



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

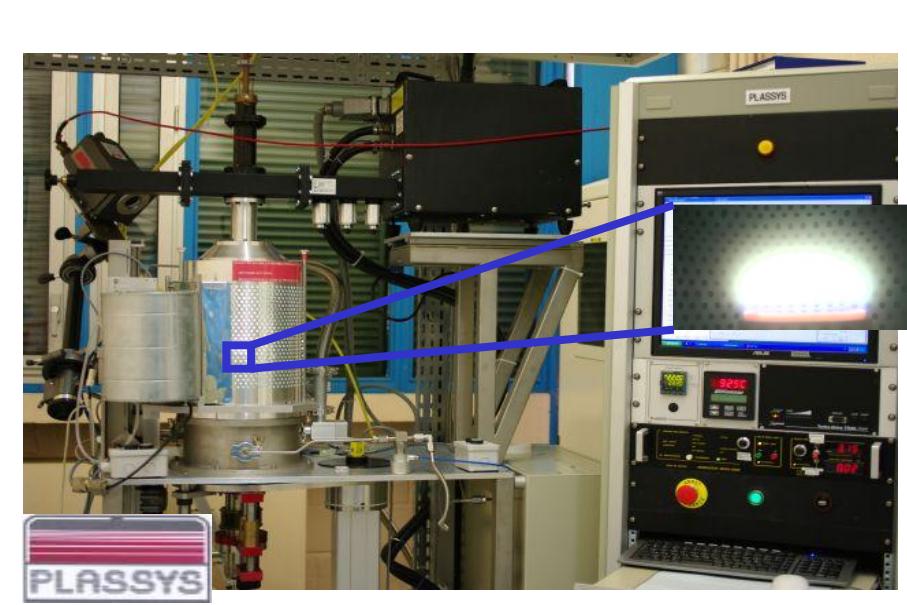
Orientation	(100)	(111)
Crystal quality	☺	☹
Growth rate	☺	☹
Boron incorporation	☺	☺

(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)	(100)	(113)
	type	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

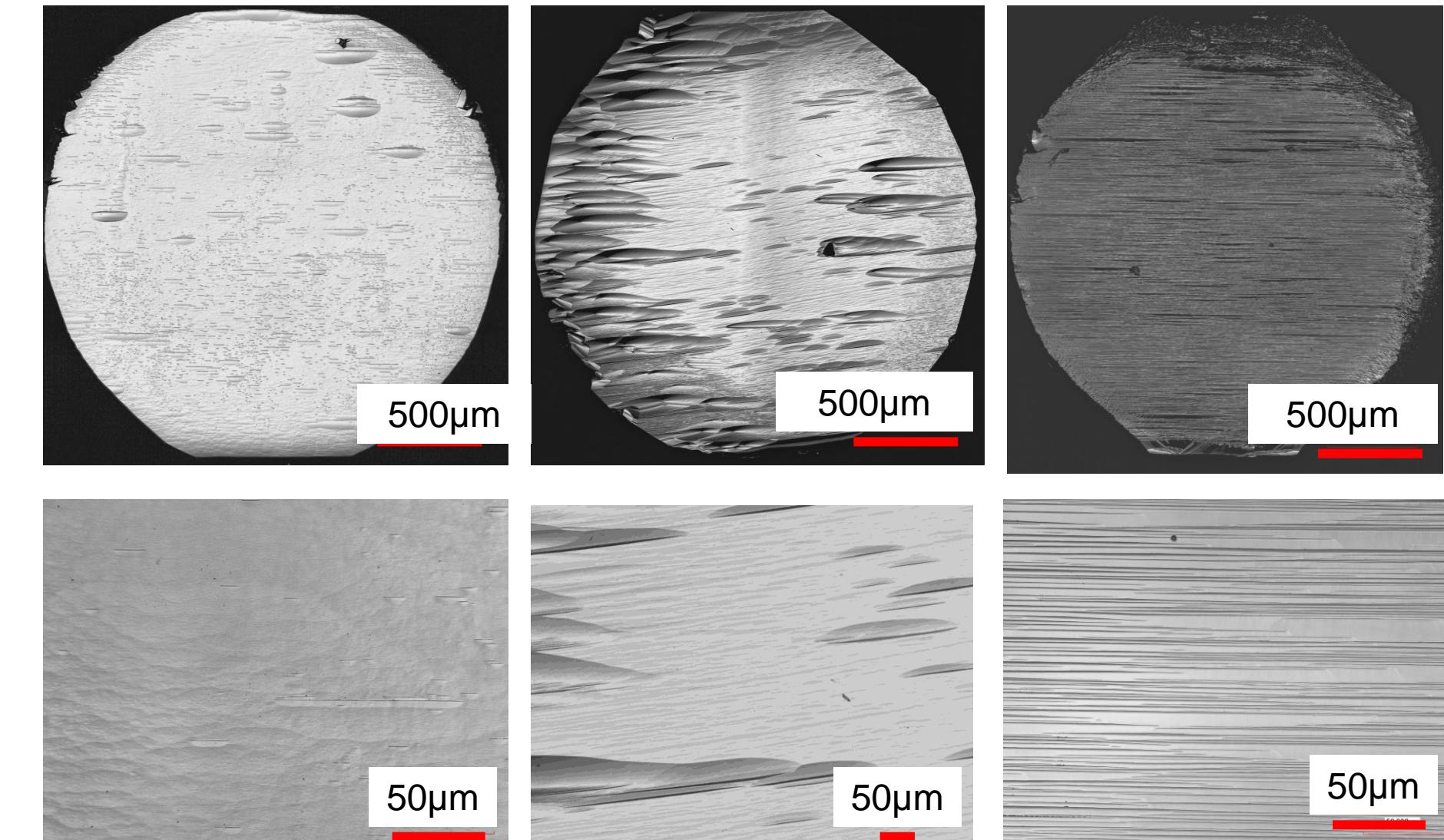
^a Non Intentionally Doped., grown in a reactor in which boron has never been introduced

^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.

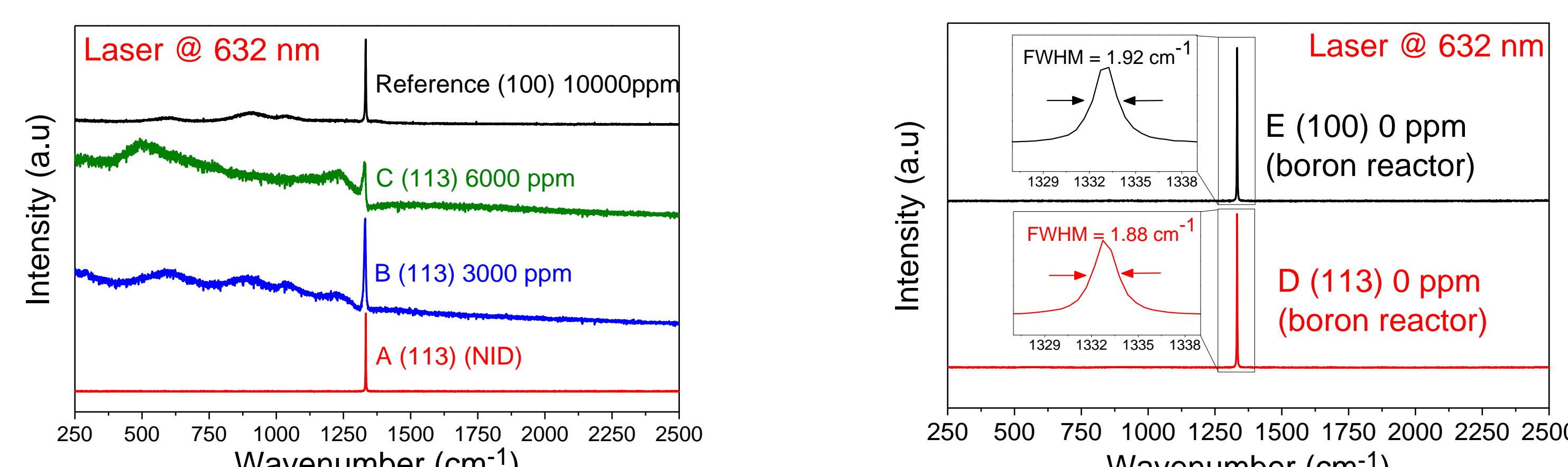


Sample A B C
[B]/[C] 0 ppm 3000 ppm 6000 ppm

- 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

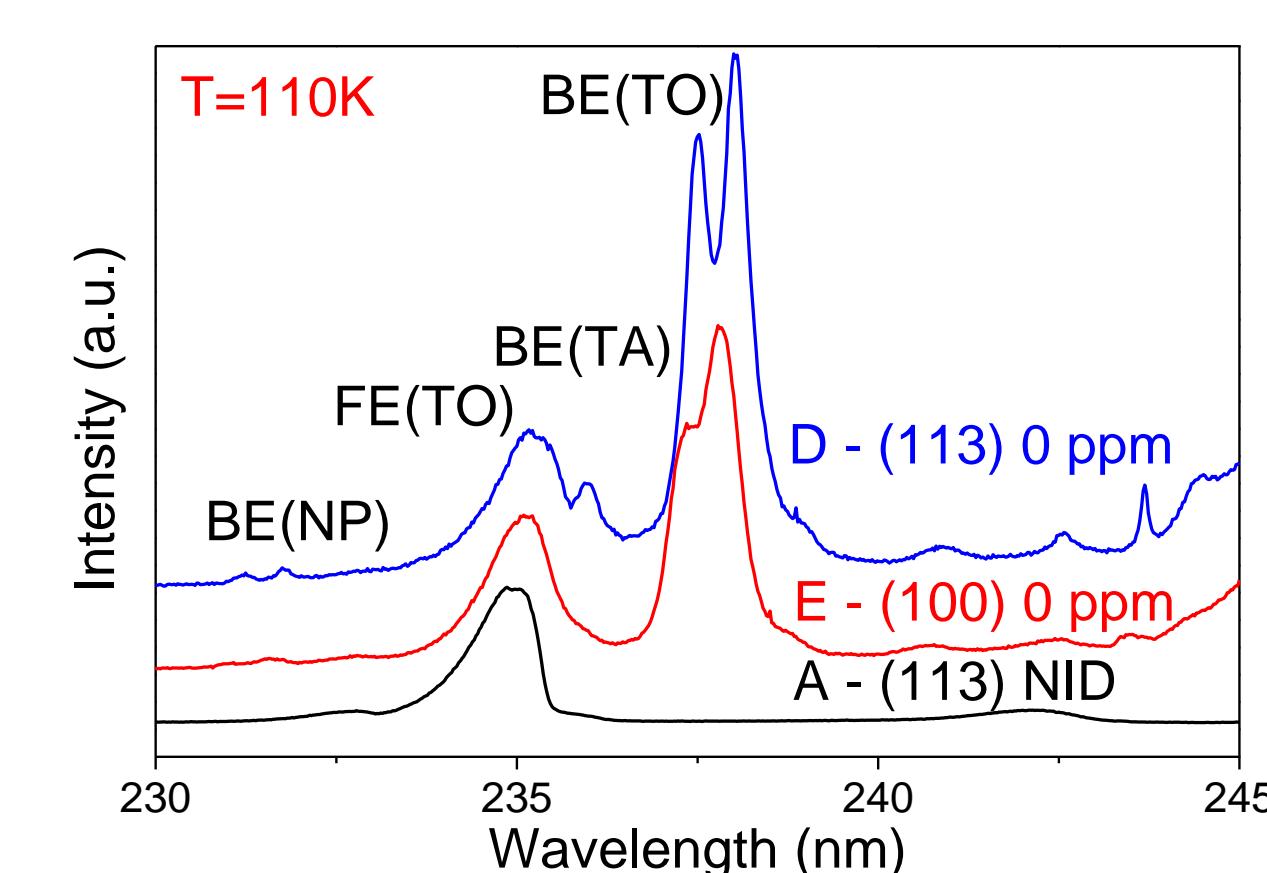
Spectra acquired using a Horiba HR800 spectrometer @RT



- 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.

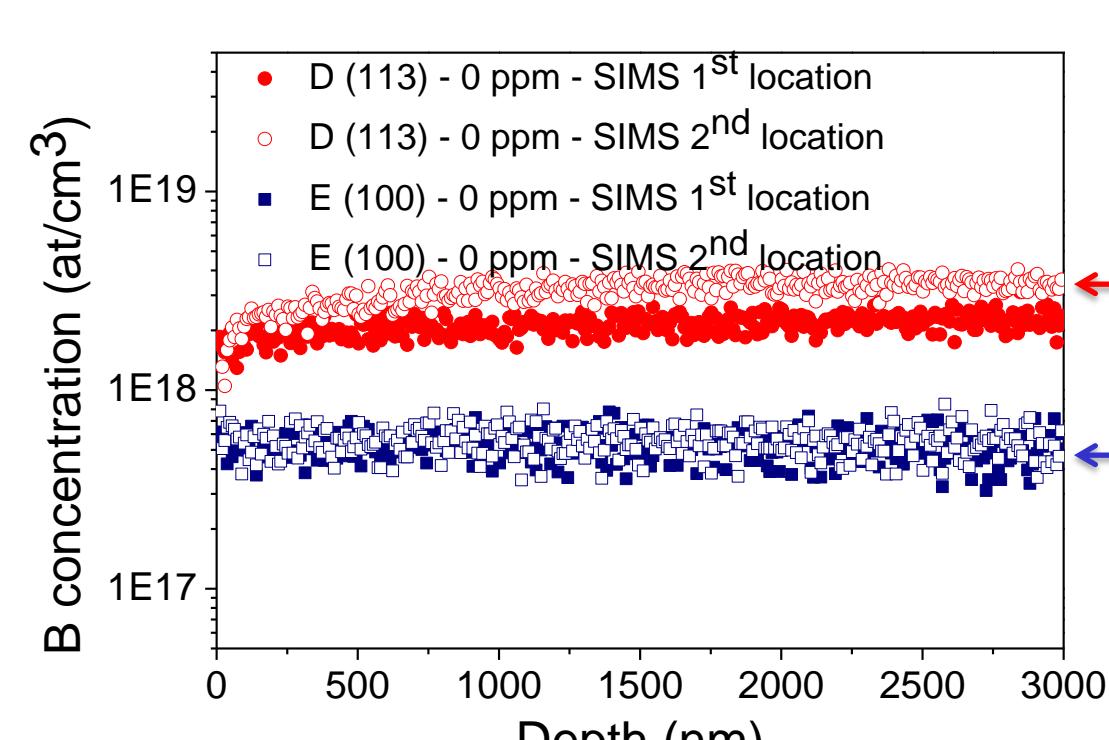


- Good crystalline quality
- Substitutional boron concentration ~ 10¹⁸ cm⁻³
- Sample A (0 ppm) : [B] < 1 × 10¹⁴ cm⁻³.

SIMS measurements

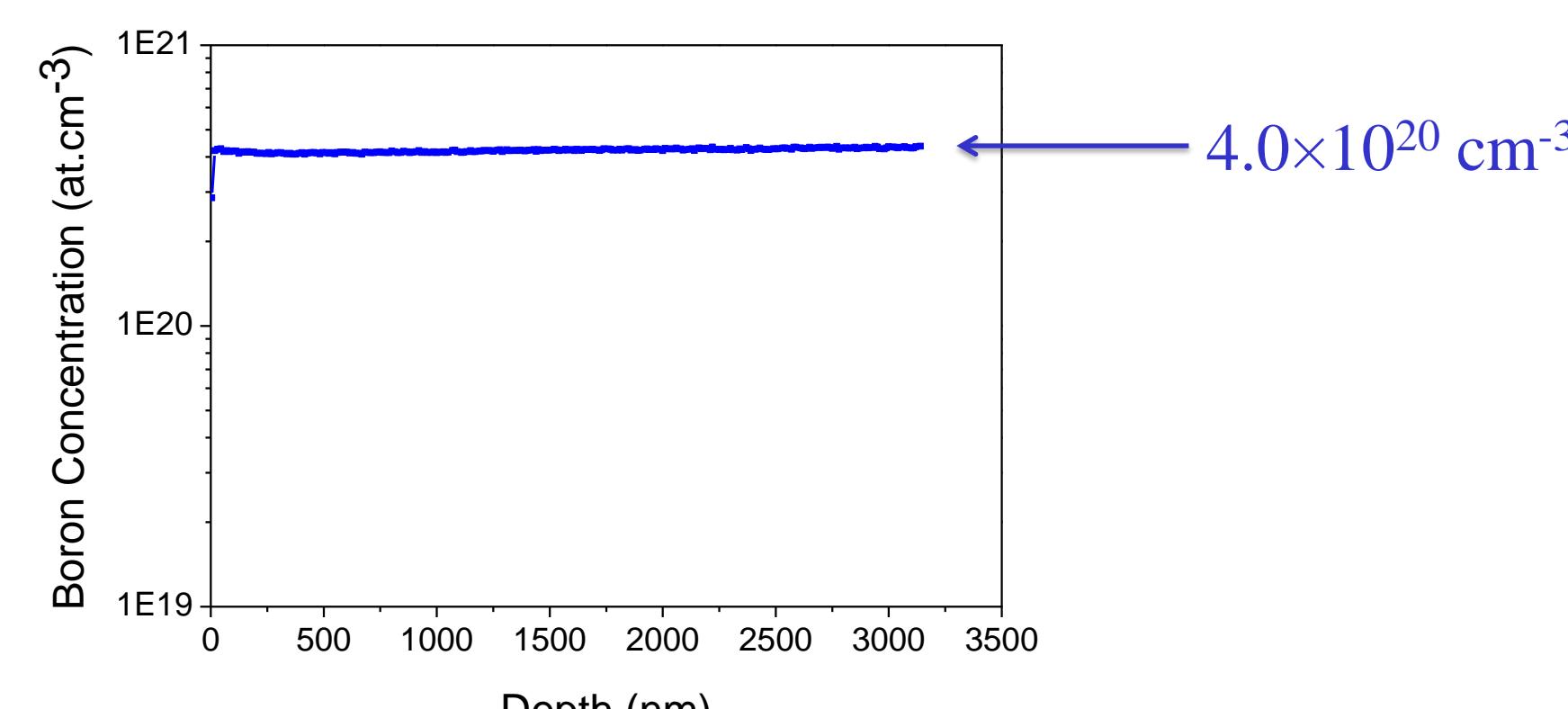
Obtained using a CAMECA IMS7f equipment with a Dektak8 step-meter.

Non-intentionally doped diamonds



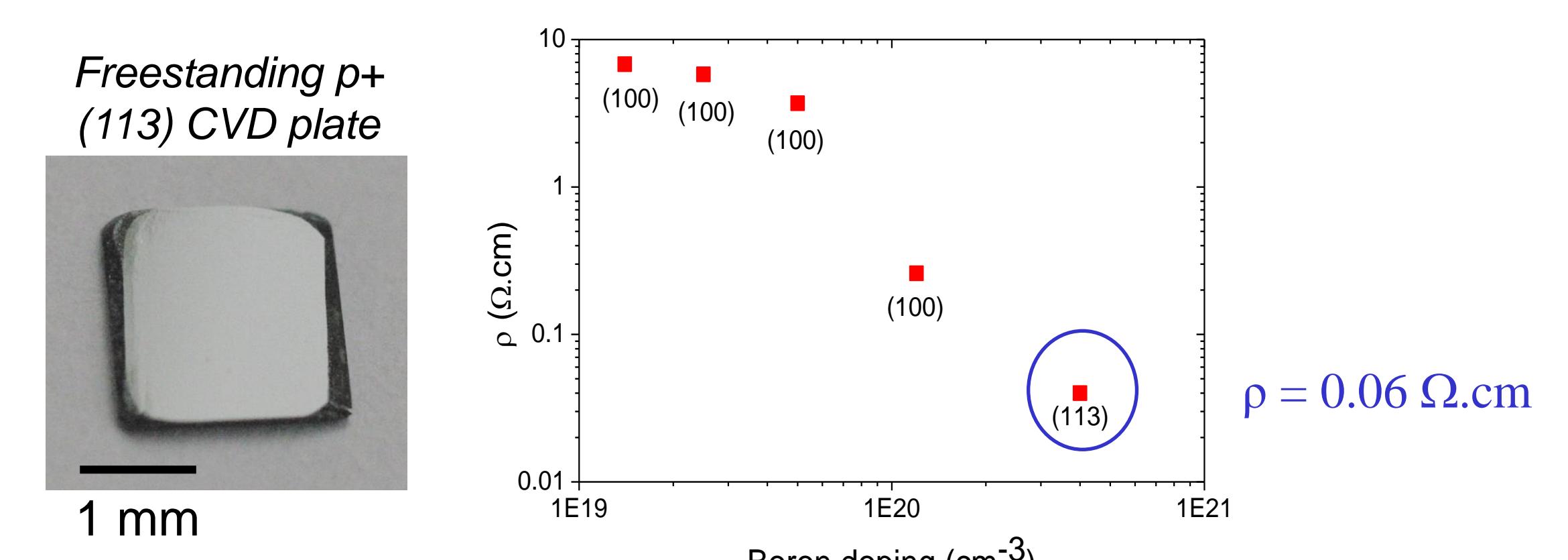
- Homogeneous concentrations.
- NID diamonds: total boron concentration ~ substitutional boron concentration
- Heavily doped diamond: boron incorporation is 4 to 5 times higher on (113) than on (100).

Heavily doped diamond



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.



- 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.

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