JTG Meeting 2007

USJ Formation and Metrology for sub-45nm Technologies

PULSION®

The ion implant solution for sub 45nm

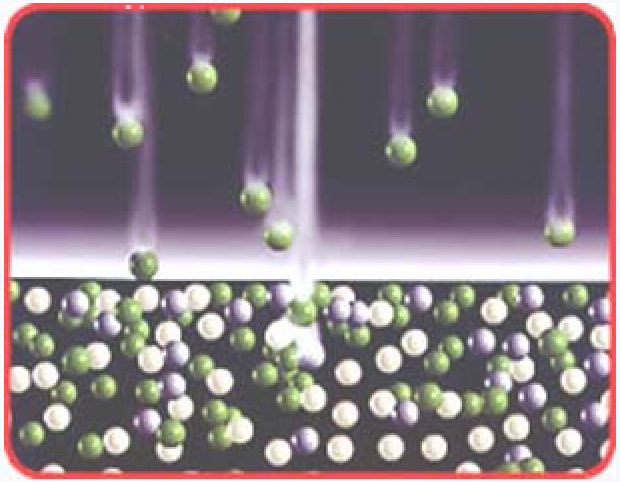
IBS profile

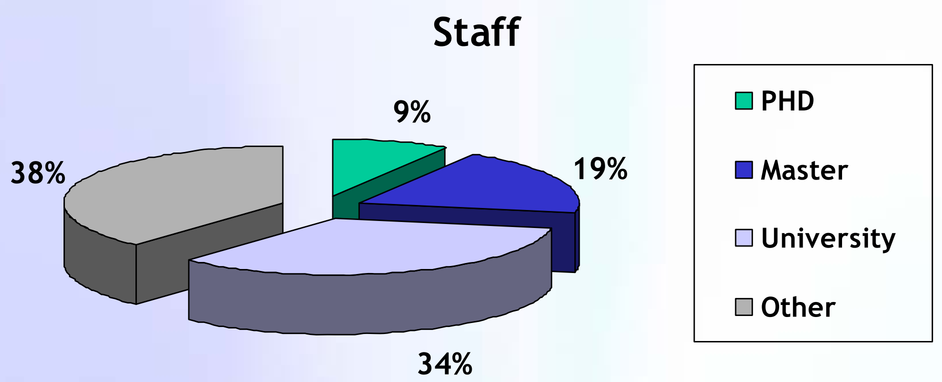
- Founded in 1987

- Locations
  - Headquarter and main facilities in Peynier, France
  - Production plant in Scotland
  - Offices : Paris, Grenoble, Dresden, Taipei

Technological know how

- Plasma and ion beam
  - Semiconductor doping
  - Surface treatment
  - Equipments design and manufacturing
- Microelectronics Processing
  - Sensors and Power devices





Products and Services

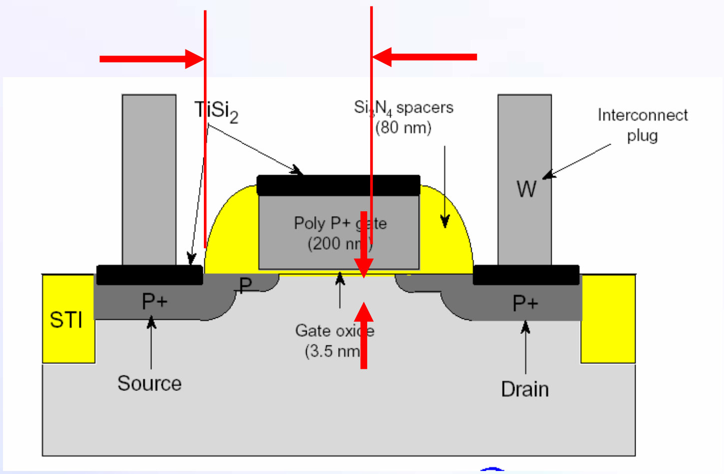
Components manufacturing services

- Custom ion implantation
- Specific devices manufacturing

Equipements and associated services

- Equipments
  - **Customized ion implanter**
  - Refurbished ion implanter
  - **PULSION: new low energy ion implanter**
- Associated services
  - Field services
  - Electronic board repair
  - Source and subassemblies refurbishing

Technological challenges



Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32
Drain extension X_j (nm) for bulk MPU/ASIC [F]	11	9	7.5	7.5	7	6.5	5.8	4.5	
Maximum drain extension sheet resistance for bulk MPU/ASIC (NMOS) (Ω/sq) [G]	653	674	640	740	677	650	548	593	

Extract of ITRS 2005 roadmap

Technological challenges

ITRS targets for doping requires new solutions

- Very low energy ion implantation
- Junction activation without diffusion
- New characterisations
- Process integration

Implantation challenge

- Classical beam line implantation has difficulties to meet ITRS below 45 nm node
  - low energy beam difficult to produce, transport and control
- 4 main alternative new solutions:
  - GILD : Gas Immersion Laser Doping
  - High mass molecule implantation
  - Very High Mass Cluster Implantation
  - Plasma Immersion Ion Implantation
- IBS choice : Plasma Immersion Ion Implantation (PIII)
  - No risk of energy contamination like in decel mode or molecular implant
  - Simultaneous implantation of the whole wafer
    - low density of the ion flow
    - low power density
    - no scanning required
  - 10 years IBS expertise in PIII for surface treatment

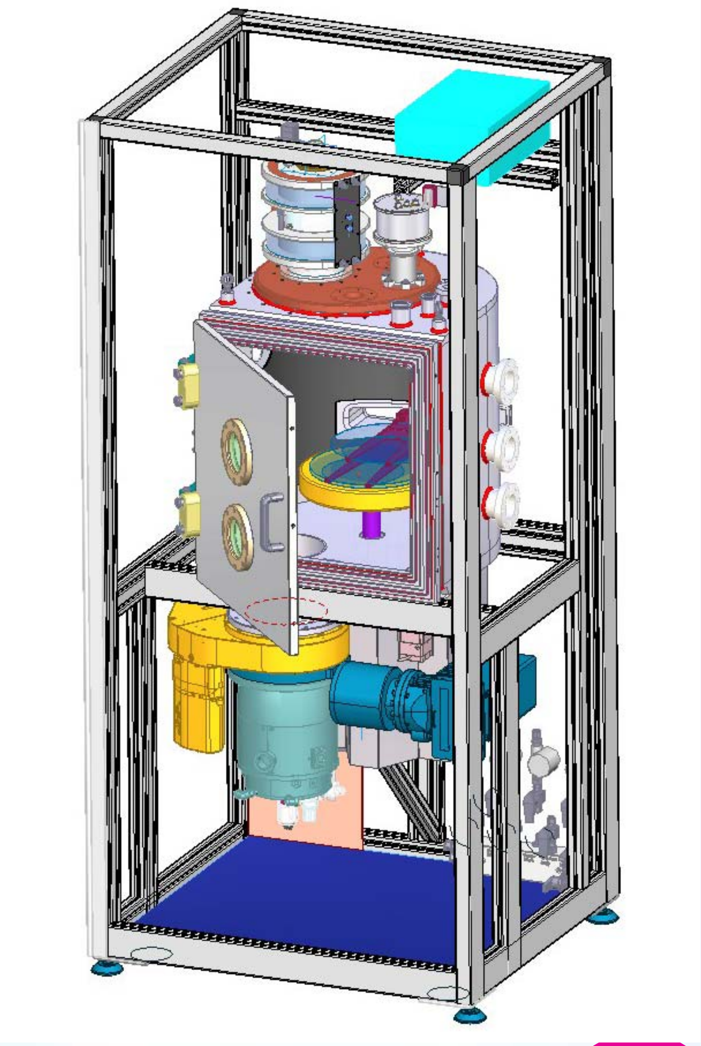
Integration challenges

- Doping requirements should be considered at the technological brick level:
  - Junction activation without diffusion and high solubility level in order to meet low resistivity requirements
  - Characterisation tools are at their limits (SIMS, 4pp, SRP, …)

- IBS partner within European project with ST, QUIMONDA, NXP, FREESCALE, IMEC , LETI, FhG…
  - NANOCMOS-45 nano-2004-2006
  - SEA-NET – 32 nano – 2006 – 2008
  - FOREMOST- 45 nano – 2006 - 2008
  - PULLNANO -22 nano- 2006-2009

IBS SOLUTION : PULSION®

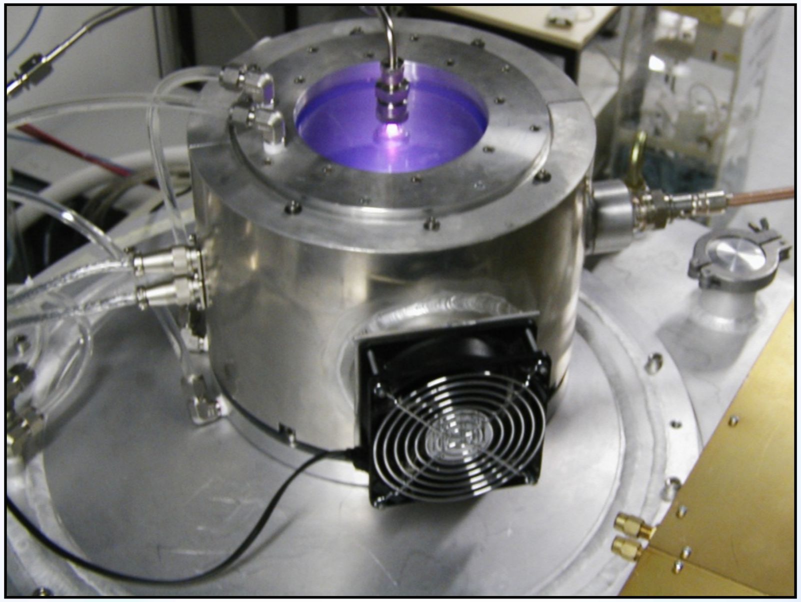
- Energy range
  - *Extremely low to medium range energy*
- Substrate size
  - *From samples, up to 300mm*
- Small footprint
  - *4 to 7 m^2*
- Low cost doping



PULSION® Characteristics

ICP source

- Source designed by IBS
  - *Flexible plasma density from 10^7 to 10^{10} cm^{-3}*
  - *Work pressure from 10^{-5} to 10^{-2}mbar*
  - *2 polarization modes :Continuous or pulsed mode*
- No contamination
  - *No contact between metallic parts and plasma*
- In situ plasma control / Dose reproducibility
  - *Mass spectrometer*
  - *Langmuir probe*



Original concept of PULSION®

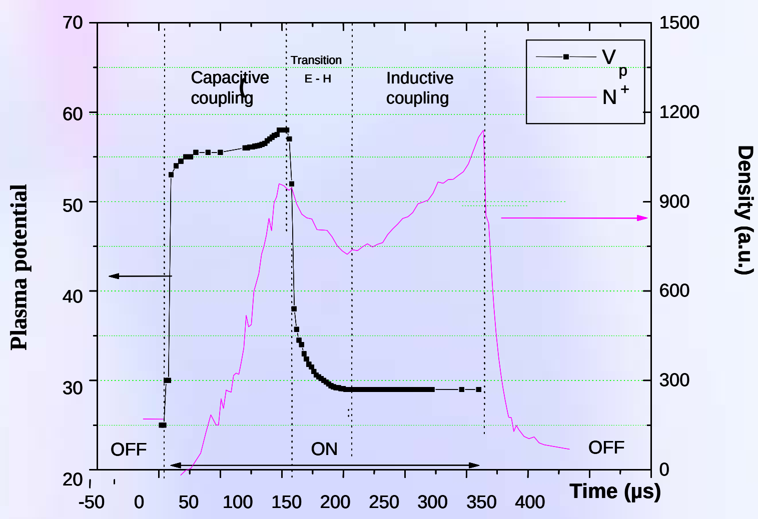
Plasma Source / plasma analysis

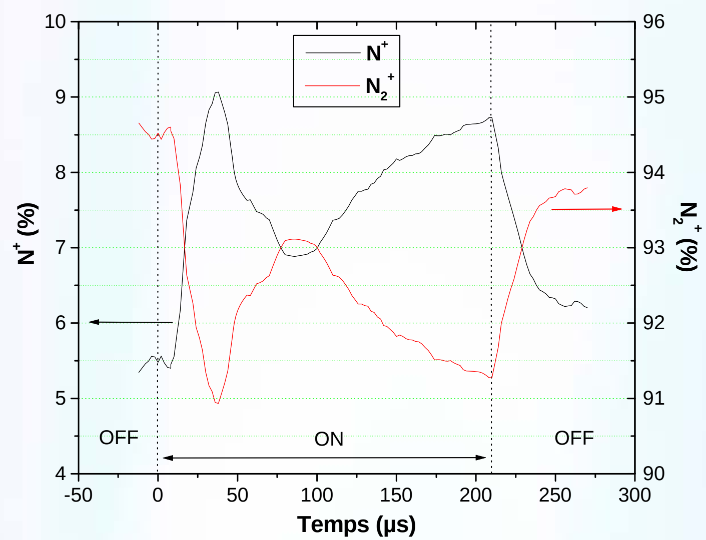
Self designed ICP souce

- Easy ignition of low elements (H2)
- Wide range of working pressure (down to 5^{E}-5 mbar)
- No metallic contamination

Possible in situ Plasma diagnostic

thanks to timed resolved energy mass spectrometer (TREMS)



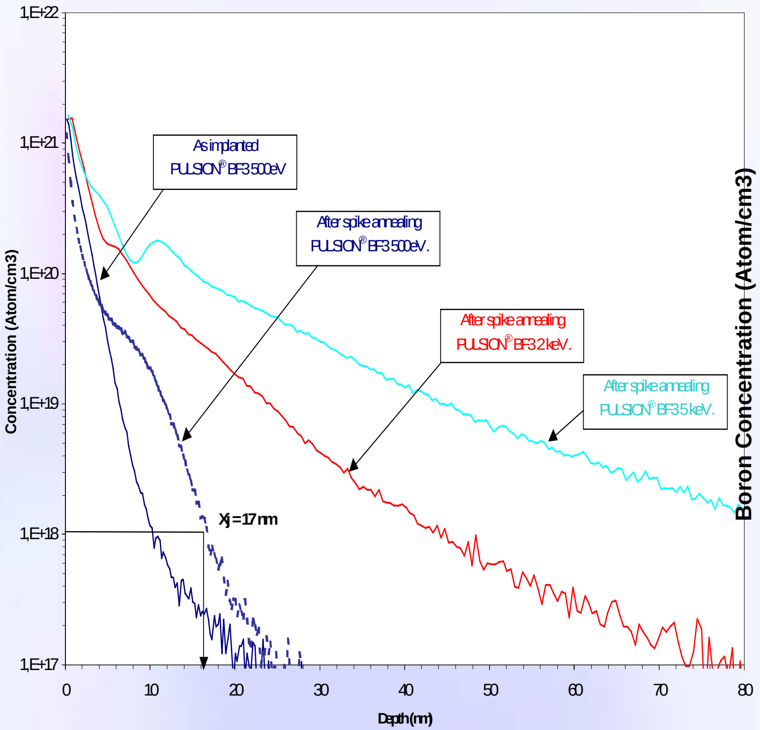


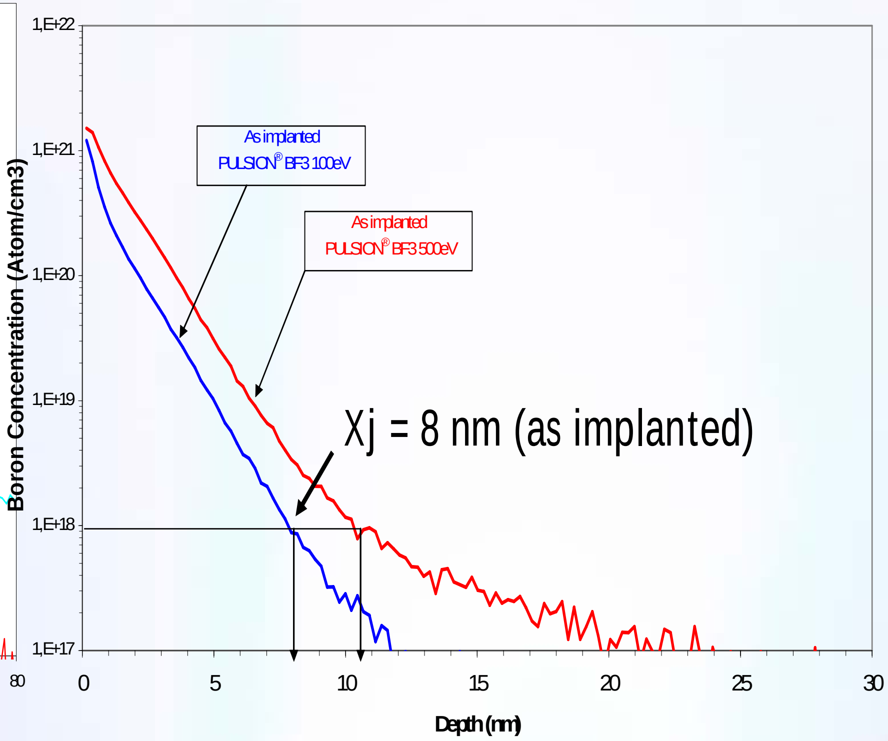
Exemple of pulsed N2 plasma

(M. Carrere, V. Kaeppelin, F. TORREGROSA, IIT 2006 P333)

Original concept of PULSION®
Polarisation modes

Mode 1 - Pulsed plasma , DC polarisation of susbtrate





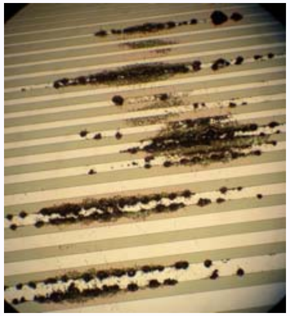
Exemple of BF3 PULSION® implantations from 100V to 5kV for USJ (IBS / LETI collaboration)

Original concept of PULSION®

Polarisation modes

Mode 1 – « continuous » like

- Advantages
  - Easy to control acceleration voltage
  - Very simple and robust
  - Suited for low cost applications
- Drawback
  - Non compatible with insulating layers, defects after implant on insulating layer



After implant (BF3 500V)

Mode 2 – « pulsed » like

- During the plasma ignition, the power supply is inhibited
- Implantation during the beginning of pulse
- End of pulse, neutralisation by electrons from plasma

- = <u>no charge induced defects</u>

After implant (BF3 500V)

PULSION® Performances

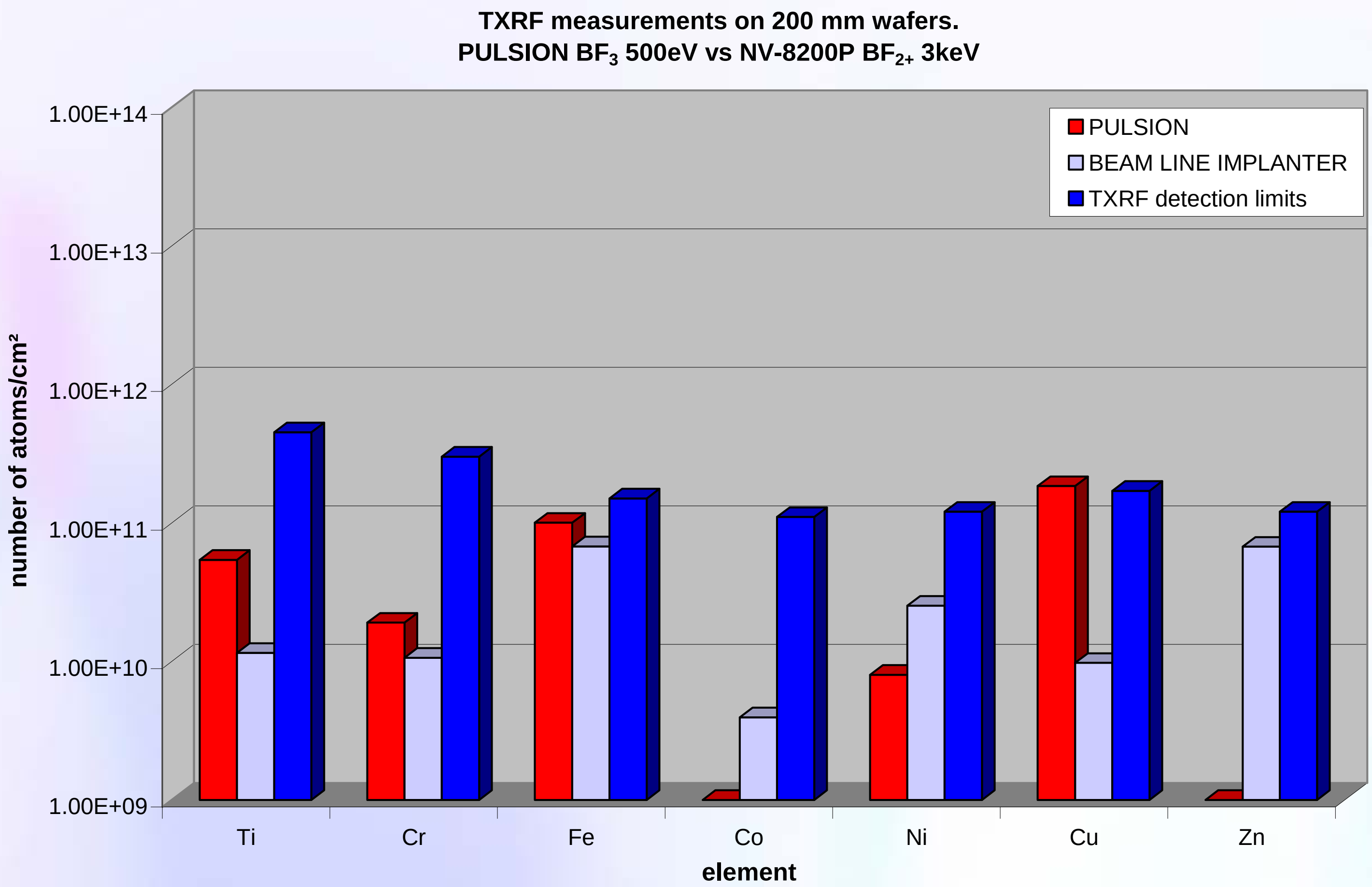
- Low metallic contamination (Si coated subtrate holder)
  - *K, Ca, Na < 10^{9}/cm^2*
  - *Ti, Cr, Fe, Co < 10^{10} /cm^2,*
  - *Others < 10^{11} /cm^2*

- Uniformity and reproducibility
  - *σ = 2,5 % on 200 mm (BF3 0,5 kV 3000 Ω/sq)*
  - *σ = 1,2 % on 200 mm (BF3 10 kV 50 Ω/sq)*

- Throughput
  - *BF3 100 to 500 V, 1.10^{15} on 300mm = 80 Wafers/h*

  (expected with one process chamber)

Metallic contamination



Metallic contamination

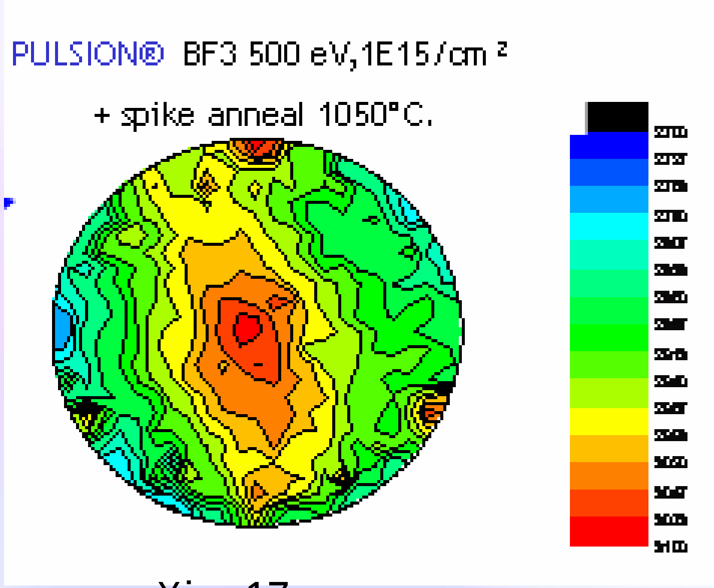
ToF-SIMS results

	BF3 implantation		Reference
	Edge	Center	
Ni	1.7E+11	9.3E+10	<1.6E9
Cu	3.4E+11	8.2E+10	1.5E+09
Al	6.2E+10	3.9E+10	<3.8E7
Sn	1.3E+10	1.0E+10	<1.7E9
Fe	1.1E+10	5.5E+09	<8.0E8
Cr	3.7E+09	3.4E+09	<2.3E8
Mg	3.9E+09	2.5E+09	<9.7E7
Na	3.3E+09	2.6E+09	6.0E+08
In	3.1E+09	1.9E+09	2.9E+08
Ti	2.4E+09	1.4E+09	<1.5E8
K	5.5E+08	3.6E+08	<1.2E7
Co	<1.4E9	1.7E+09	<1.4E9
Ca	3.1E+08	2.1E+08	<3.6E7
Li	4.8E+07	3.7E+07	<1.8E7
Ag	1.2E+10	5.0E+09	8.0E+09
Cl	9.8E+11	1.1E+12	2.3E+12
S	3.4E+12	4.6E+12	5.9E+12
B	1.0E+14	9.0E+13	9.3E+12
F	1.2E+12	1.2E+12	1.9E+11

Homogeneity on USJ

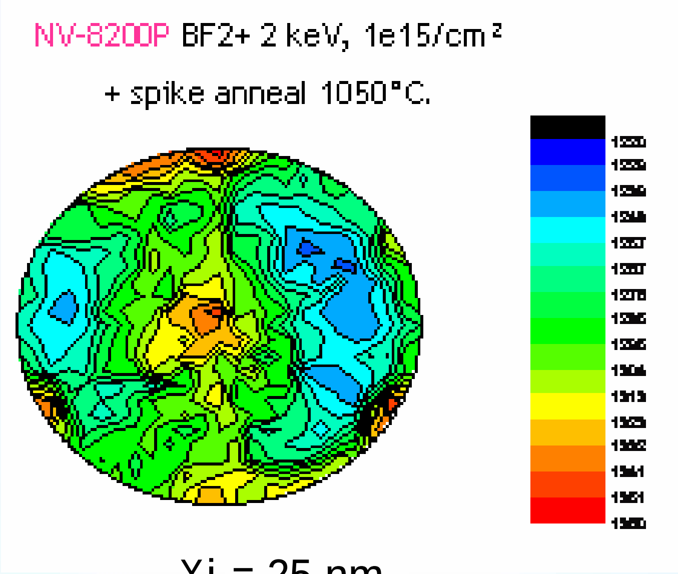
Sheet resistance measurements (PULSION vs Beam Line Implanter)

200 mm wafers



Xj = 17 nm

σ =2.4%



Xj = 25 nm

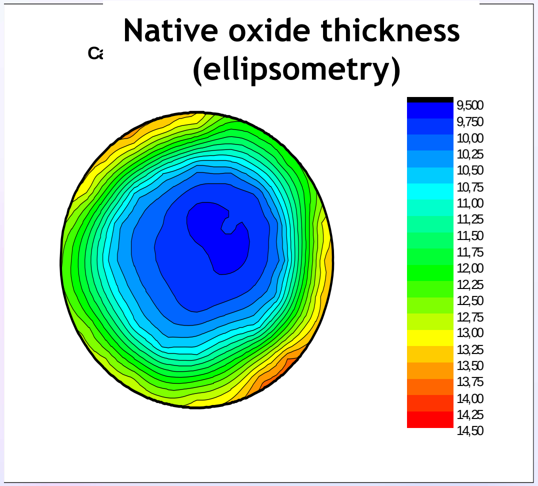
σ =2.1%

What is the contribution of spike annealing process in non homogeneity ?
(similar patterns are observed)

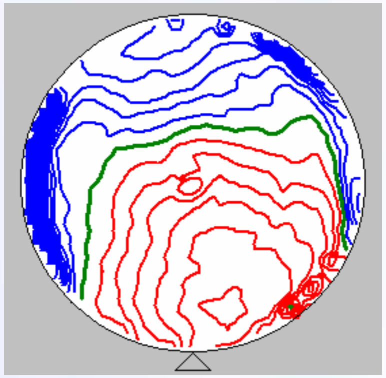
(IBS / LETI collaboration)

Homogeneity

Pb of native oxide masking (200mm wafers)

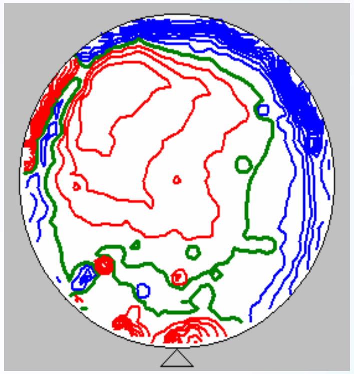


Non Implanted



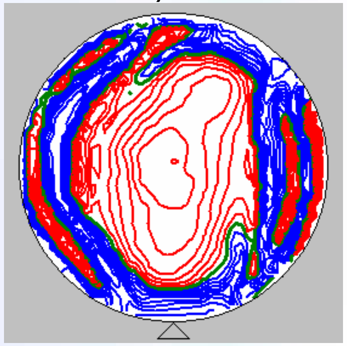
1% Contour Interval

PULSION
BF3 100eV 1E15



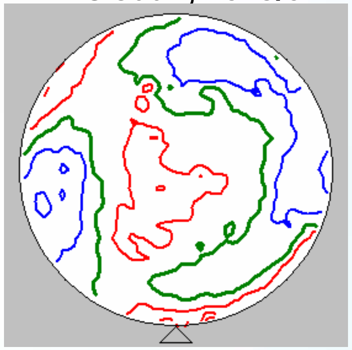
3% Contour Interval

PULSION
BF3 500V, 1e14/cm^2



5% Contour Interval

PULSION
BF3 500V, 1e15/cm^2

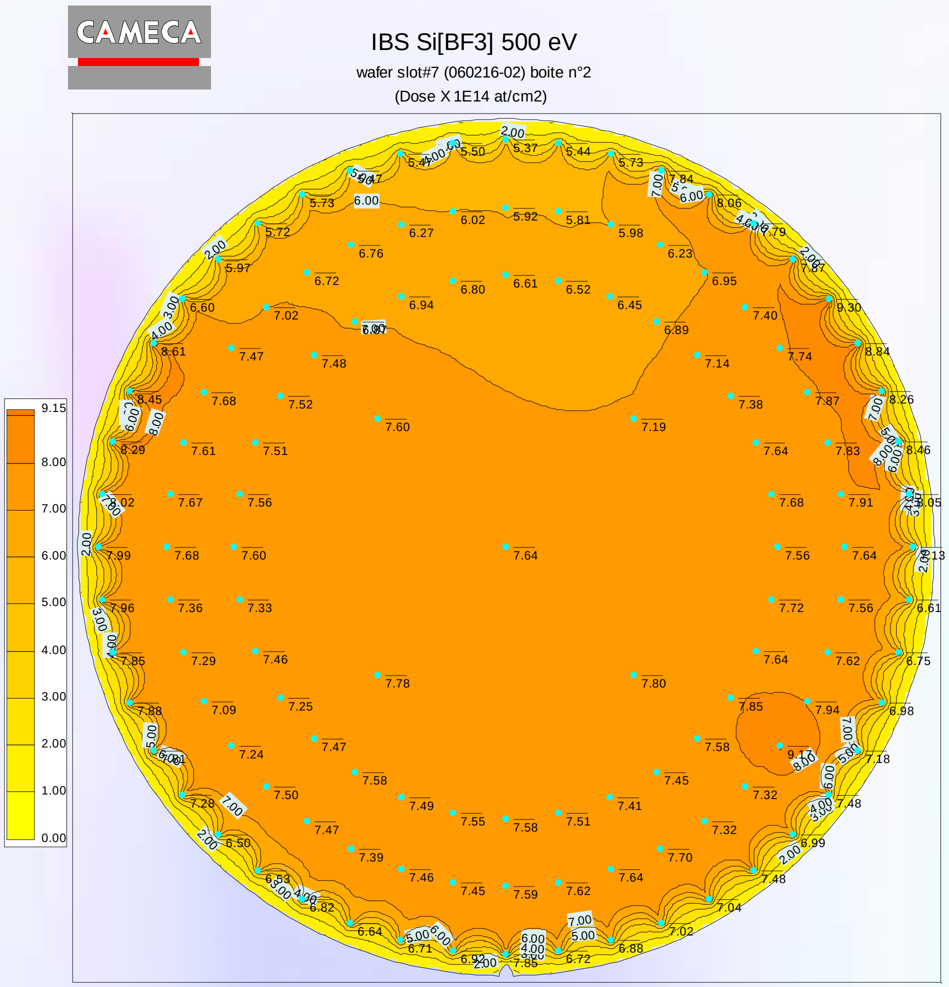


1% Contour Interval

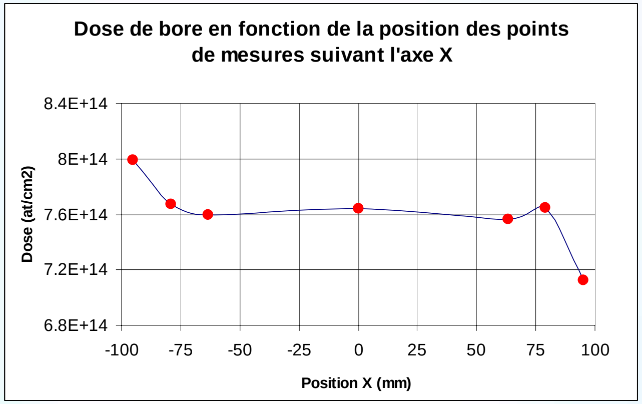
- Non uniform masking effect
- Very sensitive for low dose and ultra low energy
- Likely to disturb measurements

(IBS / QCsolution collaboration)

USJ : Good Homogeneity
As implanted characterisation: LEXFAB



- 200 mm wafer
- Pulsion BF3 500V (5nm)
- Measurement repetability : 3.7%



- Edge effect observation
- Pb of native oxide masking

⇒Increase chuck diameter

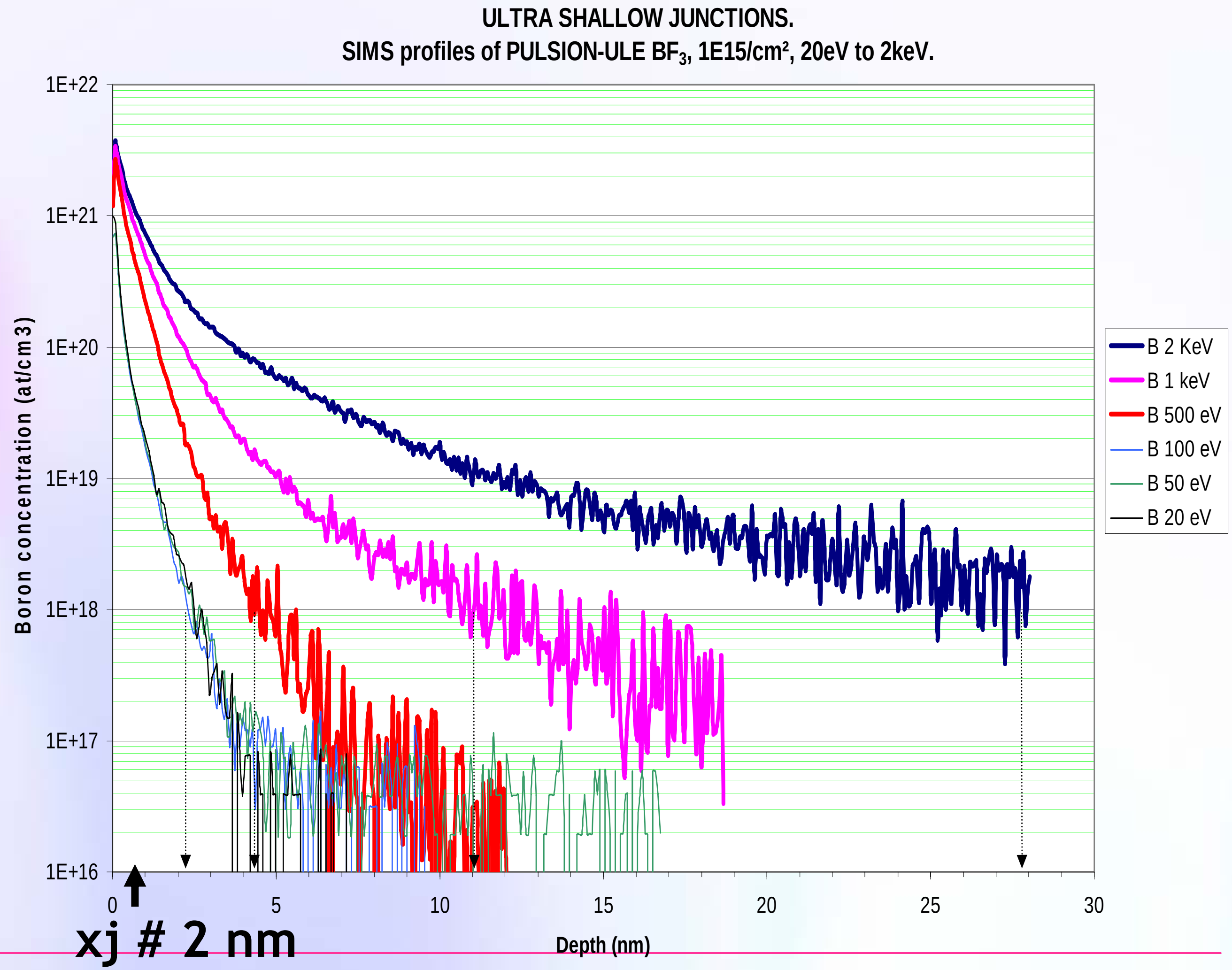
⇒Deoxidation or Stabilized oxidation before implant

PULSION® Applications

- Advanced microelectronics
  - *Ultra shallow junction for 45-32-22 nodes*
  - *Trench doping, conformal doping*
  - *Poly doping*
  - *Gate dielectrics, high k*
- *Nanoelectronics, Materials, Surface engineering*
- Low cost doping
  - *Solar cells : doping and hydrogenation*
  - *Flat panels : doping and hydrogenation*
  - *Power component : high dose doping*

USJ : Implantation profiles

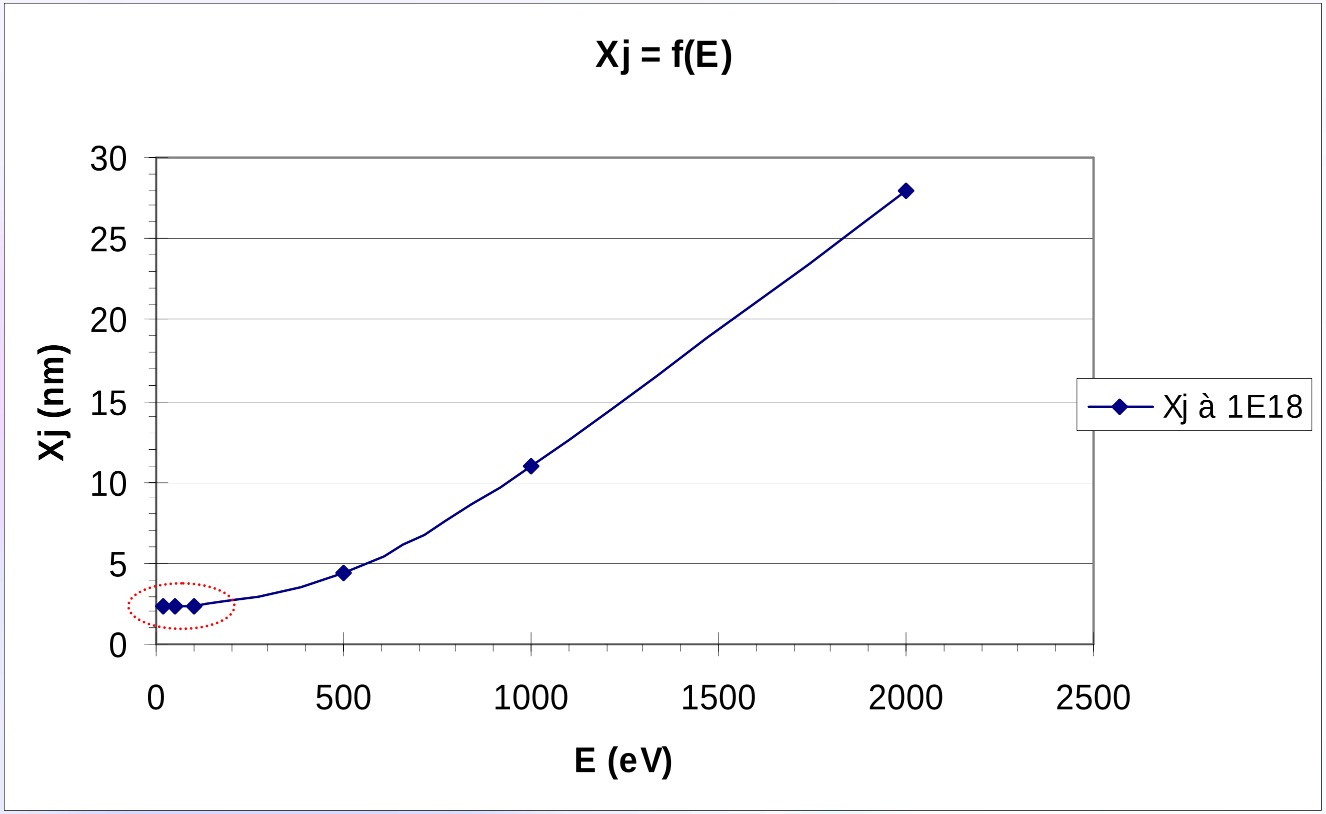
Boron profiles (PULSION® BF_3 20V to 2 kV)



xj # 2 nm

USJ : Implantation profiles

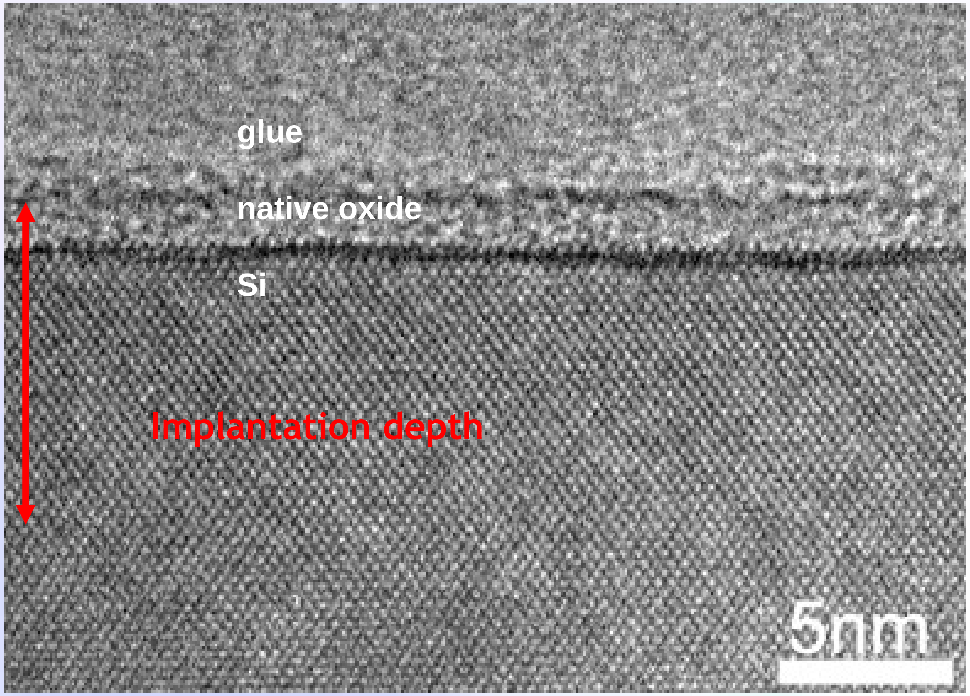
Xj = f(E) (BF_3 1E15/cm^2)



- X_J proportional to E for E> 500 eV
- SIMS saturation effect for E<100eV

USJ : Low level of Defects

TEM after PULSION® BF3 500V 1E15/cm² (with SiO2 etching before implant.)



- Very small amount of defects is observed in the implanted layer

(IBS / CNRS CEMES collaboration)

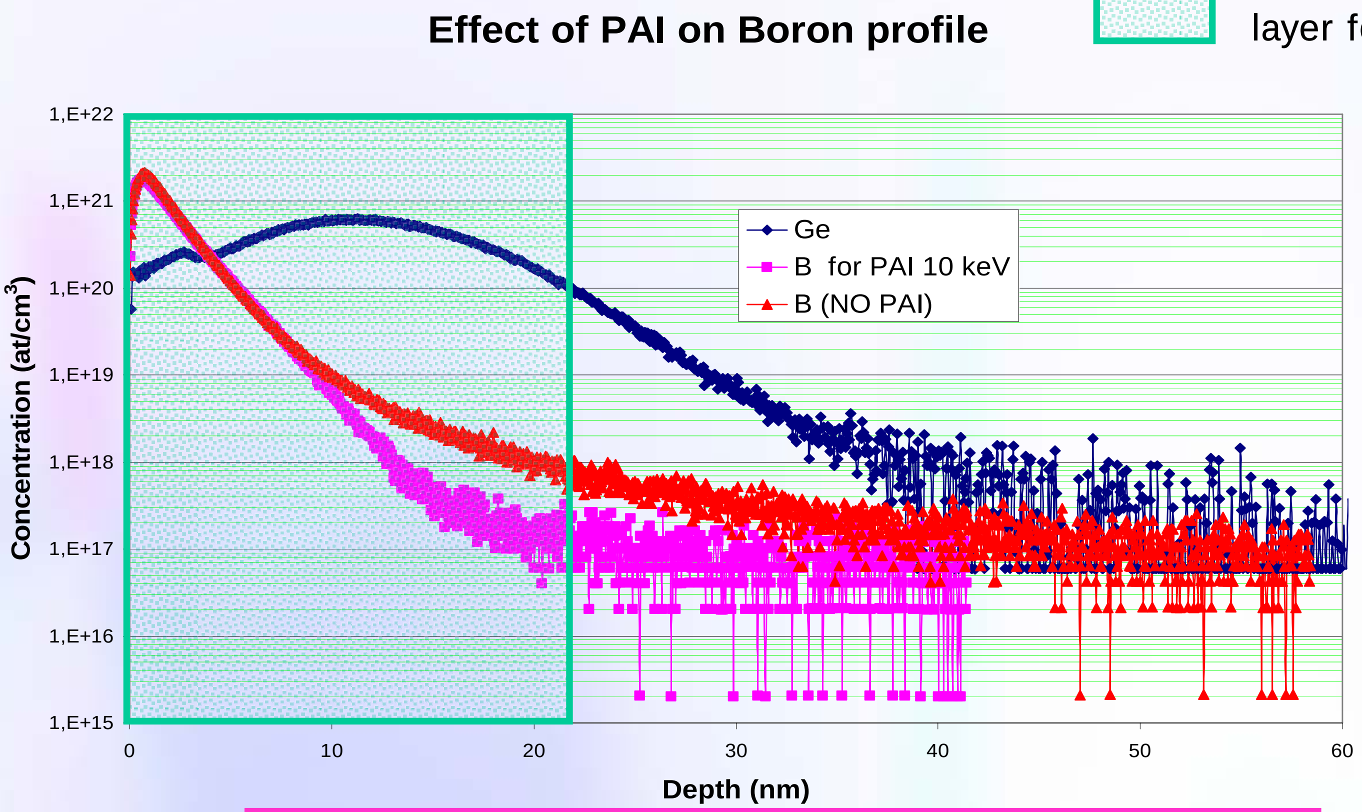
PULSION + Annealing
On going studies

- SPIKE Collaboration with CEA-Léti in FOREMOST
  - Sheet resistance and Xj still too high
  - Diffusion must be minimized (TED)
- SPER
  - Sheet resistance and junction depth still too high
  - Effects of EOR on junction leakage still has to be investigated
- LASER Collaboration with Marseille university :
  - Next step : reduce Xj by reducing PAI depth
  - Try RTP annealing to dissolve defects and reduce junction leakage
- FLASH Collaboration with Toulouse University in Pullnano
  - Cocktail implants + Flash ⇒ results expected Q4-07

Annealing process	Xj (nm)	Rsq (ohms/sq)	I_L (A/cm)
Spike	24	1598	
SPER	14	1220	
LASER without PAI	30	593	1E-7
LASER with PAI	23	561	1E-2

Effect of PAI on boron profile in as-implanted condition

Thickness of amorphous layer for Ge+ 10 keV

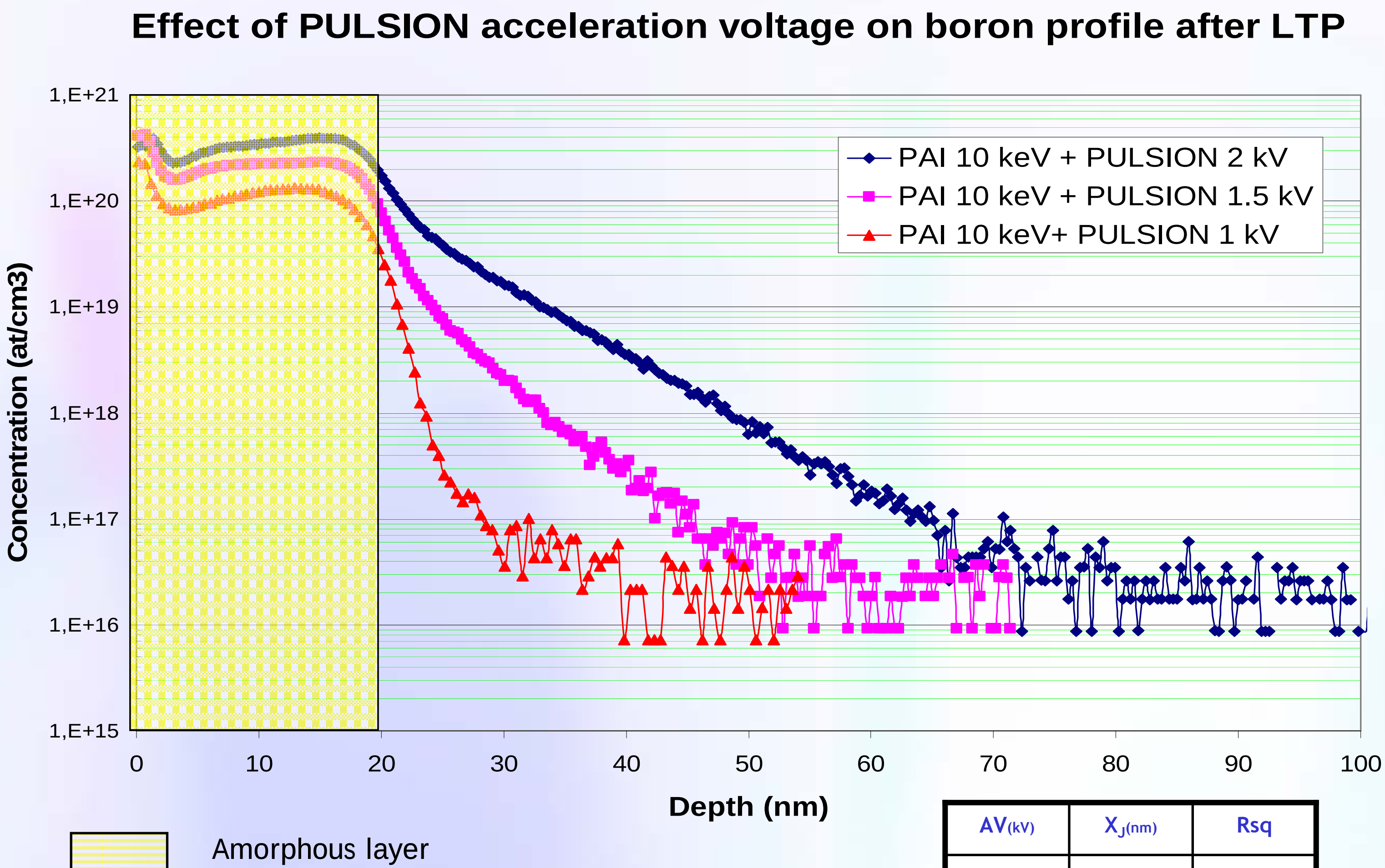


Ge affects on the boron profile

X_J ↘ with PAI

Elimination of the channelling effect

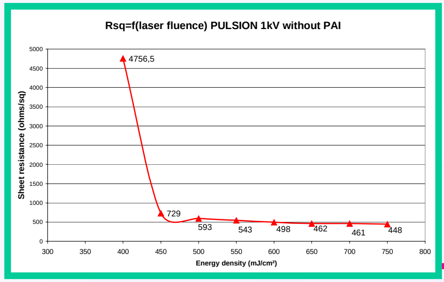
Effect of acceleration voltage on boron profile after annealing

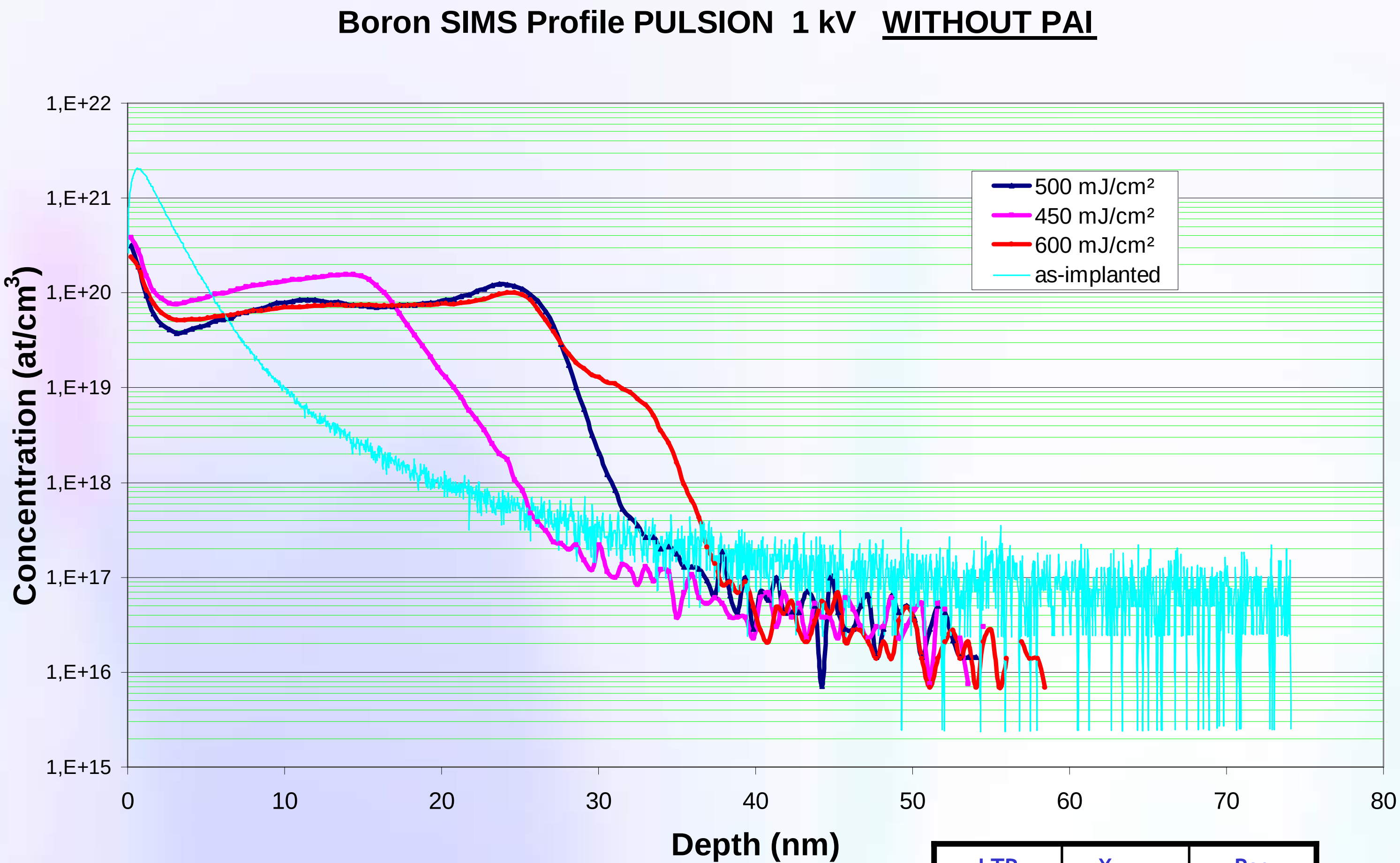


AV(kV)	$X_{J(nm)}$	Rsq
1	23	1014
1.5	33	562
2	48	235

↗ Acceleration voltage ➔ ↗ X_J ➔ ↘ Rsq

Effect of laser fluence on boron profile after LTP





↗ Laser fluence ➔ ↗ X_J ➔ ↘ Rsq

LTP	$X_{J(nm)}$	Rsq
450	24	729
500	30	593
600	34	498

USJ with PULSION and laser anneal

PULSION® gives good results for realization of USJ

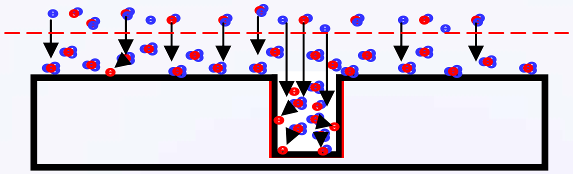
WITHOUT PAI

- Activation threshold : 500 mJ/cm²
- X_J = 30 nm
- Rsq = 593 Ω/sq
- I_L = 1E-7 A/cm²

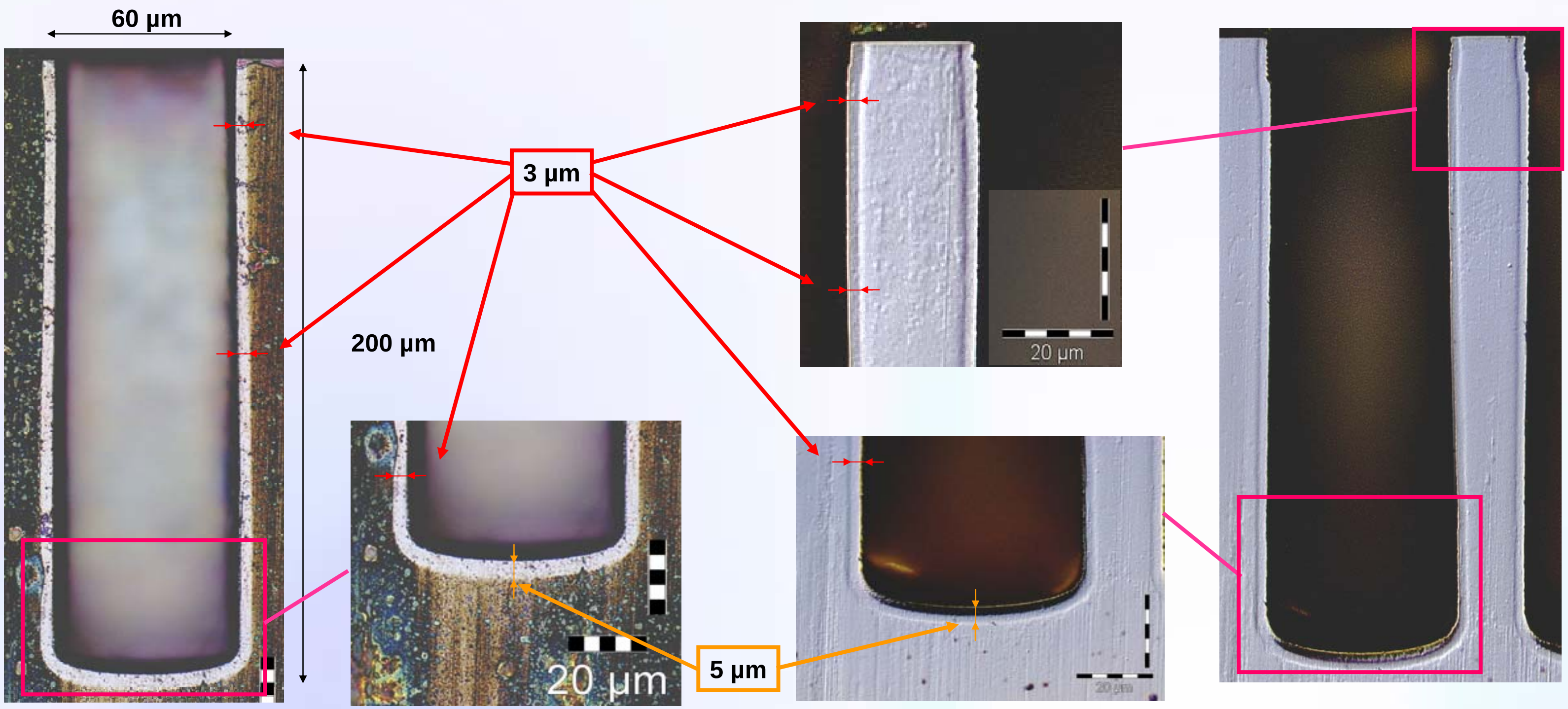
WITH Ge PAI

- Activation threshold : 450mJ/cm²
- X_J= 23 nm
- Rsq= 561 Ω/sq
- But I_L= 1E-2 A/cm²

To complete the study of PULSION® in the realization of USJ
Adding different annealing process



Trench Doping with PULSION®

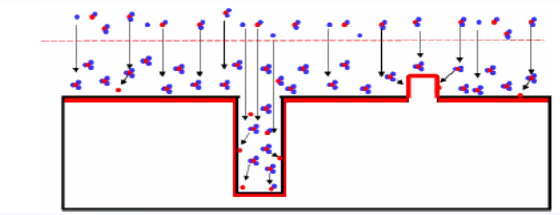


Copper junction staining

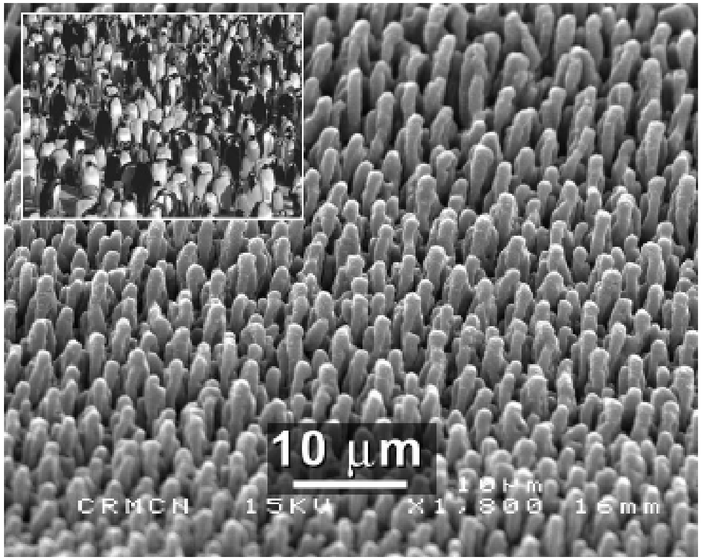
Sirtl etch junction staining

Conformal doping of 60 µm wide / 200 µm deep silicon trench

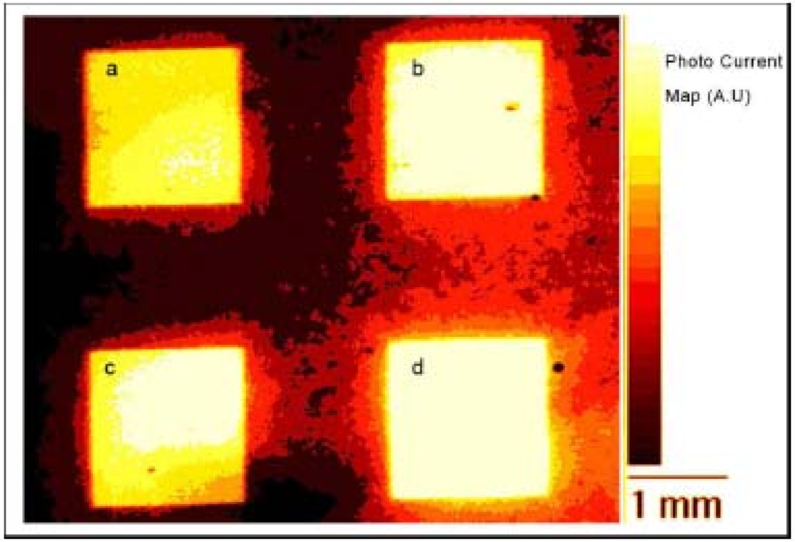
(with courtesy of LMP / ST) *(S. NIZOU, V. VERVISH, H. ETIENNE..., IIT 2006 P115)*



3D doping with PULSION®



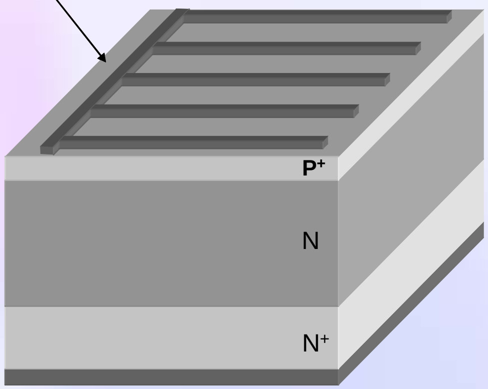
SEM photo of penguin-like structures created by femtosecond laser (top left corner is a picture of a real penguin colony in Antartica, photo by G. DARGAUD www.gdargaud.net) (with courtesy of LP3)

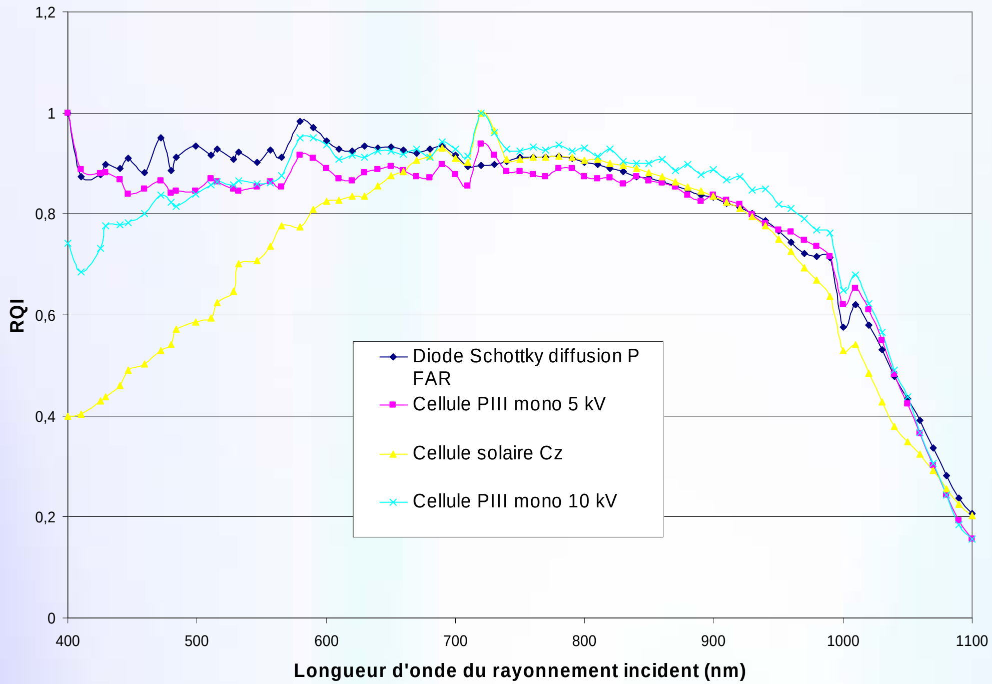


LBIC scan maps showing the increase of the photocurrent in the laser treated zones.

Solar cell doping

Shallow junctions for Solar cells improvment

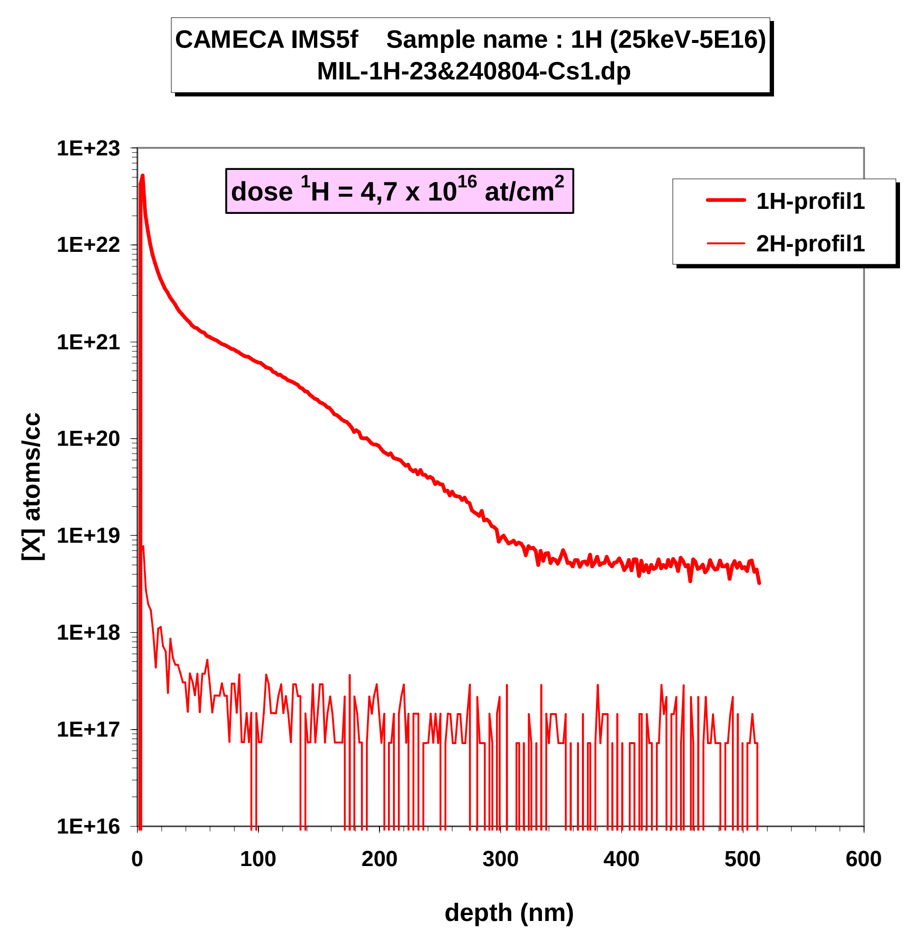




- Same diffusion lengh as classical solar cell ⇒ no metal contamination
- Higher sensitivity in low wavelength range

(V. VERVISCH, D. BARAKEL, H. ETIENNE…, IIT 2006 P248)

Hydrogenation



SIMS profile of Hydrogen implantation (5 e^{16} cm^{-2} - 25 kV)

PULSION® Summary

- New industrial equipment for low energy implantation
  - Designed for high reliability and low cost of ownership
  - Flexible to allow development of new applications for different fields
  - 200 / 300 mm tool easily scalable to 450 mm

- Successful process tests
  - USJ doping
  - Trench and 3D doping
  - Solar cells : doping and hydrogenation
  - Power components : high dose doping

- Contact : **pulsion@ion-beam-services.fr**

The Total
Ion Implantation Solution

« A global service dedicated to customer support in the field of ion implantation»

Contacts :

pulsion@ion-beam-services.fr