

# Recrystallization of thin 4H-SiC films deposited by PVD techniques, a way for new emerging fields

E. Vuillermet<sup>1</sup>, E. Usureau<sup>1</sup>, F. Jomard<sup>2</sup>, L. Le Joncour<sup>3</sup>, A. Andrieux<sup>4</sup>, A. Jacquemot<sup>5</sup>, M.Lazar<sup>1</sup>



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<sup>1</sup>Light, nanomaterials & nanotechnologies (L2n), CNRS EMR 7004, UTT, France

<sup>2</sup>GEMaC, UFR des sciences, University Versailles St-Quentin en Yvelines, France

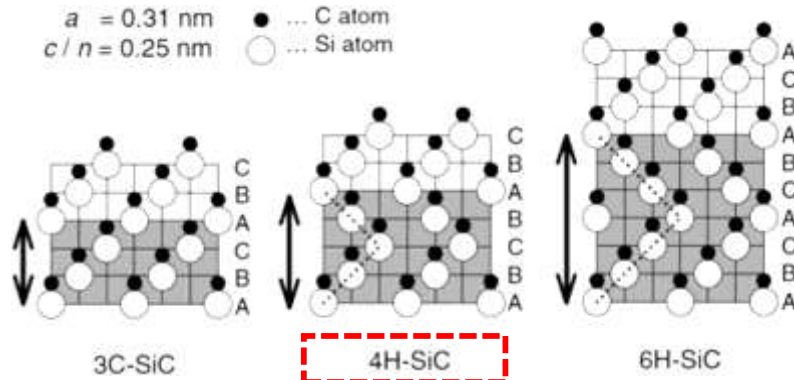
<sup>3</sup>Laboratory of Mechanical & Material Engineering (LASMIS), UTT, France

<sup>4</sup>Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB), UMR 6303 CNRS, University Bourgogne Franche-Comté, France

<sup>5</sup>MICROTEST, Z.A. La Garrigue du Rameyron, France

SiC is a wide bandgap semiconductor → application in power electronics but also in optoelectronics, and nano-photonics

## Advantages



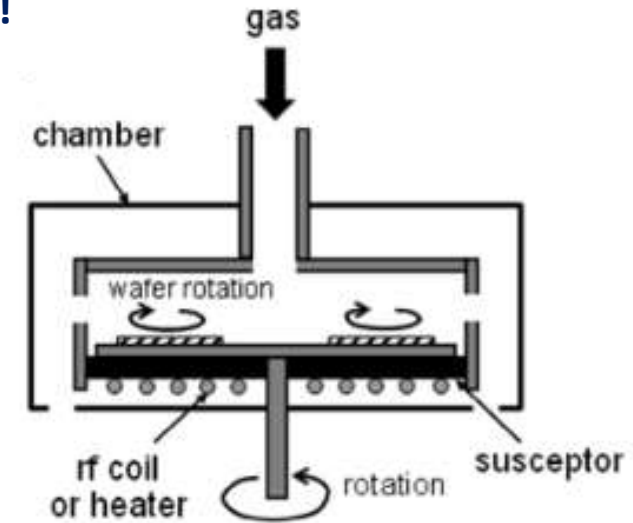
	6H-SiC	4H-SiC	3C-SiC	Si
$\lambda$ (W/cm.K)	4,9	3,7	3,6	1,56
Ts ou Tf (K)	3100	3100	3100	1693
Eg (eV)	3,0	3,3	2,2	1,12
Ec ( $\times 10^6$ ) (V/cm)	3 à 5	3 à 5	1	0,25 à 0,8

A lot of polytypes are available with different properties  
 Great thermal resistance and conductivity  
 High-critical electrical field

## Limits

Homo-epitaxial growth of SiC layers (CVD) :

- SiC growth only possible on SiC substrate
- High-temperature growth (1500-1650°C)
- **Bottom-up growth** → limitations of devices' architecture
- **Expensive !**



CVD reactor

→ Idea : Top-down growth of low cost SiC layers realized by Physical Vapor Deposition (PVD)

• **1. SiC thin films growth**

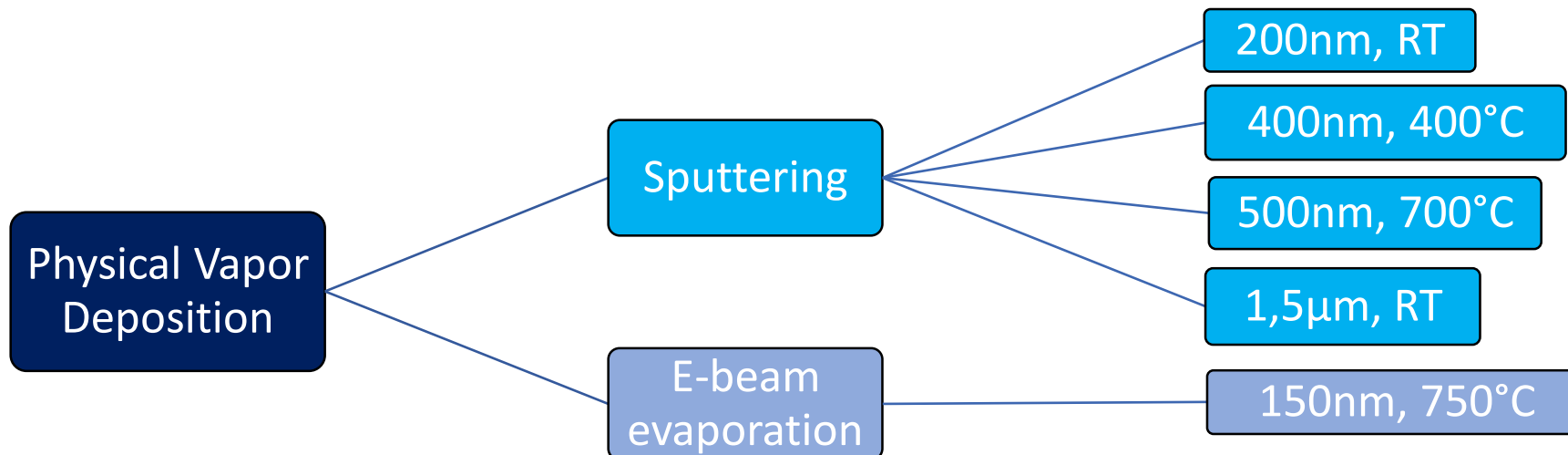
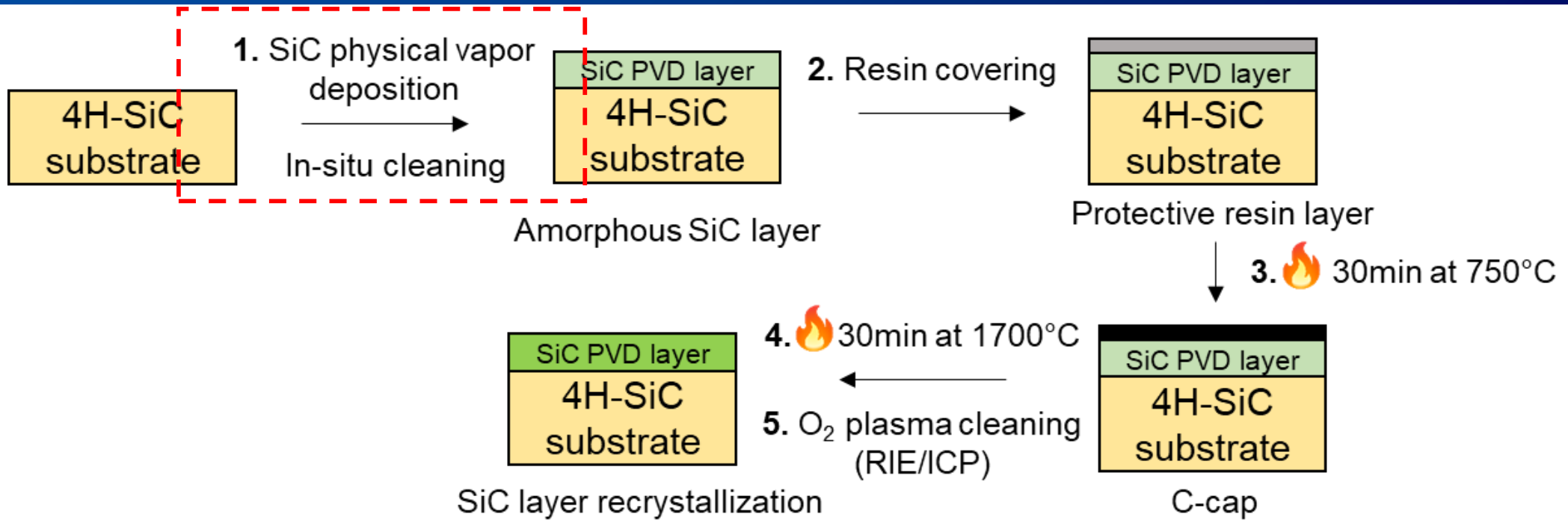
• **2. Crystallinity of the SiC layers**

• **3. Impurities present in the layers**

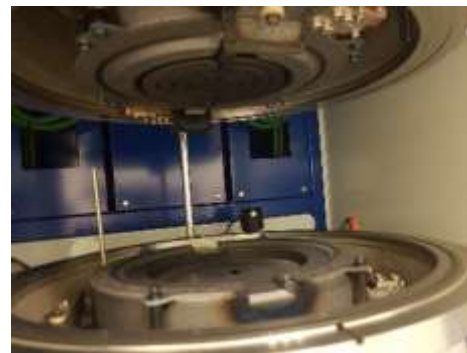
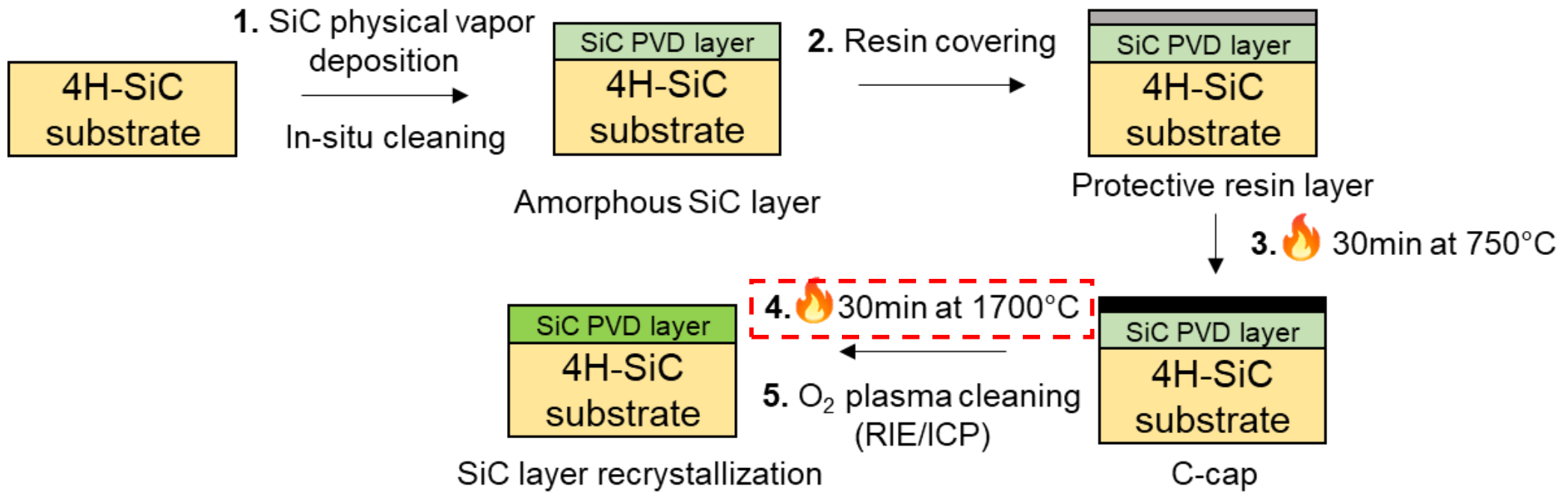
• **4. Electrical conductivity**

• **Conclusion**

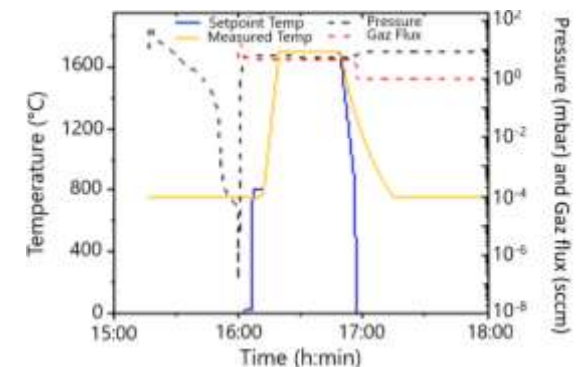
# 1. SiC THIN FILMS GROWTH



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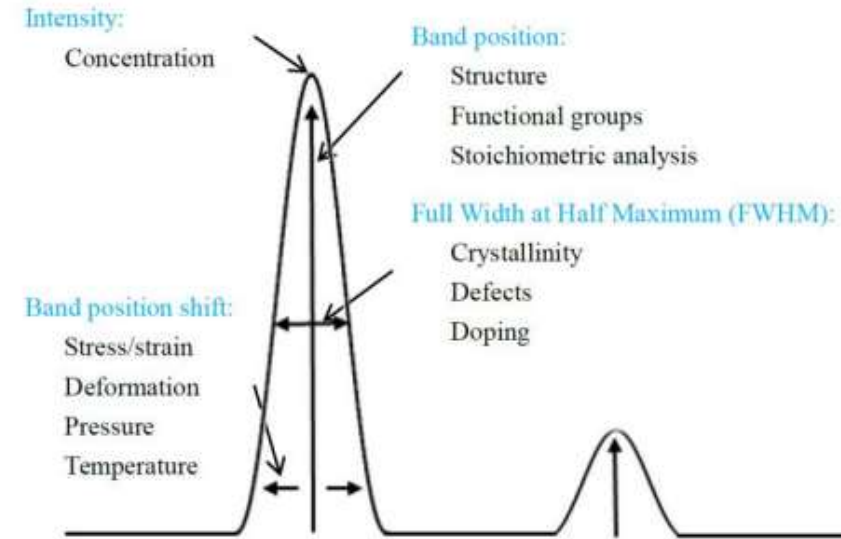
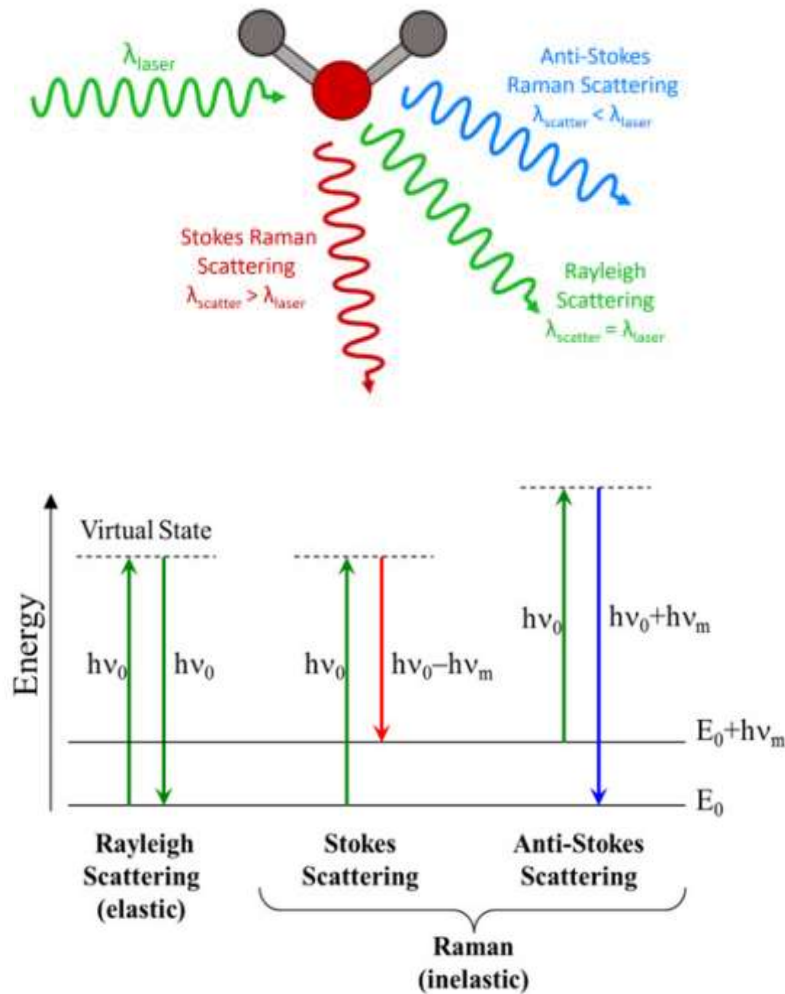
AET RTP graphite resistive furnace



Temperature and pressure profiles

# 2. CRYSTALLINITY

## a) Raman Spectroscopy - Theory

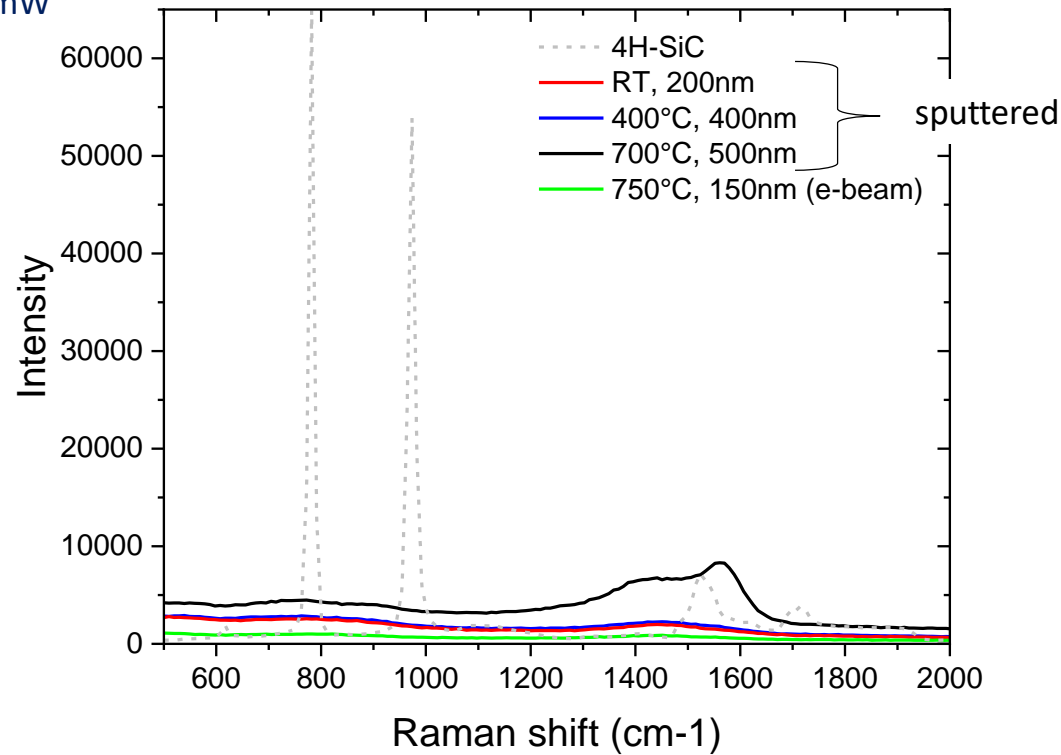


- Inelastic diffraction of light
- Depends on the vibrational states of the atoms
- Identification of the PVD layer and its crystallinity

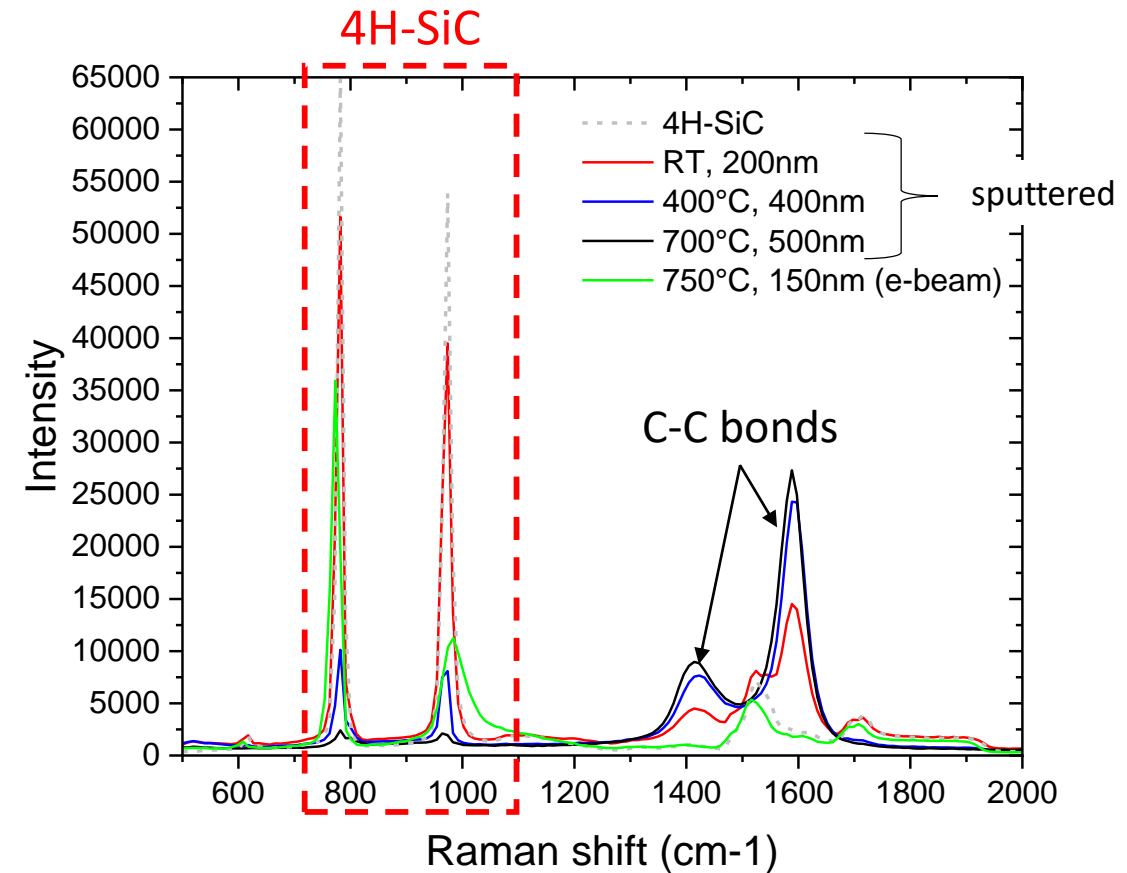
# 2. CRYSTALLINITY

## b) Raman Spectroscopy - Results

Laser 325nm at 25mW  
Grating 300g/mm



Before annealing : amorphous layers



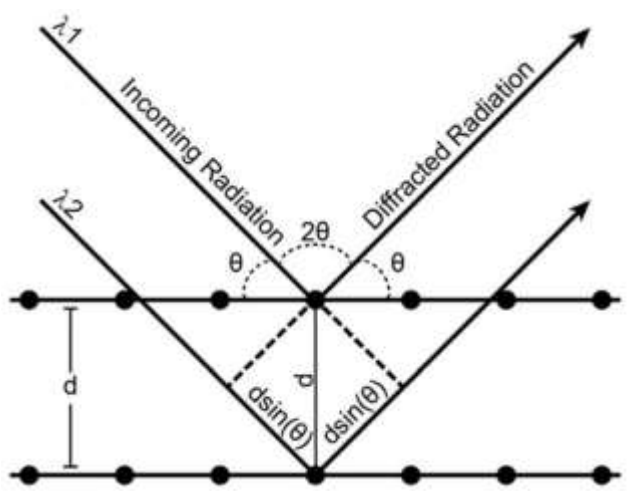
After annealing : partial recrystallization of the layers

- **No C-C bonds in the e-beam deposited layer** → great recrystallization
- Lasers go deeper in crystallized 4H-SiC compared to amorphous SiC → signal from the 4H-SiC substrate ?

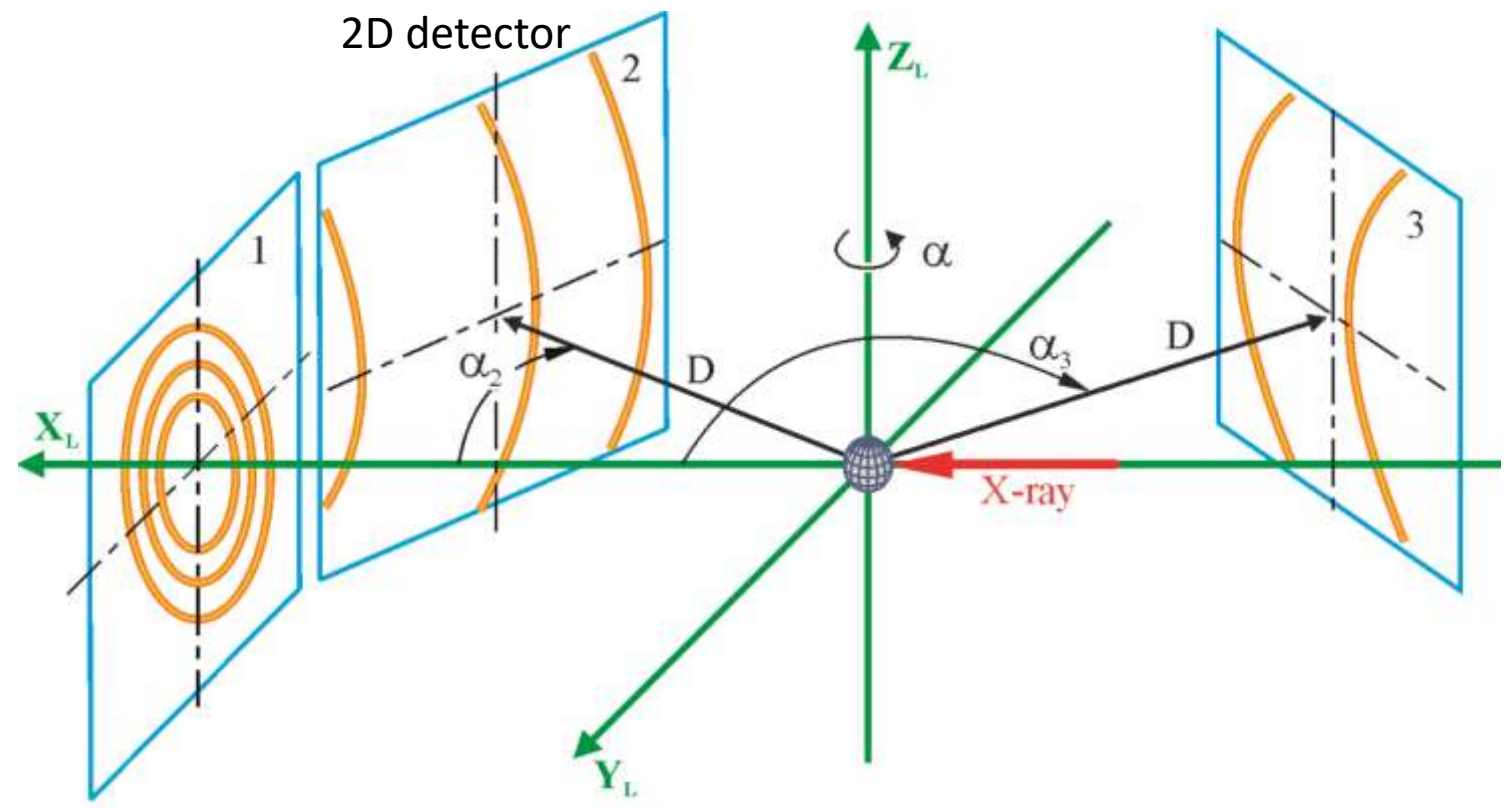
→ 4H-SiC formed with defects such as C interstitials : mono or polycrystalline material ?

# 2. CRYSTALLINITY

## c) 2D XRD - Theory



Bragg's Law :  $n\lambda = 2d\sin\theta$



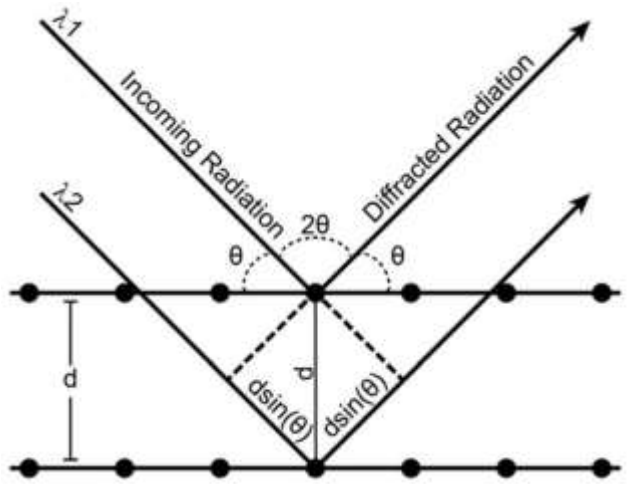
2D XRD setup

- 2D scanning
- Height determined by detector dimensions
- Length determined by scanning range
- Each pattern corresponds to a crystalline plane



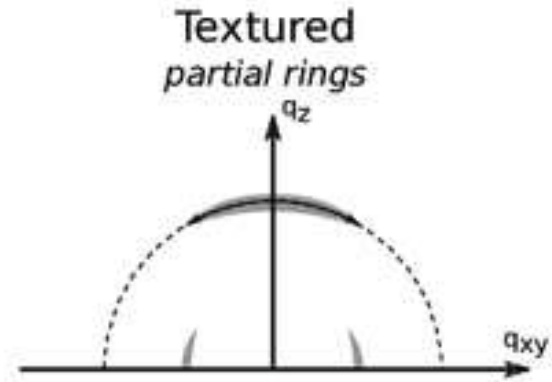
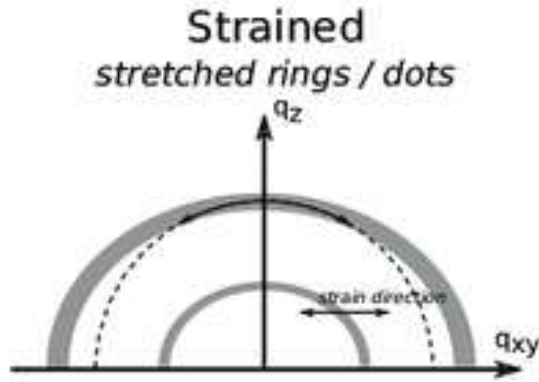
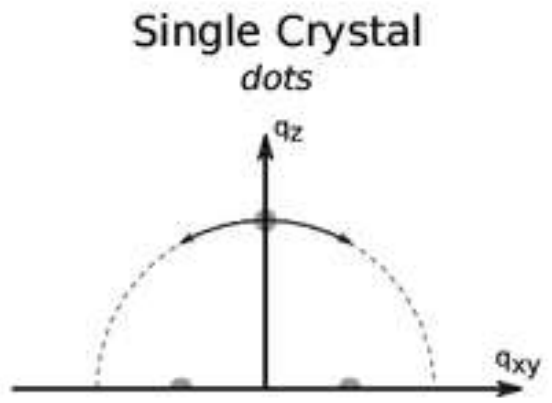
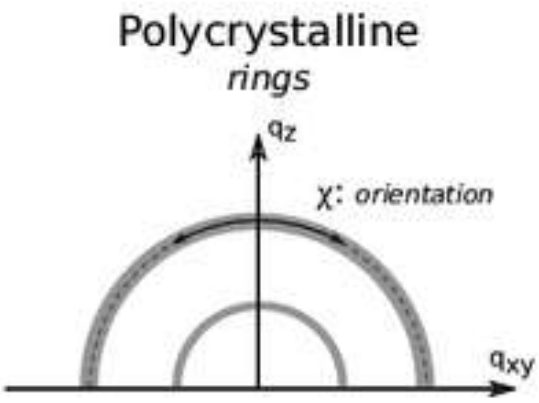
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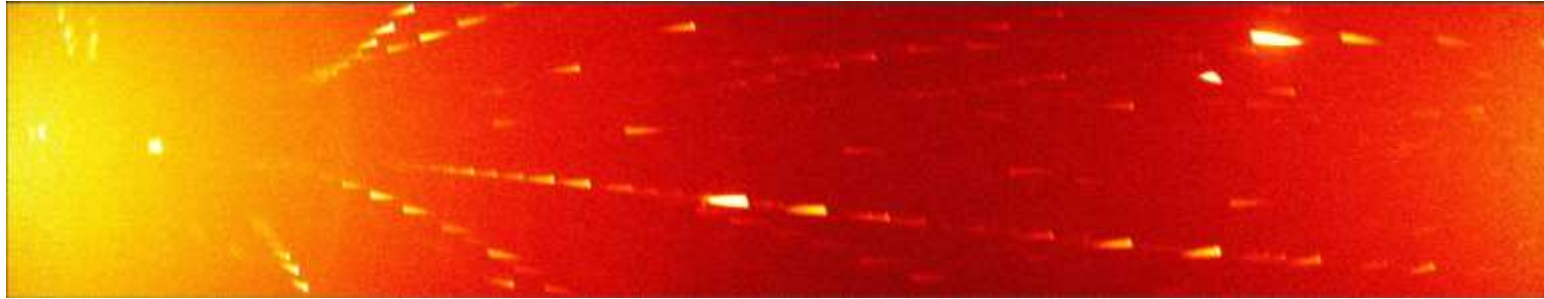
2D XRD patterns

# 2. CRYSTALLINITY



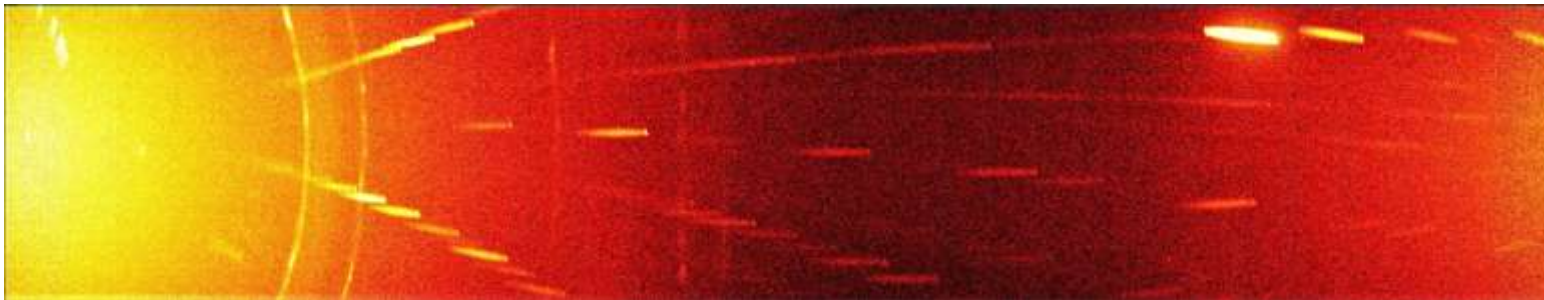
## d) 2D XRD (Bruker D8 Discover) - Results

Grazing incident XRD : 5°



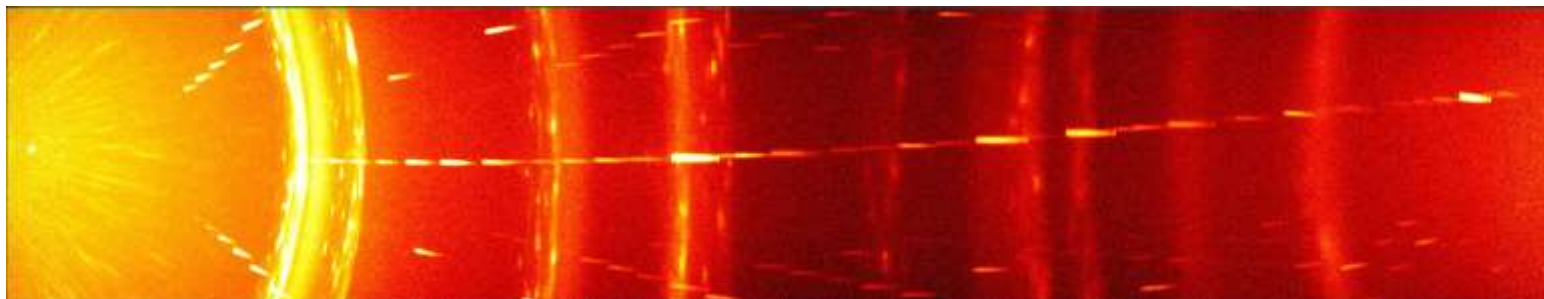
*4H-SiC substrate*

Razing XRD : dots look like ellipses → mono-crystal



*150nm thick e-beam deposited layer on 4H-SiC substrate*

Rings appear → polycrystalline SiC



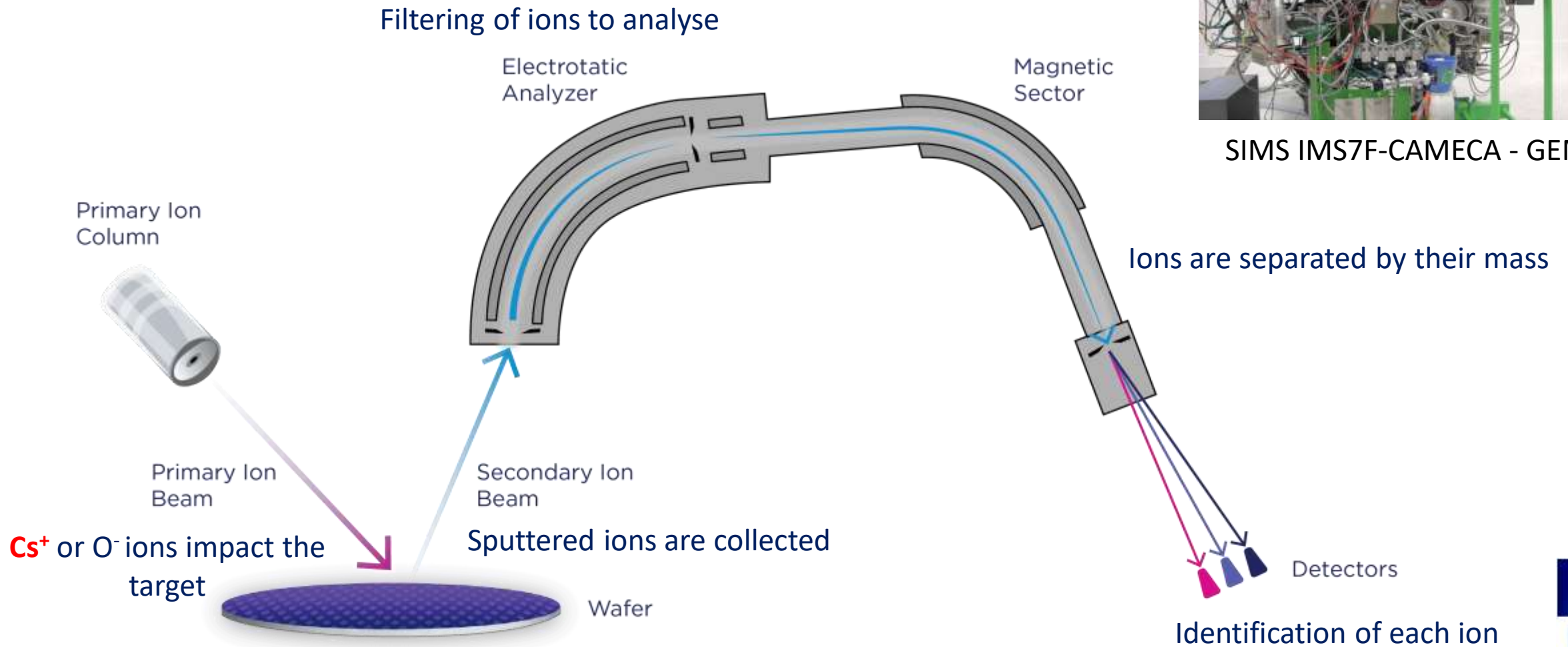
*1,5μm thick sputtered layer on 4H-SiC substrate*

More intense rings

→ Rings are observed for all PVD layers: we have formed 4H-SiC with inclusions of other polytypes

# 3. IMPURITIES

## a) Secondary ion mass spectroscopy (SIMS) - Theory



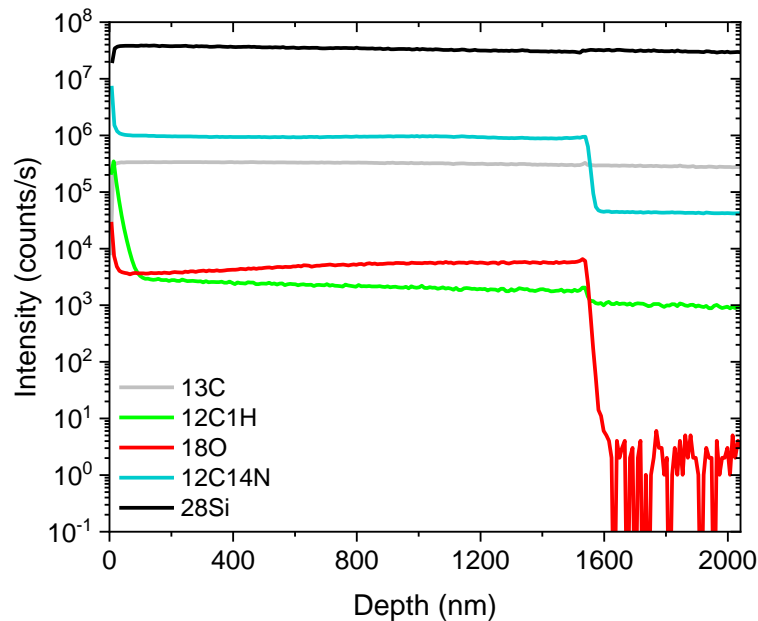
SIMS IMS7F-CAMECA - GEMAC

# 3. IMPURITIES

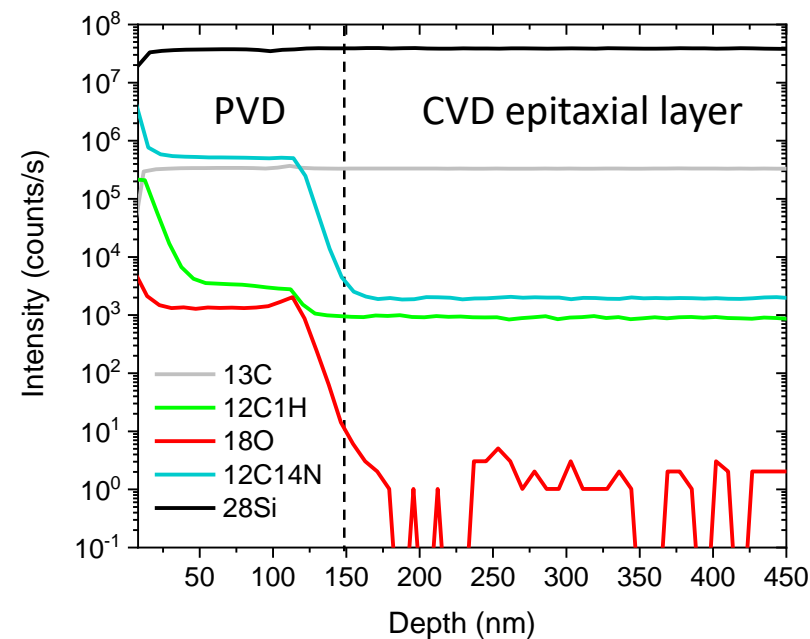
## b) Secondary ion mass spectroscopy (SIMS) - Results

*After annealing at 1700°C for 30min of sputtered layers*

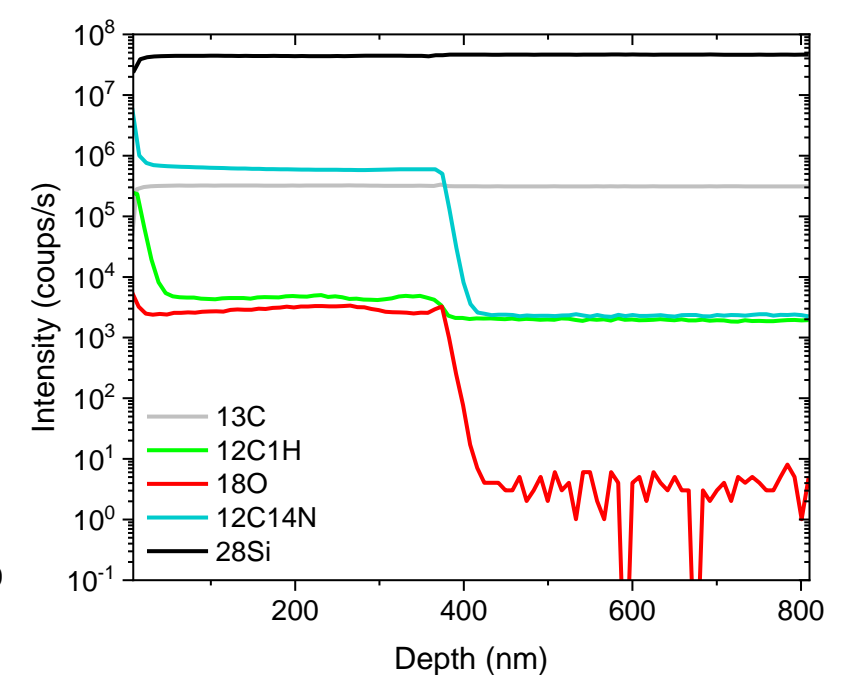
1.5µm thick layer deposited at RT



200nm thick layer deposited at RT



400nm thick layer deposited at 400°C

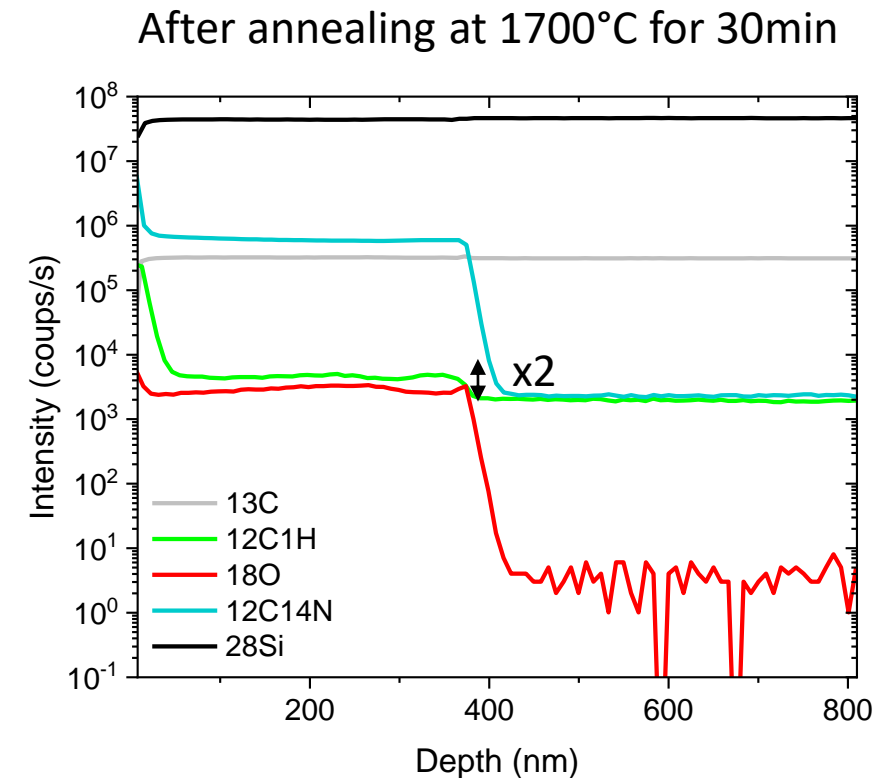
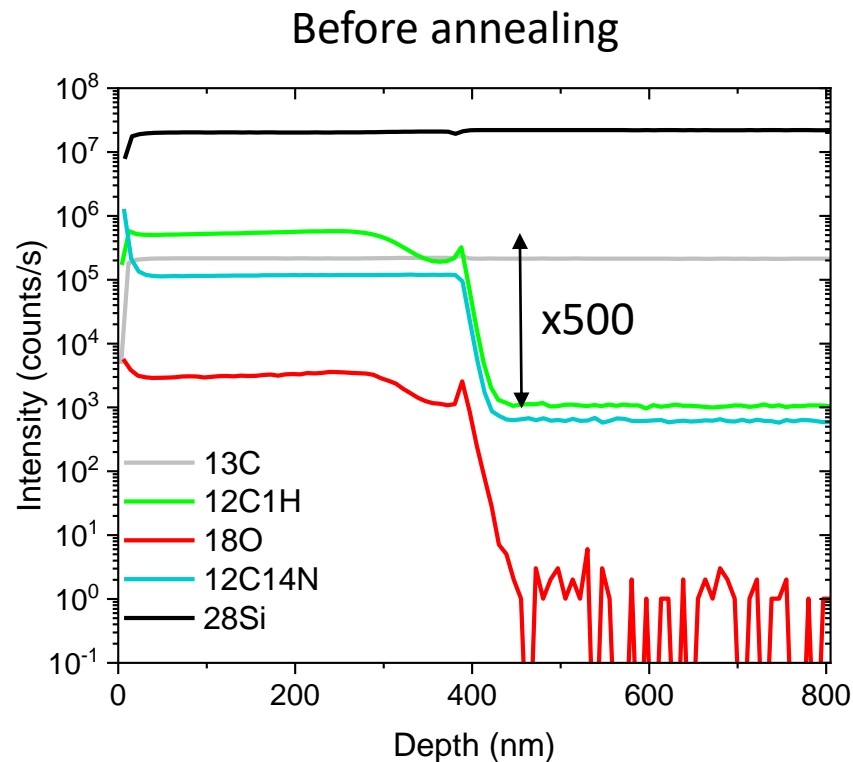


- Resistive layers (low-doped SiC) → thin Au deposition on the samples' surface before SIMS measurements
- N, O and H impurities are present in all PVD layers
- The concentration of these impurities doesn't change with the temperature of deposition or layers' thickness

# 3. IMPURITIES

## b) Secondary ion mass spectroscopy (SIMS) - Results

*400nm thick sputtered layer deposited at 400°C*

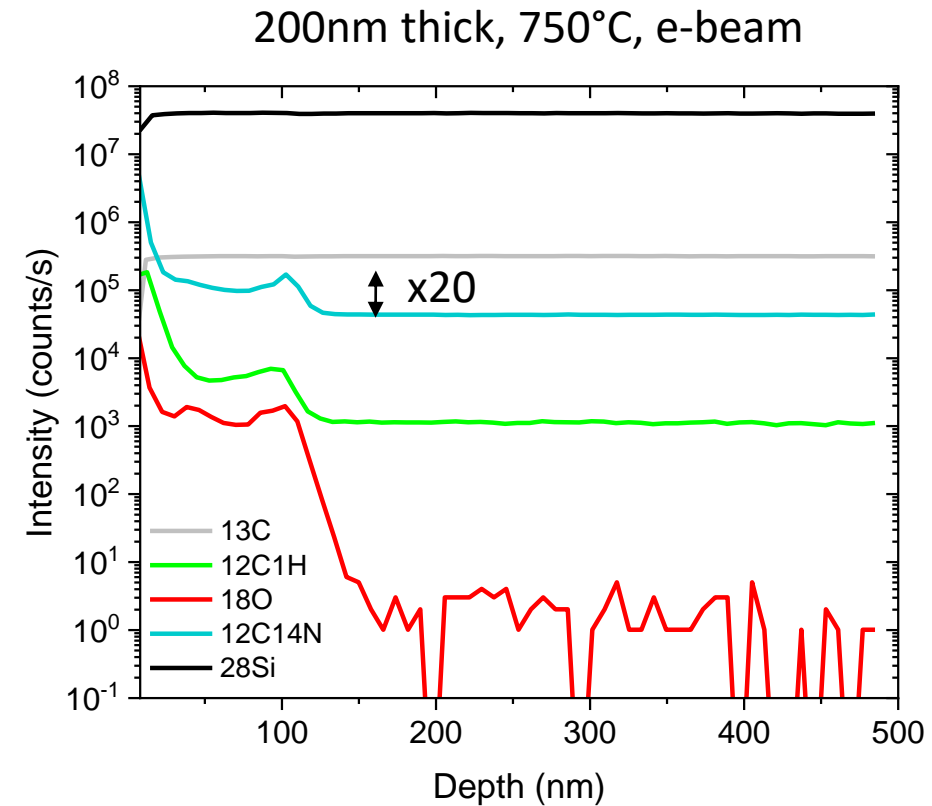
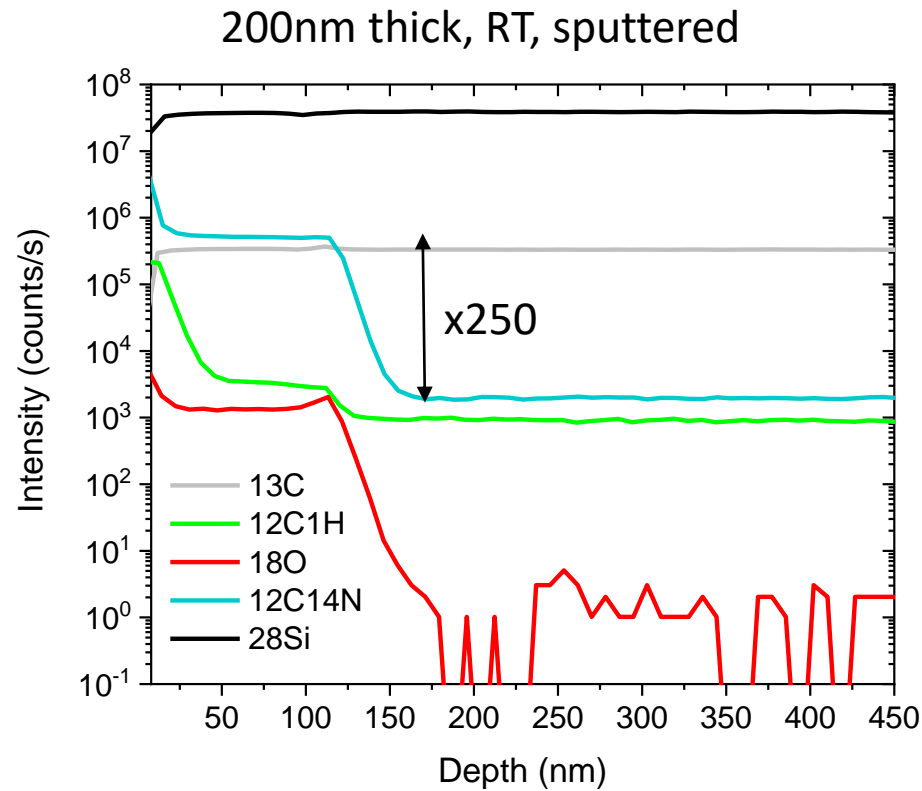


→ After annealing at 1700°C the concentration of hydrogen decreases but the oxygen and nitrogen concentrations stay still

# 3. IMPURITIES

## b) Secondary ion mass spectroscopy (SIMS) - Results

*After annealing at 1700°C for 30min*

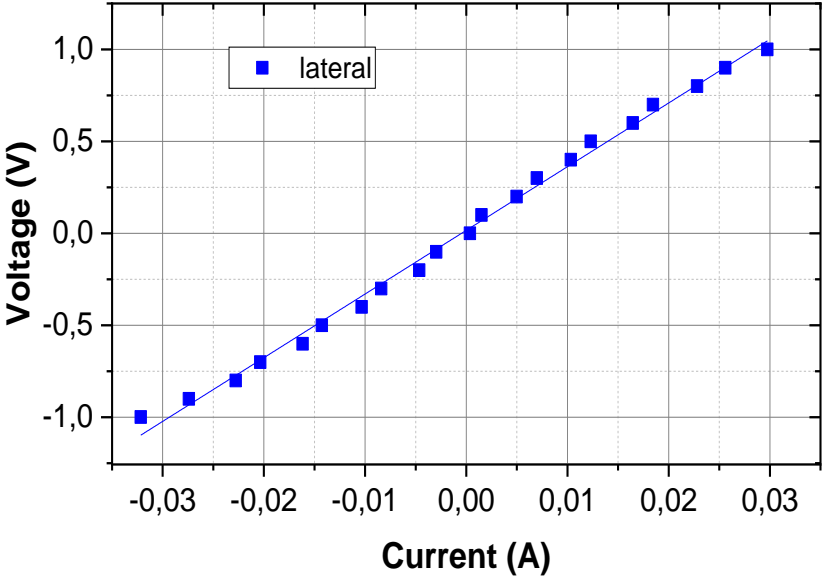


→ Less nitrogen impurities with e-beam deposition compared to sputtering  
(more intense vacuum)

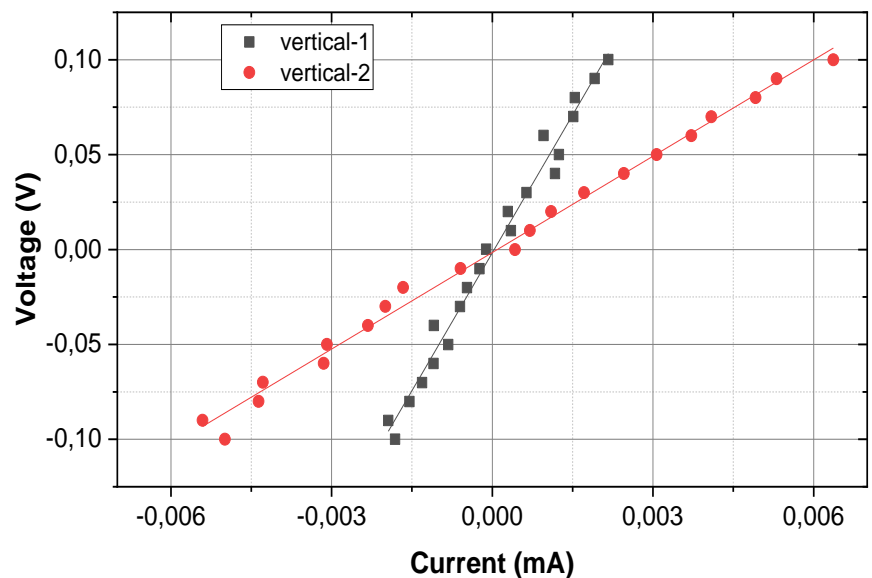
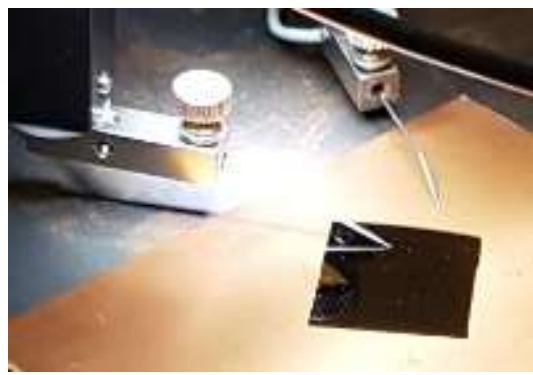
# 4. ELECTRICAL CONDUCTIVITY

*Sputtered layers after annealing at 1700°C for 30min*

Lateral I-V measurements



Vertical I-V measurements



- Incorporation of nitrogen in the PVD layers → n-type doping
- Linear I-V curves obtained for sputtered layers : good electrical conductivity
- I-V measurements for the e-beam layer : I-V curves are not linear → not enough nitrogen impurities (n-type doping)

- The e-beam PVD layer has a better crystallinity compared to sputtered ones but the layers are not perfectly mono-crystalline.
  - Nitrogen, oxygen, and hydrogen impurities are present in the PVD layers (SIMS)
    - Hydrogen concentration decreases after high-temperature annealing
    - The e-beam deposited layer has less nitrogen than the sputtered ones due to the higher vacuum during deposition
    - Thickness and temperature of deposition do not influence the impurities concentrations
  - Good electrical conductivity is obtained for nitrogen-doped layers
    - Sputtered layers: electrical and thermal conductive substrates
    - E-beam evaporated layers: better quality insulating layers
- Local and low-cost 4H-SiC deposition methods





Thank you for your attention !

Do you have any questions ?

