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

Extract of ITRS 2005 roadmap
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
Energy range
- Extremely low to medium range energy

Substrate size
- From samples, up to 300mm

Small footprint
- 4 to 7 m²

Low cost doping
**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 source
- Easy ignition of low elements (H2)
- Wide range of working pressure (down to $5 \times 10^{-5}$ 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 substrate

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

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

= no charge induced defects
Low metallic contamination (Si coated substrate holder)
- \( K, Ca, Na < 10^9/cm^2 \)
- \( Ti, Cr, Fe, Co < 10^{10}/cm^2 \)
- \( Others < 10^{11}/cm^2 \)

Uniformity and reproducibility
- \( \sigma = 2.5\% \) on 200 mm (BF3 0.5 kV 3000 \( \Omega/sq \) )
- \( \sigma = 1.2\% \) on 200 mm (BF3 10 kV 50 \( \Omega/sq \) )

Throughput
- BF3 100 to 500 V, \( 1.10^{15} \) on 300mm = 80 Wafers/h
  (expected with one process chamber)
Metallic contamination

TXRF measurements on 200 mm wafers.
PULSION BF$_3$ 500eV vs NV-8200P BF$_2$ 3keV

![Bar chart showing TXRF measurements for various elements (Ti, Cr, Fe, Co, Ni, Cu, Zn) with PULSION, BEAM LINE IMPLANTER, and TXRF detection limits.](image-url)
Metallic contamination

ToF-SIMS results

<table>
<thead>
<tr>
<th></th>
<th>BF3 implantation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Edge</td>
<td>Center</td>
</tr>
<tr>
<td>Ni</td>
<td>1.7E+11</td>
<td>9.3E+10</td>
</tr>
<tr>
<td>Cu</td>
<td>3.4E+11</td>
<td>8.2E+10</td>
</tr>
<tr>
<td>Al</td>
<td>6.2E+10</td>
<td>3.9E+10</td>
</tr>
<tr>
<td>Sn</td>
<td>1.3E+10</td>
<td>1.0E+10</td>
</tr>
<tr>
<td>Fe</td>
<td>1.1E+10</td>
<td>5.5E+09</td>
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<tr>
<td>Cr</td>
<td>3.7E+09</td>
<td>3.4E+09</td>
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<tr>
<td>Mg</td>
<td>3.9E+09</td>
<td>2.5E+09</td>
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<tr>
<td>Na</td>
<td>3.3E+09</td>
<td>2.6E+09</td>
</tr>
<tr>
<td>In</td>
<td>3.1E+09</td>
<td>1.9E+09</td>
</tr>
<tr>
<td>Ti</td>
<td>2.4E+09</td>
<td>1.4E+09</td>
</tr>
<tr>
<td>K</td>
<td>5.5E+08</td>
<td>3.6E+08</td>
</tr>
<tr>
<td>Co</td>
<td>&lt;1.4E9</td>
<td>1.7E+09</td>
</tr>
<tr>
<td>Ca</td>
<td>3.1E+08</td>
<td>2.1E+08</td>
</tr>
<tr>
<td>Li</td>
<td>4.8E+07</td>
<td>3.7E+07</td>
</tr>
<tr>
<td>Ag</td>
<td>1.2E+10</td>
<td>5.0E+09</td>
</tr>
<tr>
<td>Cl</td>
<td>9.8E+11</td>
<td>1.1E+12</td>
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<tr>
<td>S</td>
<td>3.4E+12</td>
<td>4.6E+12</td>
</tr>
<tr>
<td>B</td>
<td>1.0E+14</td>
<td>9.0E+13</td>
</tr>
<tr>
<td>F</td>
<td>1.2E+12</td>
<td>1.2E+12</td>
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</table>
Homogeneity on USJ
Sheet resistance measurements (PULSION vs Beam Line Implanter)

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

(IBS / QCsolution collaboration)

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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® BF3 20V to 2 kV)

ULTRA SHALLOW JUNCTIONS.
SIMS profiles of PULSION-ULE BF3, 1E15/cm², 20eV to 2keV.

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USJ : Implantation profiles

\[ X_j = f(E) \] (BF3 1E15/cm²)

- \( X_j \) proportional to \( E \) for \( E > 500 \text{ eV} \)
- SIMS saturation effect for \( E < 100\text{eV} \)
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)

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PULSION + Annealing
On going studies

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

**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
Effect of PAI on boron profile in as-implanted condition

Effect of PAI on Boron profile

Ge affects on the boron profile
$X_J \downarrow$ with PAI
Elimination of the channelling effect
Effect of acceleration voltage on boron profile after annealing

<table>
<thead>
<tr>
<th>AV (kV)</th>
<th>$X_J$ (nm)</th>
<th>$R_{sq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>1014</td>
</tr>
<tr>
<td>1.5</td>
<td>33</td>
<td>562</td>
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<tr>
<td>2</td>
<td>48</td>
<td>235</td>
</tr>
</tbody>
</table>

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$\Rightarrow$ Acceleration voltage $\Rightarrow$ $X_J$ $\Rightarrow$ $R_{sq}$
Effect of laser fluence on boron profile after LTP

Boron SIMS Profile PULSION 1 kV WITHOUT PAI

Laser fluence \( X_J \) \( \rightarrow \) Rsq

<table>
<thead>
<tr>
<th>Laser fluence</th>
<th>( X_J ) (nm)</th>
<th>Rsq</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>24</td>
<td>729</td>
</tr>
<tr>
<td>500</td>
<td>30</td>
<td>593</td>
</tr>
<tr>
<td>600</td>
<td>34</td>
<td>498</td>
</tr>
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</table>

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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
- $R_{sq} = 593$ Ω/sq
- $I_L = 1E-7$ A/cm²

**WITH Ge PAI**

- Activation threshold: 450 mJ/cm²
- $X_J = 23$ nm
- $R_{sq} = 561$ 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®

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)
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 improvement

- Same diffusion length as classical solar cell \( \Rightarrow \) no metal contamination
- Higher sensitivity in low wavelength range

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

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Hydrogenation

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

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CAMECA IMS5f  Sample name : 1H (25keV-5E16)  
MIL-1H-23&240804-Cs1.dp

- dose \(^1\text{H} = 4,7 \times 10^{16} \text{ at/cm}^2\)

\[ [\text{X}] \text{ atoms/cc} \]

\[ \text{depth (nm)} \]

1E+23 1E+22 1E+21 1E+20 1E+19 1E+18 1E+17 1E+16

0 100 200 300 400 500 600
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 »

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