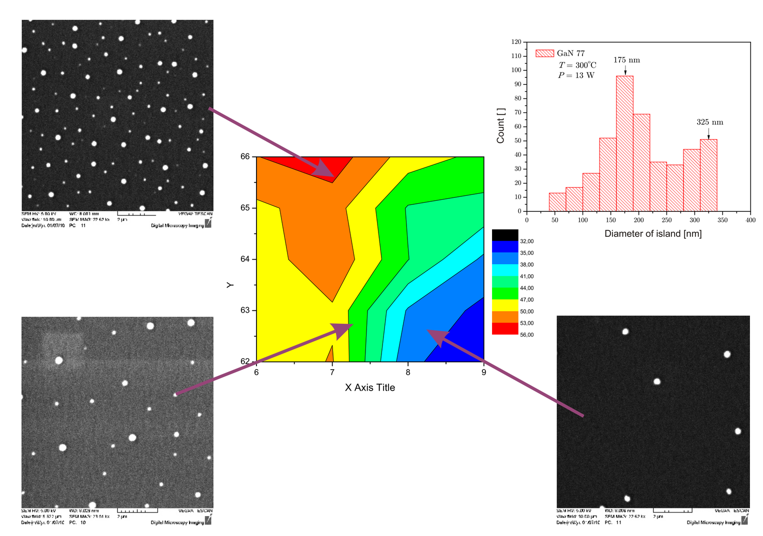
Conditions:
Ion beam energy 50 eV, Current: 800 nA, Power 14 W
Deposition time 60 min, Substrate temperature 350 °C.



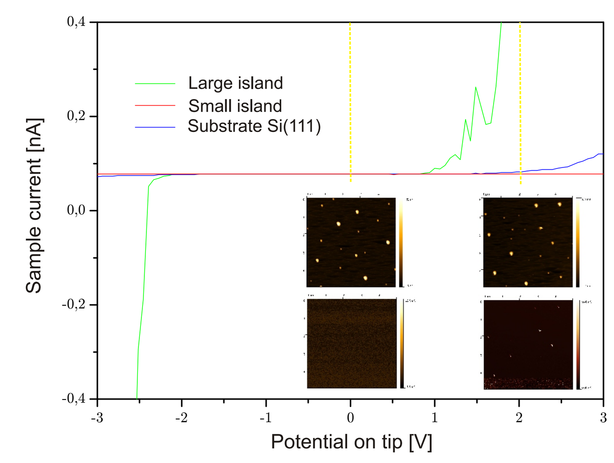
XPS spectra of a GaN film (the inset shows the Ga 2p peak fit)



Profile of GaN droplets



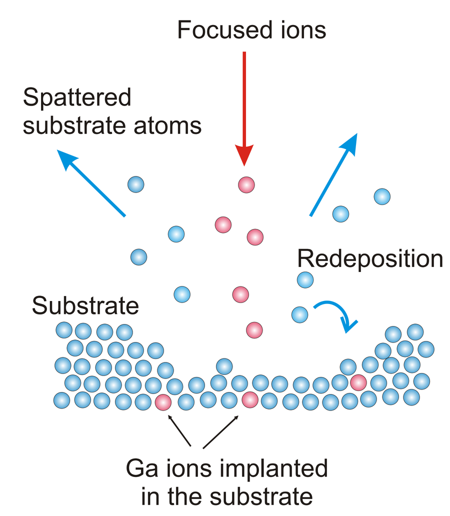
The map of GaN distinction on over the sample measured by XPS, images of samples taken by SEM



Local conductivity *of GaN droplets measured by C-AFM*

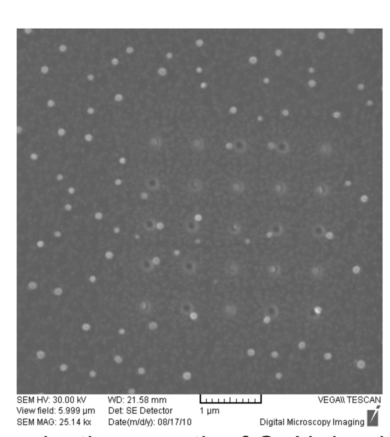
FIB

Focused ion beam (FIB) was used to create patterns on Si (111) substrates. These patterns act as nucleation centres providing the preferential growth of GaN droplets at these sites. The growth of ordered arrays of droplets depends on the shape and spacing of the patterns on the surface.



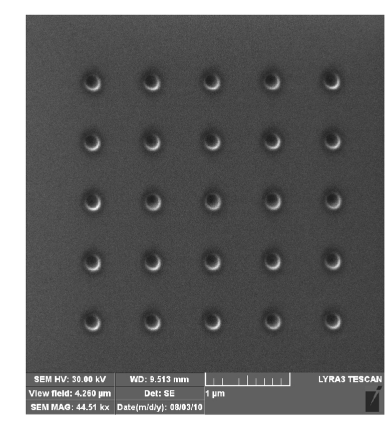
Principle of milling by FIB

c)



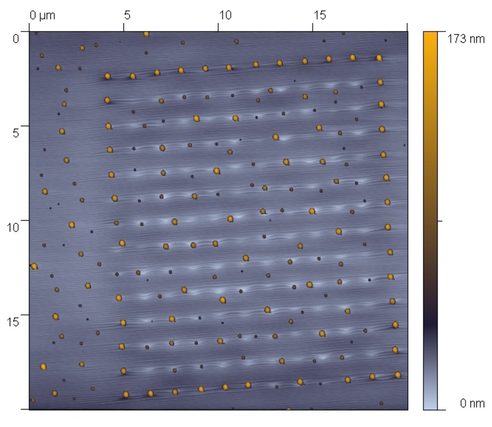
The selective growth of GaN droplets on the Si(111) 7x7 substrate pre-patterned by FIB (see Fig. b)

b)



Si(111) structures patterned by FIB (TESCAN company)

d)



Array of GaN grown on Si(111) 7x7 substrate pre-patterned by FIB

Conclusion:

- Ion-atom beam source has been used for the low temperature synthesis of GaN ultrathin films and their in situ analysis.
- XPS analysis confirms the major presence of Ga-N bonds in the film (98 atomic %).
- In-situ UHV STM/AFM analysis needed for exact morphology study of the films.