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# Characterization of silicon vacancies and divacancies in hexagonal silicon carbide formed by nitrogen and aluminum ion implantation

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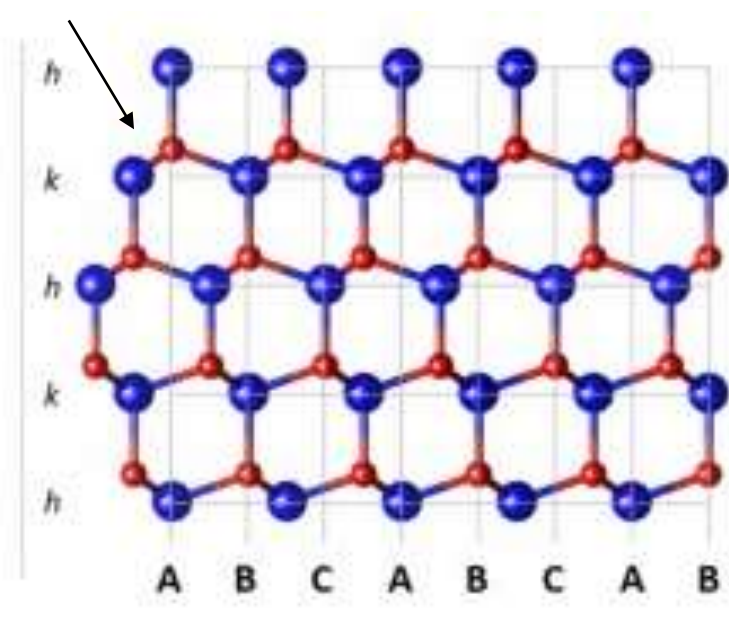
Enora Vuillermet<sup>1</sup>, Nicolas Bercu<sup>2</sup>, Florence Etienne<sup>2</sup>, Mihai Lazar<sup>1</sup>, Louis Giraudet<sup>2</sup>

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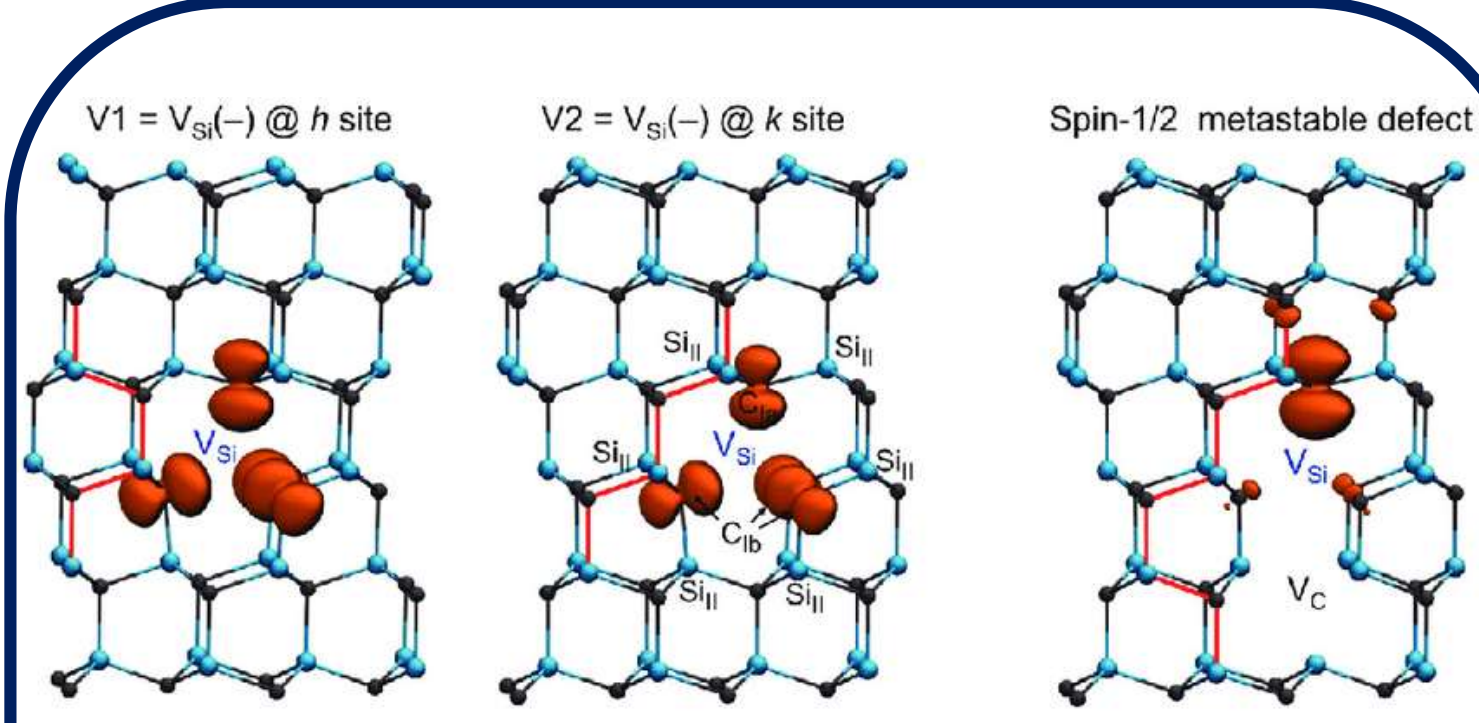
## Context and objectives

4H-SiC wafer and crystallography



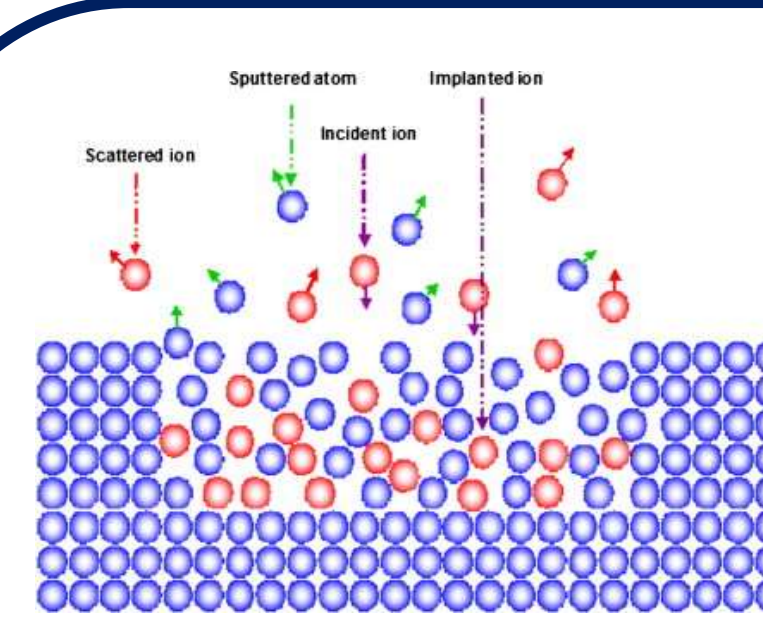
SiC is a **wide bandgap** semiconductor with :

- High thermal conductivity, chemical inertness and high critical electrical field [1]
- High technology maturity → control of defects possible [2]



**Controlled generation of point defects** (color centers) in SiC

- Emission of NIR light
- Single quantum emitters : quantum applications [3]



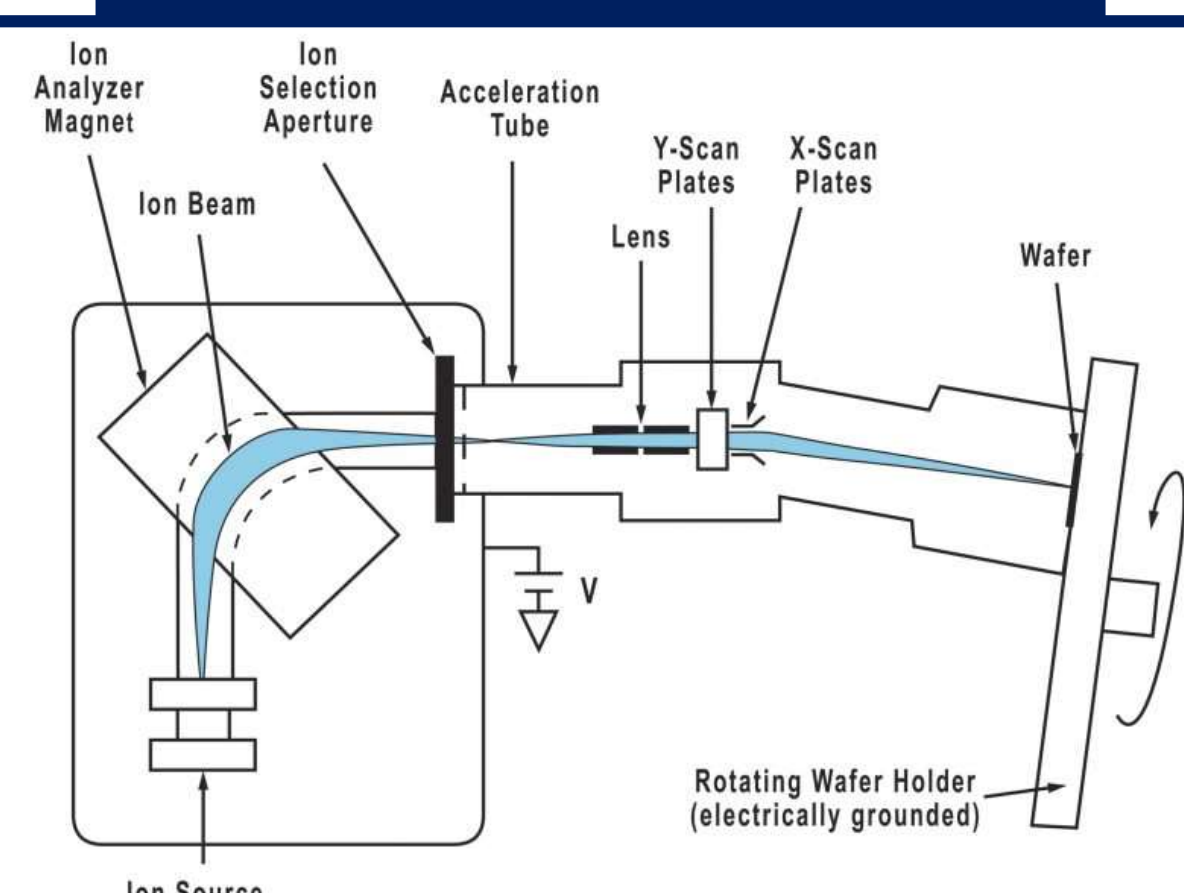
**Objective : Determination of the optimal ion implantation parameters to generate silicon vacancies ( $V_{Si}$ ) and di-vacancies ( $V_C V_{Si}$ ) in 4H-SiC**

Ion implantation allows :

- Simulations close from the experimental results
- A control of the point defects depth in the material
- Limited defects in the SiC matrix with well-controlled parameters
- Generation of color centers in **localized and large areas** [4]

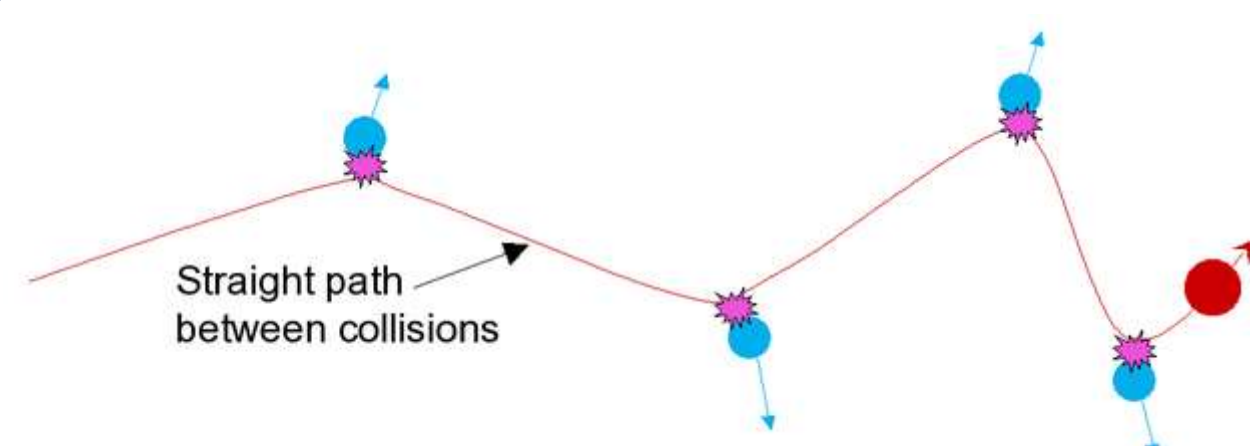
## Materials and methods

### Ion implantation



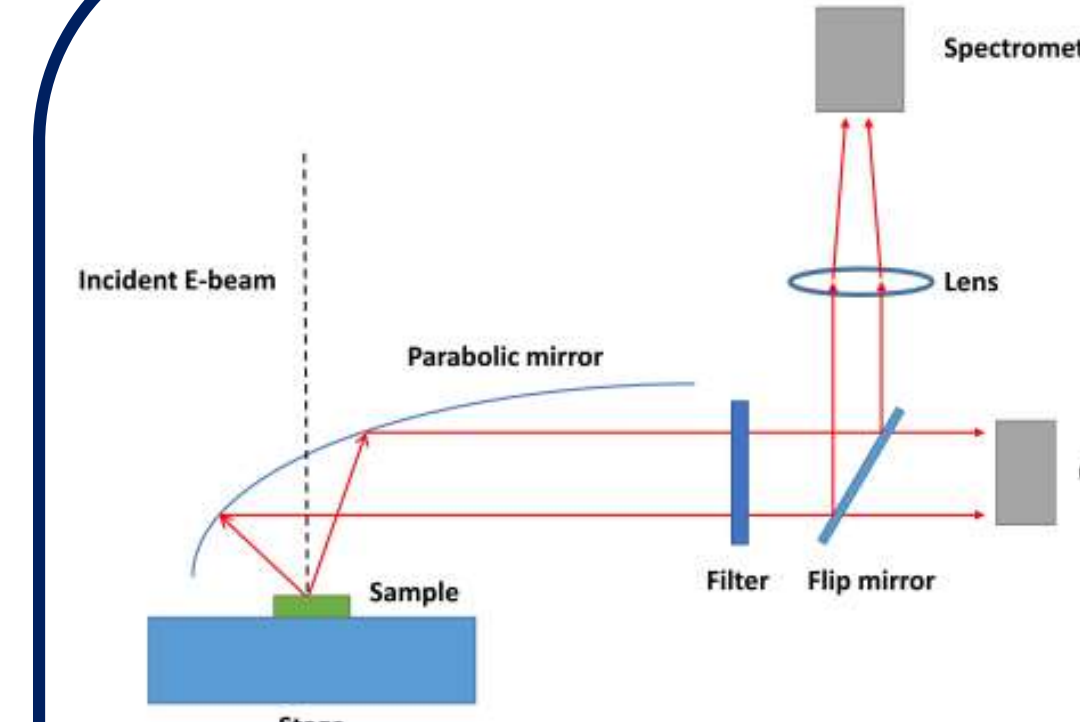
- **N or Al** implantations in 4H-SiC 10 $\mu$ m thick epilayer
- Temperature, dose and energy are changed
- Tilt and twist angles are 7 and 90° respectively

### Ion implantation simulations



**I2SiC software** based on Montecarlo method and binary collision approximation (BCA) [5]

### Cathodoluminescence with JEOL SEM



Realized before and after **annealing at 900°C** for 15min (80k, 302 l/mm, 15kV, 1nA)

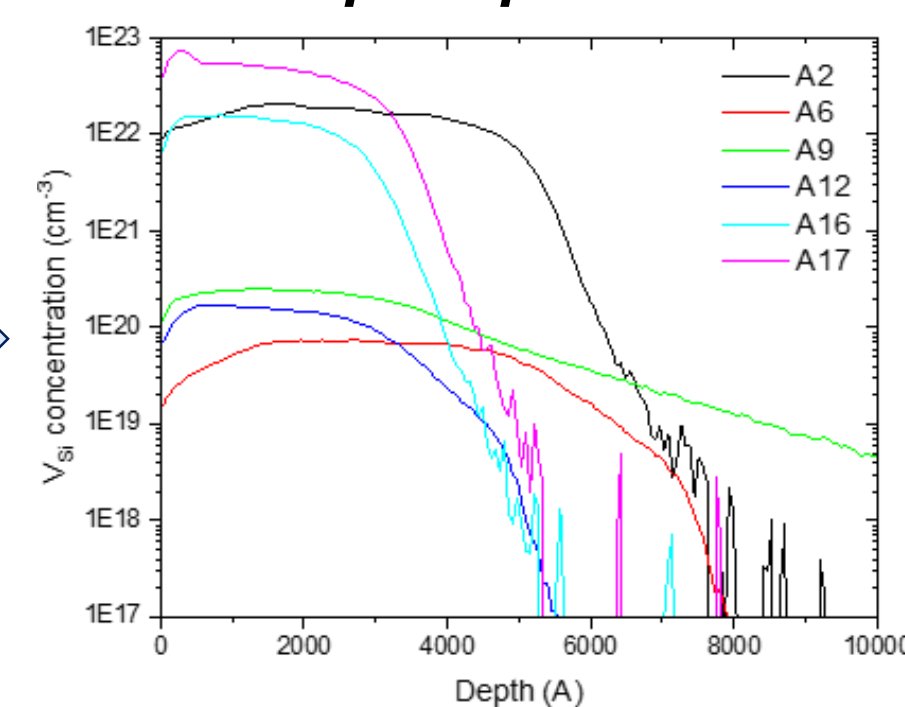
## Results and Discussion

### I2SiC simulations

#### Implantations parameters

Name	Dopant	Temperature [°C]	Energy [keV]	Dose [cm <sup>-2</sup> ]
A2	N15	RT	400	6.4E14
			270	4.6E14
			170	4E14
			100	3.8E14
Total: 1.88E15				
A6	N	RT	400	3.2E12
			270	2.3E12
			170	2E12
			100	1.9E12
Total: 9.4E12				
A9	Al	RT	300	5.93E12
			190	2.9E12
			115	2.08E12
			60	1.42E12
			25	6.81E11
Total: 1.3E13				
A12	N	RT	190	5.6E12
			135	3.6E12
			90	3.4E12
			50	3.2E12
			40	2.2E12
			30	2.2E12
Total: 1.8E13				
A16	N	300	160	5E14
			110	2.8E14
			70	2.5E14
			40	1.8E14
			30	1.3E14
			20	2.2E12
Total: 1.34E15				
A17	N	400	190	1.5E15
			135	9E14
			90	9E14
			50	8E14
			20	1.3E15
Total: 5.4E15				
A23	NA	NA	NA	NA

#### Simulated $V_{Si}$ depth profiles



- Higher implantation energy leads to a deeper generation of  $V_{Si}$
- Higher implanted dose leads to a higher concentration of  $V_{Si}$

## Conclusion

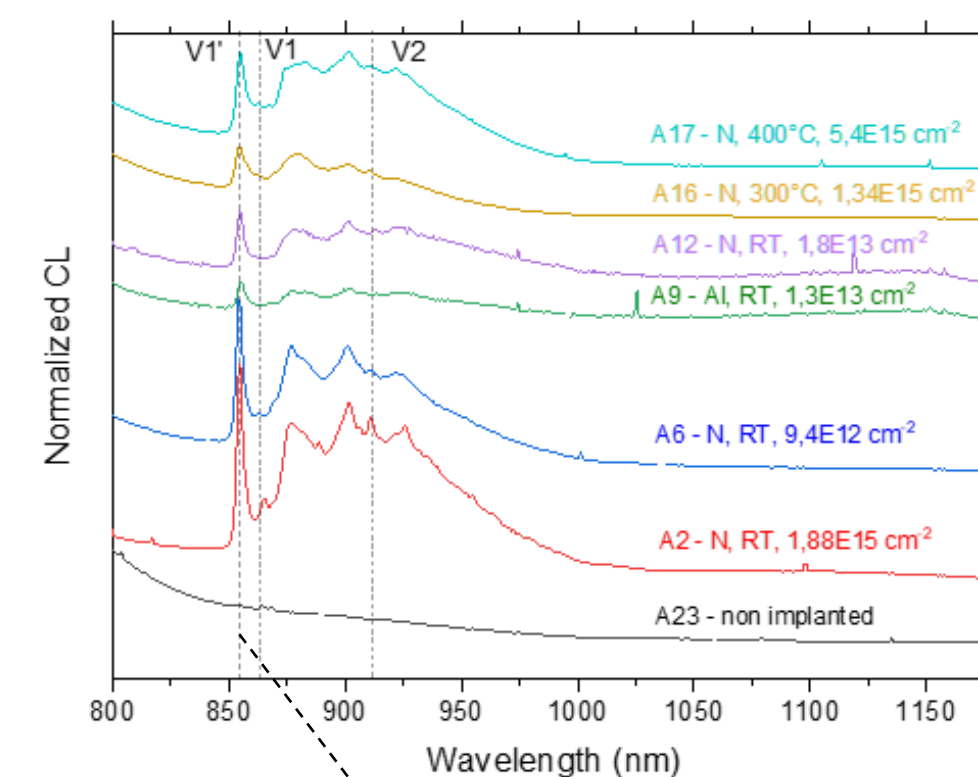
- Implantation of 4H-SiC samples realized
- Simulation of implantations realized to see  $V_{Si}$  depth profiles
- Cathodoluminescence measurements are obtained
  - Before annealing :  $V_{Si}$  concentration maximal for high energy, low dose N-implantation at RT
  - After annealing :  $V_{Si}$  concentration maximal for high energy, high dose N-implantation at RT and the concentration of  $V_C V_{Si}$  is proportional to the concentration of  $V_{Si}$

## References

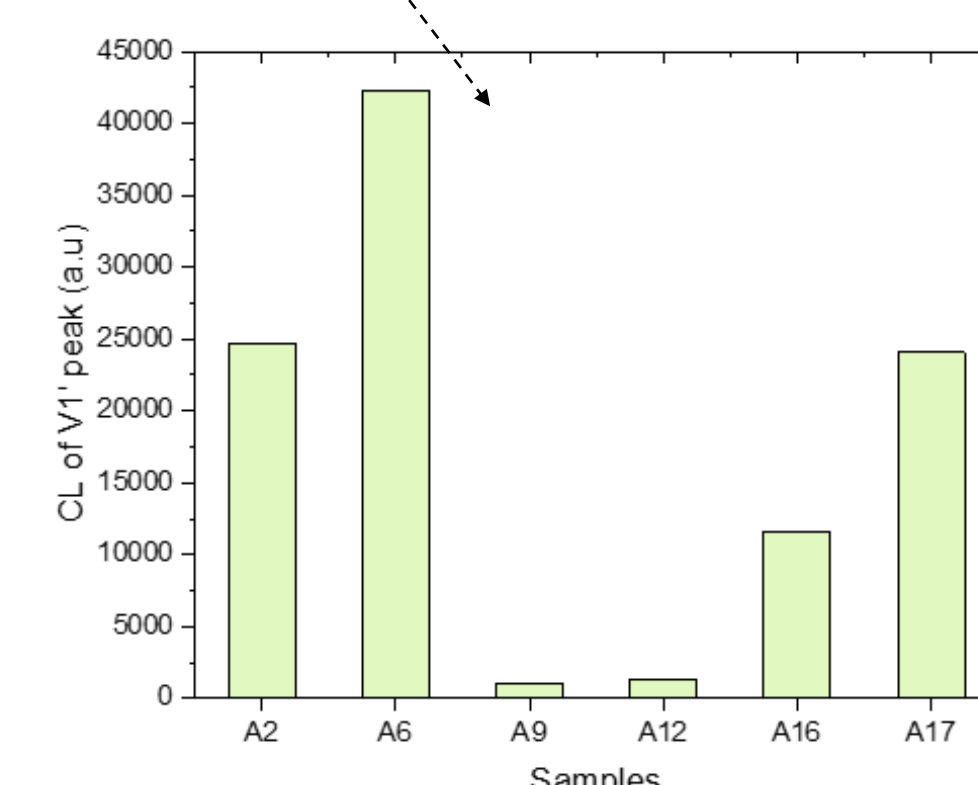
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- [2] Maximilians, J. *PhD thesis, Universität Würzburg, Germany*, **2015**
- [3] Castelletto, S et al. *J. Phys. Photonics* **2020**, *2*, 022001
- [4] Hallén, A et al. *Surf. Coat. Technol.* **2016**, *306*, 190–193
- [5] Morvan, E. *PhD thesis, Institut National des Sciences Appliquées de Lyon, France*, **1999**
- [6] Castelletto, S et al. *Nanomaterials* **2021**, *11*, 72

### Before Annealing

Normalized CL spectra

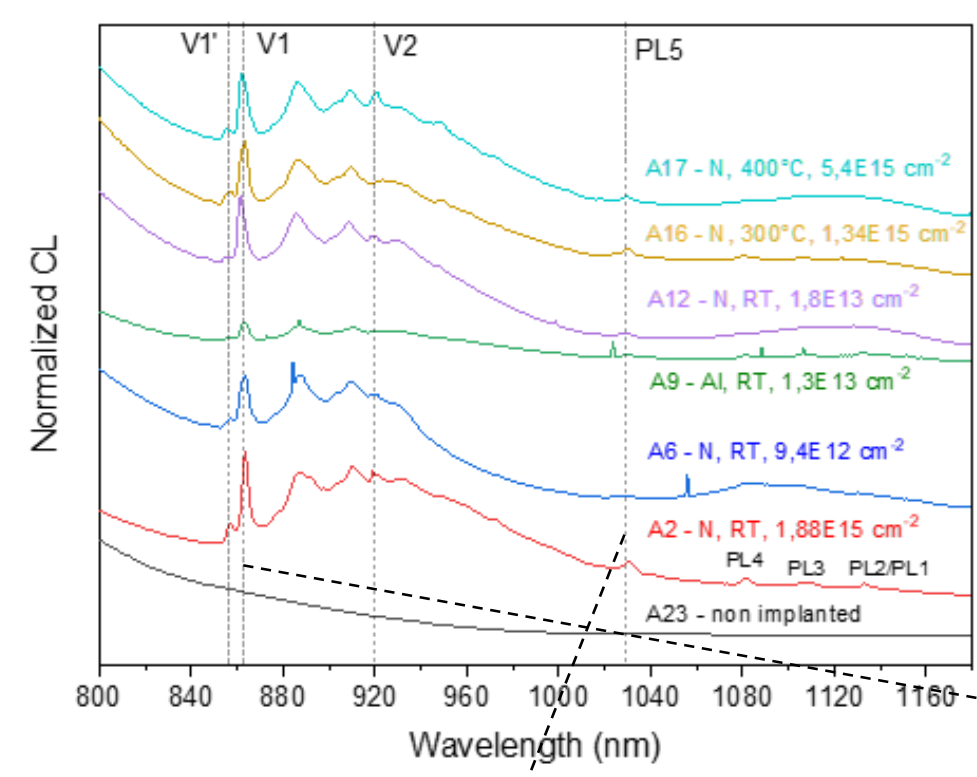


Relative intensity of CL peaks

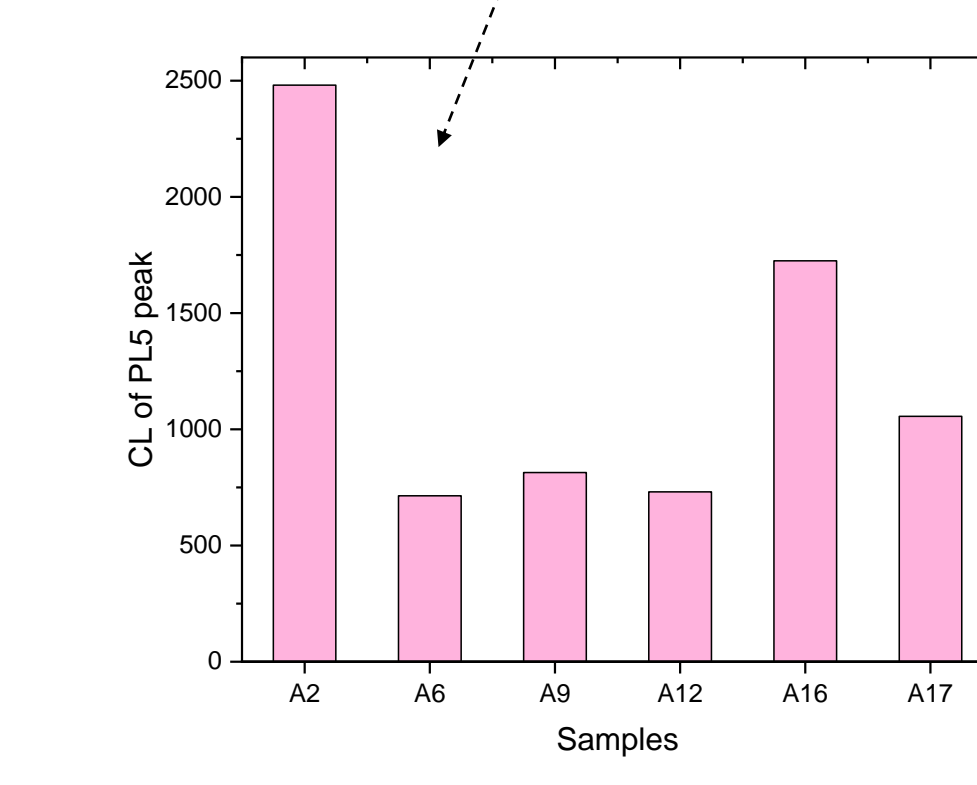


### After annealing at 900°C for 15min

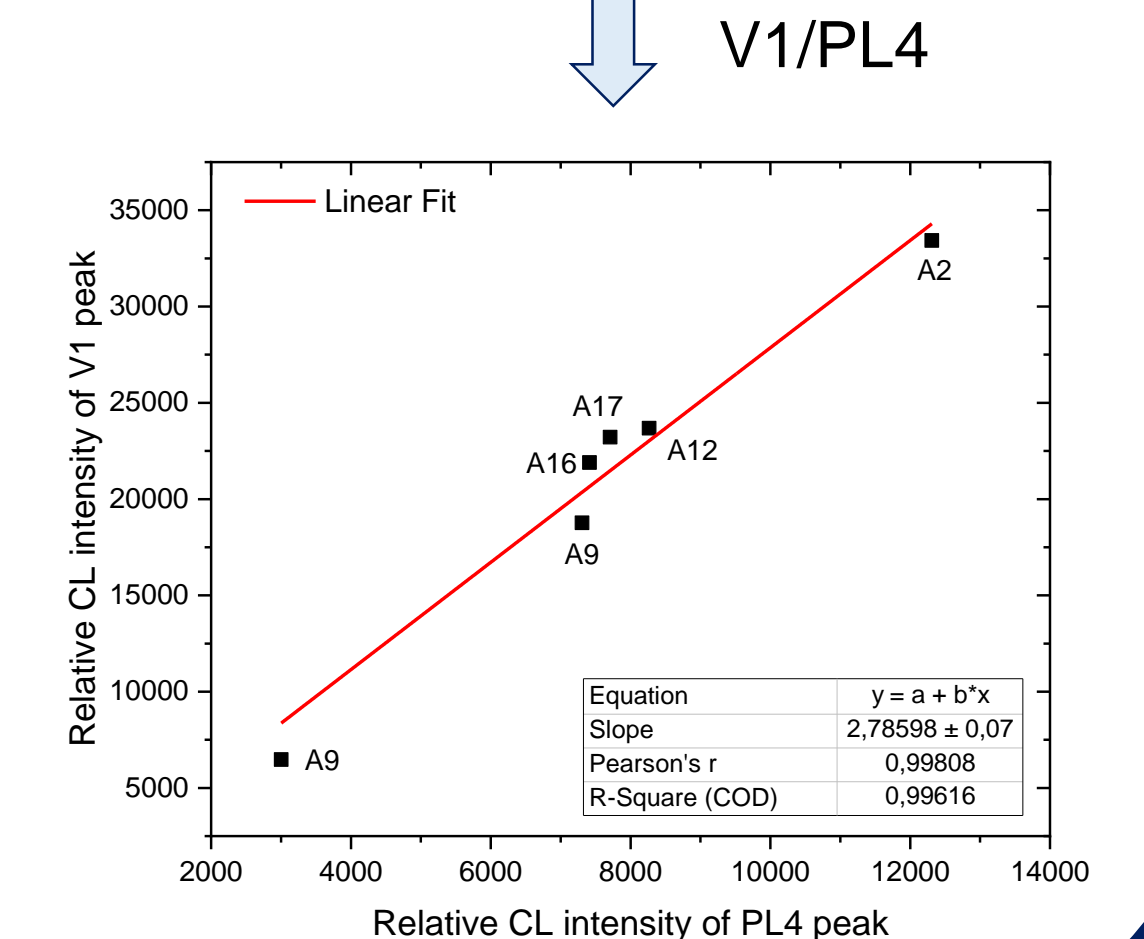
Normalized CL



Relative intensity of CL peaks



- V1' configuration favored before annealing and V1 configuration favored after annealing at 900°C for 15min.
- Concentration of  $V_C V_{Si}$  proportional to the concentration of  $V_{Si}$  in V1 configuration after annealing.
- Presence of 6H-SiC inclusions in stacking faults produced during ion implantations (PL5 peak) [6]
- Al implantation decreases the  $V_{Si}$  and  $V_C V_{Si}$  concentrations



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