Effect of surface fluorination on GaN deep dry etching defects

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Outline

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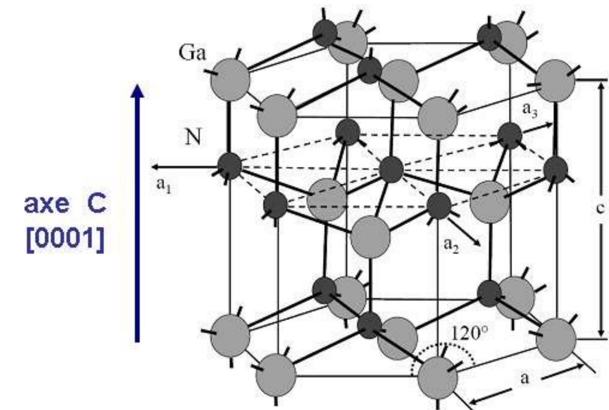
II. Experimental set-up

III. Study of fluorine addition in etching chemistries

IV. Conclusion

Introduction
Gallium nitride

- Gallium nitride (GaN) = III-V semiconductor
- GaN = direct and wide bandgap (3.4 eV)
- Hexagonal structure (Wurtzite)
- Interesting properties for power devices :
  - High breakdown voltage
  - High electron mobility
  - High saturation velocity
- Heteroepitaxial growth along c-plane on Silicon or Sapphire substrates ⇒ Defects (dislocations, vacancies, nanopipes)

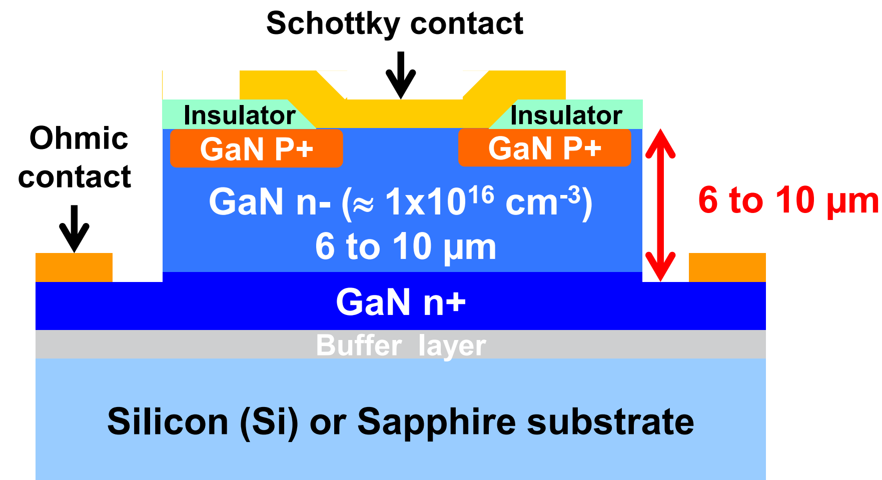


Introduction
Schottky diode structure

- Aim : Alternating current to direct current conversion

  ⇒ GaN based Schottky diode (600 V)

- Pseudo-vertical structure :

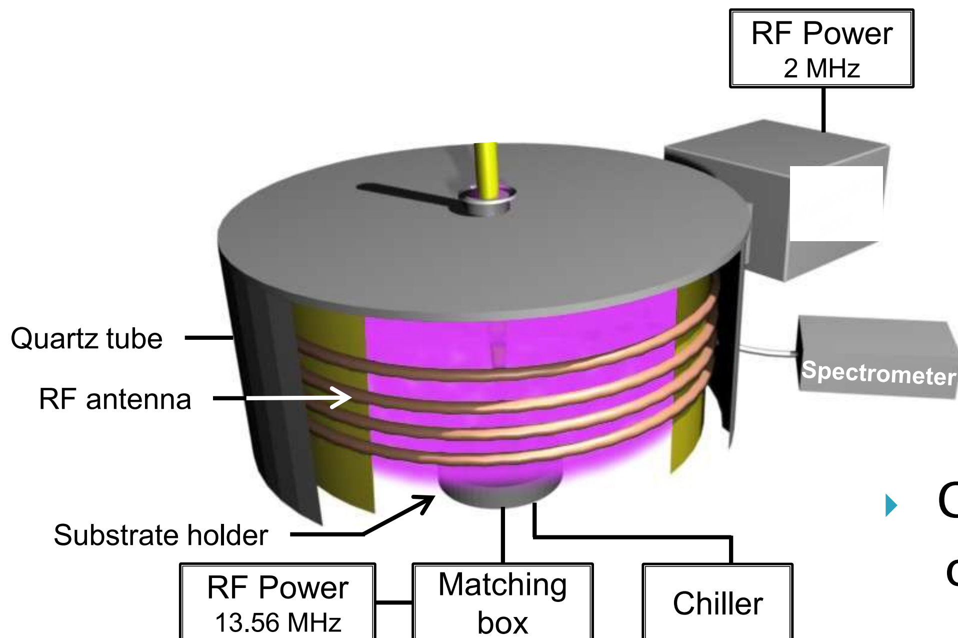


- Deep etching of GaN is needed to perform mesa structure
- Wet etching does not work on GaN c-plane ⇒ **Plasma etching**
  - Etch rate and selectivity
  - Surface defects and roughness

  } optimization

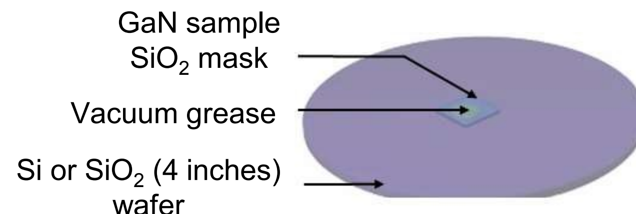
Experimental set-up

- GaN etching is performed with an ICP reactors Corial 200-IL



- ICP source
- Without diffusion chamber
- High bias voltage

- Etching on samples :



$\Rightarrow$ Importance of the carrier wafer composition

- $GaCl_3$ is the most volatile etch product of GaN

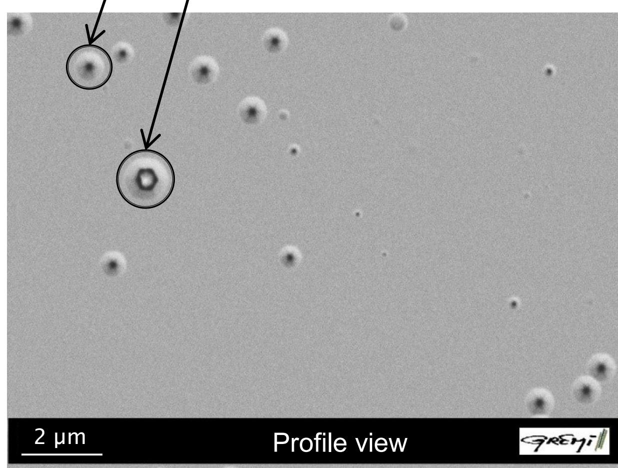
  $\Rightarrow$ Chlorine-based chemistries are used for etching

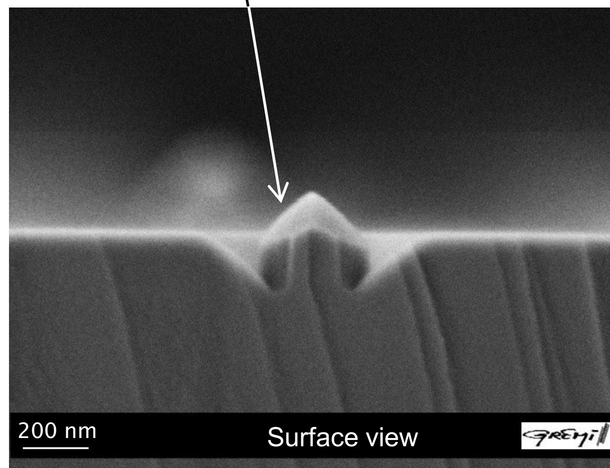
- Addition of Argon (Ar^+ ions) to enhance the desorption of volatile products and GaN etch rate

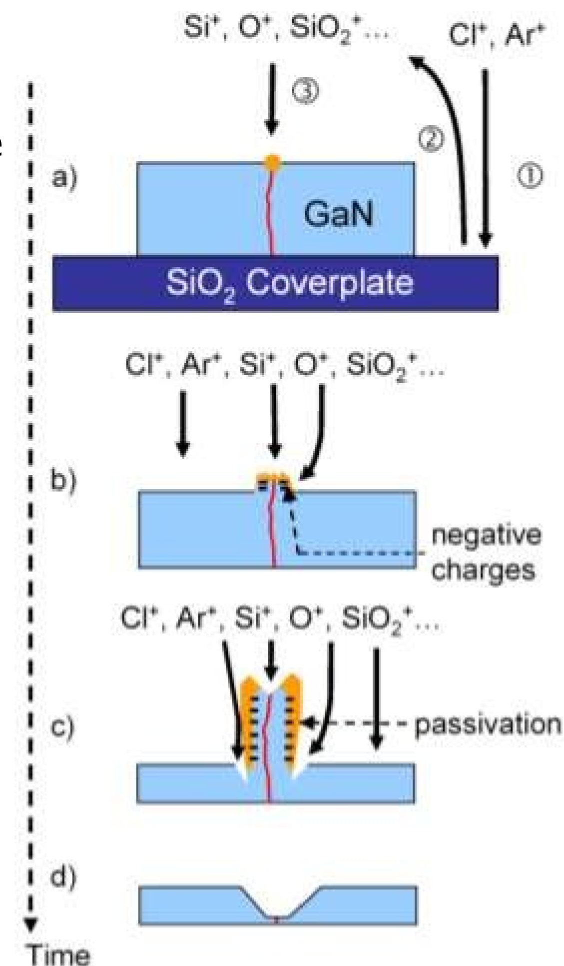
  $\Rightarrow$ Study of GaN etching in Cl_2/Ar based plasma

GaN etching and defect formation

- 2 types of defects on GaN etch surface :
  - Cavity defects
    - Due to the ion bombardment
    - Faceting with Cl_2 based etching ⇒ hexagonal structure
  - Columnar defects
    - Passivation of nanopipes present in the bulk material
    - Important role of oxygen species





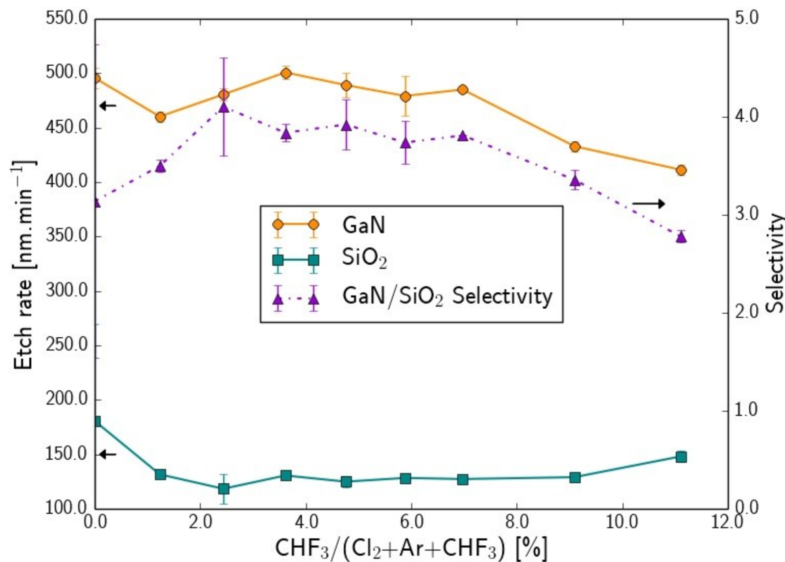


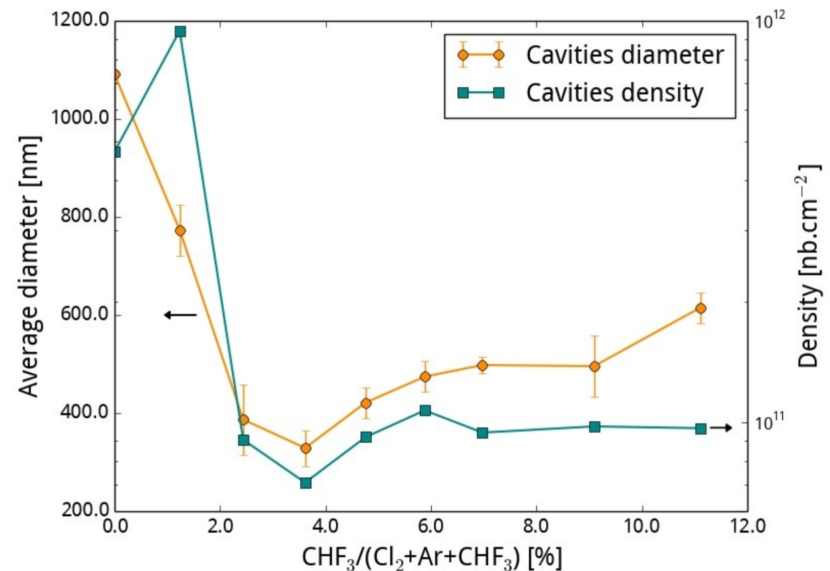
Study of fluorine addition in GaN etching chemistries
Addition of CHF_3 in Cl_2/Ar

- As shown previously, formation of columnar defects is related to oxygen species

⇒ Addition of CHF_3 in Cl_2/Ar chemistry in order to scavenge oxygen impurities

- The etch time was 5 minutes for all the following experiments





From 2 to 5 % of CHF_3 in Cl_2/Ar : – GaN Etch rate ≈ constant
– Diameter and density of defects ↘
– No (or few) columnar defects

⇒ Impact of fluorine species ?

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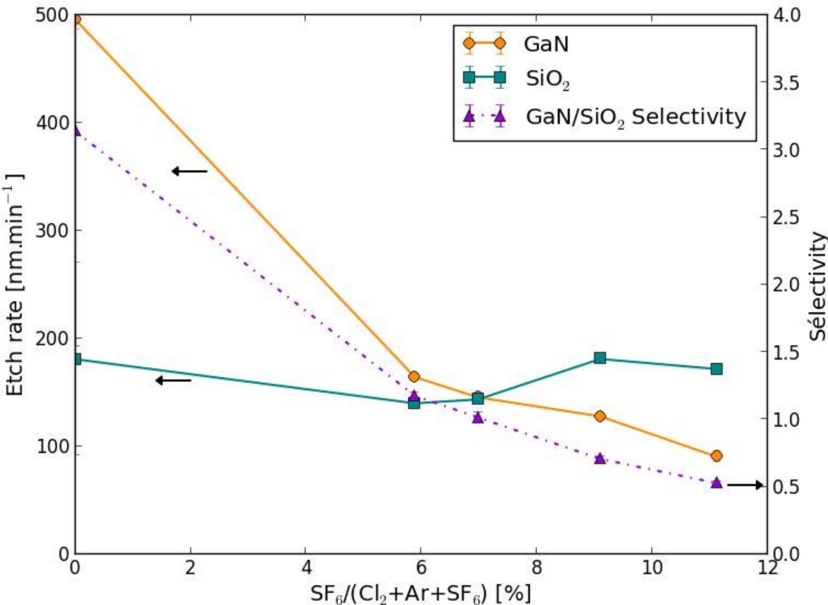
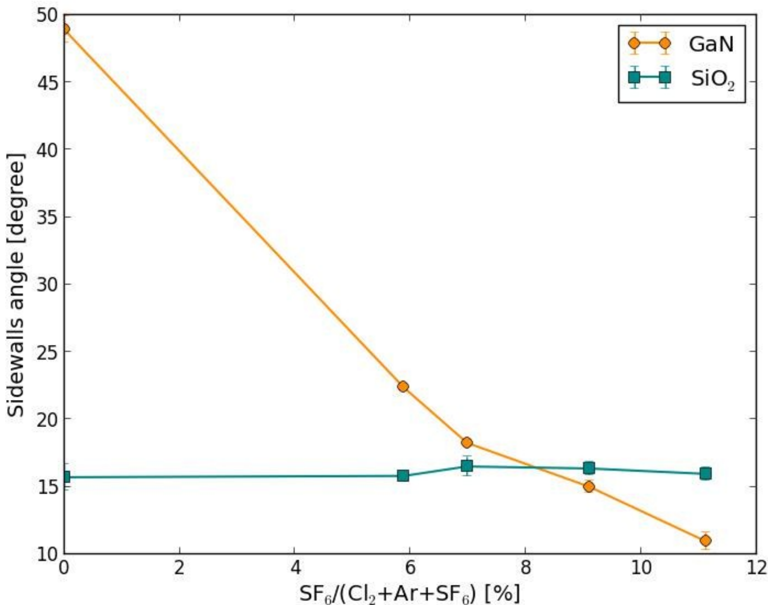
⇒ **Impact of fluorine species ?**

Study of fluorine addition in GaN etching chemistries
Addition of SF_6 in Cl_2/Ar

- SF_6 = – More fluorine radicals than in CHF_3
  – No carbon able to react with GaN and no CF_x passivation layer deposition



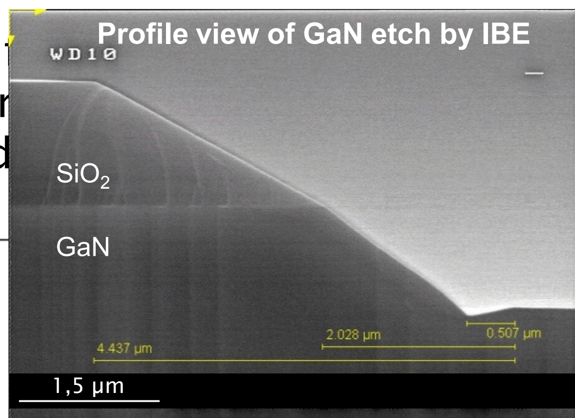


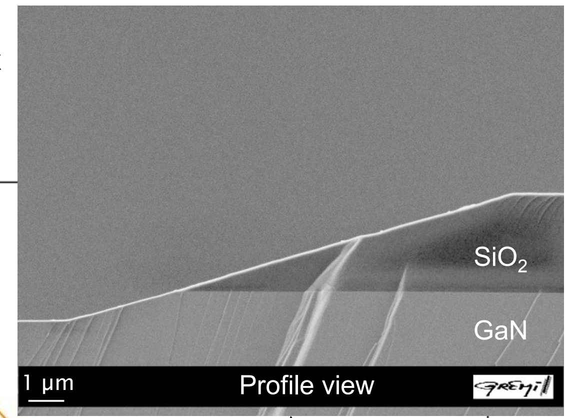
- **With SF_6 ↗ in Cl_2/Ar:**
  - **GaN etch rate ↘**
  - **Sidewalls angle of GaN ↘**

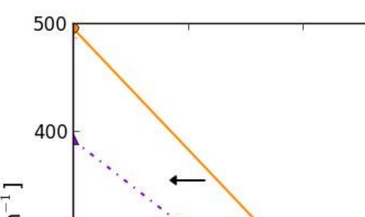
  } Looks-like pure physical etching (IBE)
- **No defects observed !**

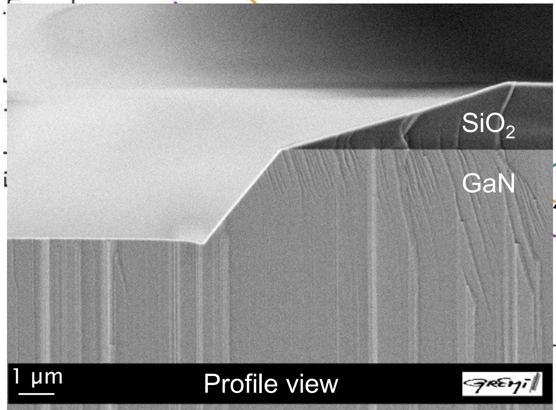
Study of fluorine addition in GaN etching chemistries
Addition of SF_6 in Cl_2/Ar

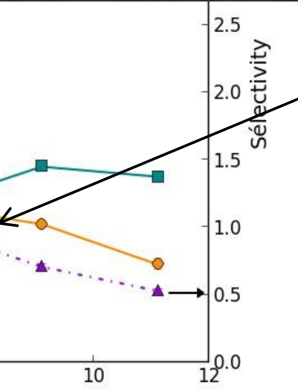
- SF_6 = – More f... F_3
  – No car... and no CF_x
  layer d...

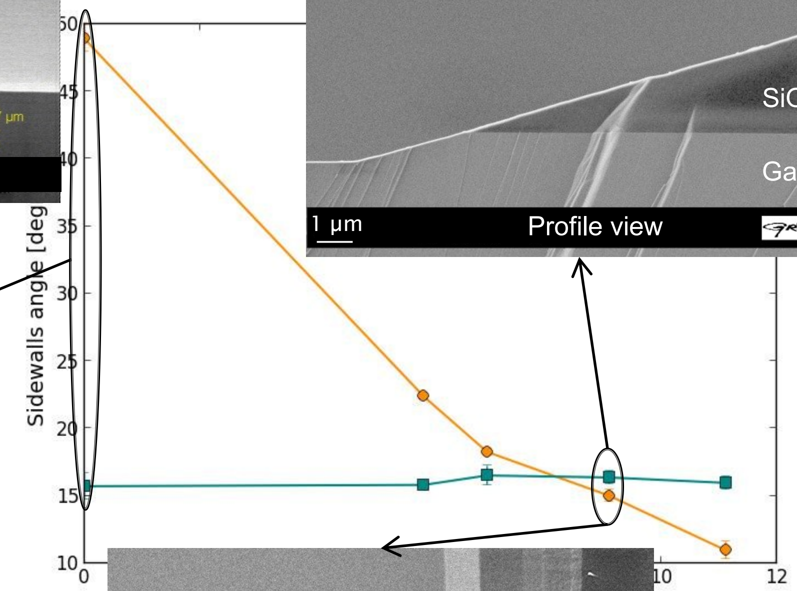


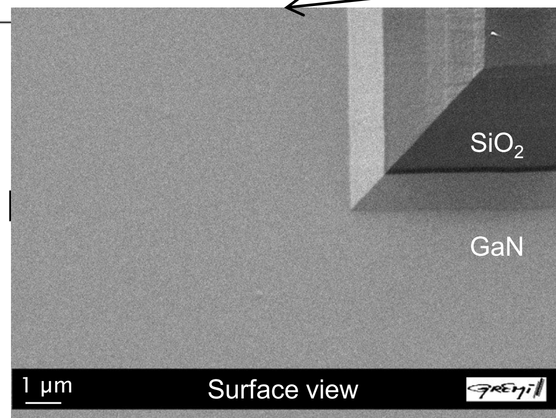










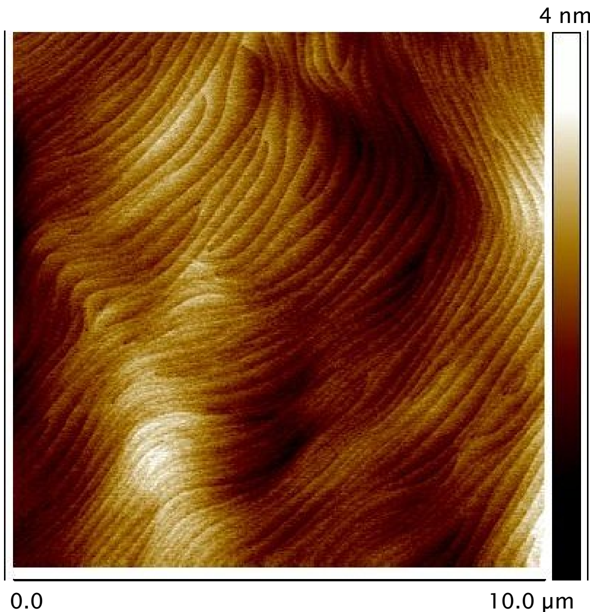


- With SF_6 ↗ in Cl_2/Ar:
  - GaN etch rate ↘
  - Sidewalls angle of GaN ↘
- No defects observed !

...tching (IBE)

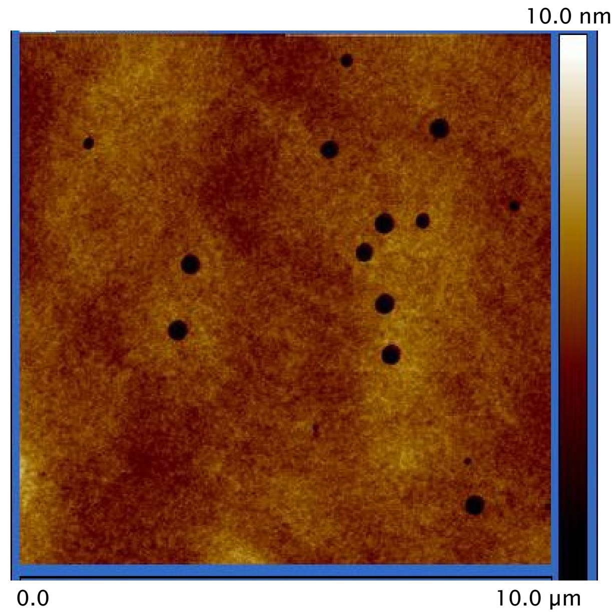
Study of fluorine addition in GaN etching chemistries
Comparison between CHF_3 and SF_6

- AFM measurements before and after etching :



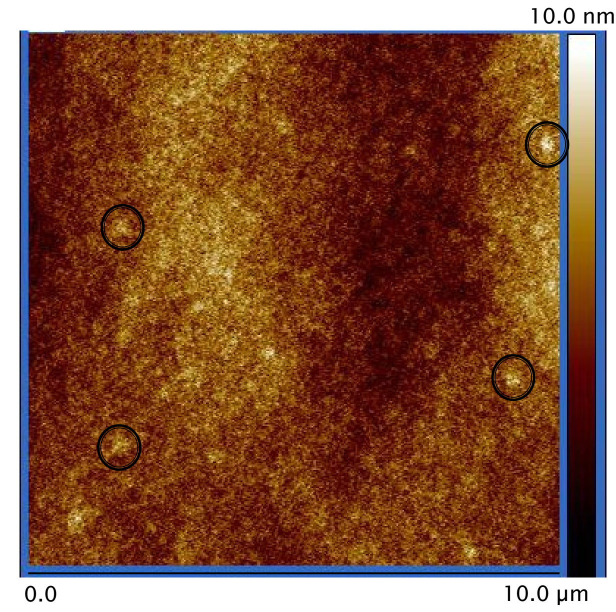
Before GaN etching

RMS = 0.181 nm



After etching with 2 sccm CHF_3

RMS = 0.378 nm



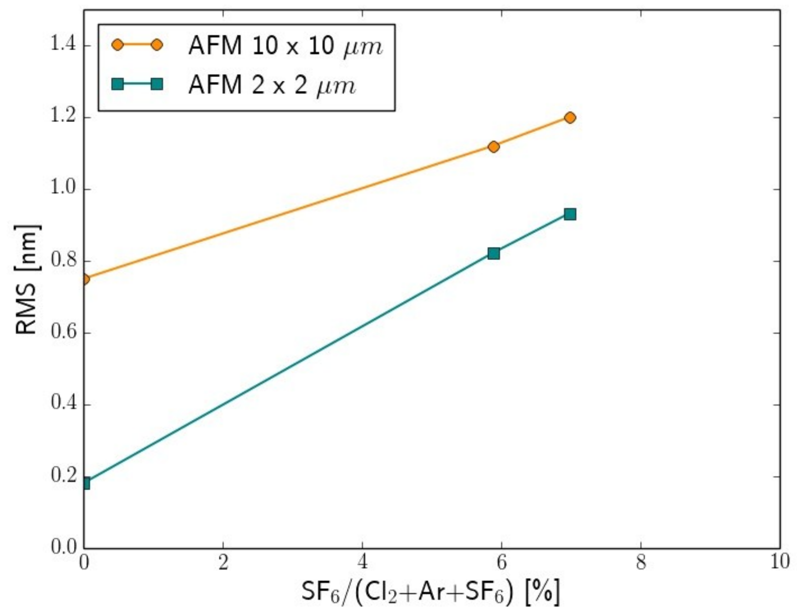
After etching with 6 sccm SF_6

RMS = 0.822 nm

- Surface roughness is more significant when etched with SF_6
- Surface morphology is different with addition of SF_6 (white dots)

Study of fluorine addition in GaN etching chemistries Comparison between CHF_3 and SF_6

AFM measurements

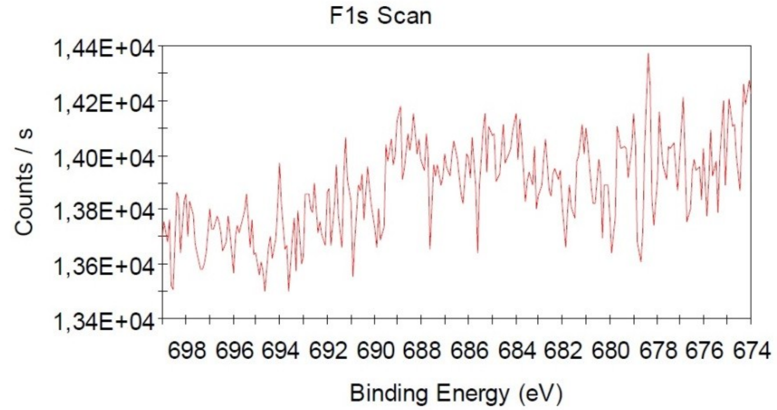


- When SF_6 flow ↗ RMS roughness of GaN ↗
  - Fluorine detected only on GaN etched surface with $Cl_2/Ar/SF_6$ chemistry

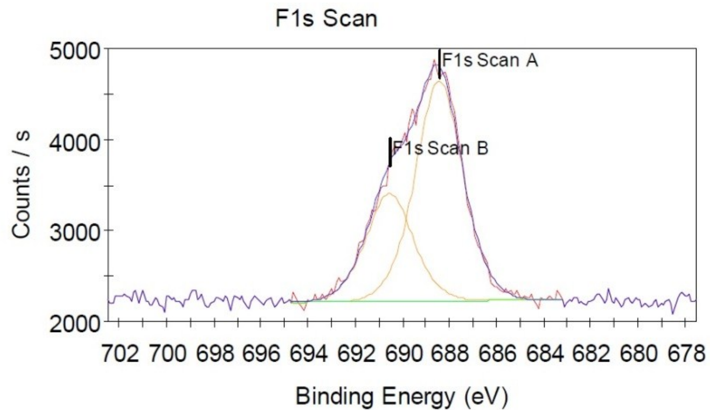
$\Rightarrow$ Formation of $Ga_xN_yF_z$ layer

No defects on the etched surface

XPS measurements



XPS spectra on GaN etch with $Cl_2/Ar/CHF_3$ chemistry



XPS spectra on GaN etch with $Cl_2/Ar/SF_6$ chemistry

Conclusion

- GaN etching in Cl_2/Ar chemistry :
  - High etch rate is possible
  - 2 types of defects are revealed : cavities and columns

- CHF_3 addition in Cl_2/Ar :
  - Important reduction of the density and diameter of the cavities
  - No columnar defects
  - Constant GaN etch rate

- SF_6 addition in Cl_2/Ar :
  - Important decrease of GaN etch rate
  - Important surface roughness
  - Fluorine species in GaN surface (XPS)

  } Formation of $Ga_xN_yF_z$

  $\Rightarrow$ No defects on GaN etch surface

Thank you for your attention