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Growth of boron doped CVD diamond on a (113) orientation for power electronic devices

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Abstract

Diamond for power electronics :

- high electron mobility ☺
- high breakdown voltage ☺
- low dimensions ☹
- difficult doping ☹

Need for **thick, heavily-doped layers of good crystal quality** for vertical devices

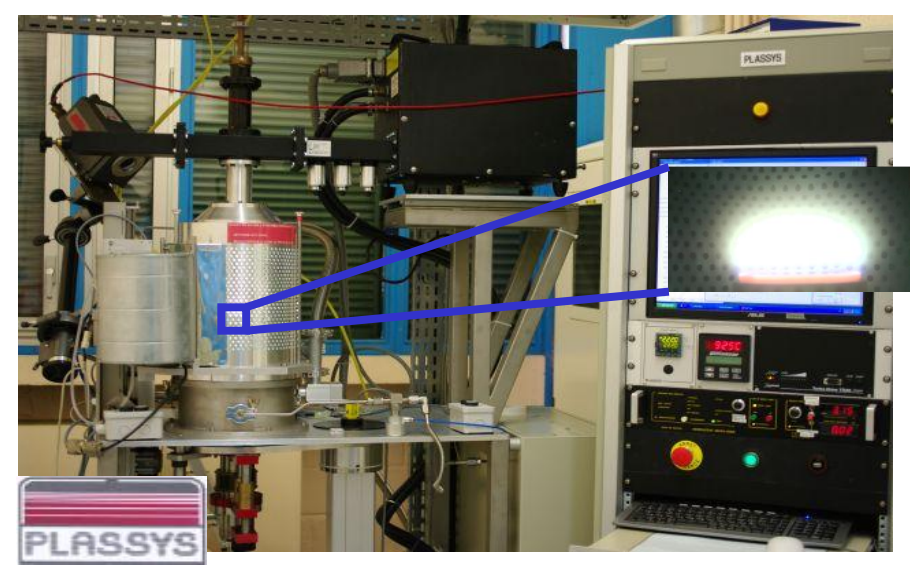
Orientation	(100)	(111)
Crystal quality	☺	☹
Growth rate	☹	☹
Boron incorporation	☹	☺

(113)-orientation as an alternative to (100)- and (111)-oriented diamonds?

- window of growth parameters?
- growth rates?
- crystal quality?
- boron incorporation?

Growth conditions

- (113)-oriented substrates were obtained from (100)-oriented substrates by laser cut and polishing.
- CVD growth in a *Plassys BJS150* bell-jar microwave plasma reactor (5 % CH₄, T = 1050°C, MW power 2.4 - 2.8 kW, pressure 140 - 180 mbar).
- Boron doping by introducing into the gas phase high-purity diborane (B₂H₆).



Sample	A	B	C	D	E	F
Substrate orientation	(113)	(113)	(113)	(113)	(100)	(113)
Substrate type	HPHT	HPHT	HPHT	HPHT	HPHT	CVD
[B]/[C] _{gas} (ppm)	NID ^a	3000	6000	0 ^b	0 ^b	6000
Growth rate (μm/h)	4.3	6.3	3.9	4.7	2.4	3.9
Thickness (μm)	95 ± 5	150 ± 5	190 ± 5	110 ± 5	70 ± 5	480 ± 5

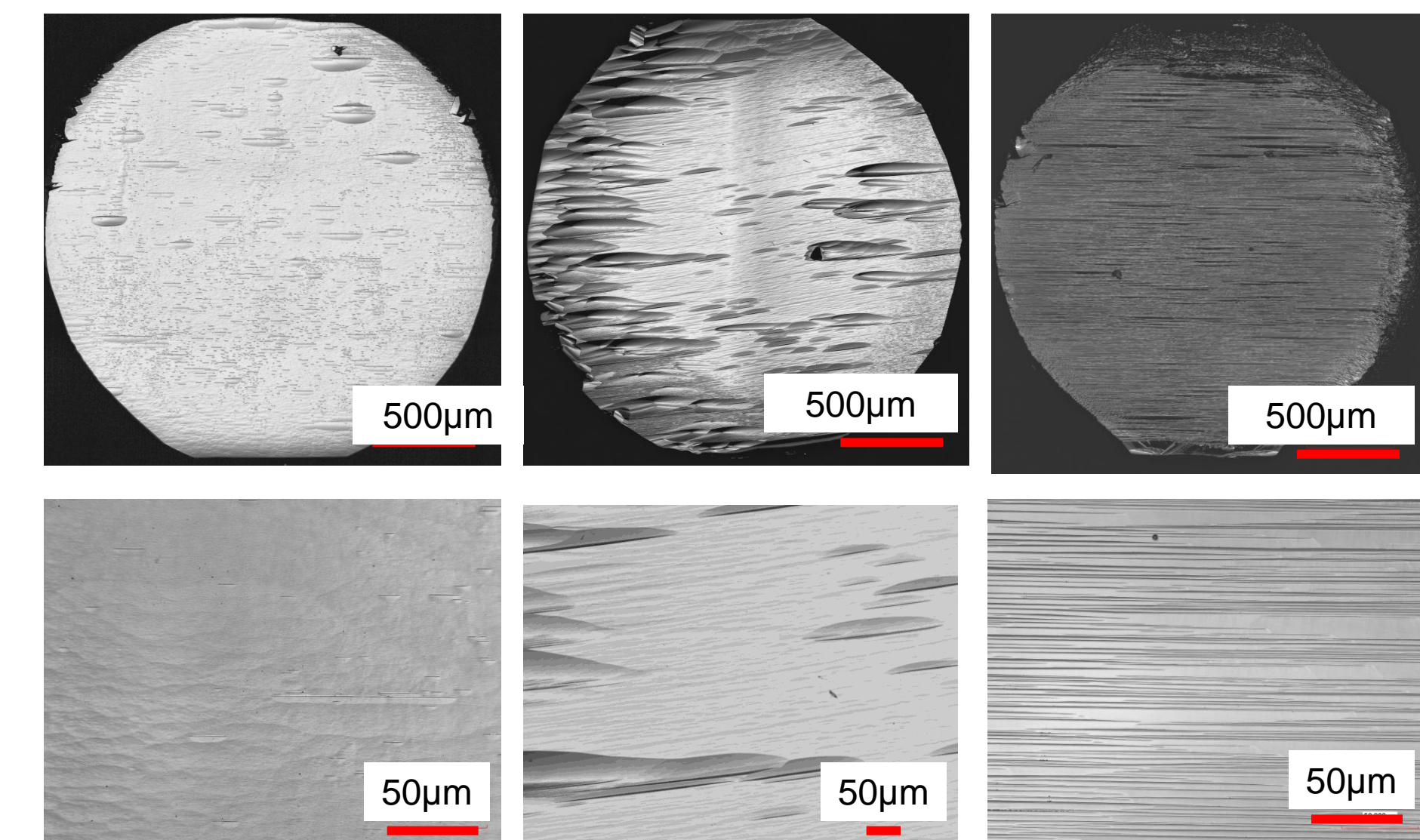
^a Non Intentionally Doped., grown in a reactor in which boron has never been introduced

^b grown in a boron-contaminated reactor without any intentional diborane addition

- ▶ Increase of growth rates.
- ▶ The window of optimal growth parameters is extended.

Surface morphologies

Images obtained using a *Keyence VK-9700* 3D Laser Scanning Microscope.

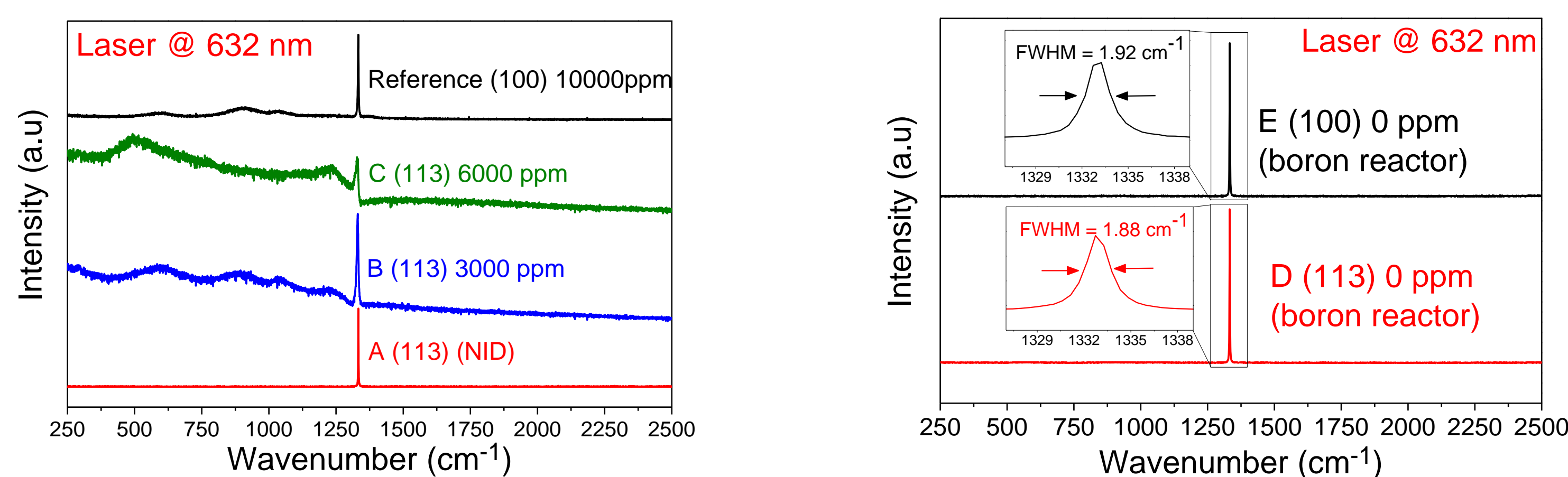


Sample	A	B	C
[B]/[C]	0 ppm	3000 ppm	6000 ppm

- ▶ The surface of the samples is free of unepitaxial crystallites.
- ▶ Minor increase of the roughness at high [B₂H₆] due to the appearance of macro-steps.

Raman spectra

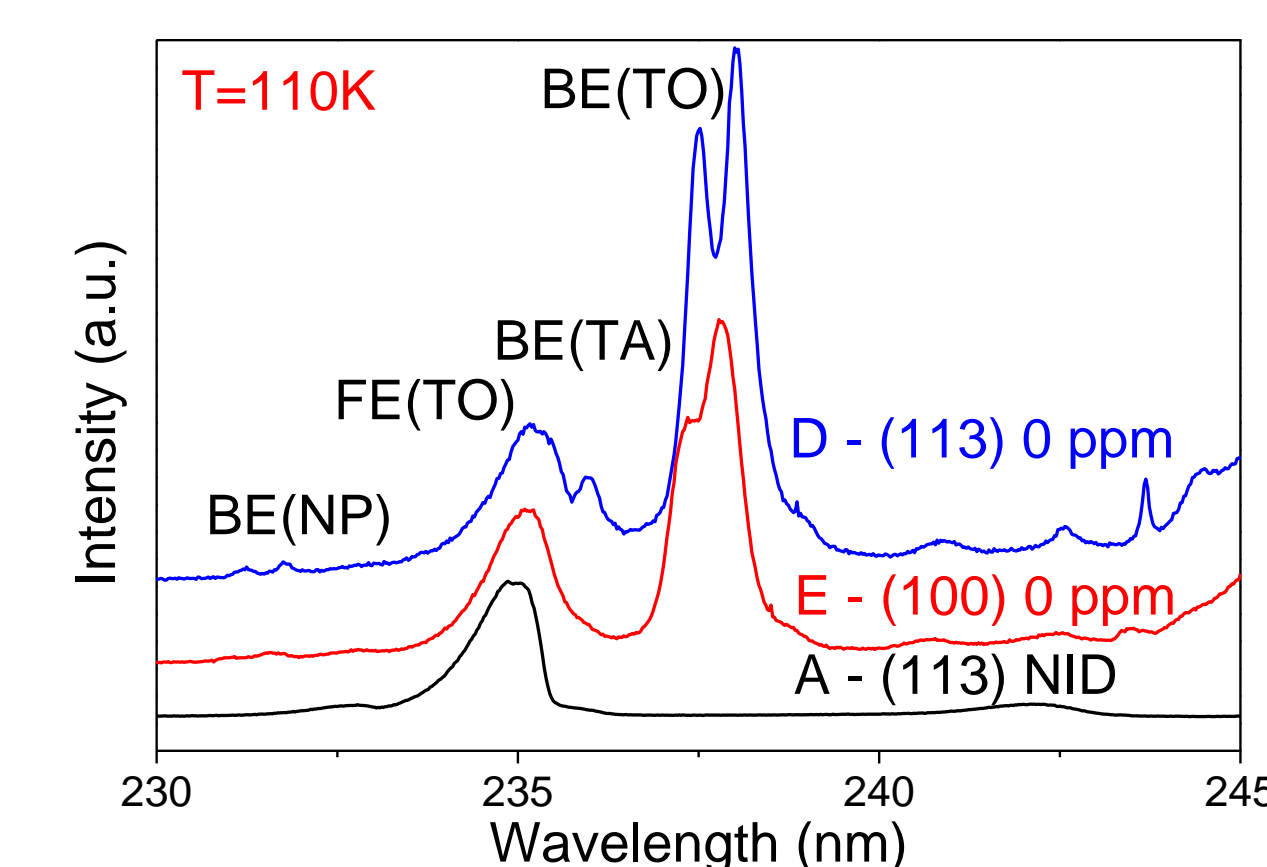
Spectra acquired using a *Horiba HR800* spectrometer @RT



- ▶ Clear effect of [B] increase.
- ▶ Samples A, D & E : low FWHMs show a good crystalline quality.
- ▶ Higher boron-doping on (113)-oriented diamond than on (100)-oriented diamond.
- ▶ No evidence of N or Si.

Cathodoluminescence spectra

Spectra recorded with a *Horiba HCLUE* system attached to a *ZEISS EVO MA15* SEM.

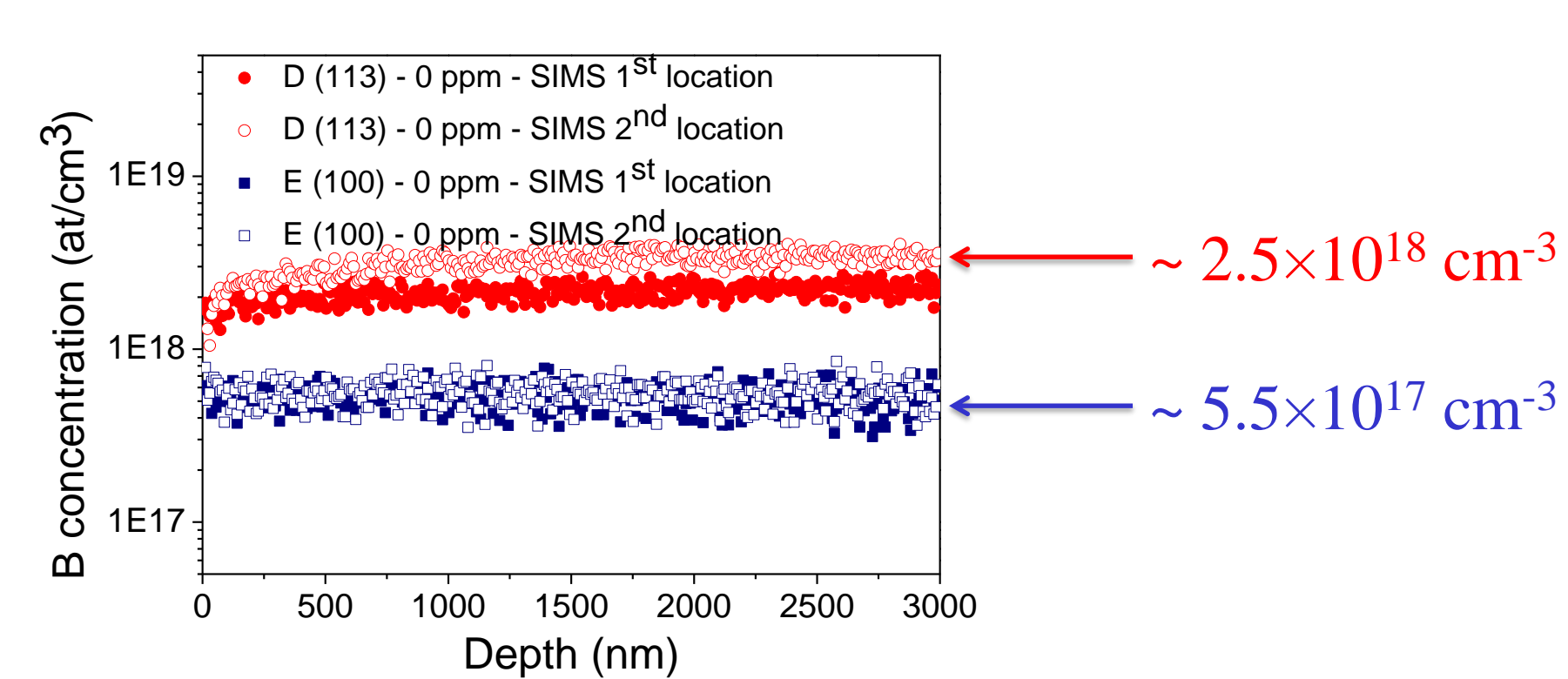


- ▶ Good crystalline quality
- ▶ Substitutional boron concentration ~ 10¹⁸ cm⁻³
- ▶ Sample A (0 ppm) : [B] < 1 × 10¹⁴ cm⁻³.

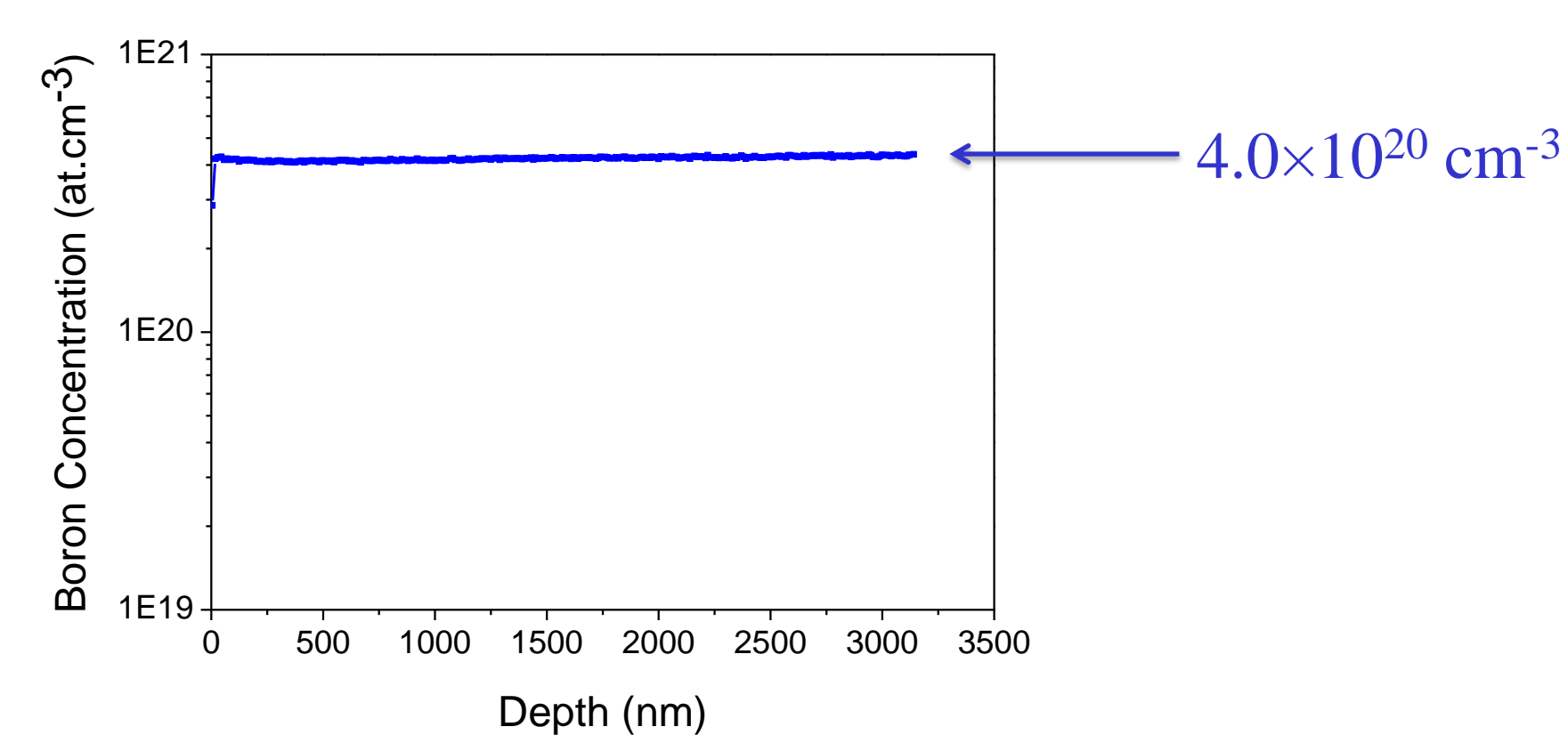
SIMS measurements

Obtained using a *CAMECA IMS7f* equipment with a *Dektak8* step-meter.

Non-intentionally doped diamonds



Heavily doped diamond

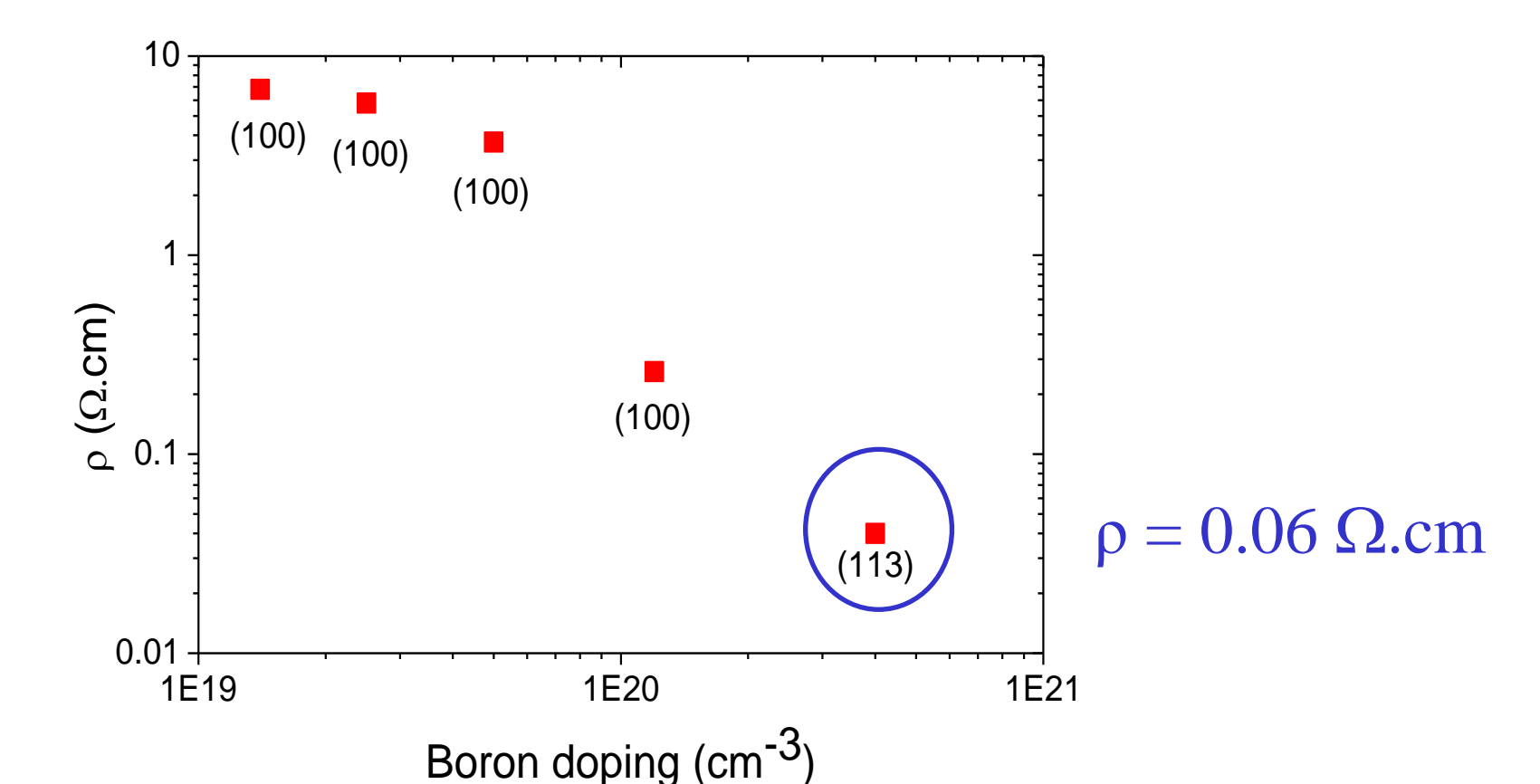
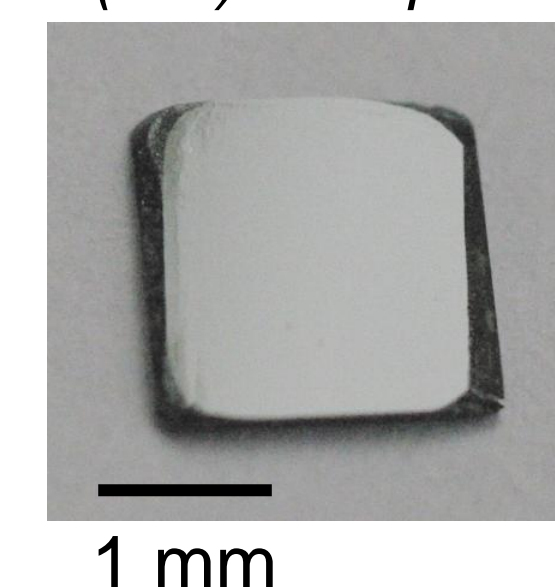


- ▶ Homogeneous concentrations.
- ▶ NID diamonds: total boron concentration ~ substitutional boron concentration
- ▶ Heavily doped diamond: boron incorporation is 4 to 5 times higher on (113) than on (100).

Resistivity measurements

Measured in a collinear four-point probe configuration with a 635 μm spacing using a *JANDEL* system @RT on a freestanding plate cut from sample F.

Freestanding p+ (113) CVD plate



- ▶ Higher boron incorporation
- ▶ Metallic transition without soot formation during growth

Conclusion

Growth of (113)-oriented diamonds:

- window of growth parameters => extended
- growth rates => increased
- crystal quality => good
- boron incorporation => increased

Orientation	(100)	(113)	(111)
Crystal quality	☺	☺	☹
Growth rate	☹	☺	☹
Boron incorporation	☹	☺	☺
Availability of substrates	☺	☹	☹

(113)-oriented diamonds are an alternative to (100)- and (111)-oriented diamonds.

Development of vertical electronic devices with higher doping can be considered.