Progresses and questions about sCVD Diamond Detectors for Particle Tracking

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On behalf of the
MONODIAM-HE Project
ANR-12-BS05-0014

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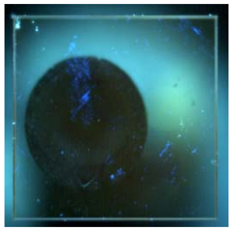
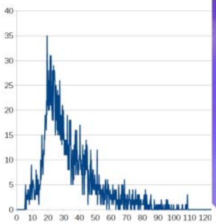
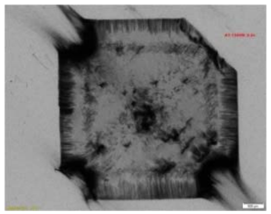



The 2015 RD42 Collaboration

M. Artuso[24], F. Bachmair[28], L. Bäni[28], M. Bartosik[3], V. Bellini[2], V. Belyaev[15], B. Bentele[23], E. Berdermann[8], P. Bergonzo[14], A. Bes[32], J-M. Brom[10], M. Bruzzi[5], M. Cerv[3], C. Chau[19], G. Chiodini[31], D. Chren[22], V. Cindro[12], G. Claus[10], J. Collot[32], S. Costa[2], J. Cumalat[23], A. Dabrowski[3], R. D'Alessandro[6], W. de Boer[13], B. Dehning[3], D. Dobos[3], V. Eremin[9], R. Eusebi[29], G. Forcolin[26], J. Forneris[18], H. Frais-Kölbl[4], K.K. Gan[16], M. Gastal[3], C. Giroletti[20], M. Goffe[10], J. Goldstein[20], A. Golubev[11], L. Gonella[1], A. Gorišek[12], L. Graber[27], E. Grigoriev[11], J. Grosse-Knetter[27], M. Guthoff[3], I. Haughton[26], D. Hidas[17], D. Hits[28], M. Hoeferkamp[25], T. Hofmann[3], J. Hosslet[10], J-Y. Hostachy[32], F. Hügging[1], C. Hutton[20], H. Jansen[3], J. Janssen[1], H. Kagan[16,◊], K. Kanxheri[33], G. Kasieczka[28], R. Kass[16], F. Kassel[13], M. Kis[8], G. Kramberger[12], S. Kuleshov[11], A. Lacoste[32], S. Lagomarsino[6], A. Lo Giudice[18], E. Lukosi[30], C. Maazouzi[10], I. Mandic[12], C. Mathieu[10], N. McFadden[25], G. McGoldrick[19], M. Menichelli[33], M. Mikuž[12], A. Morozzi[33], J. Moss[16], R. Mountain[24], S. Murphy[26], G. Oakham[21], A. Oh[26], P. Olivero[18], G. Parrini[6], D. Passeri[33], M. Pauluzzi[33], H. Pernegger[3], R. Perrino[31], F. Picollo[18], M. Pomorski[14], R. Potenza[2], A. Quadt[27], A. Re[18], G. Riley[30], S. Roe[3], M. Sapinski[3], M. Scaringella[5], S. Schnetzer[17], T. Schreiner[4], S. Sciortino[6], A. Scorzoni[33], S. Seidel[25], L. Servoli[33], A. Sfyrla[3], G. Shimchuk[11], S. Smith[16], B. Sopko[22], V. Sopko[22], S. Spagnolo[31], S. Spanier[30], K. Stenson[23], R. Stone[17], C. Sutera[2], A. Taylor[25], M. Traeger[8], D. Tromson[14], W. Trischuk[19,◊], C. Tuve[2], L. Uplegger[7], J. Velthuis[20], N. Venturi[19], E. Vittone[18], S. Wagner[23], R. Wallny[28], J.C. Wang[24], P. Weilhammer[3], J. Weingarten[27], C. Weiss[3], T. Wengler[3], N. Wermes[1], M. Yamouni[32], M. Zavrtanik[12]

CVD Diamond : what everybody knows (or should know)

- No need for cooling
- High radiation tolerance (up to 2^{15} p/cm^2
- High charge mobility
- Full charge collection at field < 1 V/µ

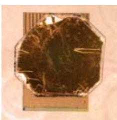
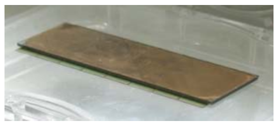
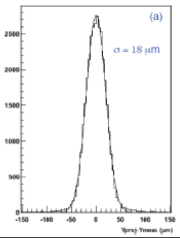
Very few manufacturers (industrial)

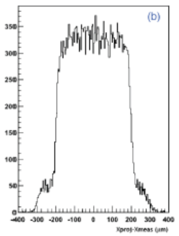
- Industrial secrets
- Commercial interest ?
- Reproducibility

	CVD DIamond	Si
Energy Gap	5,5 eV	1,21 to 1,1eV
Breakdown	10^7 V/cm	3.10^5 V/cm
Resistivity	$10^{13} – 10^{16}$ Ωcm	$10^5 – 10^6$ Ωcm
Mobility (electrons)	2000 cm^2/V/s	1350 cm^2/V/s
Mobility (holes)	1600 cm^2/V/s	480 cm^2/V/s
Displacmt Energy (e$^-$)	43 eV/atom	13 à 20 eV/atom
Pairs Creation	13 eV	3.6 eV
Charge Coll. Dist.	200 – 500 µm	…m
Mean signal (MIP)	3600 e$^-$ / µm	8900 e$^-$ / µm
Dielectric Constant	5.5	10 à 12
Thermal Conductivity	33.2 W/(cm·K)	1.3 W/(cm·K)

CVD diamond already tested as pixel sensors

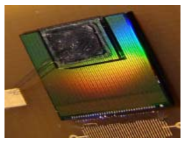
By ATLAS (pCVD)

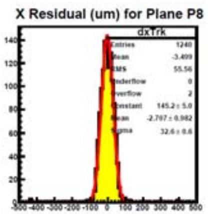




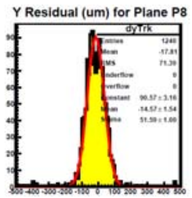


Correct…

By CMS (sCVD)

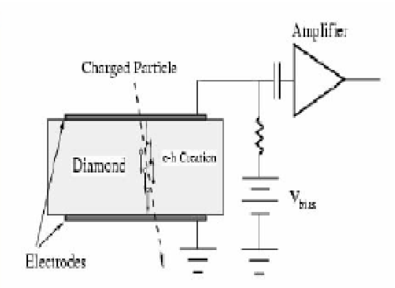


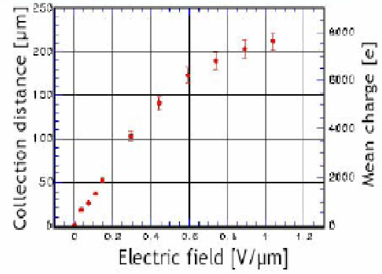




But :
Results mostly about **ONE** single prototype
from **ONE** single manufacturer
TWO diamonds from the same manufacturer may be different
(reproducibility is never guaranteed)
THREE important parameters : - growing method
- surface finishing
- assembly

Charge Collection Distance:
- Fraction of charge that is collected
  - $Q = \frac{d}{t} Q_0$, t=thickness
  - $d = (\mu_e \tau_e + \mu_h \tau_h) E$ =collection dist.
- Corresponds to average distance an e-h pair moves apart





CCD = Q_{col} / (36 e⁻ per μm)

CCD = MFP for thickness >> CCD

Goal : >10 000 e⁻ for MIP
CCD = Thickness for 300 μm

Observations and needs :
- HV limit (should correspond at least to 1 V/μ)
- CCD > 280μ (should lead to 10 000 e^- / MIP)
- Polarization (not always observed ?)

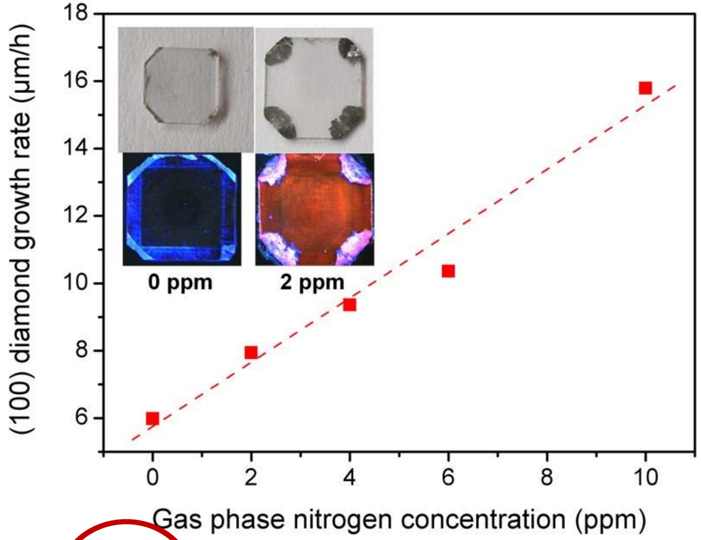
The fundamental problems is : Understanding what makes a "good" diamond

MONODIAM-HE Project (ANR-12-BS05-0014)

Work with a laboratory expert in growing diamonds (LSPM – Paris)
- growing **sCVD** and comparison with industrial sCVDs
- Understanding the important parameters
- Improving the quality (for tracking at HE)

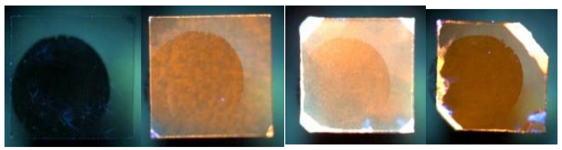
1. Growing conditions : Nitrogen impurities

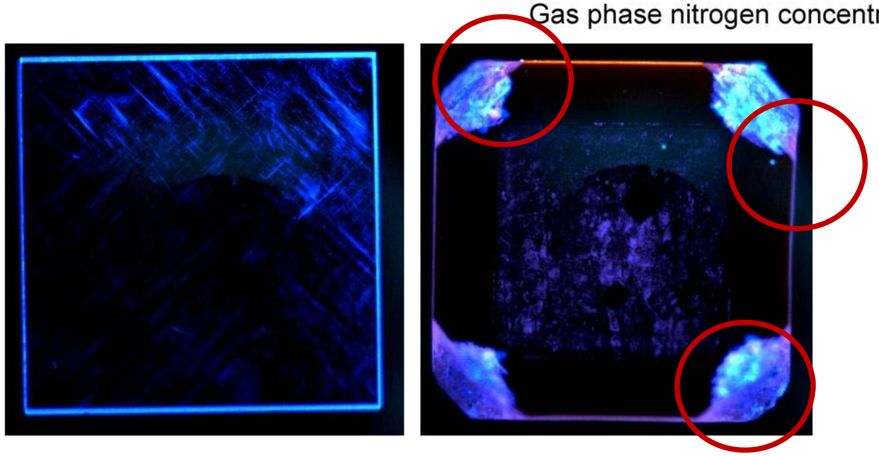
Adding Nitrogen :
- Strong effect on growth rates (up to 100 µ/h)
  - Twinning at the edges
- Limitation of twinning at the surface
- Effect on CCD
  - (incorporation of N2 in the crystal)



Prototypes made at LSPM with variable N2 contents

Increasing N_2 impurities

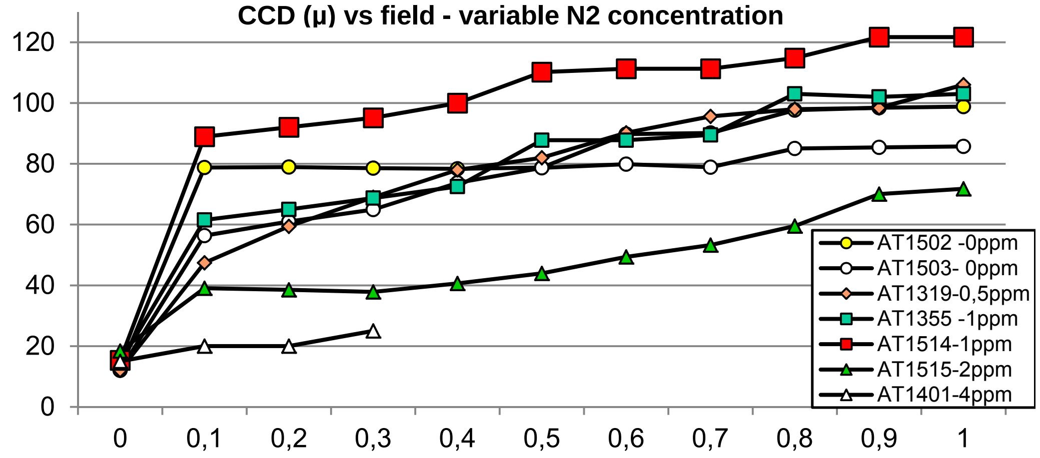


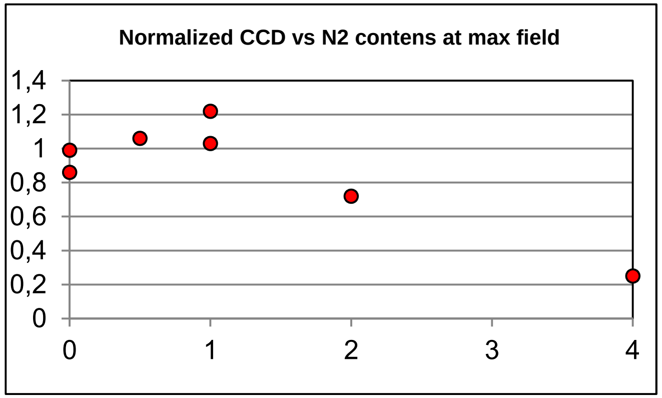


Industrial sCVD
(no N2 ?)

Laboratory sCVD
(2 ppm N2)

thickness	N2 cont.	CCD max.	CCD Norm.	HT Lim
518	0	512	99	500
582	0	499	86	500
500	0,5	530	106	500
430	1	412	103	400
452	1	550	122	500
571	2	410	72	500
518	4	130	25	150





Study made on several prototypes
- same laboratory (LSPM)
- same growing protocol
- same finishing
- same metallisation
- **variable N2 contents**

Optimal : 0 to 1 ppm

2. Surface finishing

Observation :

2 possible problems :

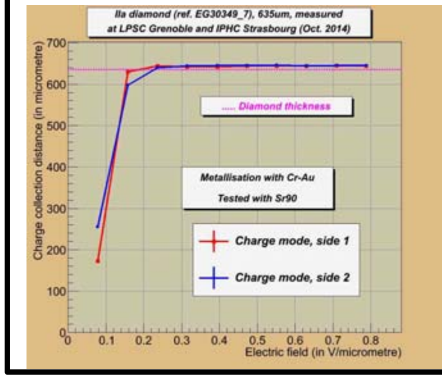
- CCD not correct (less than 10000 e^-)
- High voltage limitation (less than 1V/µ)

Possibility ?

CCD related to defects (traps) in the bulk

HV limitation due to surface problems

Evaluation of the quality of a diamond detector :
Measurement of the CCD using MIP (^{90} Sr)
Need : 10 000 e^- : CCD ≈ 280 – 300µ
≈ 100% for a 300µ sCVD

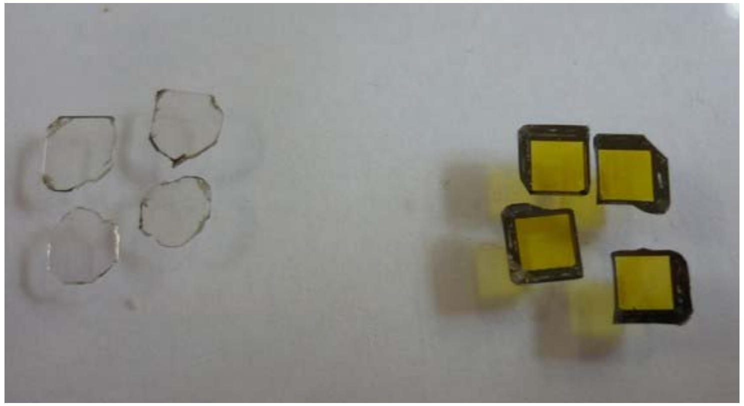


Example :
Industrial sCVD
Thickness : 635 µ
CCD about 600 µ

Use 4 LSPM prototypes sCVD (MM7- 1 to 4)

grown under the same conditions
in the same reactor
at the same time
prepared the same way (same company)
laser cut to separate the HPHT seed
precise polishing
Cleaned
metallised (Cr-Au) in laboratory
Measured (CCD and HV limts)

Use 1 industrial (good) sCVD (IND-1)



Reprocessing :

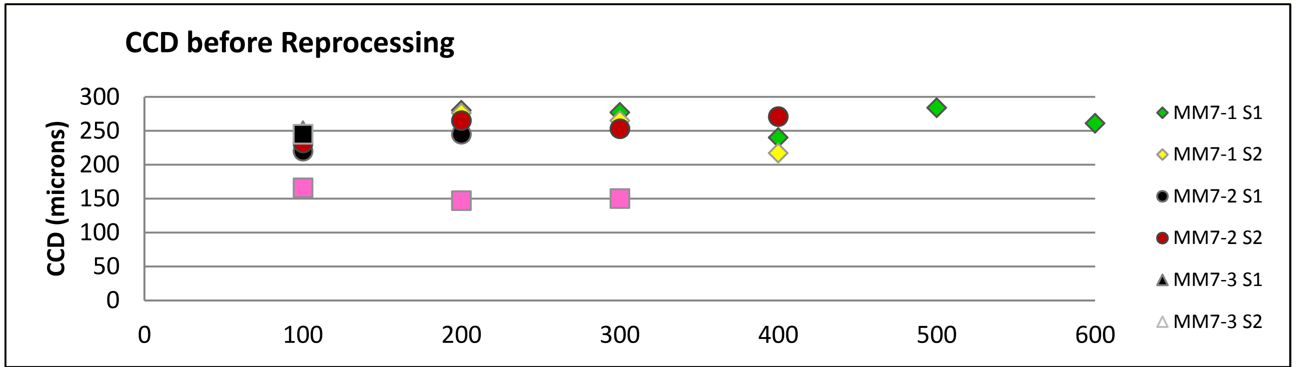
MM7-1 : precise re-polishing by another company (specialized in pCVD)
MM7- 2 : re-etched by RIE at laboratory
MM7- 3 : Terminated by VUV (172nm) in O2 flux
MM7- 4 : untouched . For calibration
IND - 1 : badly re-polished (on purpose)

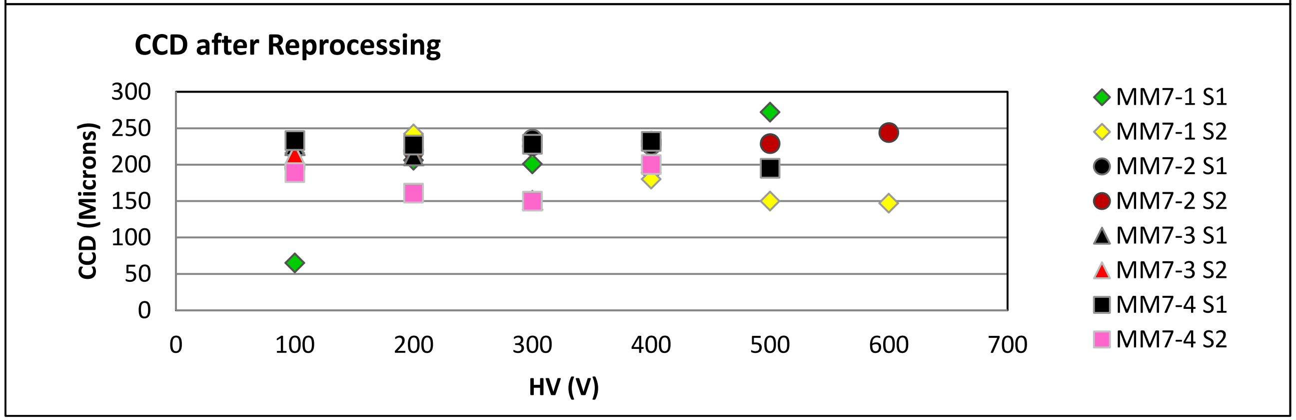
And metallisation Cr-Au

On HV Limits

	Before reprocessing		After reprocessing		Observation
sCVD	Side 1	Side 2	Side 1	Side 2	
IND - 1	500V	600V	500V	300V	degradation
MM7-1	600V	400V	600V	400V	same
MM7-2	200V	400V	400V	500V	**Improvement**
MM7-3	100V	100V	300V	100V	**Little improvement**
MM7-4	500V	350V	500V	400V	same

As good as it is , polishing may not be enough…
Reactive Ion etching
Ozonization
(and probably very agressive cleaning)
Seems to be having an effect on the HV limitation





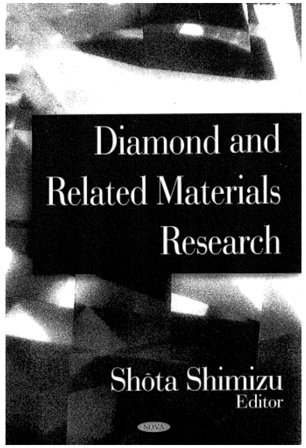
Reprocessing
has a little effect on CCD
(given the measuerment
uncertainties)

Conclusion :

- CCD is related to Bulk quality
- HV limitation is related to surface quality and **may be improved.**

3. Metallisation

Metallisation needed for contacts (wire bonding or bump-bonding)
Early prototypes showed a Schottky Diode Behaviour
Extensive researches on diamond contacts
see, for example «



> Though there are numerous reports of rectifying Schottky contacts and low resistance Ohmic contacts to diamond, currently there is no standardised process for fabrication of Schottky or Ohmic contacts to diamond.

Use Two (industrial) reference detectors

metalised Cr-Au
Tested on different benches

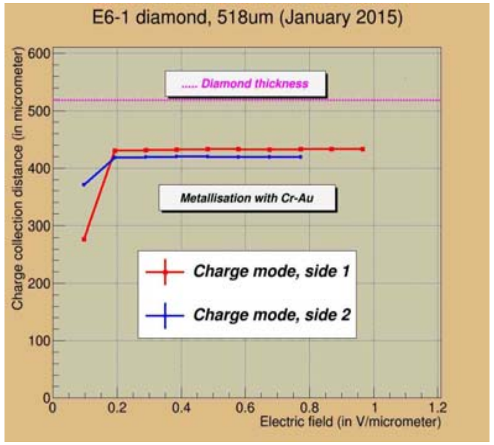
Cleaned
Metallisation (pulverisation)
Tests : **Cr- Au**
W
Cu
Al
In (Cu-In)

At LSPC-Grenoble

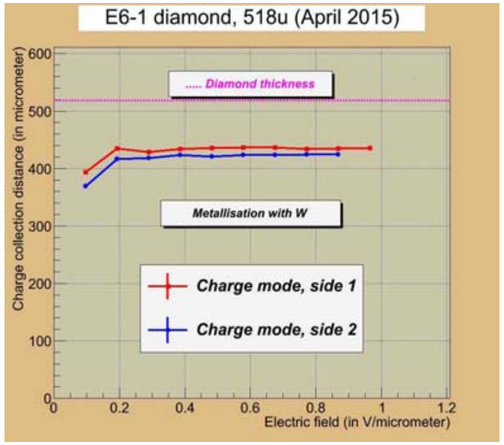
Metal deposition by
by microwave plasma-assisted sputtering
Cleaning by
2 steps of plasma-assisted cleaning

At Icube - Strasbourg

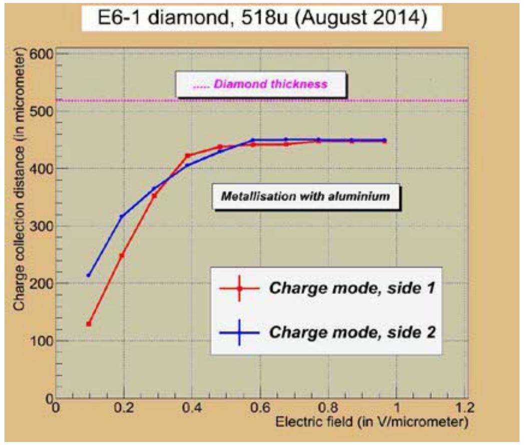
Metal deposition by
Vacuum evaporation
Cleaning by
Hot H_2S0_4 – KNO_3



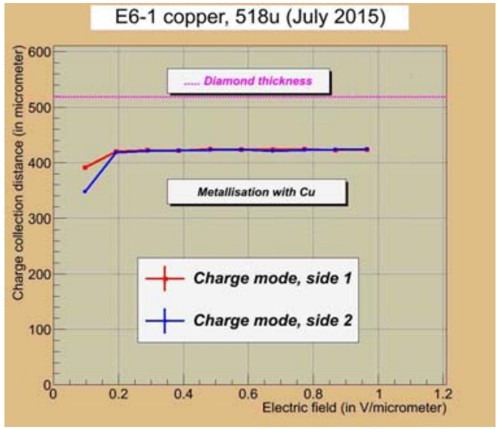
Cr-Au



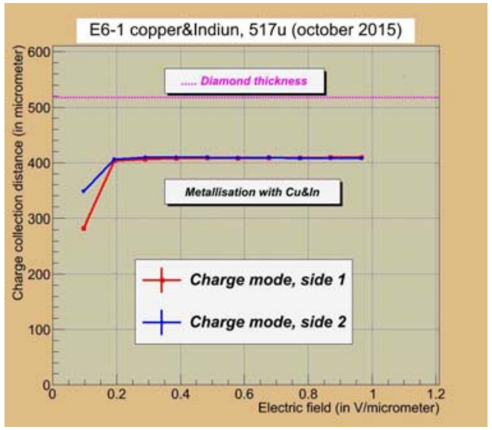
W



Al

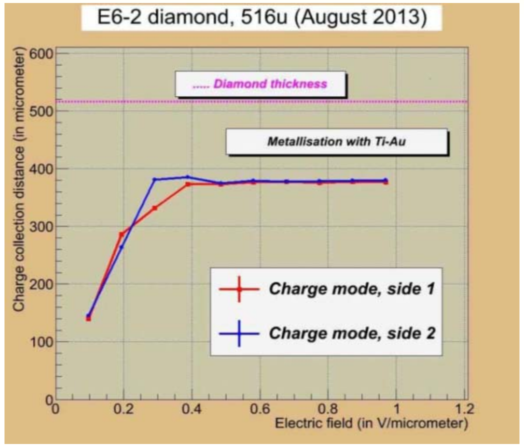


Cu

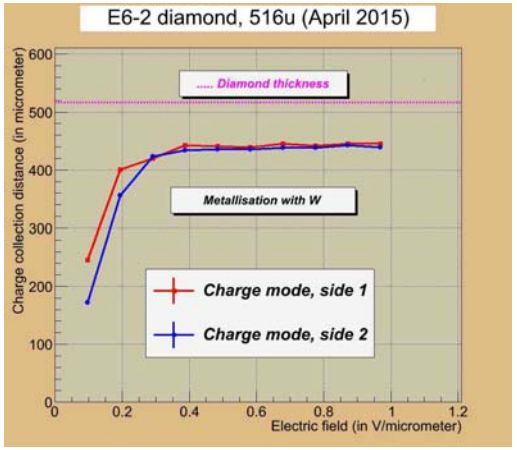


Cu-In

Cr-Au :	HT limits	500V / 400V
	CCD	440 µm / 420 µm
W :	HT limits	500V / 450V
	CCD	440 µm / 420 µm
Al :	HT limits	500V / 500V
	CCD	440 µm / 440 µm
Cu :	HT limits	500V / 500V
	CCD	425 µm / 425 µm
Cu-In :	HT limits	500V / 500V
	CCD	410 µm / 410 µm



Ti-Au



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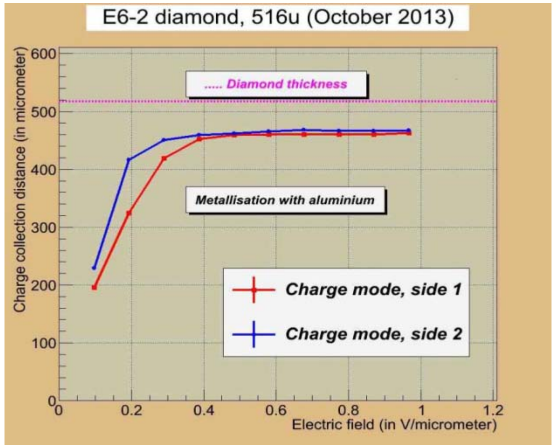

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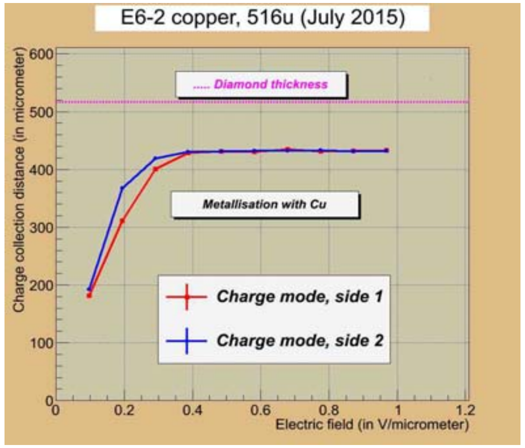
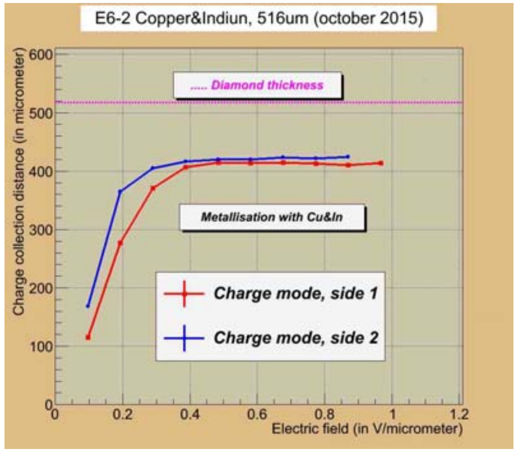


Cu



Cu-In

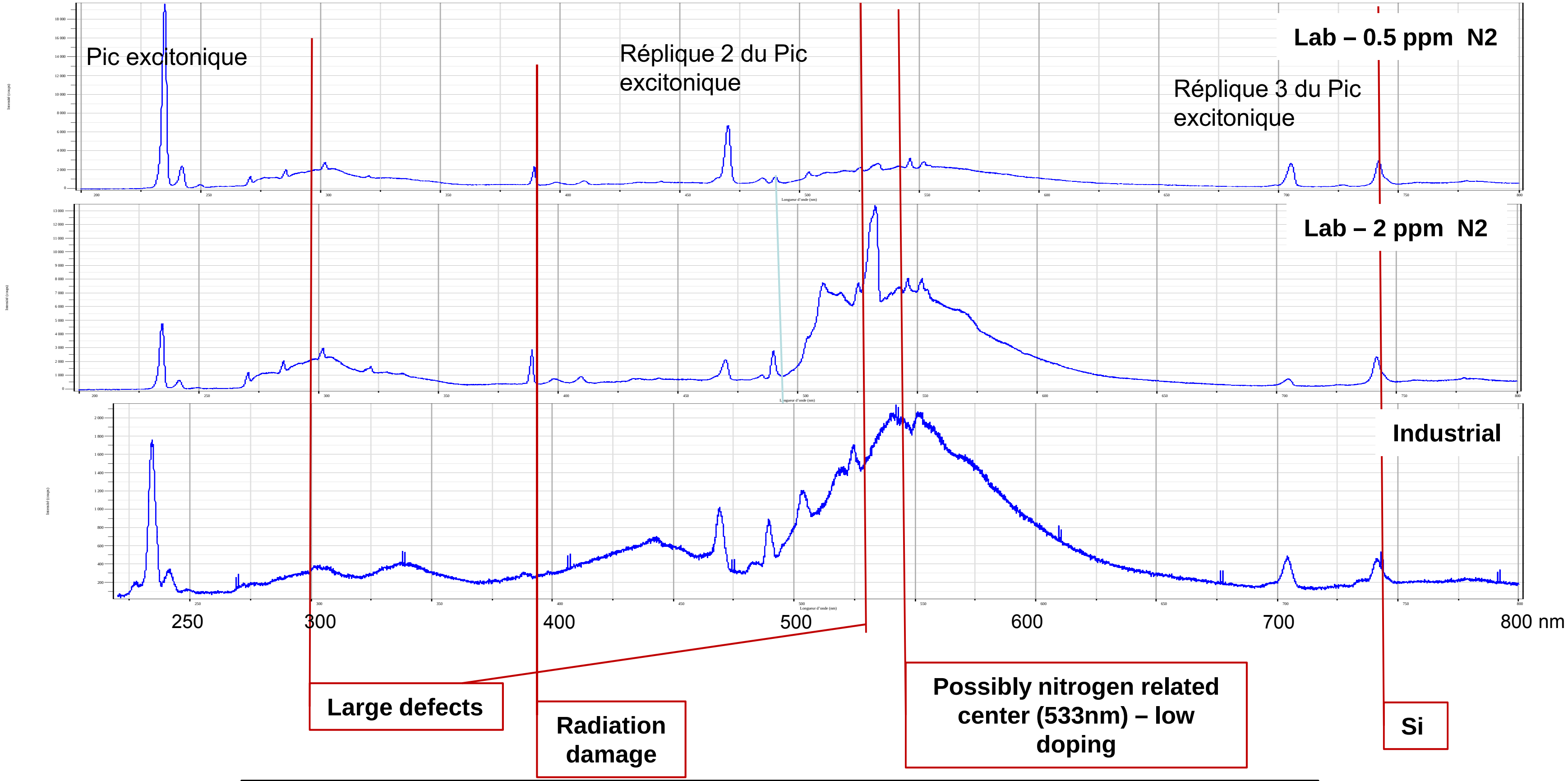
Ti-Au	:	HT limit	500V / 500V
		CCD	380 µm / 380 µm
W	:	HT limit	500V / 500V
		CCD	425 µm / 425 µm
Al	:	HT limit	500V / 500V
		CCD	460 µm / 460 µm
Cu	:	HT limit	500V / 500V
		CCD	410 µm / 410 µm
Cu-In	:	HT limit	500V / 450V
		CCD	410 µm / 420 µm

Various metallisations have **very little effect** on CCD
(Schottky element already stabilized by cleaning ?)
HT limit related to **surface quality**

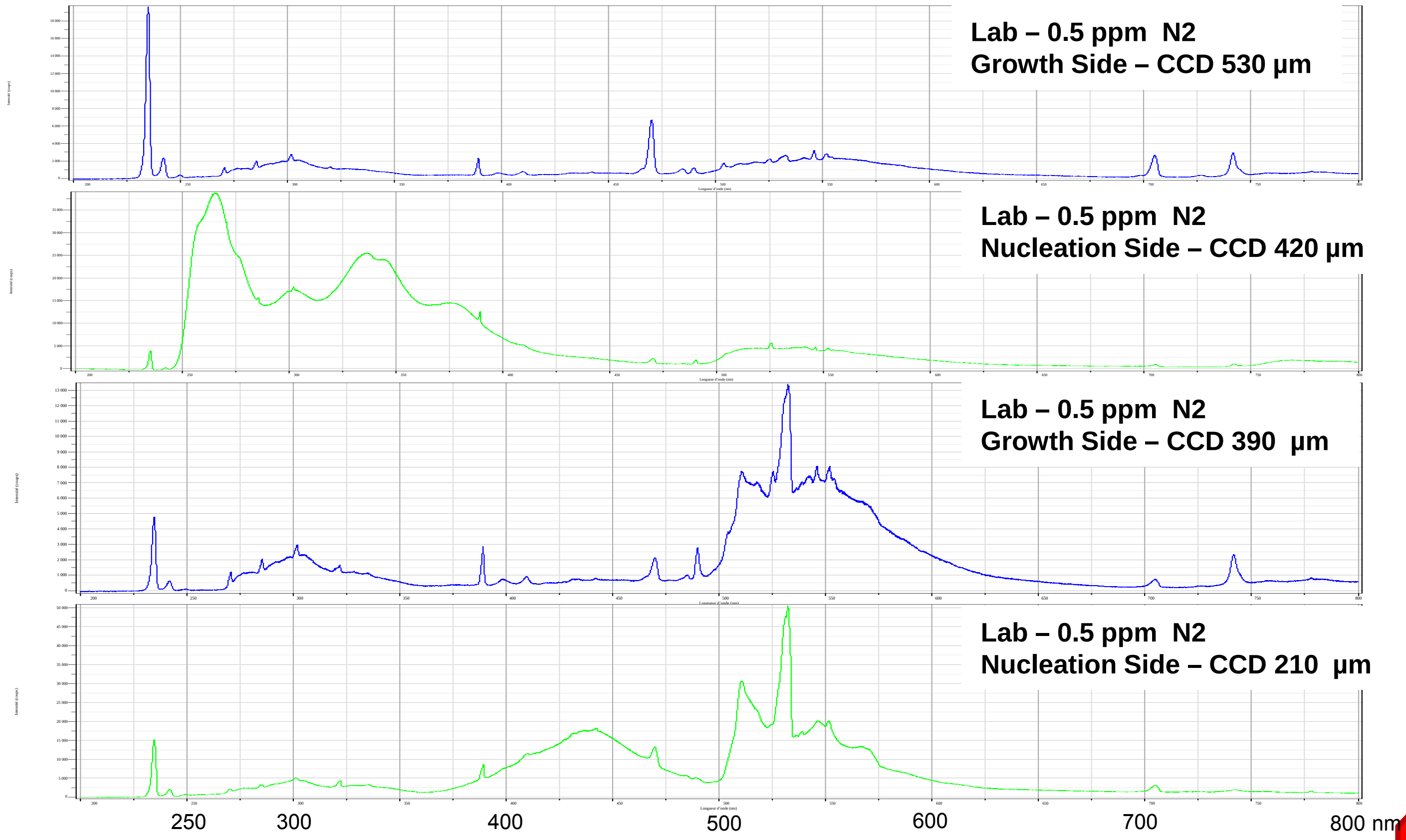
4. Bulk Studies

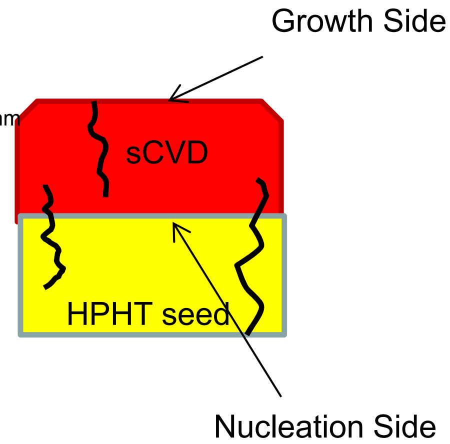
By Cathodo-luminescence at low temperature
(electron beam 10kV, 7nA – T=110°K)

Lab – 0.5 ppm N2 : Limit HT, limited CCD
Lab – 2 ppm N2 : HT OK, CCD OK
Ind - ? : HT OK, CCD OK



One can see clearly the presence of Nitrogen
There are extended defects in all diamonds
Test under source (74 MBq) induces damages: Radiation hardness ?

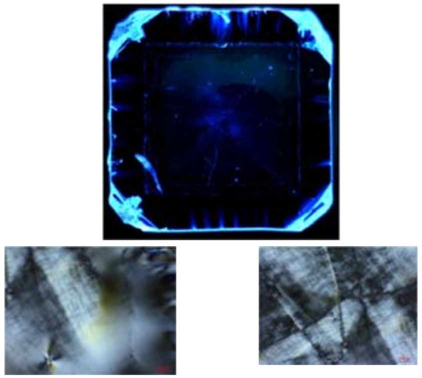




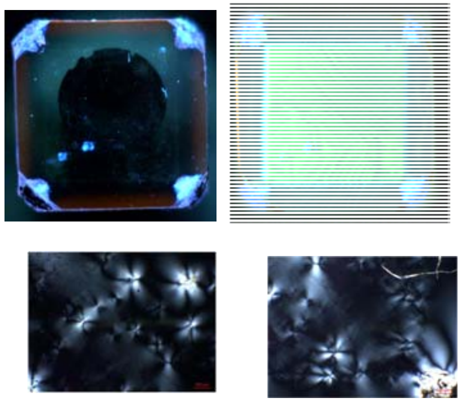
More extended defects on the nucleation side (HPHT mirror effect)
Even the sCVD are asymetrics (known for the pCVDs)
(with consequences on the CCD)

5. Bulk and surface Studies

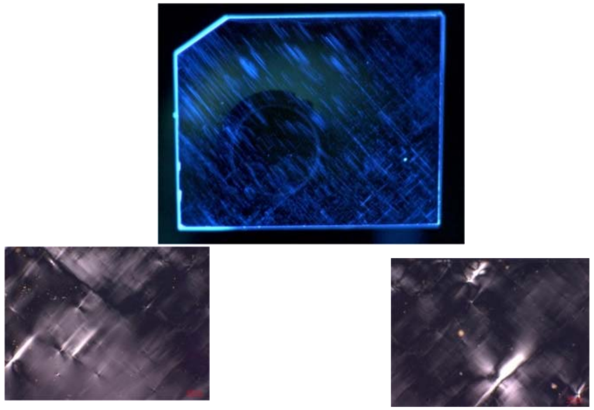
By Images (Fluorescence / polarised light / X-ray Tomography)



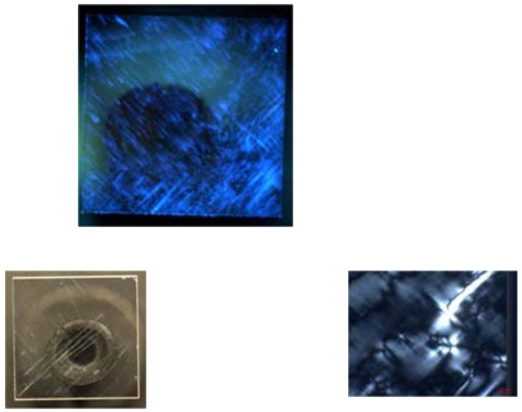
LSPM – 0 ppm N2
results on CCD OK



LSPM – 1 ppm N2
results on CCD OK



Industry
results on CCD very good

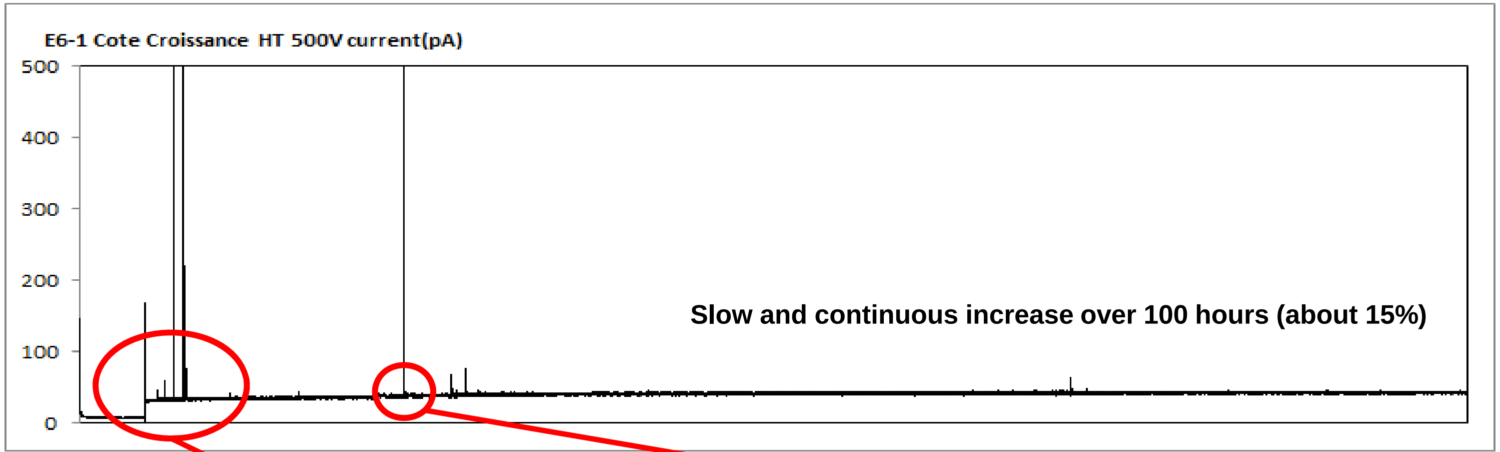


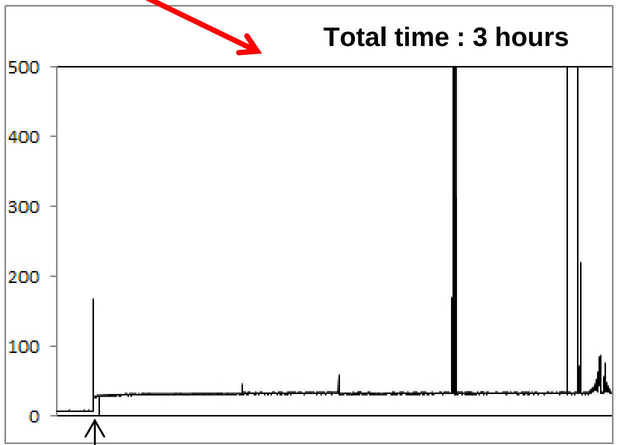
All sCVD show defects

- deep dislocations
- bad polishing
- N2 incorporation
- …

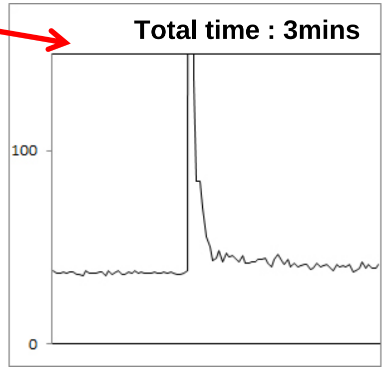
6. Long term effects – ''Polarisation'' ?

Long term measurement leakage current at max field (≈1 V/µm)



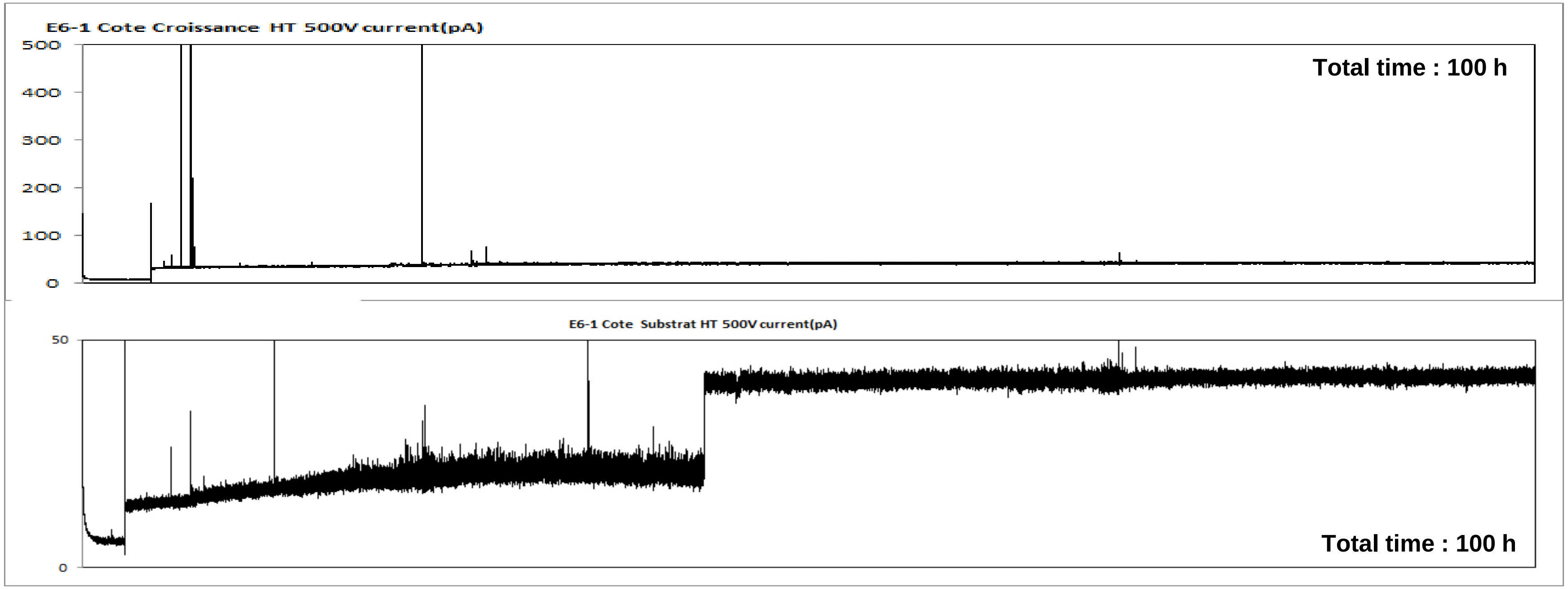


74 MBq source

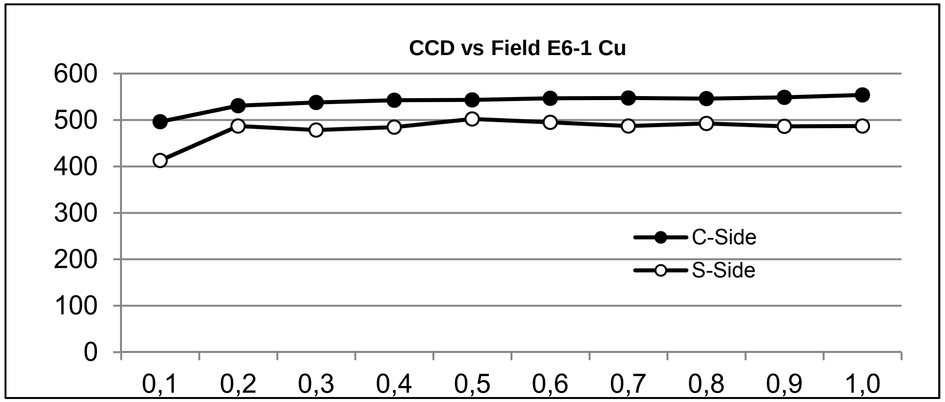


Back to normal after 20 mins

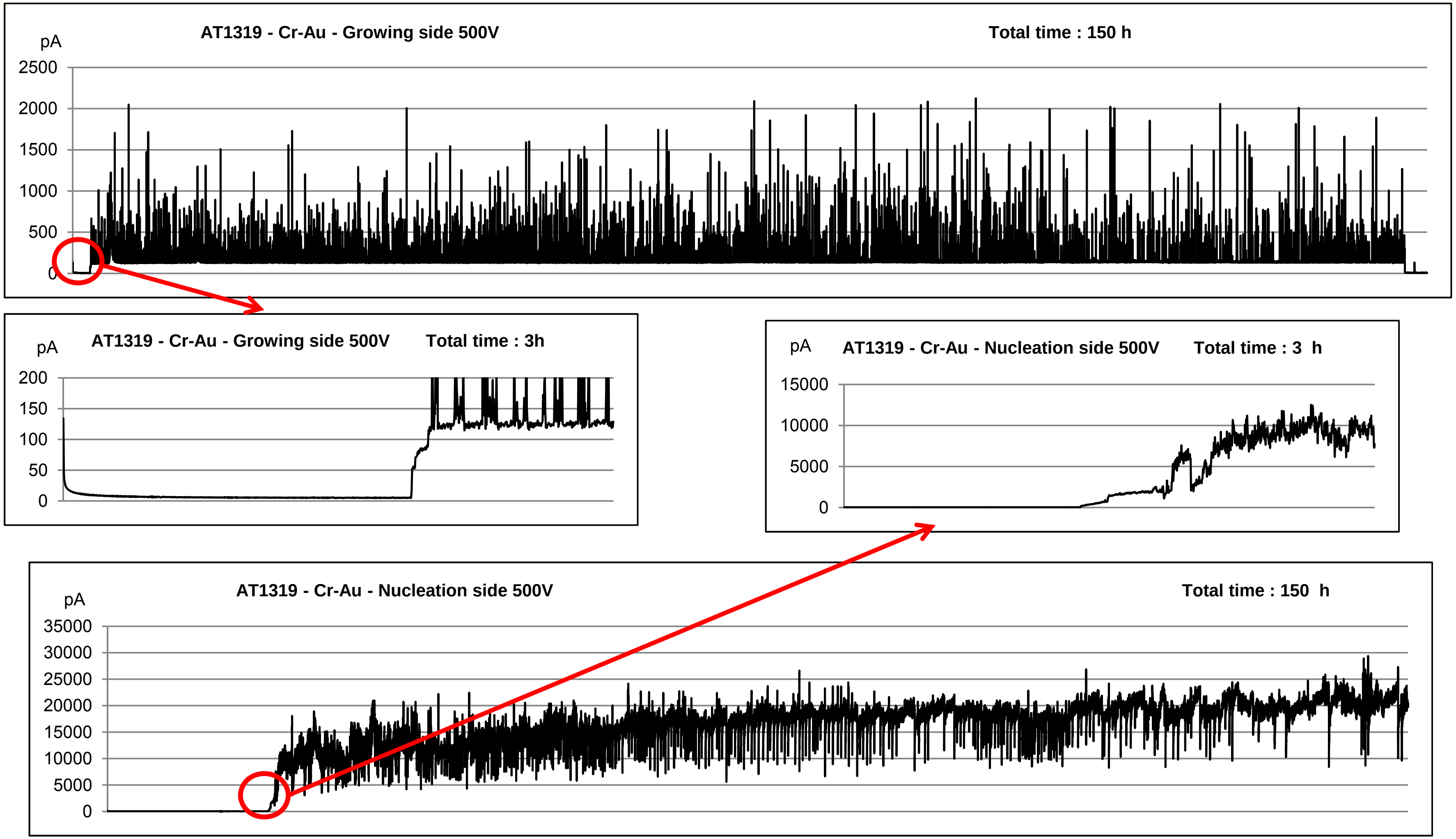
Clear source effect
'' slow '' discharges (charging – discharging of traps)



For a ''good'' (industrial) sCVD



Difference between sides
Lower CCD on the nucleation side
More defects (traps) on the nucleation side



Strong difference between sides
More defects (traps) on the nucleation side
Could be a way to evaluate the defects rate ??

Conclusion and prospectives (?)

We have started to adress fundamental problems :

Diamond bulk effects
- impurities (Nitrogen – Boron)
- bulk defects importance
  - defects rate have to be understood, and under control
  - **some ideas exist :**
    - **differential growing, immediate anealing, disorientation)**

Diamond surface effects
- surface finishing
- metallisation
  - **problem considered as solved (?)**

The main lesson :

True :

Developpements in the Research Community may lead to Industrial Developpements.

Wrong :

Objects developped in the Industrial World can be easily used in the Research Community.

Be optimistic…. And stay tuned…