ion beam services
the total ion implantation solution

PULSION®
Plasma Implant Update

JULY 2015 – Semicon SFO

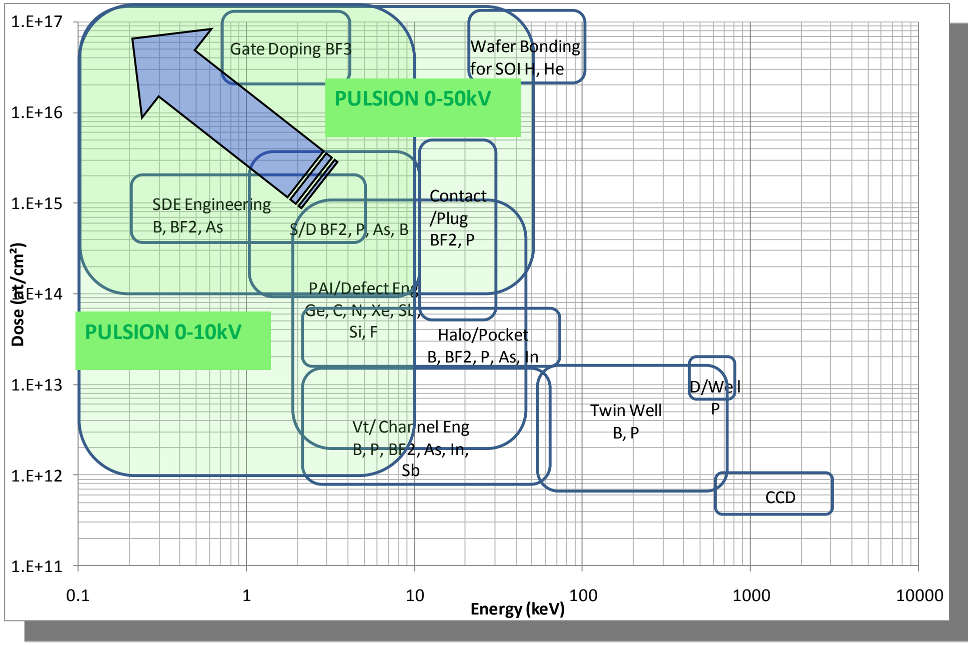
IBS PULSION®

A Differentiated Plasma Doping Technology
for
Advanced Device Manufacturing
and
High Productivity Applications

Agenda

- Advanced Technical Needs and Trends
- PULSION™ Design Advantages and Validation
- Safety Validation
- New PULSION™ Developments
  - Options
  - Marathon Performance
  - Manufacturability
  - Dose Calibration
  - 450mm
- Update On Applications and Species
  - FinFET
  - 3D Modeling Project
  - Hot As
  - FDSOI
  - III-V

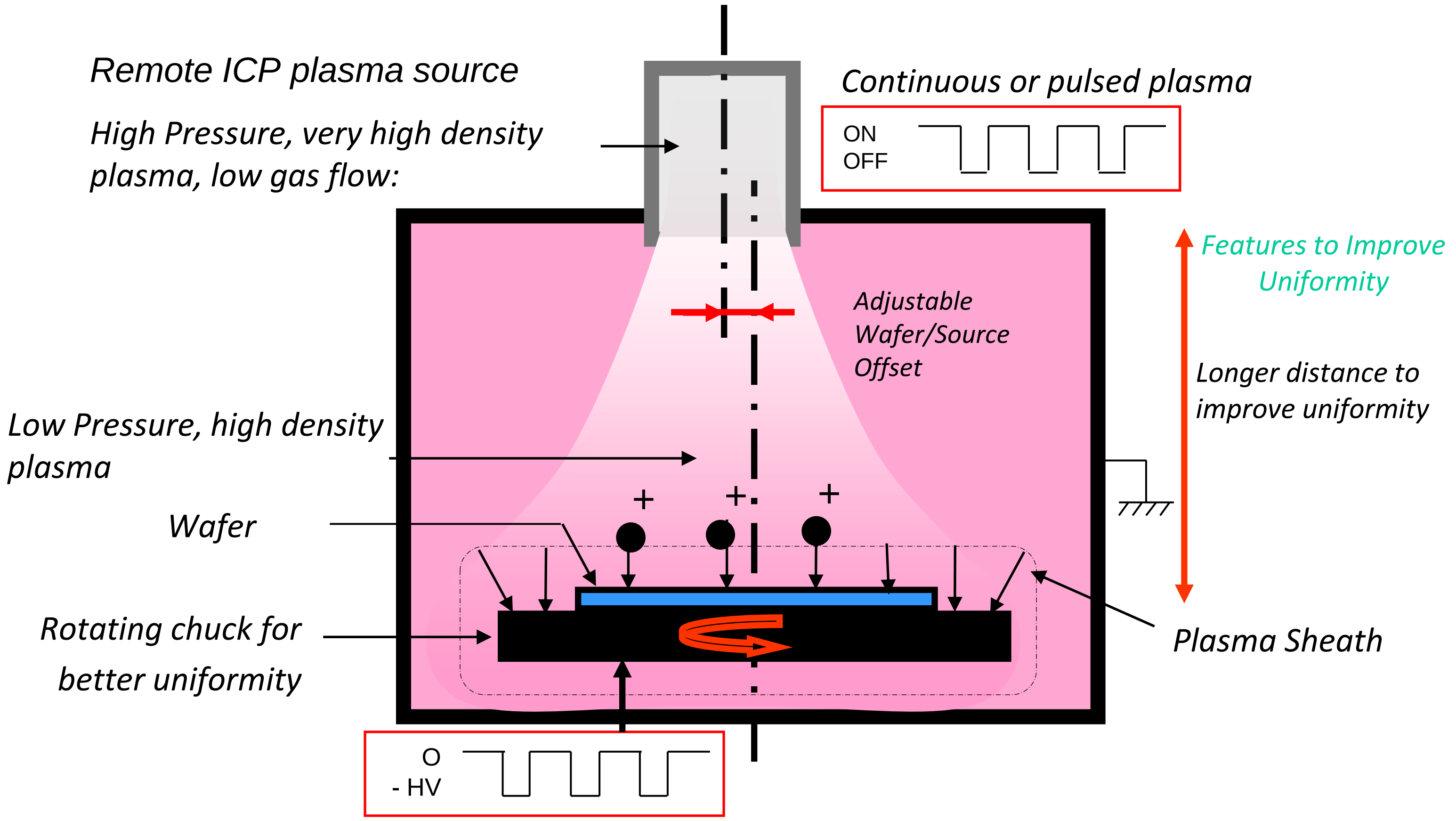
Why Plasma Immersion Ion Implantation (PIII)?



- **New technology requirements**
  - Lower Energy
  - Higher Dose
    - Material modification
    - 3D structures

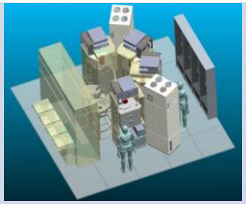
- **Plasma Implantation (PIII)**
  - No risk of high energy contamination
  - Simultaneous implantation of the whole wafer
    - No scanning required
  - Ultra Low Energy (down to eV)
  - High implantation current even at low energies
  - 3D doping

PULSION ® - Dual Region Chamber Design



PULSION® schematic: unique features enabling high performance process

PULSION® Configurations

PULSION nano	PULSION nano Auto-loading	PULSION HP
		  
Manual loading 1 chamber	Auto loading 1-2 chambers	Auto loading 1-4 chambers
Labs	Device qualification	Production

+ Substrate heating (up to 500° C on chuck)

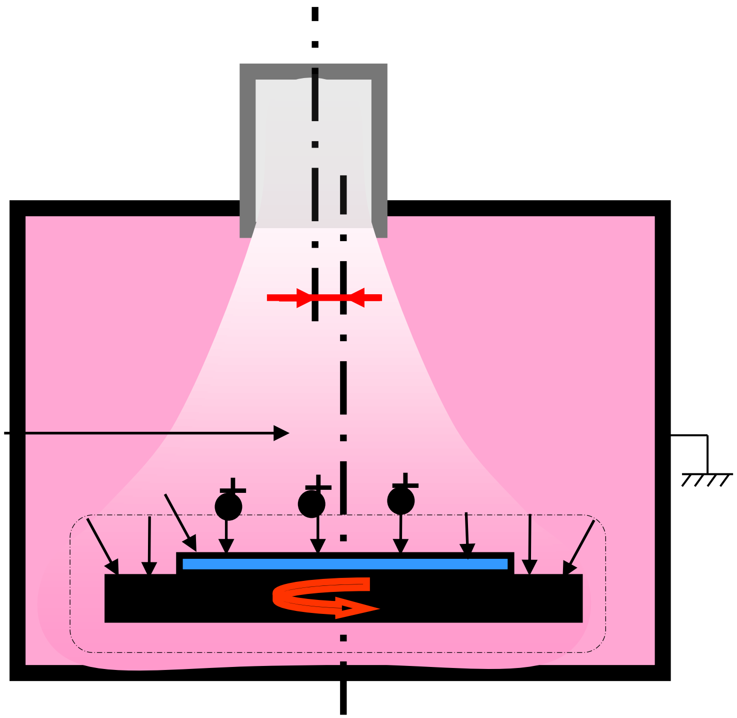
PULSION™ Overview

<u>Plasma Immersion Ion Implantation</u>

- 100V to 10kV (20kV option)
- 1e14 /cm² to 1e18/cm² Dose
- 200 or 300mm
- Up To 4 Chambers
- Up To 6 Gas Lines/Chamber
- In-situ Dosimetry
- Available Species
    - Gas Precursor
    - Liquid Precursor
- Passivation/ Outgassing Chamber
- High Temp Implant Option (up to 450° C)

PULSION ® - Available Species

- Current Species Used
  - B (BF3, B2H6)
  - P (PH3)
  - As (AsH3)
  - C (CH4, CF4)
  - N (N2)
  - O (O2)
  - F (several)
  - Si (SiH4, SiF4)
  - S (SF6)
  - H (H2)
  - He
  - Ge (GeH4, GeF4, under study)
  - Al



Safety

- Customer Concerns Regarding As Outgassing
  - As < detectable limits with normal PULSION configuration
  - Past experience with other PIII systems drove OG chamber
  - Also used for Passivation applications and others.....
- S2/S8 Certification Complete
- Fab Interlock interfaces complete and verified

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Technical Advantages
From Unique PULSION™ Design

PULSION® Key Technical Advantages

- Small volume, remote plasma source
  - De-coupling of plasma source and process chamber
  - Tunable etching/deposition ratio
  - Excellent conformal doping of 3D/Fin structures
    - no erosion and residual damage
  - Very low gas consumption and exhaust
  - Lower acquisition and installation costs
  - Best choice for low energy and/or high dose applications
  - Versatility for Materials Modification

- More process parameter tuning options than BL or other Plasma tools
  - Multiple controls of ion behavior

PULSION® Key Productivity & Cost Advantages

- **Throughput 2 to 4 times higher than BL**
  - ~50% footprint area of BL tools
  - High Dose/Low Energy Applications
- **Low (2 to 10 sccm) gas consumption**
- **Cost per wafer is <50% of BL cost**
- **Lower Installation Costs (on board gas distribution)**
- **PULSION is the GREEN Plasma Doping Solution**

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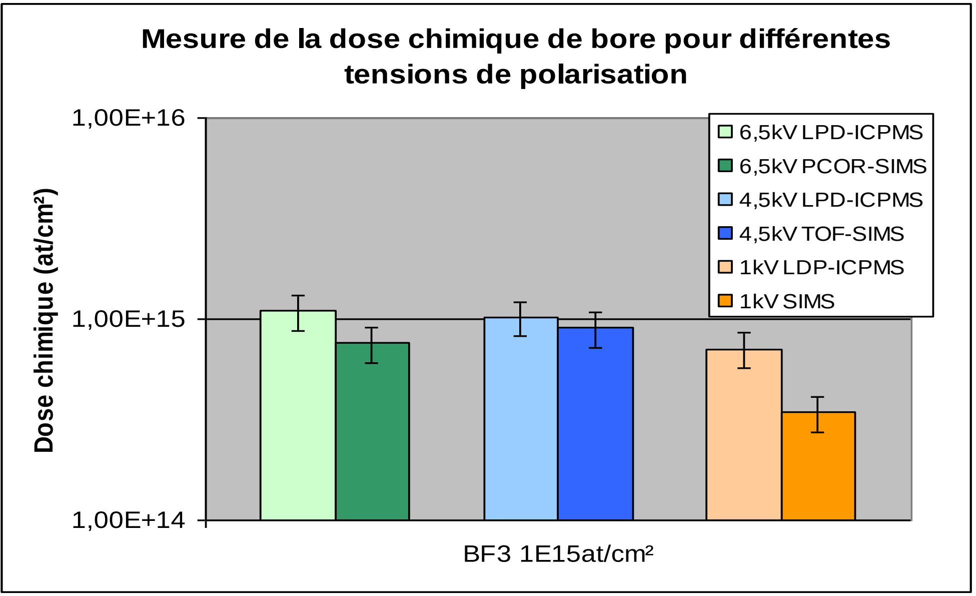
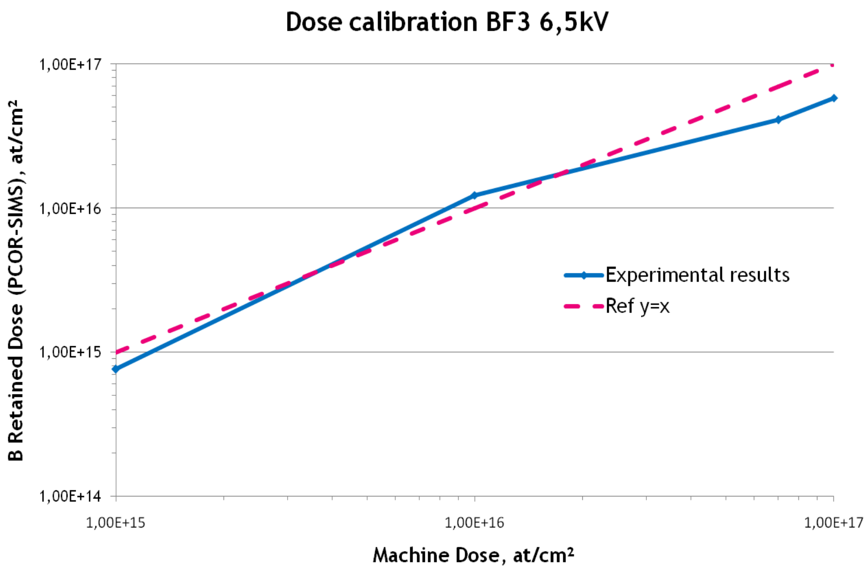
DOSIMETRY

Dosimetry

In PIII at low energy, retained dose of doping species can't be precisely measured by a simple current integration (even using a Faraday cup system) , calibration is needed.

- Dose calibration examples for BF_3





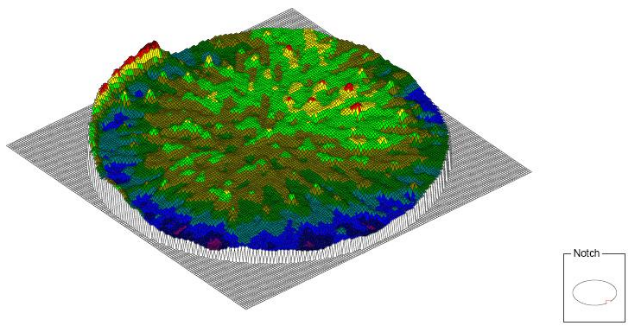
PULSION™ PERFORMANCE

Doping Uniformity (300 mm wafers)

USJ Application

BF_3 1 kV 1E15/cm²

(implant depth 10nm @ 1E19/cm3)



RTA Anneal

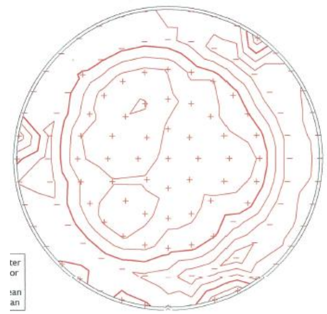
R_s uniformity : 0.98% (1σ)

DRAM Poly Gate Counter-Doping

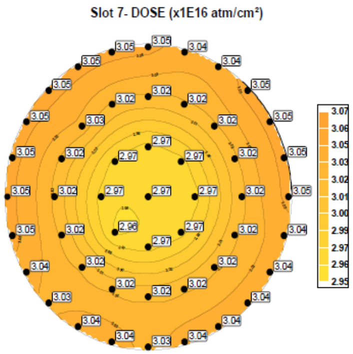
BF_3 6.5kV 7E16 cm^{-2}

HF strip before anneal

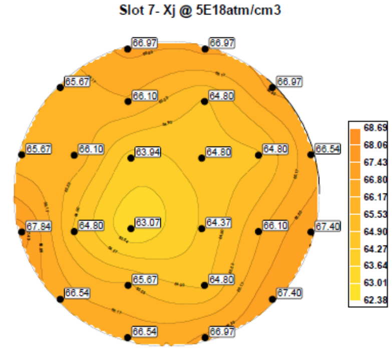
1000C, 10 sec anneal



Sheet resistance mapping
σ =0,802%



LEXES Boron Dose mapping
σ =0,73%



LEXES depth mapping @5e18/cm3
σ =1,86%

R_s uniformity : 0.8% (1σ)

Dose uniformity : 0.73% (1σ)

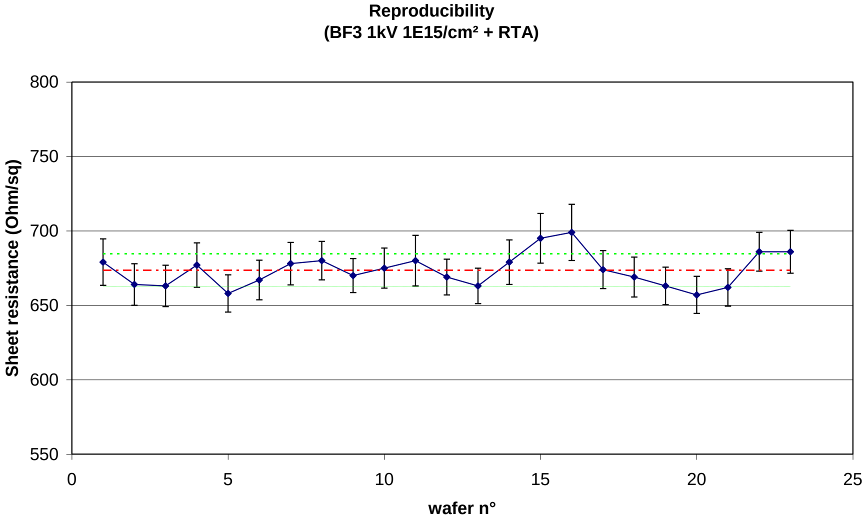
Depth uniformity : 1.86% (1σ)

Uniformity & Repeatability (300 mm wafers)

USJ Application

BF_3, 1 kV, 1E15 cm^{-2}

RTA Anneal



Uniformity (1σ) < 1%
Repeatability (1σ) = 1.6%

DRAM Poly Gate Counter-Doping

BF_3, 6.5 kV, 7E16 cm^{-2}

HF strip before anneal

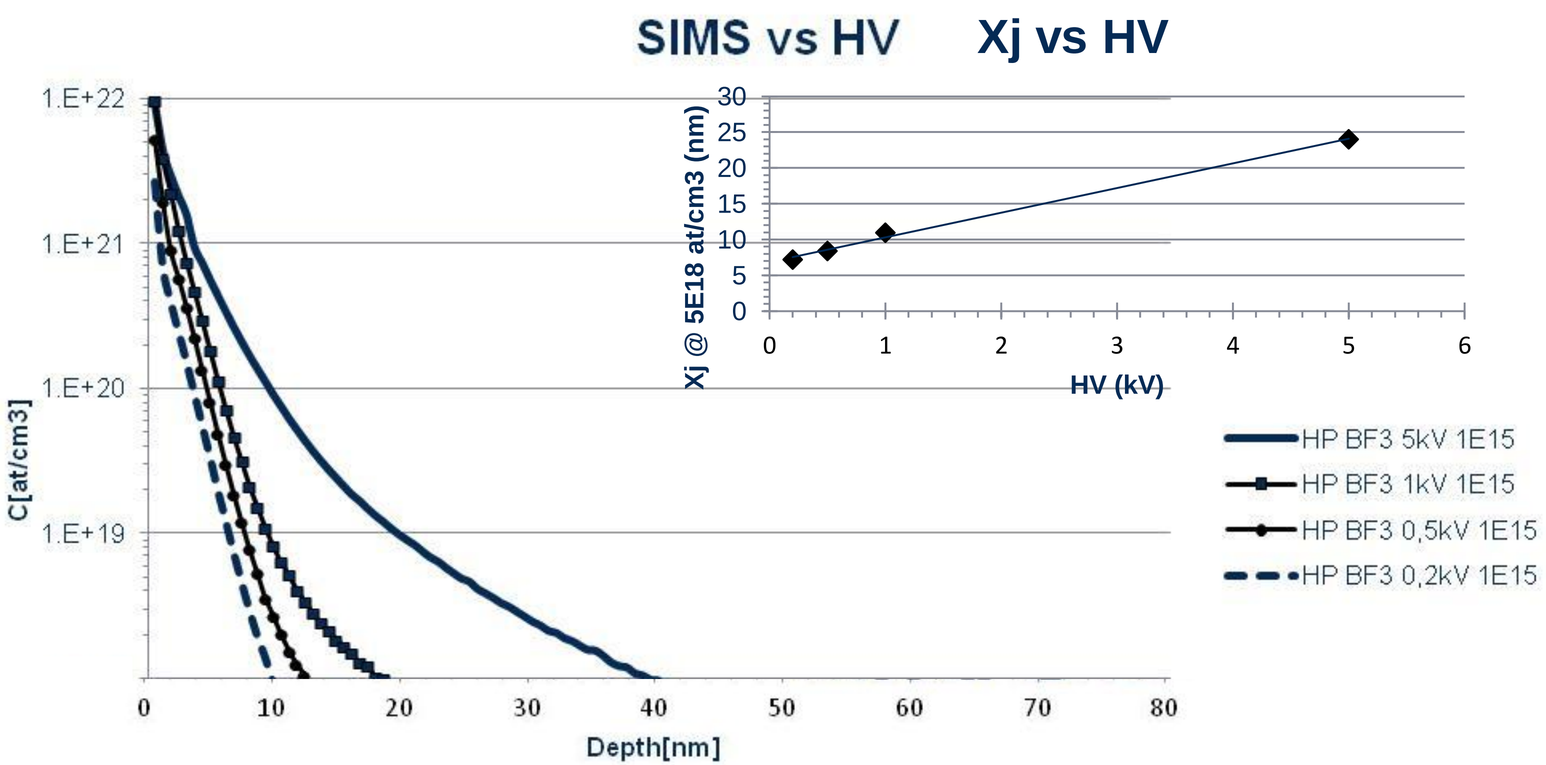
1000C, 10 sec anneal

Mean Rs (ohms/sq.)	Uniformity (%, 1σ)
162.55	0.828
161.19	0.780
160.17	0.787
157.96	0.777
158.66	0.840

Uniformity (1σ) < 1%
Repeatability (1σ) = 1.16%

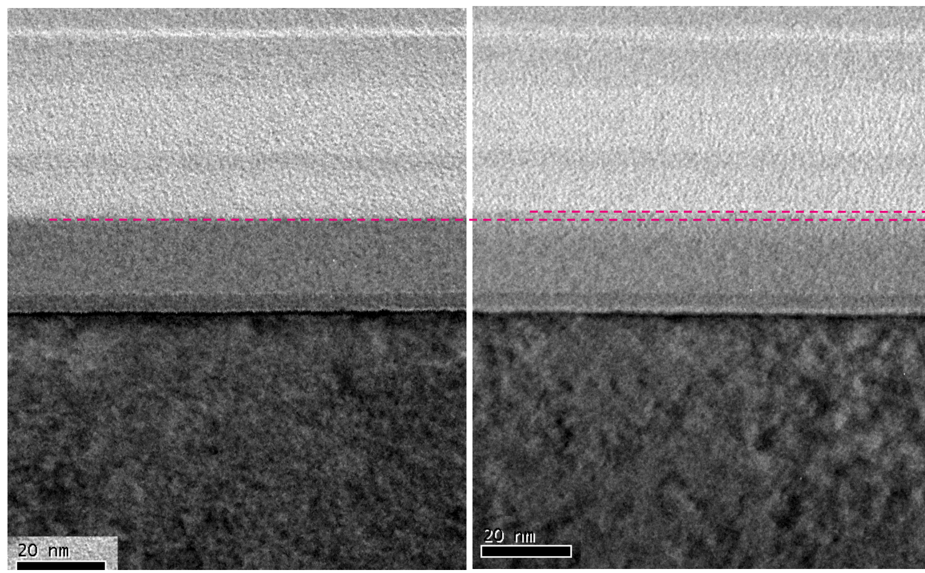
SIMS Profiles: Voltage Response for BF_3

- Implant depth control proportional to wafer voltage
- USJ depths below 10nm can be achieved by reducing the wafer voltage



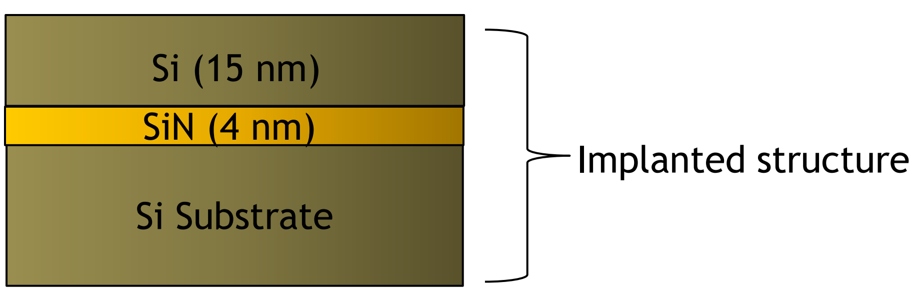
Control of Si Etching with F containing species

HRTEM : Implanted (BF_3 4kV, 1.5E16 atoms/cm^2) / Unimplanted Samples



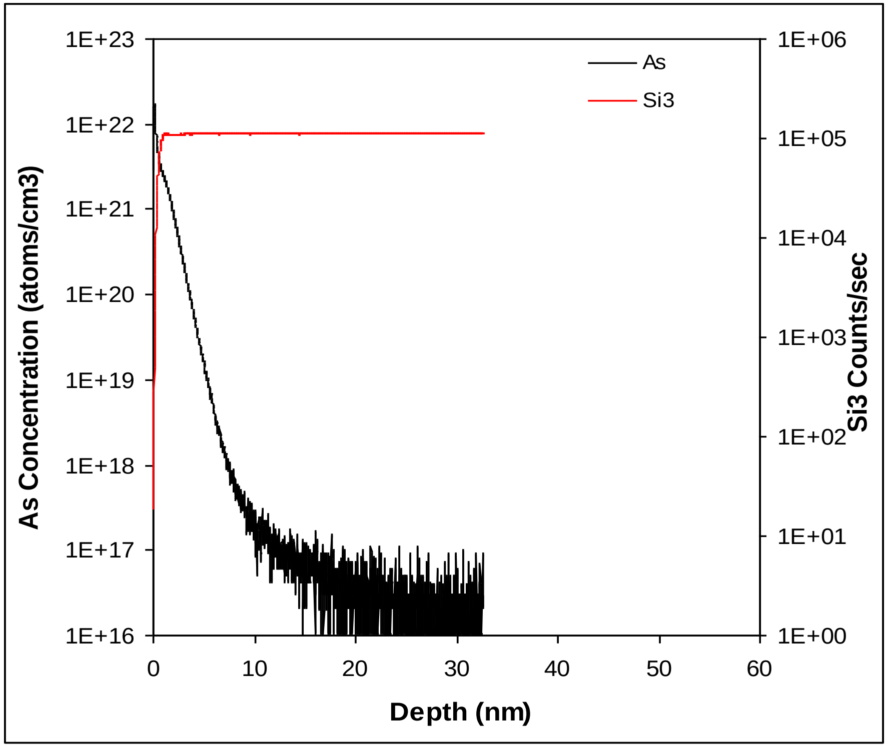
+~1 nm of Oxide Growth

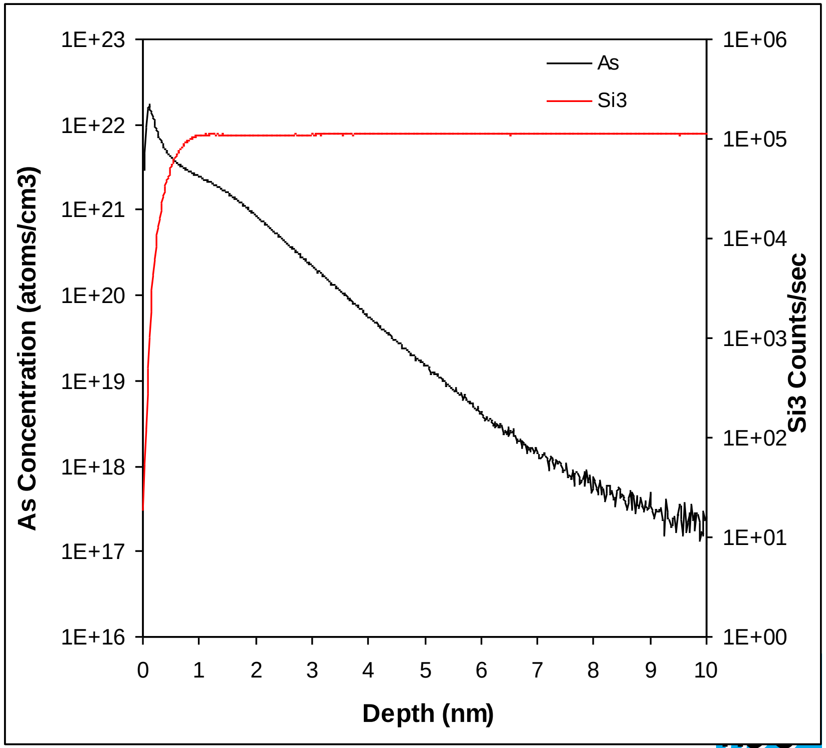
Unimplanted   Implanted



SIMS Profile of Arsenic USJ with Flash Anneal

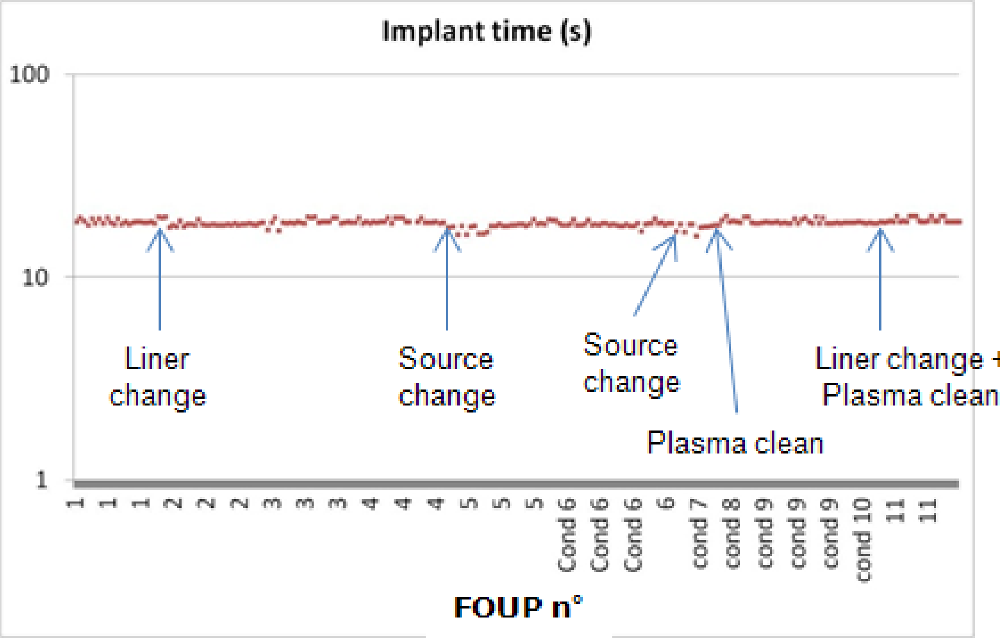
AsH_3, 0.3 kV, 2E14 cm^{-2}
1200C flash anneal
As depth at 1E18 cm^{-3} is 7 nm





Effect of PM and Species Change

Implant time (Implant current) stability (BF3 recipe)

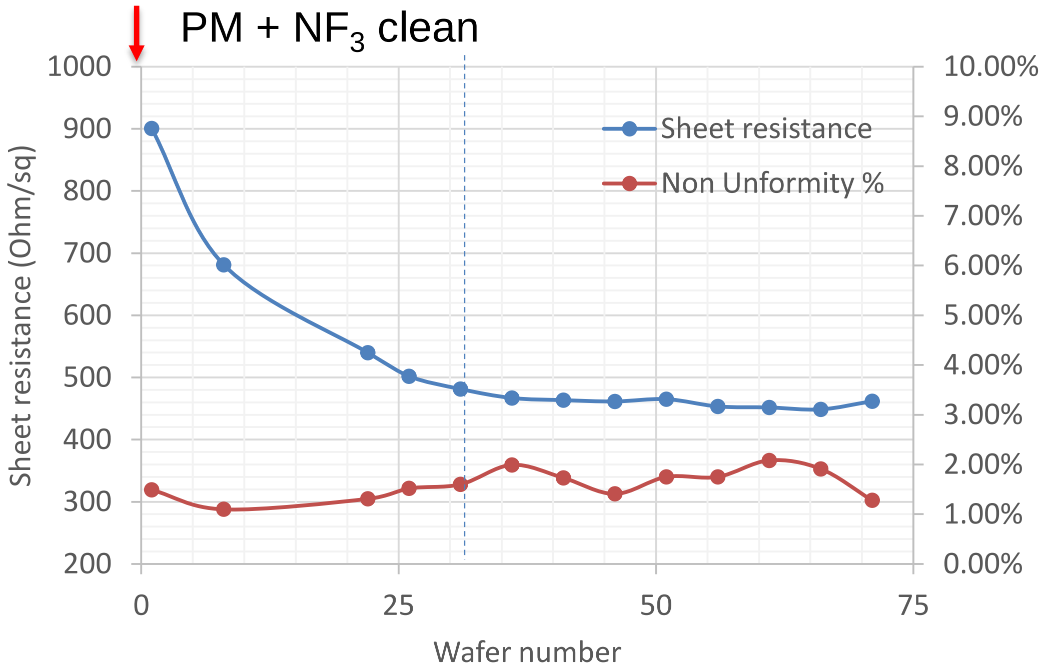


- Minimized impact of PM or species change on implant current and implant time

Tool Conditioning after PM for BF_3

BF_3 sheet resistance and non uniformity

(BF_3 5kV 4E15/cm² + RTA 1050° C)



- 25 to 50 wafers are needed to condition the tool after PM (total dose of 1.2E17/cm²)
- Non uniformity : 1 to 2 %
- Wafer to wafer reproducibility after 35 wafers : 1.5%

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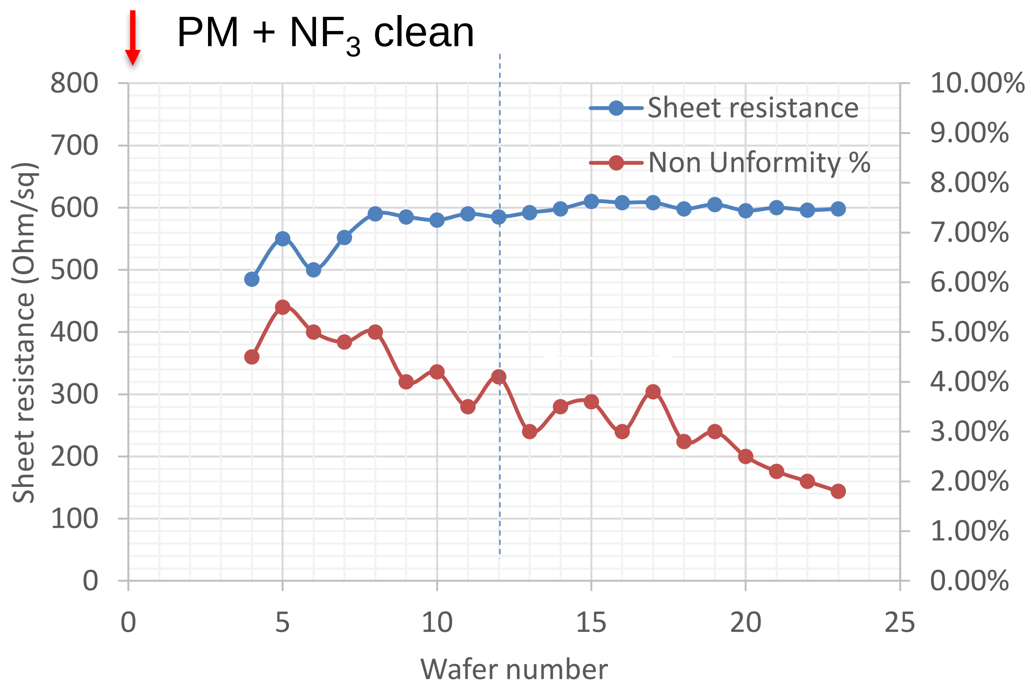
Tool Conditioning after PM for AsH_3

AsH_3 sheet resistance and non uniformity

(AsH_3 4kV 4E15/cm² + RTA 1050° C)



- 10 to 25 wafers are needed to condition the tool after PM (total dose of 1.2E17/cm²)
- Non uniformity improves to < 2% after 25 wafers
- Wafer to wafer reproducibility after 12 wafers : 1.2 %

Particles

Handling :

- Front side : < 1 adder @ 65 nm
- Backside :
  - 700 to 1000 adders @ > 120 nm demonstrated

Argon implant :

- Front side particle : Ar 1kV 1E15/cm² and 1E16/cm²

	Ar 1 kV $1^{E}15$ /cm²			Ar 1 kV $1^{E}16$ /cm²		
size	> 65nm	> 80nm	> 120nm	> 65nm	> 80nm	> 120nm
adders	6	5	3	7	6	5

IBS PULSION®

450 mm Scalaibility

450 mm PULSION® Scalability

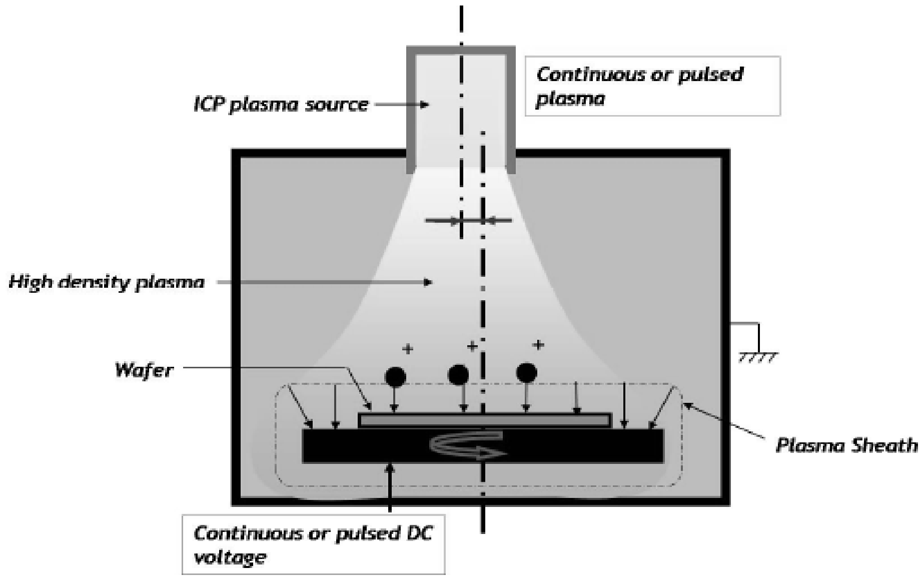
PULSION® advantages for 450 mm :

- Implant time is independent from the surface
- Doping efficiency proven on the technology which will be installed on 450 mm

(FinFET doping, material modification, memories)

300mm PULSION® tool

450mm prototype : same design



Roadmap for 450 mm :

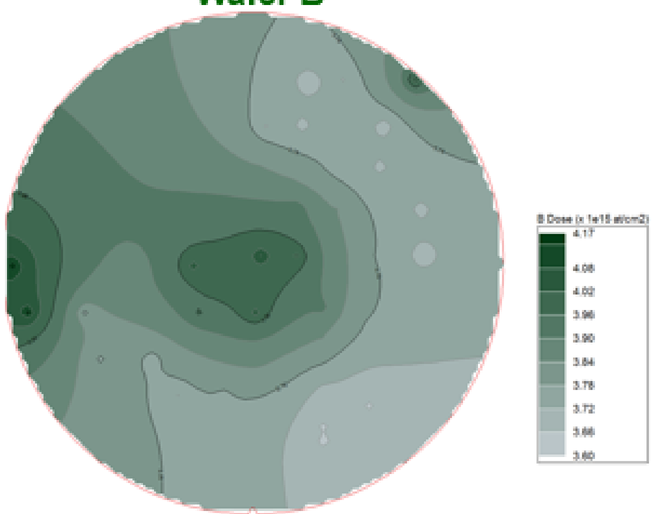
- Phase 1 : demonstrate scalability : target < 4% non homogeneity
- Phase 2 : final design : < 1% non homogeneity

450 mm PULSION® Scalability

BF3 6kV implant on n-type 450 mm wafers
Dose and implant depth uniformity meseared by CAMECA LEXES
=> Less than 4% non uniformity demonstrated

450 mm wafer dose non-uniformity
47 points mapping

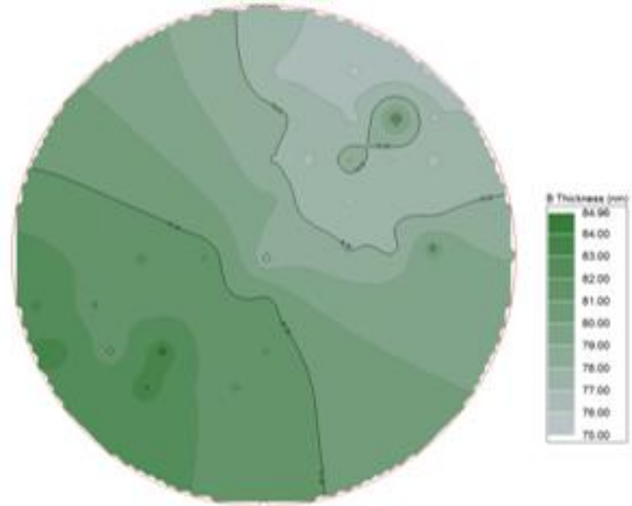
Wafer B



B average dose: 3.80e15 at/cm2
Non-uniformity : 3.91%

450 mm wafer thickness non-uniformity
32 points mapping

Wafer B



B average thickness: 79.59 nm
Non-uniformity : 3.59%

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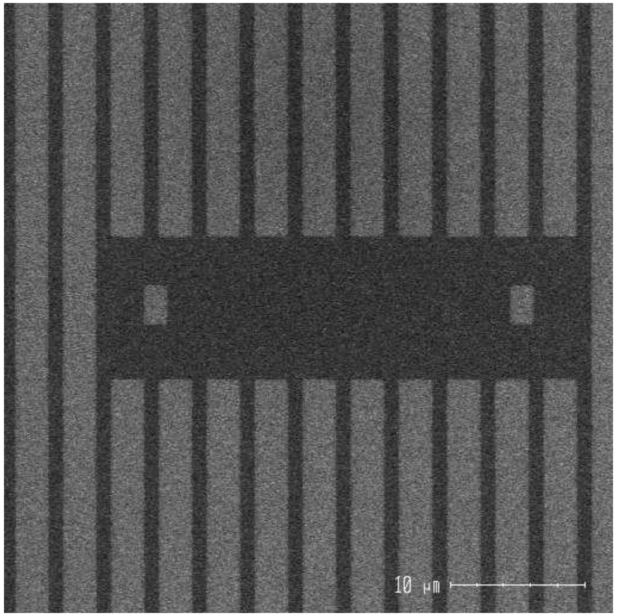
IBS PULSION®

Compatibility with CMOS devices

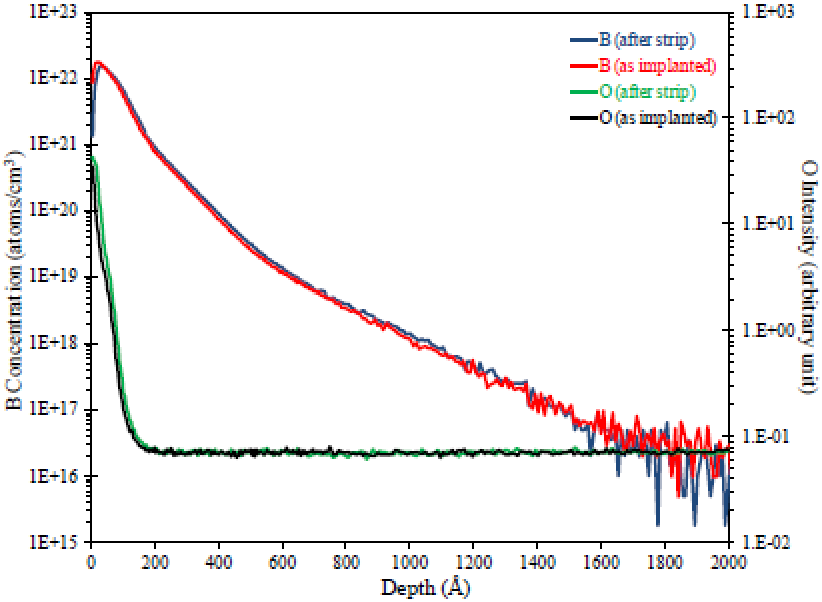
PULSION® General Performance: fully CMOS compatible

- **Compatibility with resist**



No resist damages

- **Compatibility with standard resist strip processes used for beam line implantation**

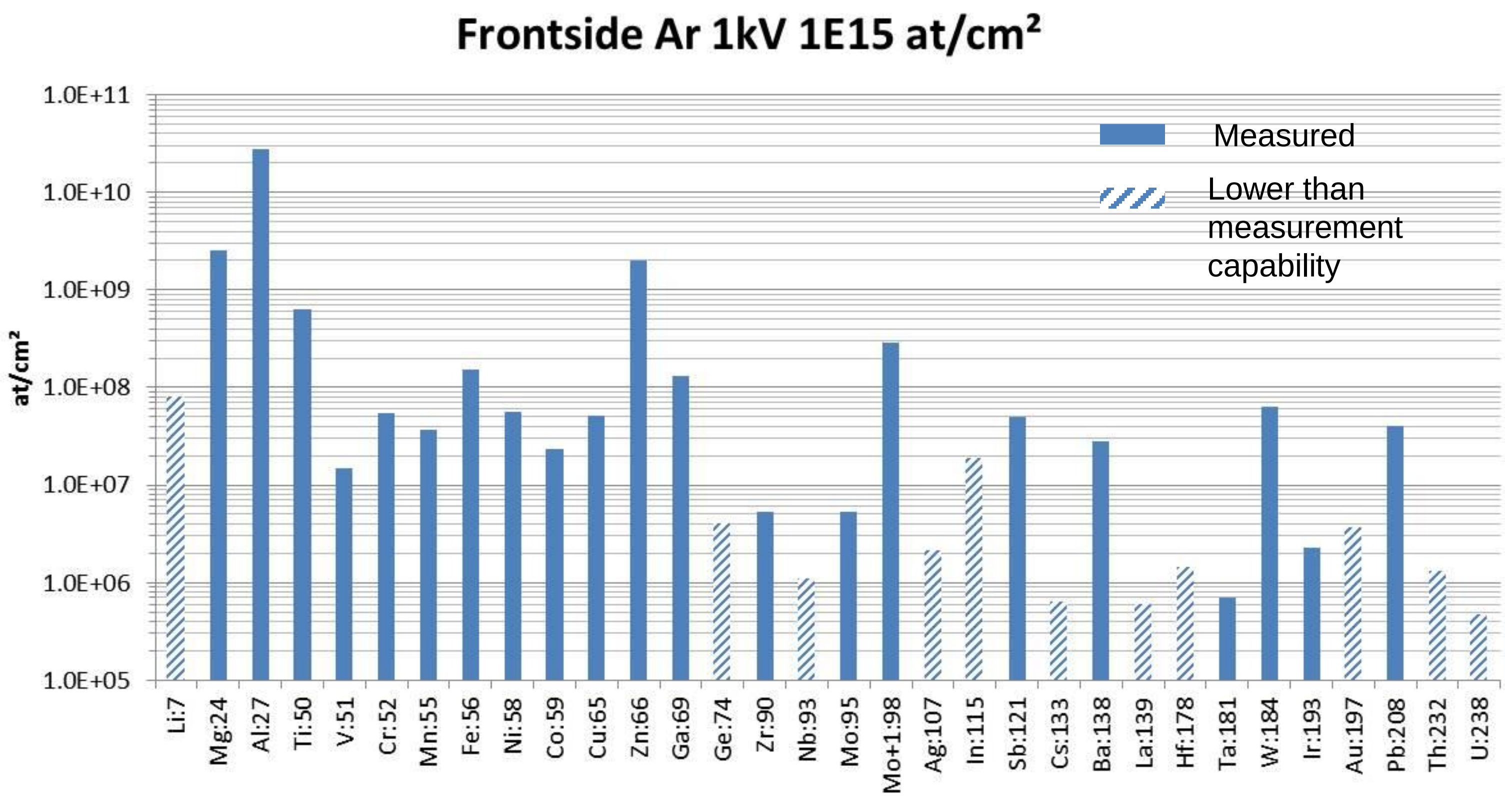


PCOR-SIMS depth profiles of n-type wafers plasma doped with BF_3 6kV 5E16/cm^2

No dose loss or excessive oxidation after plasma strip resist process

PULSION® General Performance: metal contamination

- Ar implantation : Measurement by VPD-ICPMS

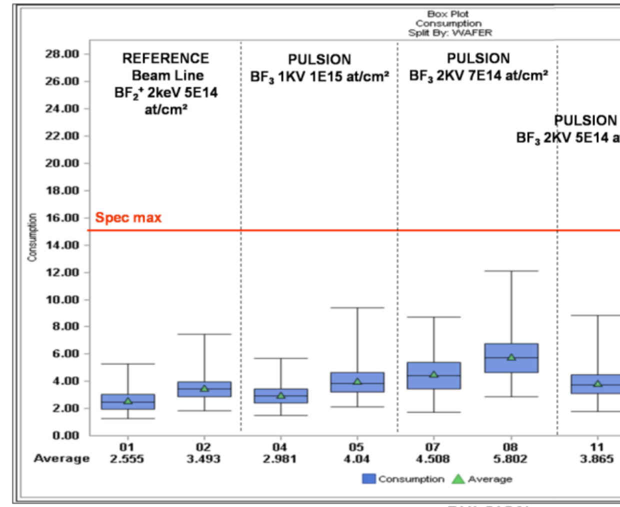


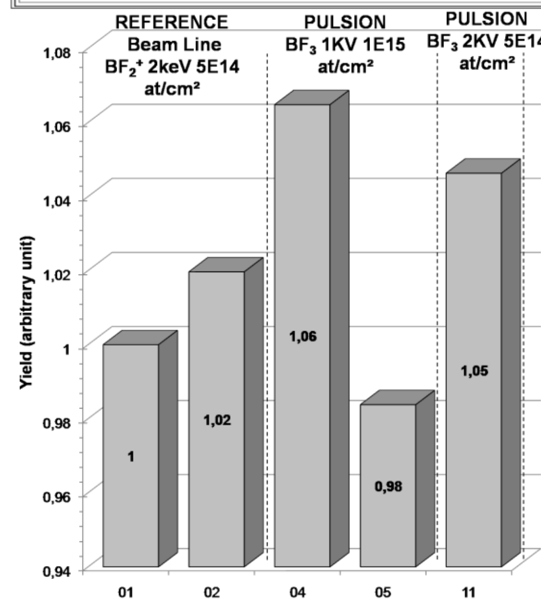
PULSION® General Performances : fully CMOS compatible

- **Customer need:**
  - Similar doping results than beamline implantation
  - **<u>No process flow modification</u>**
  - Higher throughput and performances

- **Typical application**
  - S/D for CMOS devices

- **PULSION benefits**
  - LDD Doping of 120 nm CMOS Devices
    - High throughput
    - Die consumption below spec, comparable to beamline implant
    - Relative yields comparable to or better than beamline implant

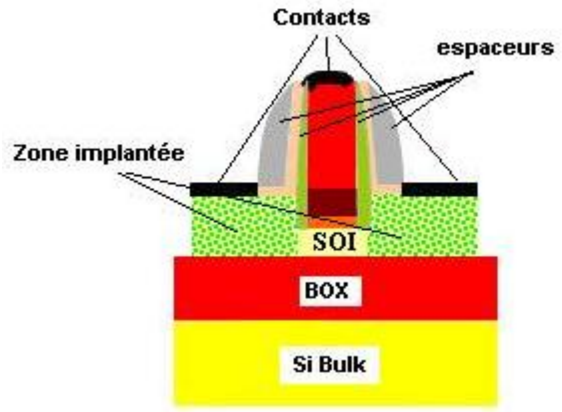


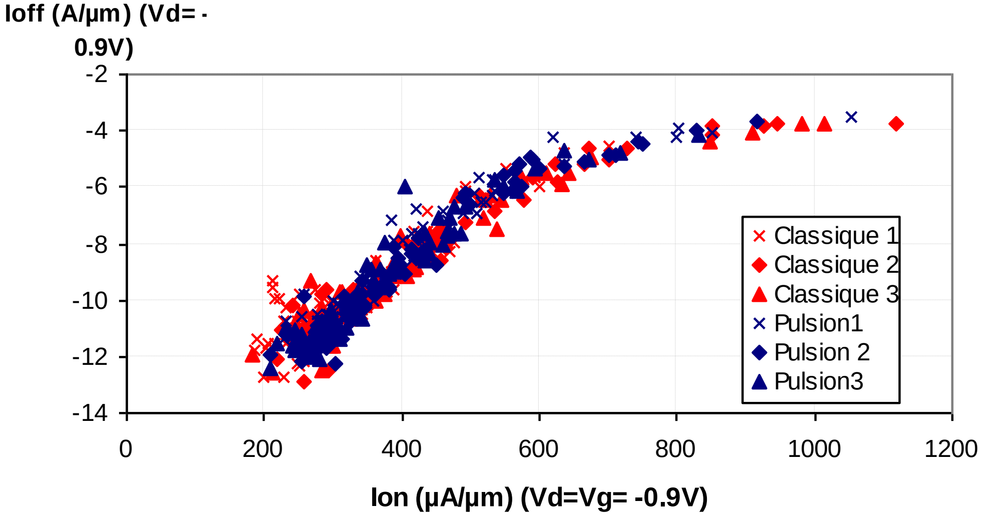


ST Rousset / IBS Collaboration (presented at IIT 2010)

USJ applications

- **Application on SOI transistor : collaboration with CEA LETI, IIT2012**
  - Less amorphization than beam line for equivalent implant depth
  - As efficient as beam line on electrical characteristics of devices
  - Only solution for FD-SOI where < 300 eV implantation is needed



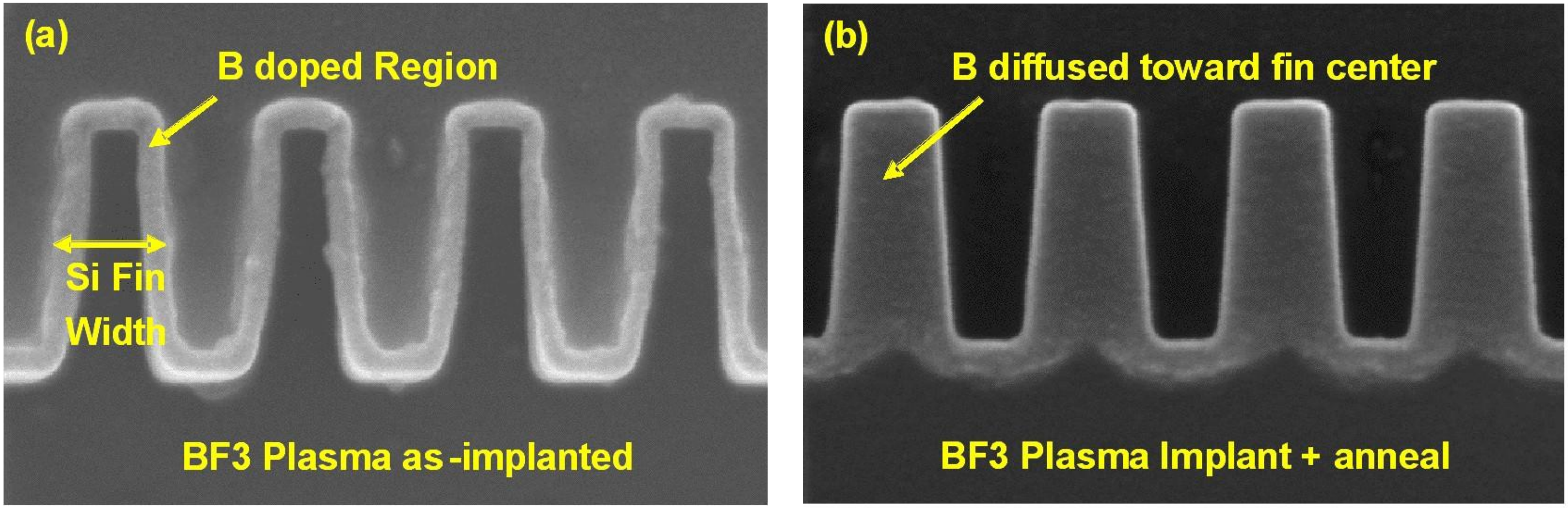


With courtesi of CEA LETI

ADVANCED PULSION™ IMPLANT PROCESSES

FINFET DOPING

FinFET BF_3 Doping using PULSION® : conformal doping

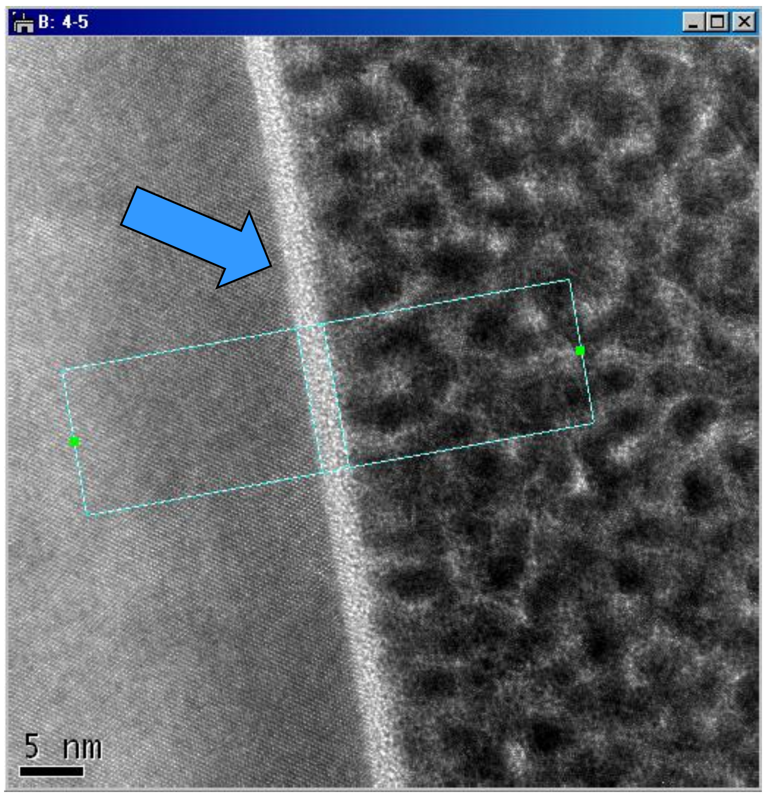


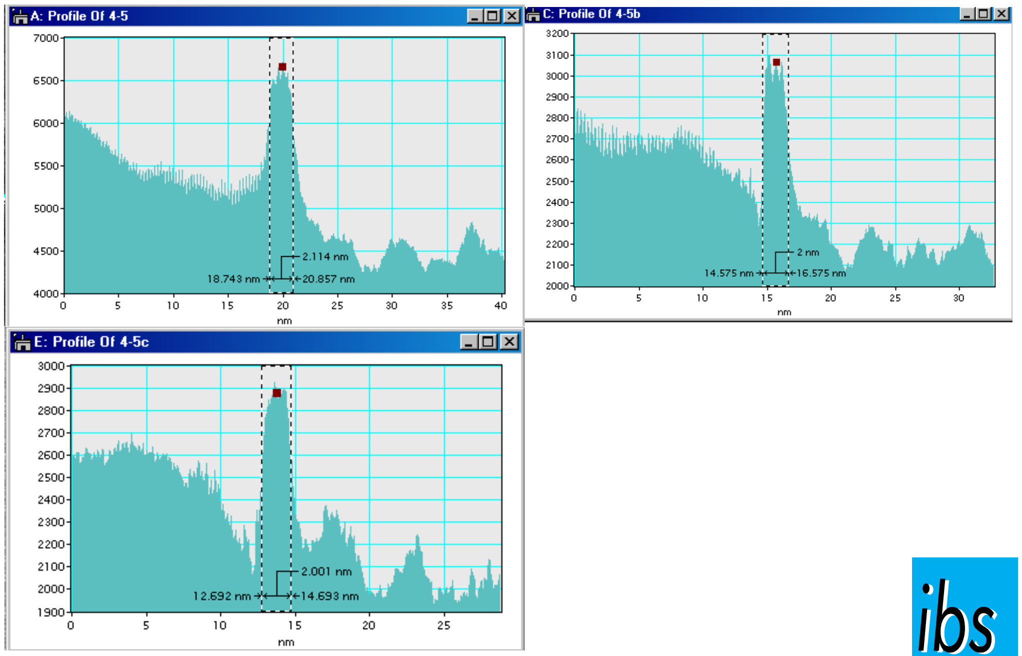
S. Felch et al. (Sematech, CNSE, IBS), IWJT11

- Conformal doping of as-implanted sample
  - White regions on top of fins, along sidewalls, and between fins are B-doped, not B deposition on surfaces of fins.
  - Equal thicknesses of all regions. No dimensional fin changes.
- Entire fin is light-colored after PMOS source/drain anneal
  - Anneal caused B to diffuse toward center of fin

FinFET BF_3 Doping using PULSION® : defects

- HRTEM image of BF_3, 0.5 kV, 1E15 cm^{-2} implant
- Thickness of amorphous layer ~2 nm (SiO2)
  - Thin enough to leave crystalline Si region in interior of 16nm node fin and enable complete regrowth of fin Si



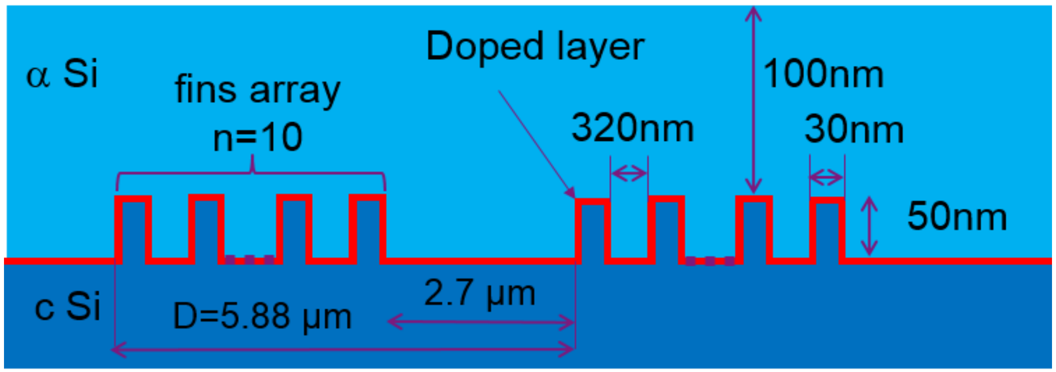


FinFET AsH_3 Doping using PULSION®

FinFET doping requirements for < 10 nm nodes

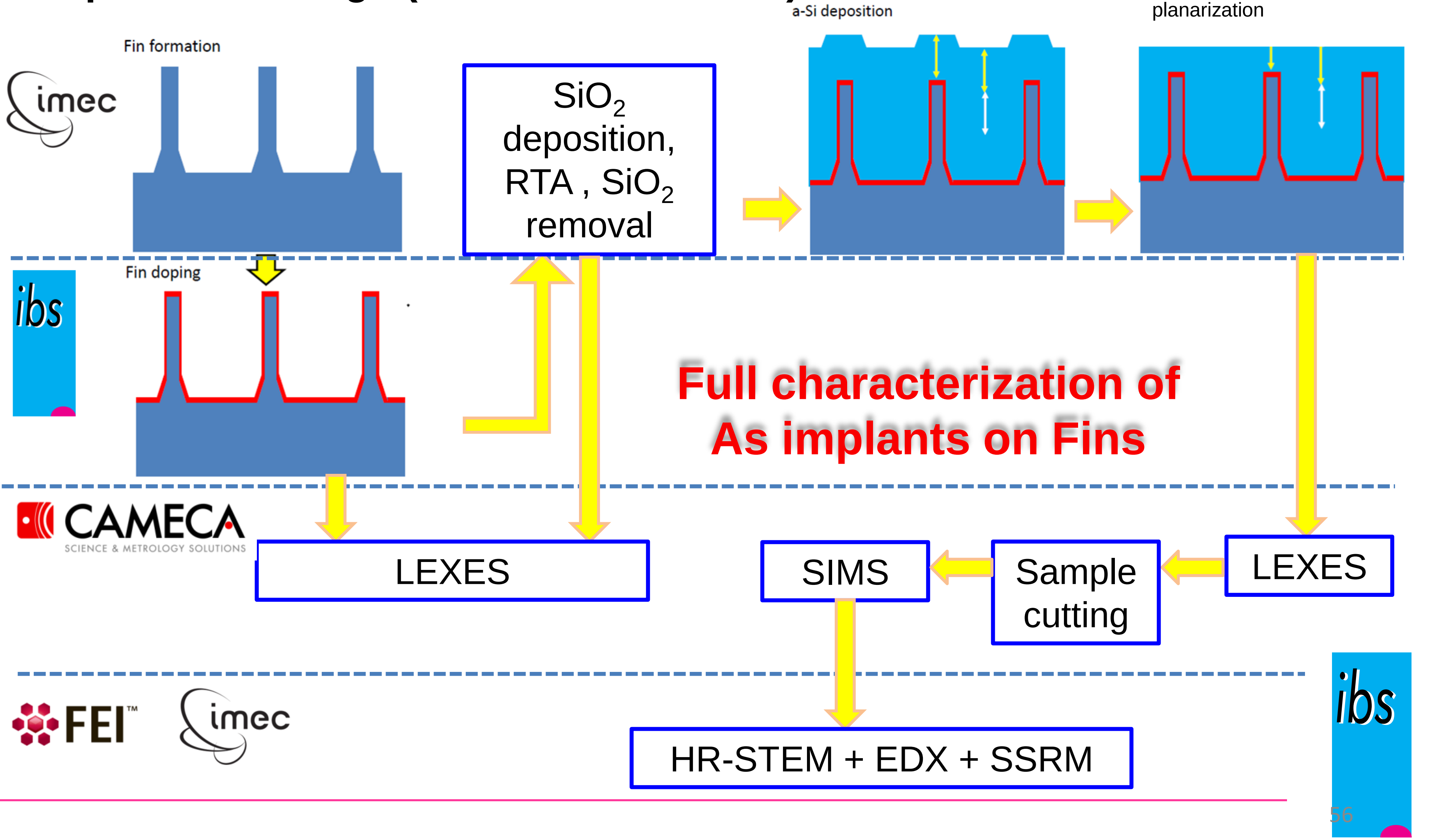
- Ultra shallow junction (< 5 nm)
- Conformal doping
- No Fin erosion
- High retained dose
- Perfect crystal recovery after activation annealing

Tested on the following structure :



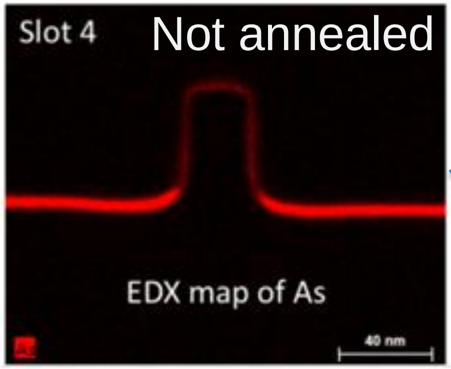
FinFET AsH_3 Doping using PULSION®

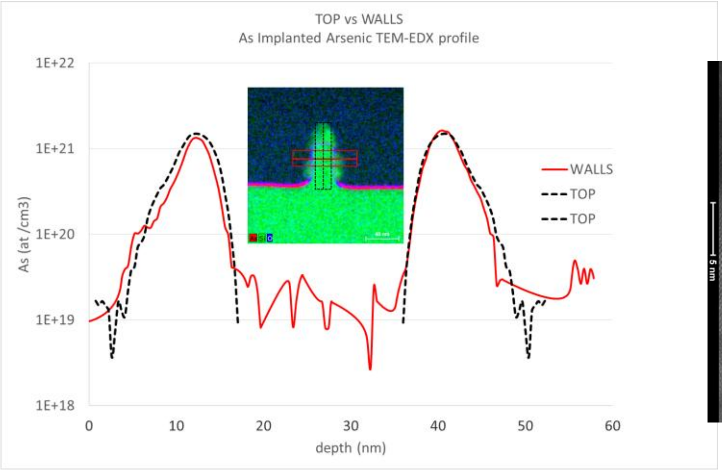
Experiment design (30 nm x 50 nm Fins)

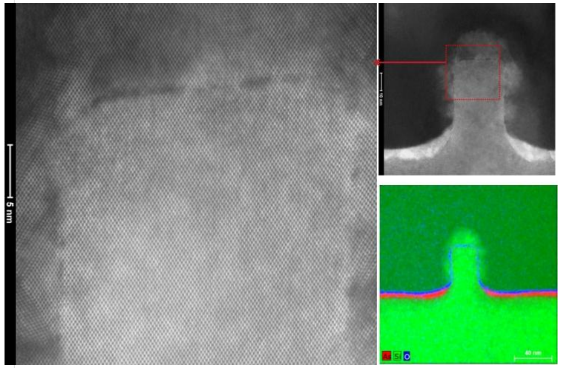


FinFET AsH_3 Doping using PULSION®

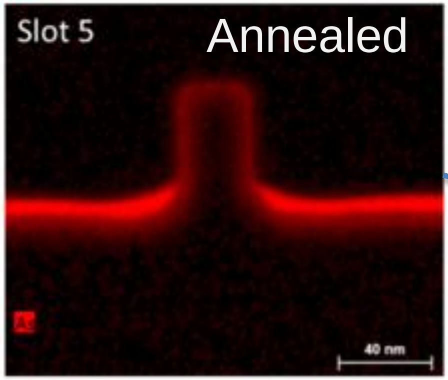
Main results : TEM-EDX

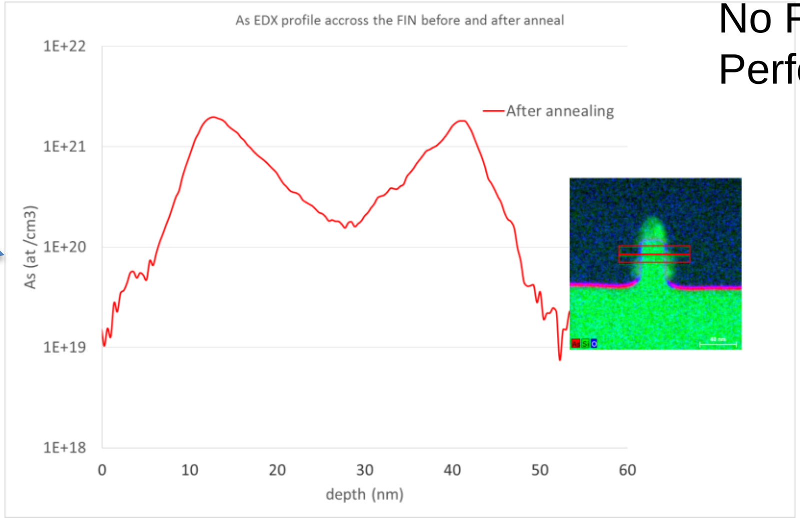






No Fin etching
Perfect cristal regrowth





Very good conformality,
Efficiency of SiO2 cap layer to avoid dose loss

FinFET AsH_3 Doping using PULSION®

Main results :

Sample	SIMS (center)		EDX (center)	
	Dose Top / Sidewall (at/cm²)	Conformality	Dose Top / Sidewall (at/cm²)	Conformality
Slot 4 (as implanted)	8.9E14 / 8.0E14	90 %	7.8E14 / 7.0E14	90 %
Slot 5 (annealed)	2.1E15 / 2.1E15	100 %	1.5E15 / 1.5E15	100 %

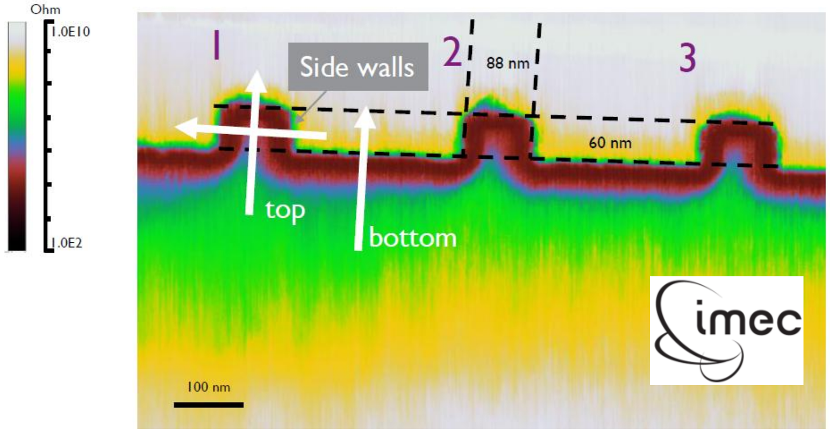
SIMS uses integral deconvolution to calculate As dose at fin top and fin sidewall.

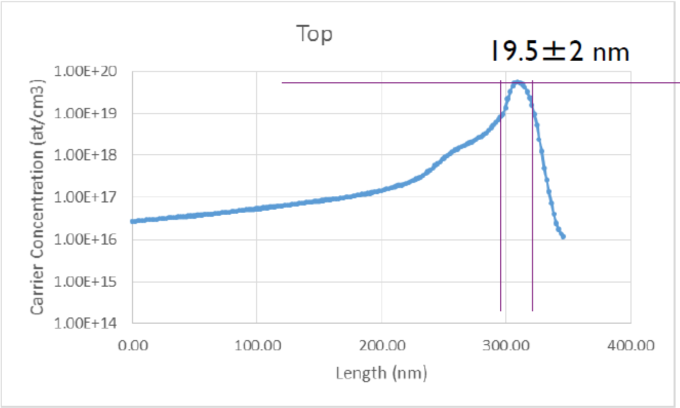
EDX dose is calculated by the integral of the EDX profiles

Very good and coherent conformality were measured

FinFET AsH_3 Doping using PULSION®

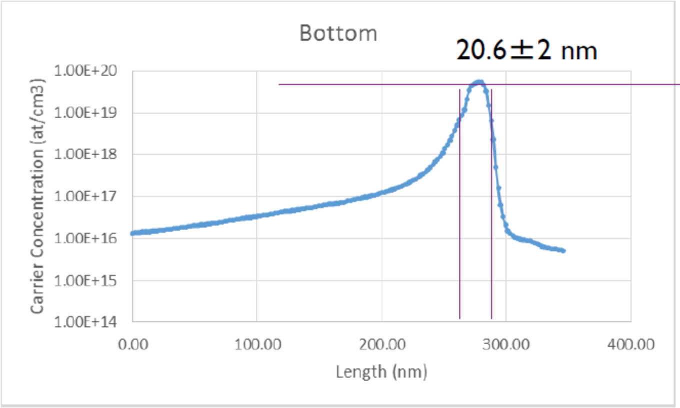
SSRM: (wider structures on the same wafers)





5.6E19/cm3

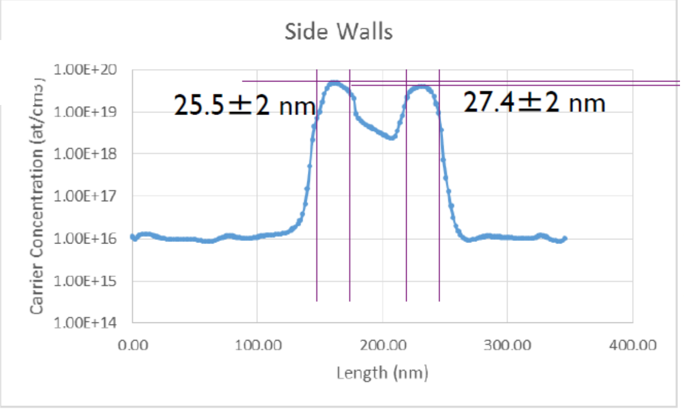
Comments:
Keep in mind SSRM measures active carriers, not dopants. There is a significant difference with SIMS indicating that not all carriers are active.



5.3E19/cm3

Comments:
The calibration was performed using an n-type epi standard and thus the calibration is only valid in the n-type region.

All sections are 10 line smoothed averages



5.0E19/cm3

Comments:
Very small difference observed between top/bottom carriers and side wall carriers.
Good conformality

- Good conformality of active carriers on FIN structures

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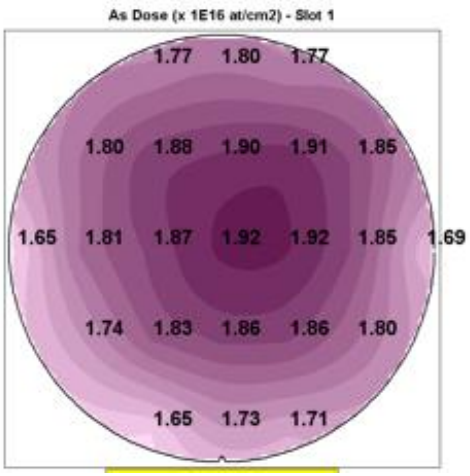
FinFET AsH_3 Doping using PULSION®

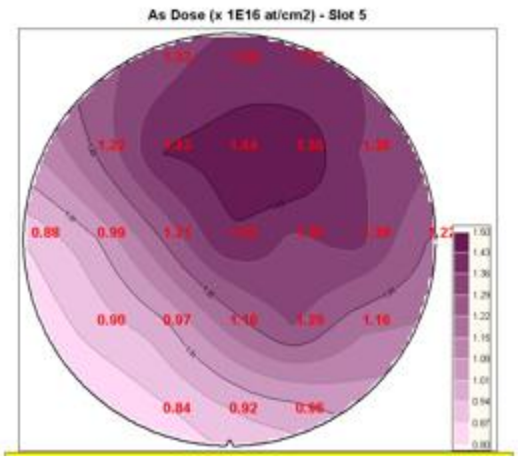
Main results : LEXES dose non uniformity and dose loss

As implanted



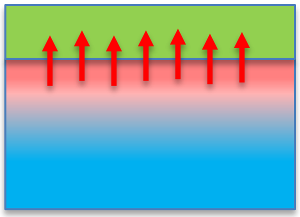
Good non uniformity of PULSION implantation on Fin structured wafers (Non unif < 3%)

After SiO_2 cap dep. / annealing / SiO_2 cap etching

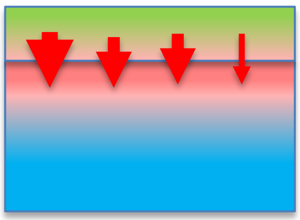


Dose loss (50%) and non uniformity (Non unif = 15%)

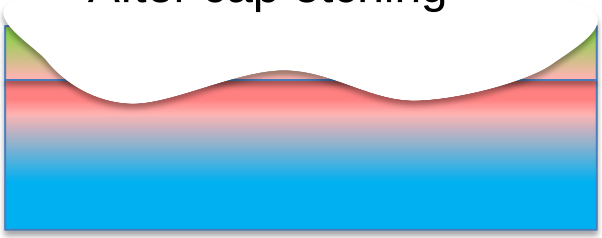
During SiO_2 cap deposition



During annealing



After cap etching



SiO_2 cap layer deposition, annealing and cap etching processes are the main sources of dose loss and non uniformity

FinFET AsH_3 Doping Using PULSION®

Summary :

- AsH_3 PULSION® implantation shows a very good conformality on FIN structures
- No Fin erosion nor crystal defect after annealing was observed
- SiO_2 cap layer is effective to avoid dose loss during annealing and allow high dose retention in silicon.
- SiO_2 cap layer deposition and etching as well as RTA processes must be well controlled not to degrade the good non-uniformity obtained after implantation

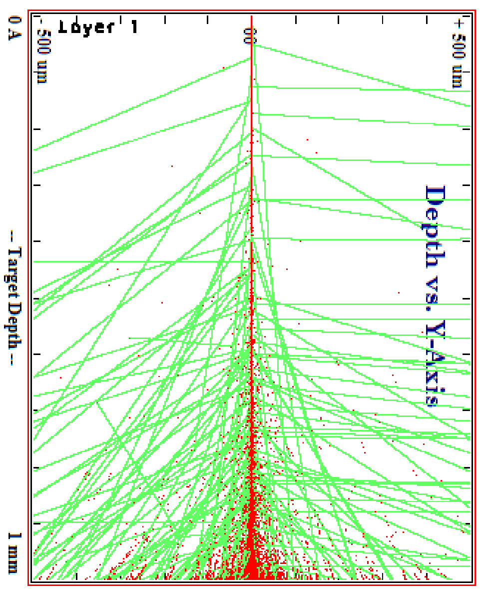
3D PULSION Modeling

Approach n° 1 (very simple) : use of SRIM to implant through a gas layer

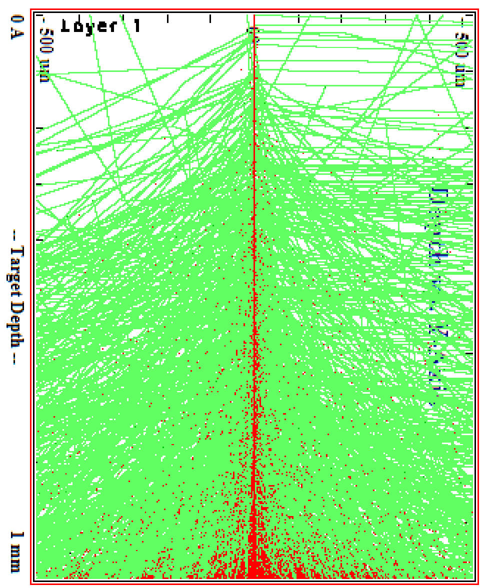
Voltage , plasma density and Pressure → Density and thickness of target layer (the sheath) → SRIM → Energy & angle distribution of each ion

Example for AsH3 plasma : implantation of As at 500 eV through 1 mm of As gas

Pressure : P1



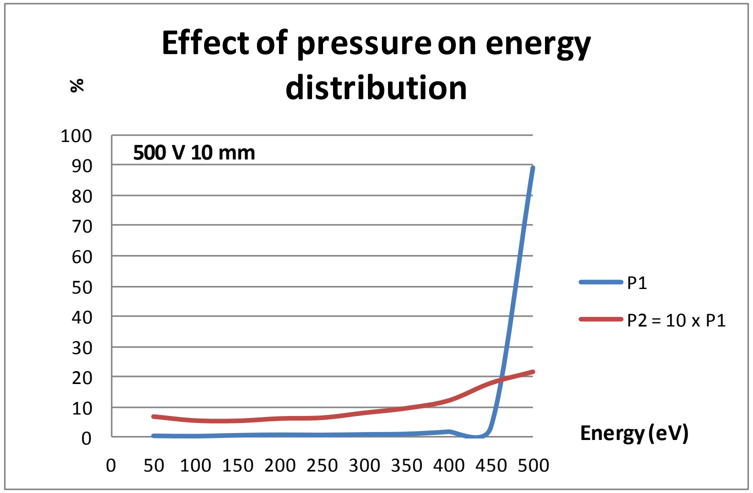
Pressure : P2 =10 x P1

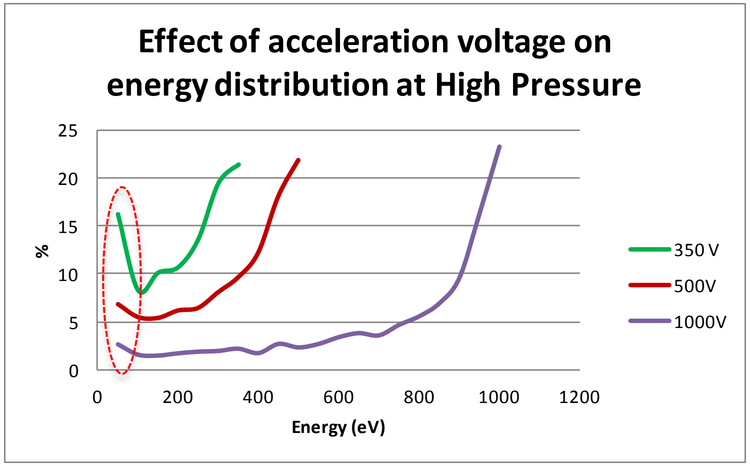


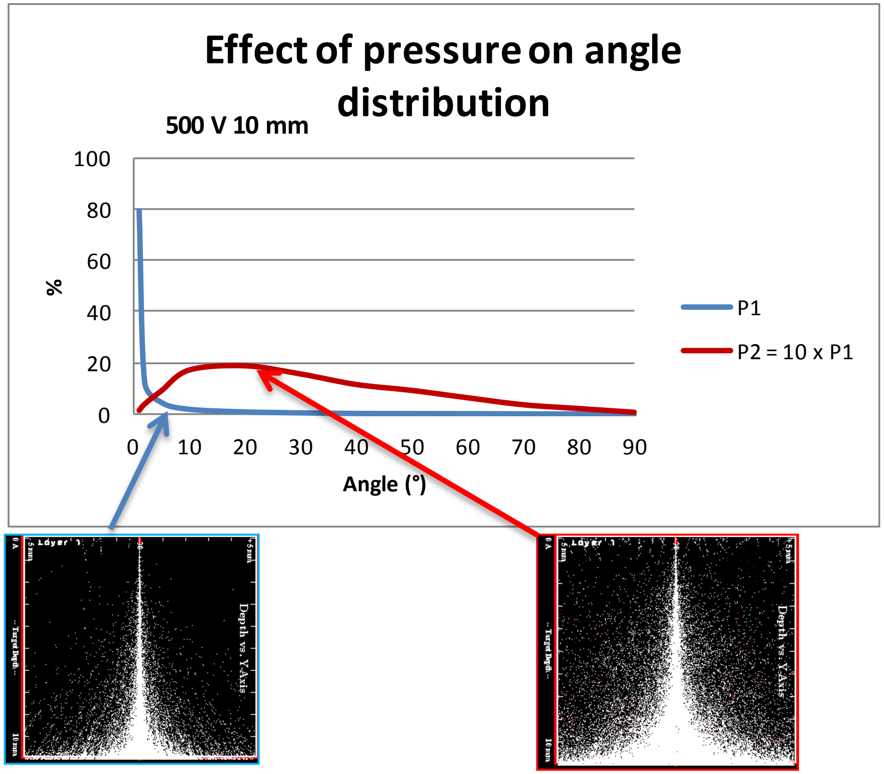
- Scattering of transmitted ions
- Recoil atoms due to colisions

3D Modeling

Some tendencies (AsH3) : Transmitted ions







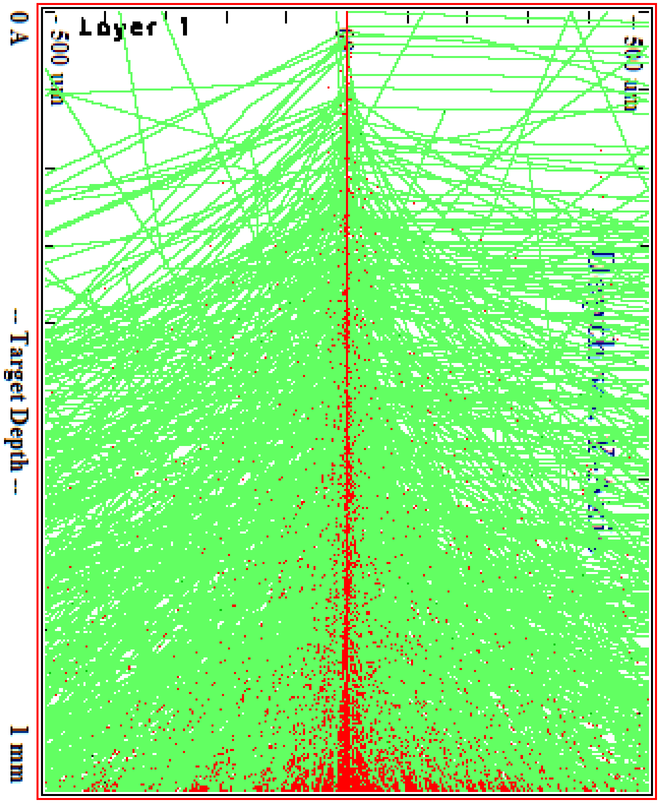
Scattering of transmitted ions
-Angle distribution (3D implant)
-Energy distribution

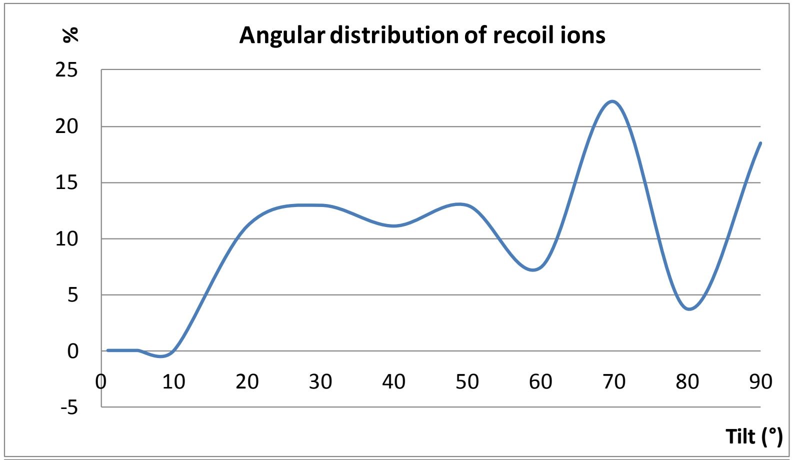
Low energy + high pressure → conformal implantation (and deposition)

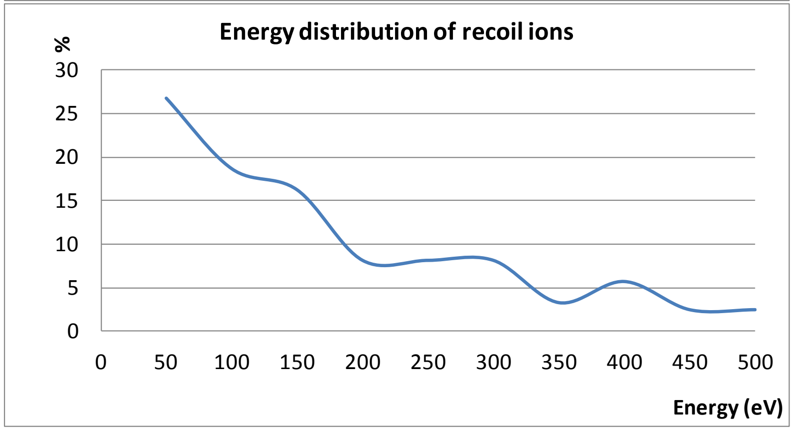
3D Modeling

Some tendencies (AsH3) : Recoil atoms

500V, P2





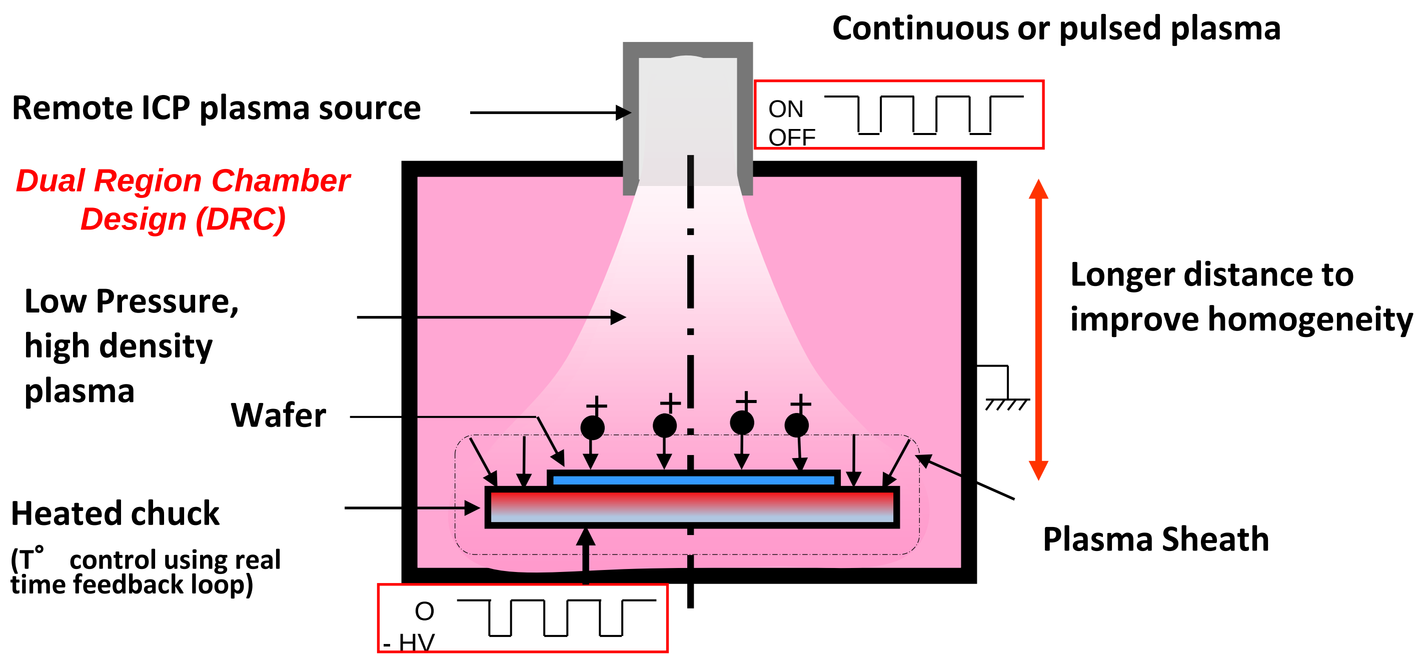


Low energy + uniformaly tilted atoms → conformal deposition

ADVANCED PULSION™ IMPLANT PROCESSES

HOT IMPLANTATION

PULSION® PIII Implanter



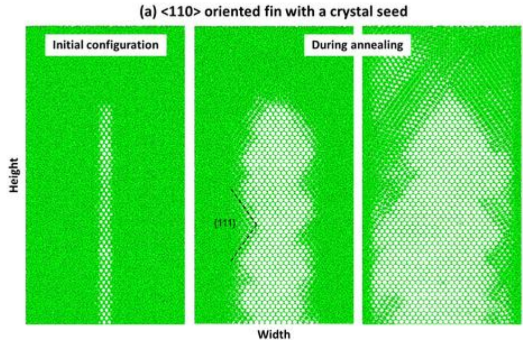
Schematic of PULSION® with high temp chuck option

- Heated chuck with realtime feedback loop to compensate heating by plasma and implant.
- Up to 500° C

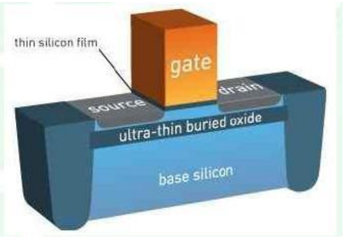
Hot Implantation

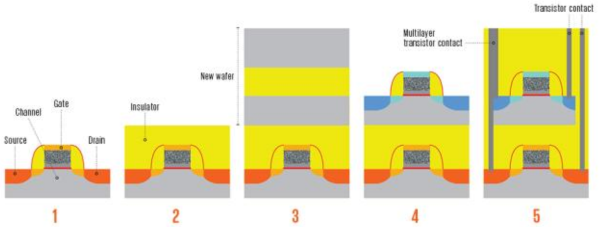
Advanced device requirements for Ion Implantation :

- FinFET : 3D conformal shallow doping + no amorphization of the FIN for good crystal regrowth
- FD-SOI : shallow doping + no amorphization of the Si-Top film to allow crystal Epi regrowth and Epi layer deposition (elevated S/D)
- III-V, SiGe, SiC, Diamond, or other exotic and thermally unstable semiconductor : need to reduce defects during implant to limit thermal budget of post implant annealing
- 3D integration : Need to reduce thermal budget for activation and crystal recovery after implantation



L. A. Marqués et al., J. Appl. Phys. 111, 034302 (2012)





PIII + hot implantation

= PULSION® with high temp. option

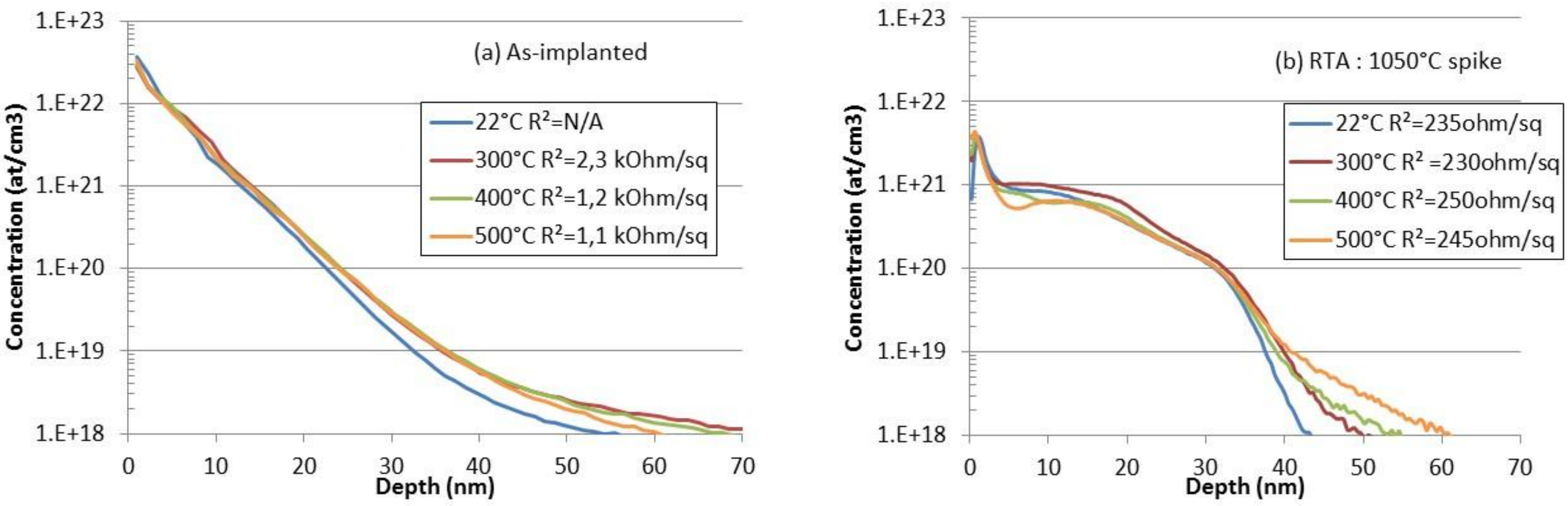
High Temp Implant Summary

- Up to 500° C Plasma Immersion Ion Implantation is now available on PULSION® and has been qualified using AsH_3 plasma
- High temperature PIII implant allows drastic reduction of the thickness of amorphous layer after Arsenic implantation, even at high dose.
- Hot implantation induces 10% deeper profile (also observed on beam line) due to enhanced diffusion of interstitials and vacancies during implant and channeling.
- Partial activation is observed after high temperature implantation even at 300° C, but after annealing sheet resistance does not depend on implant temperature if the as-implanted retained dose is the same.
- No big differences are observed between 400° C and 500° C implantations.

→ Application for FINFET doping and FD-SOI is under study (Places2Be European project)

Experiment 1 : AsH_3 10 kV high dose

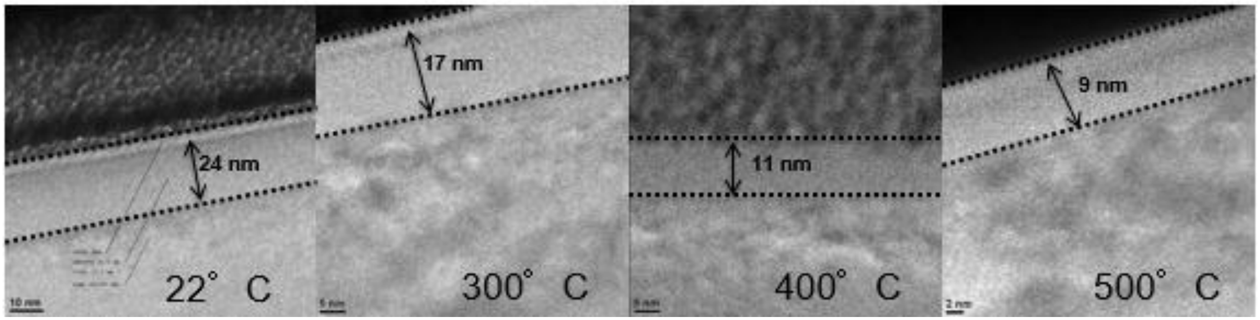
For the same as-implanted retained dose (~ 1.2 E16 /cm²)

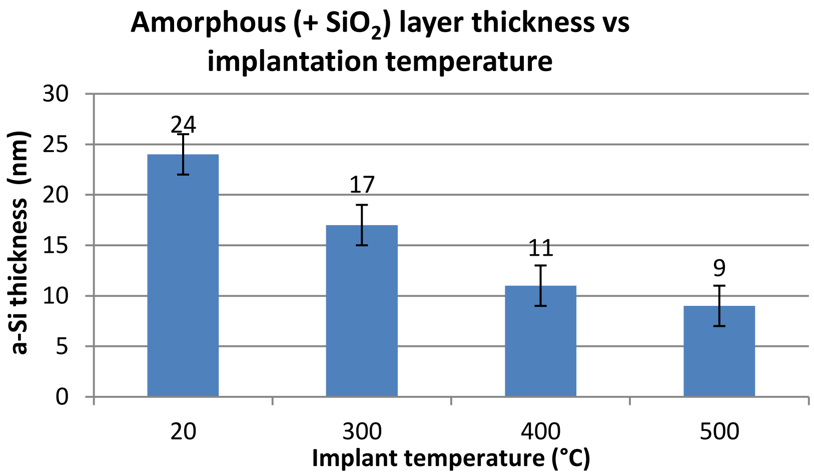


- After implant :
  - High temp implant are ~ 10% deeper
  - Same "channeling" tail for samples implanted at high temp.
- After annealing :
  - no big difference in profile above 1E19/cm³
  - below 1E19/cm³ the tail increases with implant temperature

Experiment 1 : AsH_3 10 kV high dose

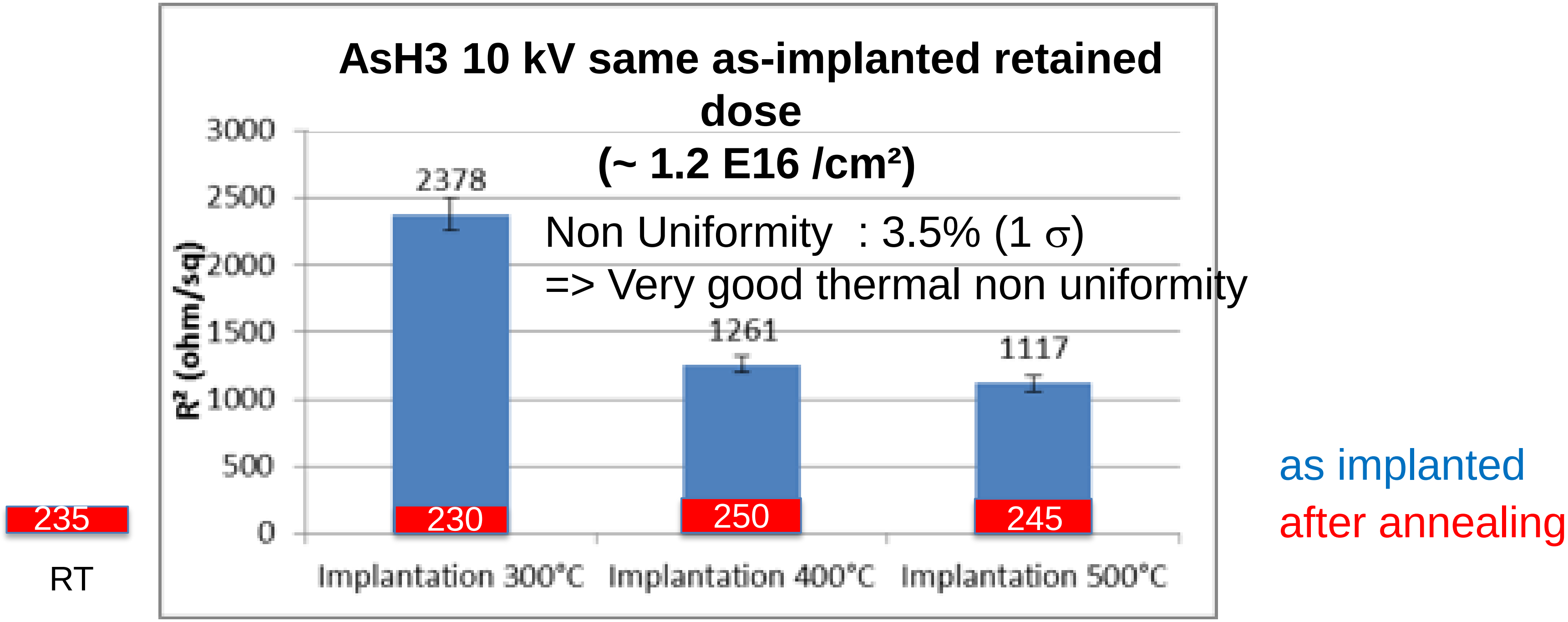
TEM images and thickness measurement of the amorphous layer on as implanted samples as a function of implant temperature





- Important reduction of the amorphous layer thickness is observed when implanting above 400° C

Experiment 1 : AsH_3 10 kV high dose



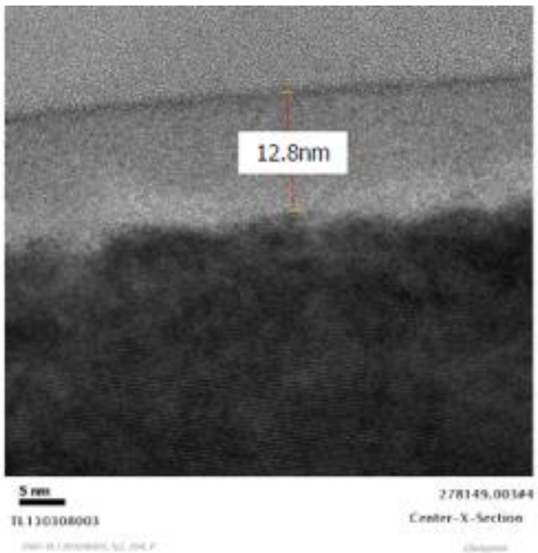
- Partial activation is observed just after implantation when implanting at high temperature
- No significant change of the sheet resistance after annealing
  ~ (240 +/-10) Ω/sq regardless of implantation temperature

➢ Possible to make high dose As implantation (~ 1.2 E16 /cm²) on 30 nm with only 9 nm amorphous layer (without affecting final sheet resistance)

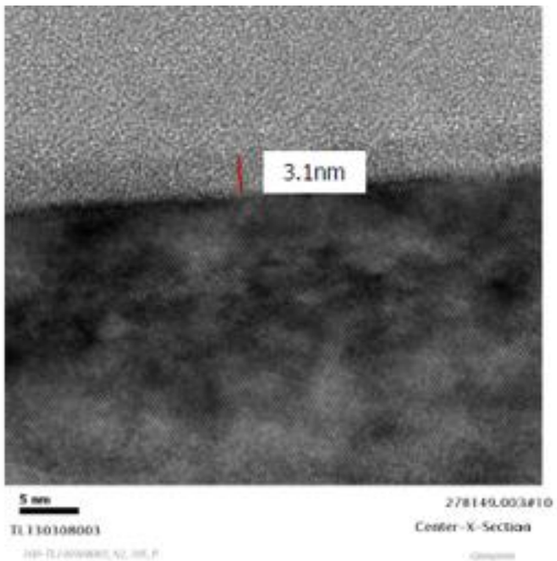
Experiment 2 : AsH_3 10 kV lower dose ($2^E15/cm^2$)

TEM on as implanted wafers (20 nm implant depth)

RT



500° C



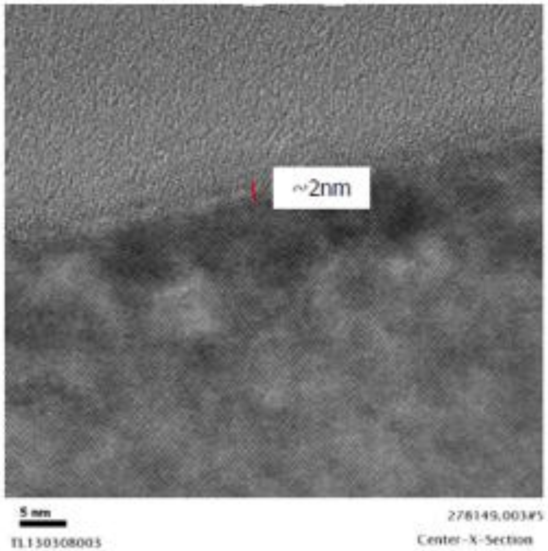
	Room T°	500°C
Amorphous layer thickness (as implanted)	12.8 nm	3.1 nm

- Drastic reduction of the amorphous layer thickness

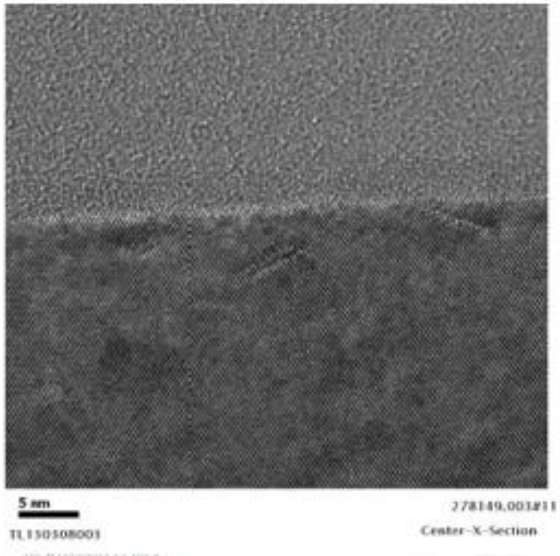
Experiment 3 : AsH_3 1 kV $2^{E}15/cm^2$

TEM on as implanted wafers (7 nm implant depth)

RT



500° C



	Room T°	500°C
Amorphous layer thickness (as implanted)	2 nm	0 nm

- Suppression of the amorphous layer
- Some remaining defects are visible

ADVANCED PULSION™ IMPLANT PROCESSES

FDSOI

ADVANCED PULSION™ IMPLANT PROCESSES

III-V DOPING

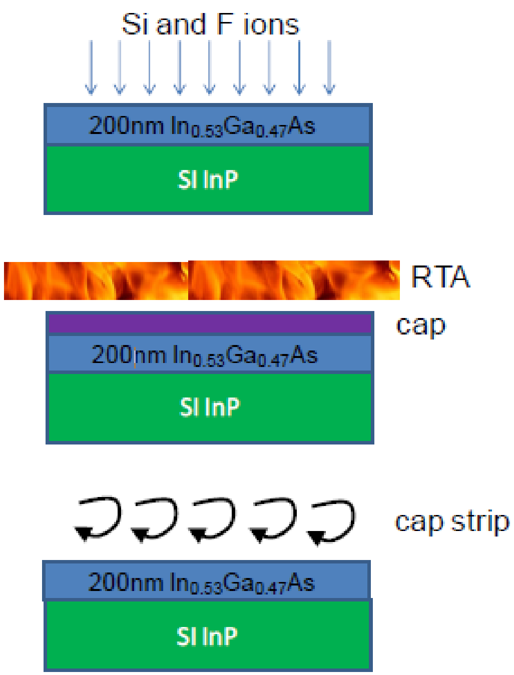
III-V (InGaAs) doping

Challenges for III-V doping :

- Very sensitive to implant defects
- Limited thermal budget allowed for post-implant annealing
- USJ and 3D doping needed

Process Steps for III-V Samples

- 200nm InGaAs on semi-insulating InP
- Pulsion Implant
  - Si plasma doping
  - SIMs for samples without Anneal
- Cap deposition
- RTA Soak Anneal
  - 500 ~ 800°C, 30s
- Cap
  - DHF (1:100), 5mins
- Physical Analysis

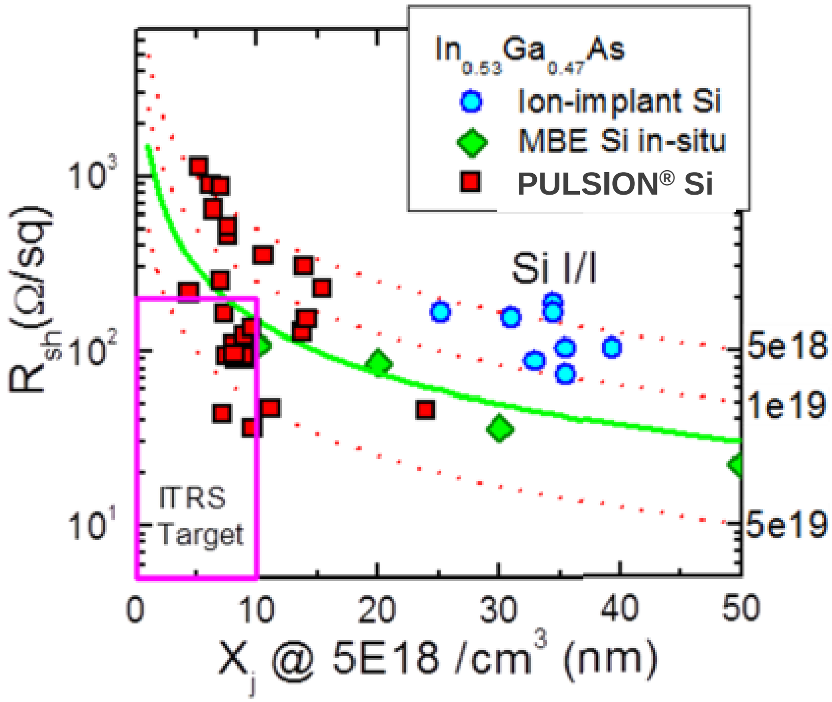


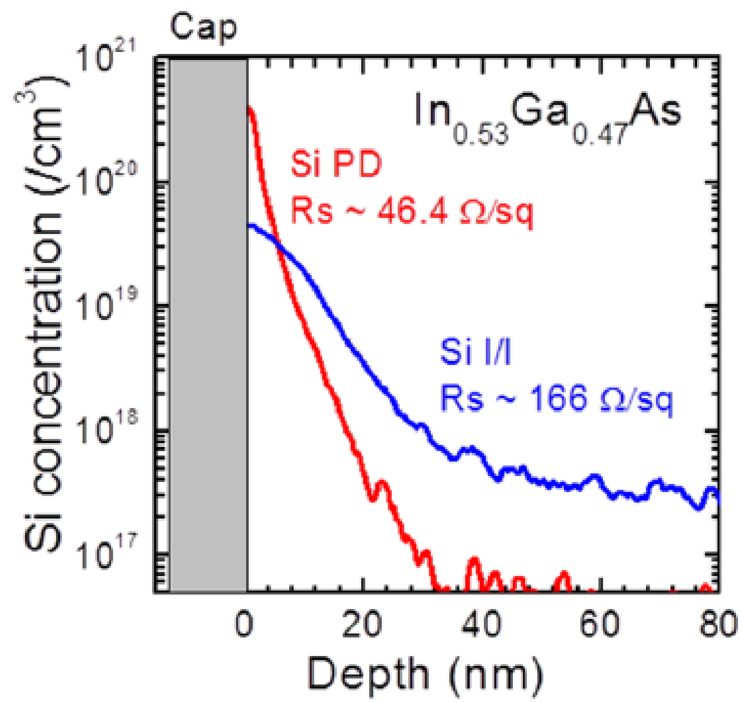
Study using PULSION® doping:

- Test of different Silicon containing plasmas
- Test of different plasma and implant conditions

III-V (InGaAs) doping

Some results :





- Si PULSION® doping results in significantly shallower junction depth and higher dopant incorporation compared to ion-implantation and in-situ doping technique (MBE)

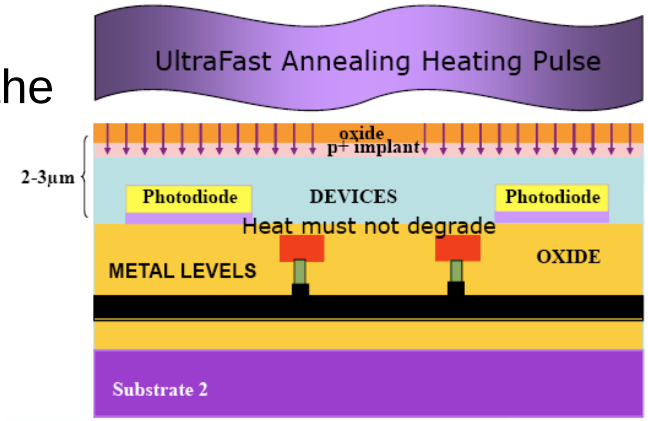
- High dependency of Rsq and mobility on Si precursors and process conditions

CMOS IMAGER

CMOS imager – BSI back side doping

Passivated layer by implant and laser annealing:

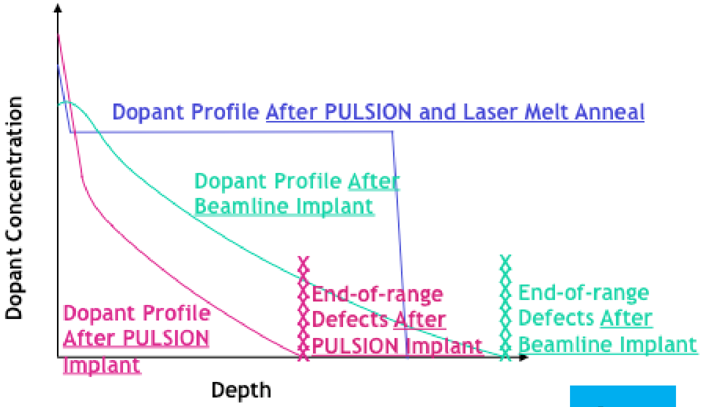
- Minimize recombination of electron-hole pairs at the backside surface
  - Reflect photo-electrons back to photodiodes to increase charge collection efficiency
- Minimize dark current created by residual implant damage after anneal
  - Reduce number of hot pixels
- Temperature rise from anneal must be <400° C at metal levels (--> laser anneal)



ST Microelectronics, H. Bourdon et al., RTP 2007 Conference (IEEE)

PULSION™ Advantages:

*1. Shallower implant profile keeps all dopants and defects into melted area: few residual defects, and **lower dark current** (leakage)*
*2. Ultra-low implant energy with **zero high-energy contamination**: minimize dead layer*
*3. Lower energies available while keeping **higher throughput***



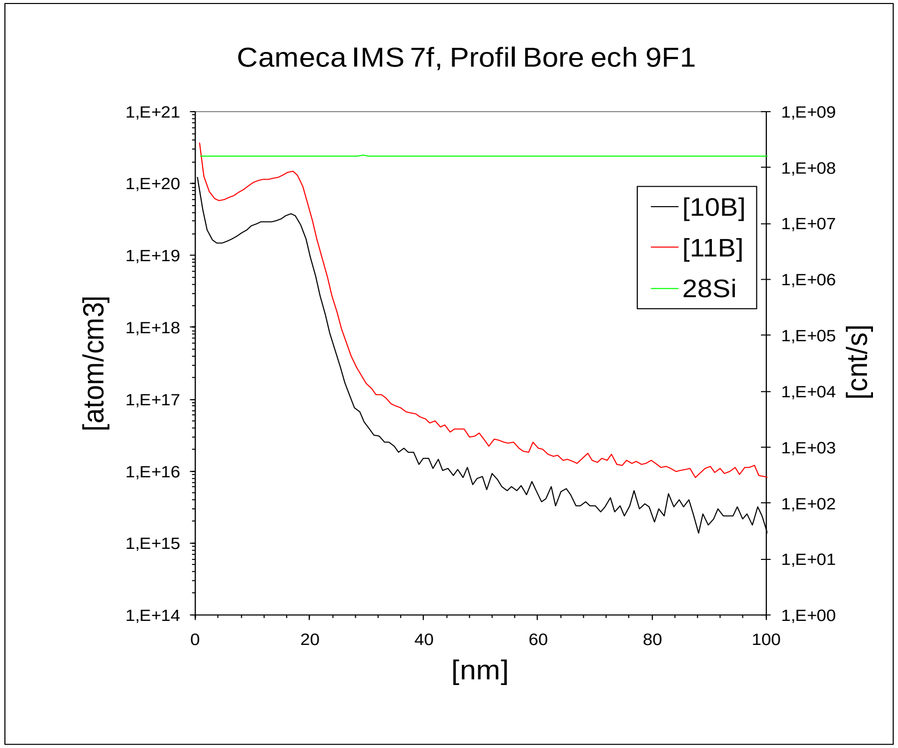
Pulsion + Laser annealing

Applications :

-Doping processes for backside applications (**Cmos imagers**, thin substrates, sensors, power devices, security...)

-Doping processes for advanced materials (SiC, III-V, SiGe…)

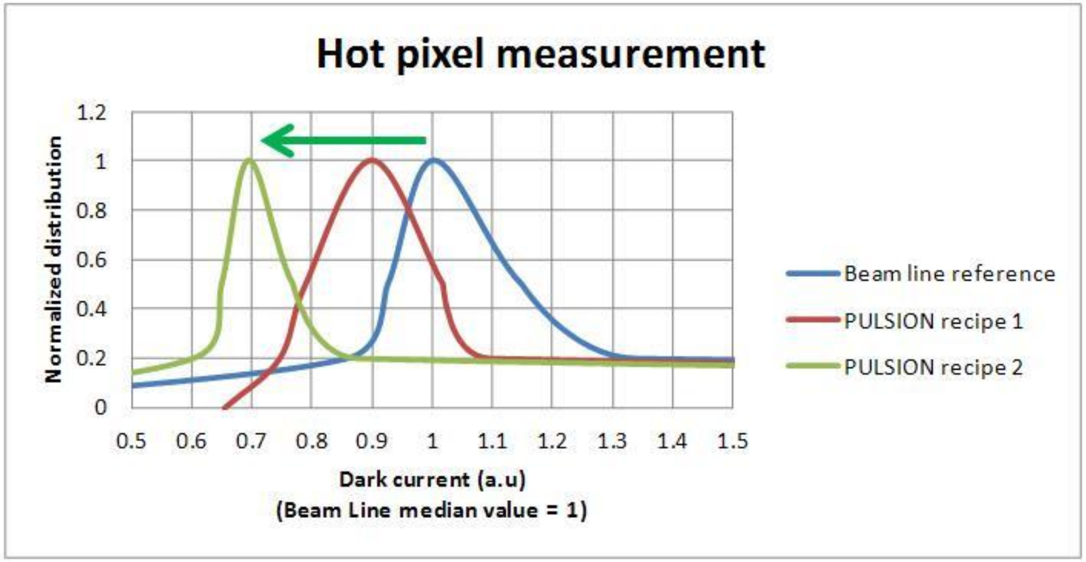
-Develop doping processes for advanced microelectronics (32-22nm nodes)



Example :
SIMS profile of a CMOS BSI doping PULSION BF_3 + laser anneal

CMOS Imager Application : BSI

- **Application to CMOS imager (BSI) :** IBS / Customer A
  - PULSION Boron implantation
  - Laser anneal



Normalized results from customer feedback

Dark current reduction : 30%
This is due to the fact that the implant depth is ultra shallow and that PIII creates less defects than beam line
=> All the Implant defects are suppressed by the laser annealing

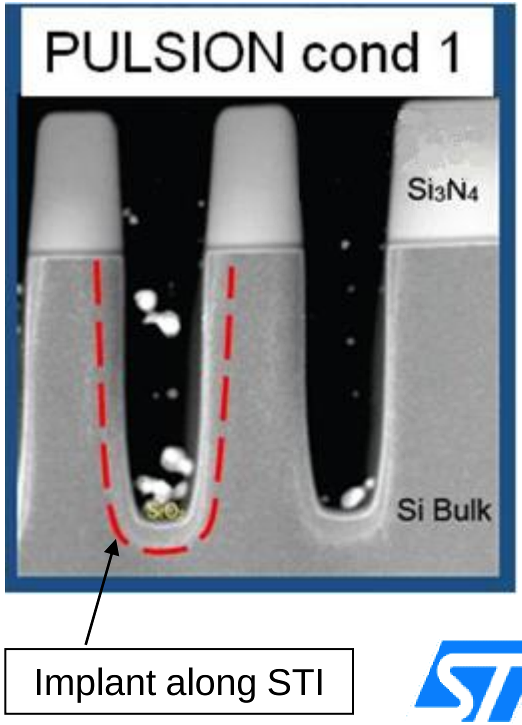
CMOS imager - STI trench doping

<u>STI doping requirements:</u>

- Shallow, conformal doping around STI (Shallow Trench Isolation)
- Screen defective sidewalls and edges of STI from depletion region of photodiode
- Frontside CMOS imager application

PULSION™ Advantages:

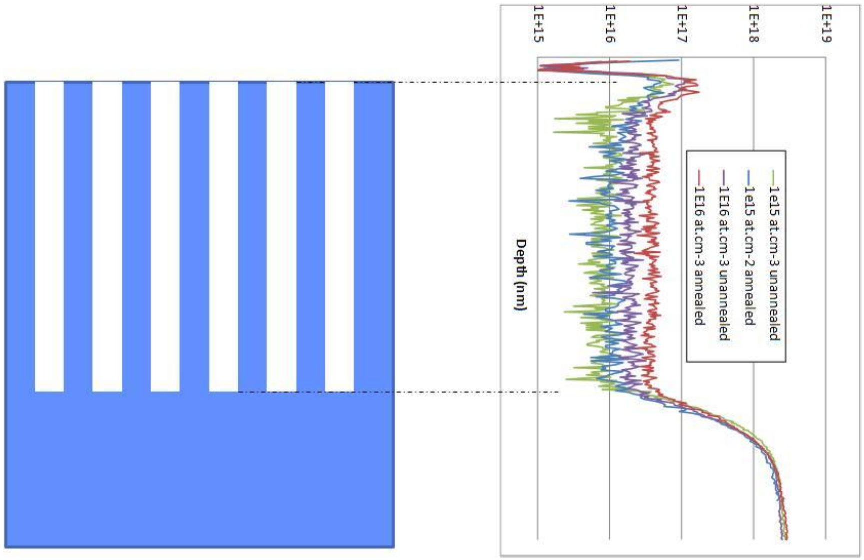
*1. **Conformal doping** with single wafer placement*
2. "Dual or Quad implants" and similar beamline techniques are not effective
*3. Higher dose capability for **dark current improvement**, while keeping high throughput*



Real Devices
Conformal doping along STI

CMOS Imager Application : DTI Trench doping

- **Application to CMOS imager (DTI) :** IBS / STM



Several µm

Test structures: 20/1 form factor
Uniform doping on the trench walls demonstrated
Possibility to adjust doping concentration along the wall

Atemox European R&D project

CMOS Imager Doping Summary

- PULSION is an efficient solution for Boron USJ doping before laser anneal for BSI Application

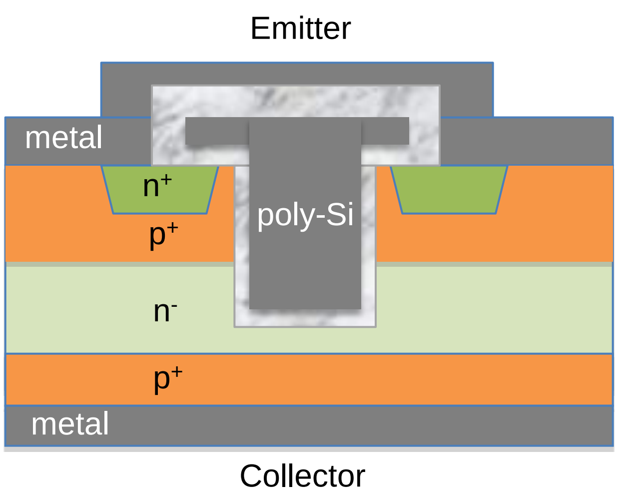
- PULSION can do uniform and conformal trench doping for DTI application (20:1 form factor)

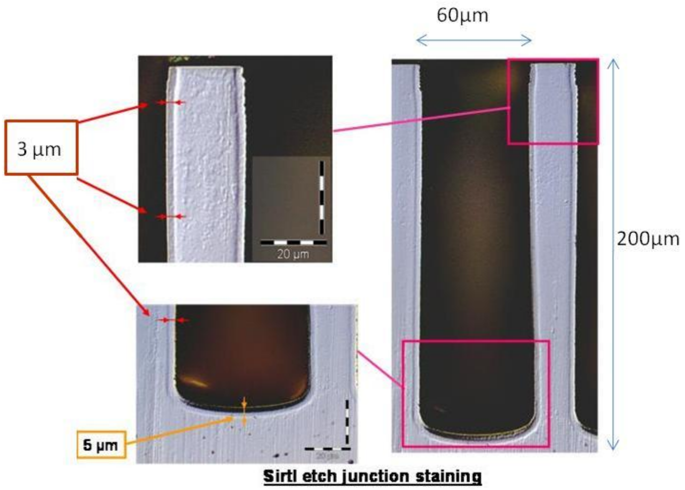
POWER DEVICES

Poly doping for Cool Mos Application

Studied application (with 2 different customers in Europe)

- Poly doping for Cool Mos Application (Boron and Phosphorus)
- Super junction for Cool Mos (low dose, 3D with high aspect ratio)
- SFET plug contact doping (3D trench doping)
- IGBT : backside doping / trench doping





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

MATERIAL MODIFICATION

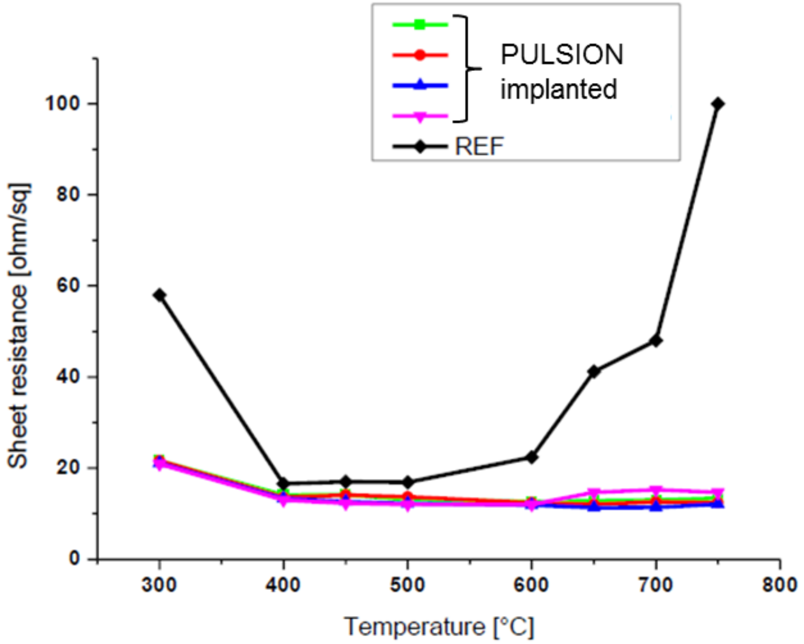
Experiment - Silicidation Improvement (NiSi)

Substrate
- 300 mm P-type wafers

PULSION® Implantation
- Dose & Energy split (confidential)

Silicidation
- 6 nm Ni deposition
- Annealing 300°C to 750°C during 10 s.
- 96%N2+4%H2

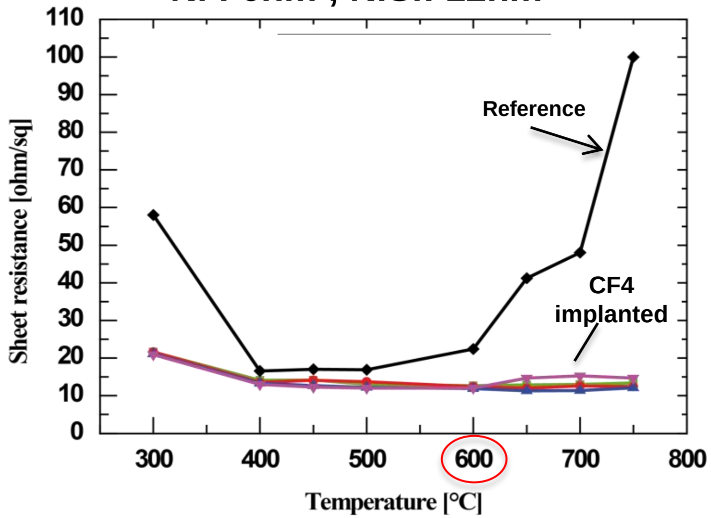
Characterization
- Sheet resistance measurement



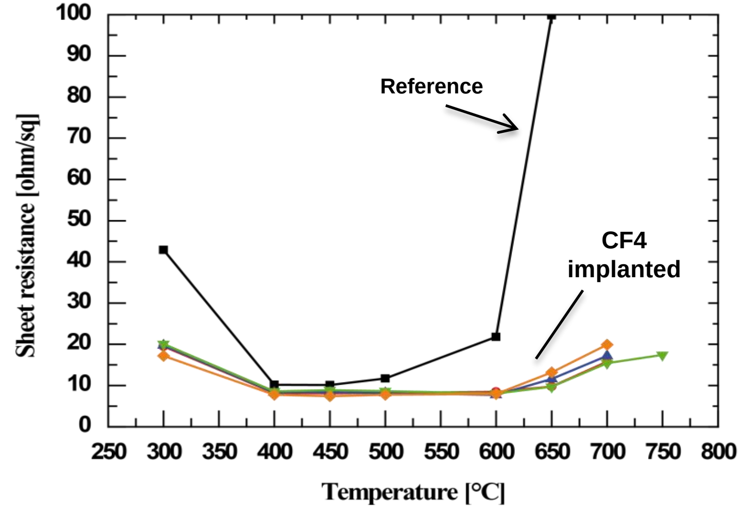
- Improved thermal stability and lower sheet resistance on all PULSION® implanted samples
- No differences between the conditions used : very stable process

Thermal stability : Sheet resistance measurement

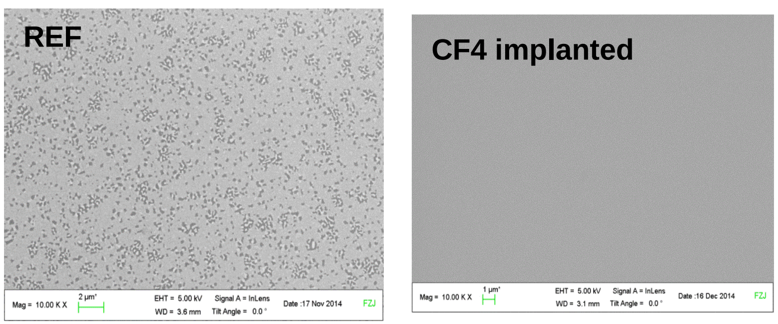
Ni : 6nm ; NiSi: 12nm



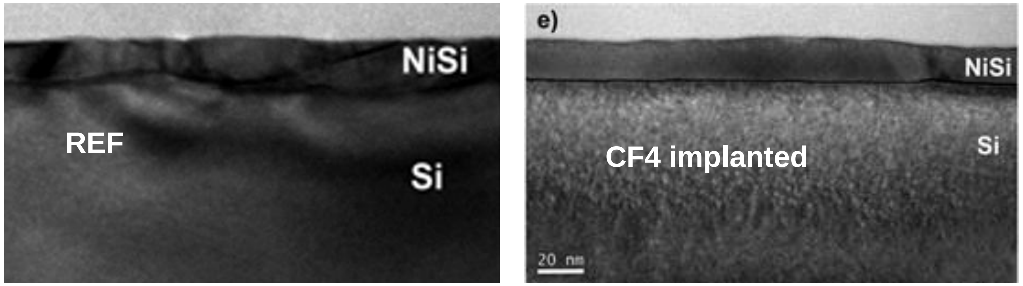
Ni : 8nm ; NiSi :18nm



SEM pictures of the surface for 600° C



TEM pictures of the interface for 600° C

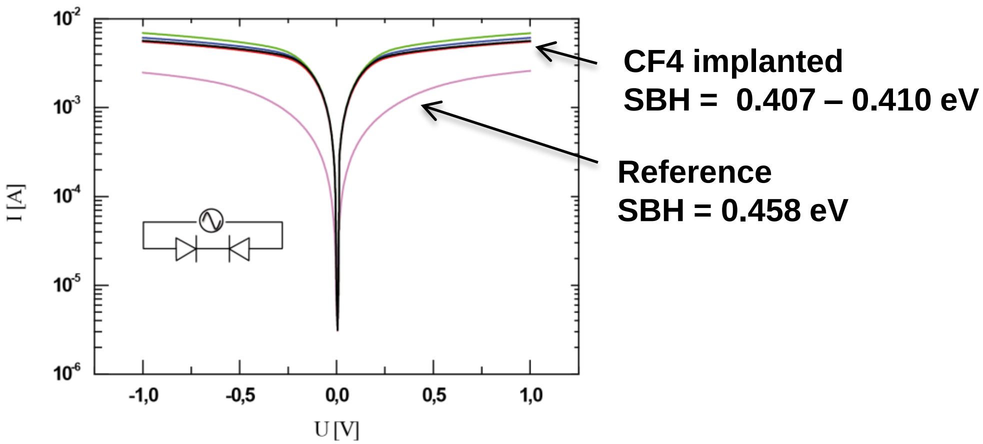


- Enhanced of sheet resistance and thermal stability after CF_4 PULSION®
- Suppression of surface agglomerates
- Improvement Si / NiSi Interface and NiSi thickness uniformity

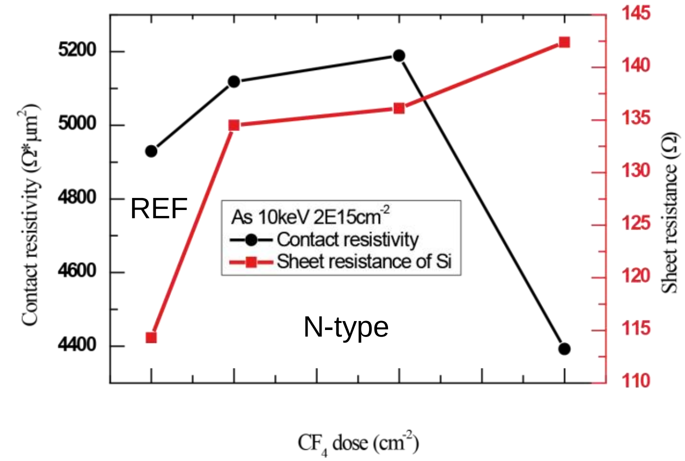
Haitao Zhang[1], Julian Duchaine[2] at al. : IITC MAM 2015 :
Improved NiSi contacts on Si by CF4 Plasma Immersion Ion Implantation for 16nm node MOSFETs

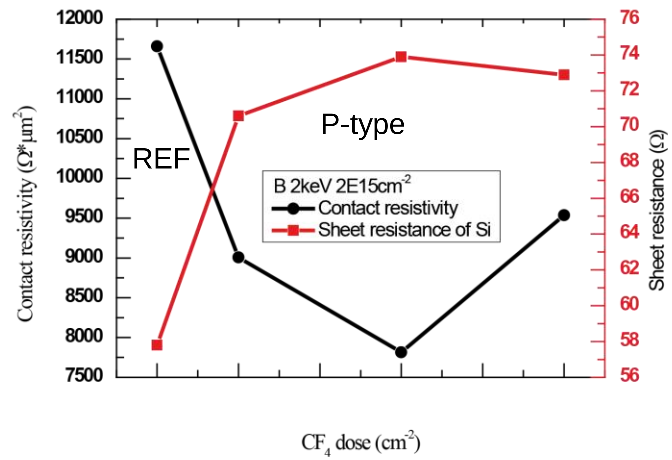
Shotcky Barrier Height and Contact resistance

I-V characteristics of two back-to-back NiSi/p-Si Schottky diodes at room temperature



Contact resistance on p and n type implanted silicon (TLM)





- Lower SBH after CF_4 PULSION® implantation
- Better contact resistance
  - -15% for N type
  - -30% for P type
- But increase of Si sheet resistance
  - +21% for P and N type

Under optimization …

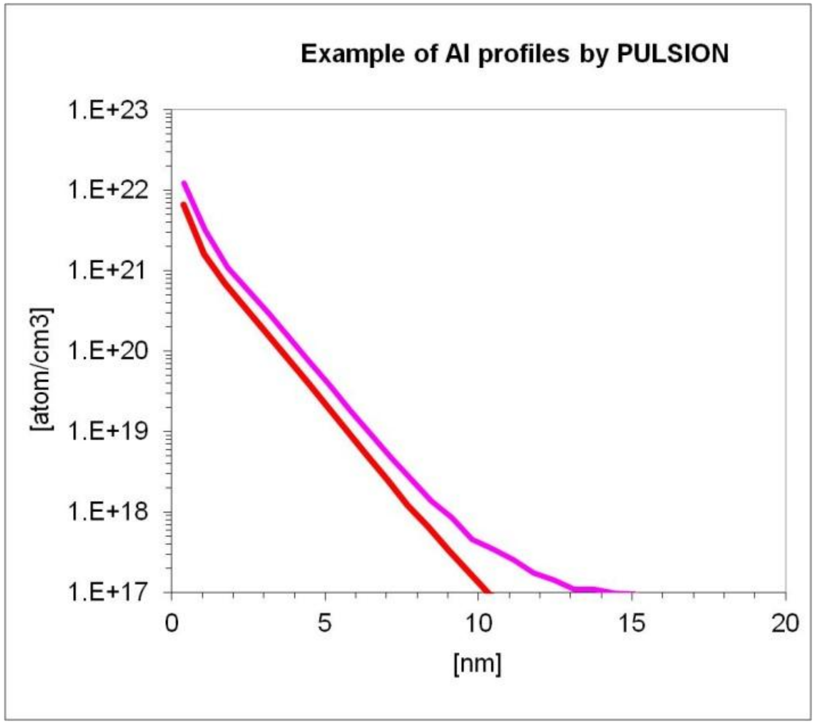
Haitao Zhang[1], Julian Duchaine[2] at al. : IITC MAM 2015 :
Improved NiSi contacts on Si by CF4 Plasma Immersion Ion Implantation for 16nm node MOSFETs

Vth Tuning for metal gate

Al implantation using TMA :

- In progress
- First demos have been done with 2 customers

Up to 130 mV Vth shift observed



THANK YOU FOR INVITING IBS TO PROVIDE THIS UPDATE