Molecular Implant for Advance USJs

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Understanding ClusterBoron® Implants

- 18 Dopant Atoms per ClusterBoron® molecule
- Extract and Transport at 20X (higher energy)
- Increase effective dose rate by 18X
- Low Energy, High Dose Implant

Is Process Equivalent to:

\[ \frac{20 \text{ keV} \ B_{18}H_{22}^{+}}{1 \ mA} \]

\[ \frac{1 \ keV \ B^+}{18 \ mA} \]

- Highest throughput
- Best implant quality
- Shallowest junctions
- Simplified process
- Extend process capability
- Improved device quality
Molecular Implant Features

- **Self-amorphization**
  - Amorphization is required, Ge PAI leaves defects
  - Recrystallization forces substitutionality

- **No EOR defects**
  - Complete recrystallization even with ms only

- **High productivity at low energy**

- **Drift mode**
  - No energy contamination

- **Excellent beam control**
Molecular Implant Options

- **ClusterBoron®**
  - B18, B36

- **Decaborane, B10**

- **ClusterCarbon™**
  - C16, C14, C7, C5

- **N-type**
  - P4, As4
USJ Requirements for PMOS SDE

45nm Node:
- $R_s \sim 1000 \, \Omega/\text{sq}, \, X_j < 20 \, \text{nm}$
- $R_s \cdot X_j < 20 \, (\text{k}\Omega \cdot \text{nm})$

32nm Node:
- $R_s < 1000 \, \Omega/\text{sq}, \, X_j < 15 \, \text{nm}$
- $R_s \cdot X_j < 15 \, (\text{k}\Omega \cdot \text{nm})$

28nm Node:
- $R_s < 1000 \, \Omega/\text{sq}, \, X_j < 12 \, \text{nm}$
- $R_s \cdot X_j < 12 \, (\text{k}\Omega \cdot \text{nm})$

22nm Node:
- $R_s < 1000 \, \Omega/\text{sq}, \, X_j < 10 \, \text{nm}$
- $R_s \cdot X_j < 10 \, (\text{k}\Omega \cdot \text{nm})$
Junction Trends 2010

- Xj requirements push implant energy lower
- Rs requirements push anneal temp higher
  - Flash, laser necessary
- Process integration teams prefer keeping diffusion
  - Ms plus spike process common
  - “Several ms” anneals to tune diffusion
- Insufficient anneal to eliminate EOR defects
  - Damage engineering
- Diffusionless processes starting to appear
B_{18}H_{22} and BF_{2} with Co-implants

B_{18}H_{22} with co-implant

BF_{2} with co-implant

B_{18}H_{22} & BF_{2} implant - 500eV (equiv), 1e15

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$R_s \cdot X_j$: 32 nm Node

Anneal Conditions for $B_{18}H_{22}$

$R_s \cdot X_j$ shows that the flash anneal satisfies the 32nm requirement.
B$_{18}$H$_{22}$ X-TEM with various anneals
(JOB & NEC, IWJT2006 & SST2006)

(a) B$_{18}$H$_{22}$ 6.2nm self-amorphous layer (as-implanted)
(b) SPE with no EOR damage
(c) Laser with no EOR damage
(d) Flash with no EOR damage
Junction Leakage Current

- Non-PAI $B_{18}$ has > 2 orders of magnitude lower junction leakage current using diffusion-less laser and SPE anneals
- This is consistent with low damage junction in PL results
ClusterCarbon™ Co-Implant

Carbon co-implant provides the following:

- Shallower Junctions
- Higher Solid Solubility
- Improved Junction Abruptness

(Cluster Boron 500eV, 1e15

– Spike anneal 1050°C with and without Carbon)
45nm results
$B_{18}H_{22}$ 500eV & $C_{16}H_{10}$ 3keV @ 1E15 atoms/cm$^2$

X$_j$ < 20nm below 1050°C

R$_s$ < 1000 Ω/sq for spike anneal temp ≥ 1000°C
High boron concentration at Ge EOR defect region. Reduced concentration with $C_{16}H_{10}$ at iRTP 900$^\circ$C. The concentration is removed at the higher flash temperature $T_{pk} = 1350^\circ$C.
ClusterBoron Dimer Technology

- ClusterIon source with ClusterBoron (B18H22) feed material produces ClusterBoron-Dimer (B36Hx) ion beam

- Dimer production by ion source is less than the B18 primary beam, but transport conditions produce dose rate advantage for the dimer at low energy (<400eV)

- B36 Process Evaluation
  - Amorphization
  - Depth Profile
  - Activation
Self-amorphization - $B_{18}$ vs $B_{36}$

300eV@1e15

- Thicker amorphous layer leaves less Si interstitials for residual EOR defect formation and also less TED. All leads to higher dopant activation.

$B_{18}$ α-Si thickness ~ 50Å.

Dimer $B_{18}$ α-Si thickness ~ 63Å.
Amorphization threshold is lower with $\text{B}_36$ compared to $\text{B}_{18}$ even for $E_{\text{B36}} < E_{\text{B18}}$.
$B_{36}H_x$ – 300eV, $2.33 \times 10^{15}$ atoms/cm$^2$ – No EOR defect

Excico Laser Anneal

No obvious extended defects observed even with high boron dose.

Expected EOR region.
**B_{36}H_x at 300eV – Dose Sequence**

**SIMS Profile PCOR**

For 300eV dimer B_{36} implant, beyond 7e14 dose, the Rp shifts deeper.

Xj ranges from 8nm to 12.5nm for dose range from 2e14 to 2e15 atoms/cm²

**Knock-on Effect:**

- Matsuo et al MRS (1998)p.17 (at cluster size > 10, Rp is larger than monomer)

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$B_{18}$ vs $B_{36} - 300\text{eV @ } 7.5\times10^{14}\text{ atoms/cm}^2$

SIMS profile for $B_{36}$ is slightly deeper than $B_{18}$. At a boron concentration of $5\times10^{18}\text{ atoms/cm}^3$, the difference in $X_j$ between $B_{18}$ and $B_{36}$ is around $5\text{Å}$. 

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B_{18}H_{22} & B_{36}H_x \@ 300eV \_1e15

HDR & PCOR protocol

SIMS profile for HDR protocol is shallower than PCOR protocol.

At concentration of 1e18, the difference in Xj is about 4nm.
B$_{36}$H$_x$ – 300eV, 2.33e15 atoms/cm$^2$

**Excico Laser Anneal**

![Graph showing boron concentration vs. depth]

Practically no change in Xj after anneal at 5e18 atoms/cm$^3$. 
Rs, Xj and Abruptness:
B_{18} vs B_{36} – 300eV, 9e14 atoms/cm^2

<table>
<thead>
<tr>
<th>Species</th>
<th>Rs % diff.</th>
<th>Xj (5e18 atoms/cm^3)_HDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>as-imp</td>
<td>29</td>
<td>29</td>
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<tr>
<th>Abruptness</th>
<th>SIMS Dose (atoms/cm^2)</th>
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<tbody>
<tr>
<td>as-imp</td>
<td>1P_ 1.5J/cm^2</td>
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<tr>
<td>as-imp</td>
<td></td>
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<tr>
<td>B_{18}</td>
<td>1.75</td>
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<tr>
<td>B_{36}</td>
<td>x</td>
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30% better Rs with B_{36}. The difference in Xj between B_{18} & B_{36} is < 10Å. Abruptness < 2Å
Rs Results:

B_{18} vs B_{36} – 300eV, 9e14 atoms/cm²

30% better Rs in the case of B_{36}.
% of Boron within α-Si layer

HDR (300eV, 1e15 atoms/cm²)

40Å α-Si ~ 70% boron within the α-layer
60Å α-Si ~ 98% boron within the α-layer

2.5e20 atoms/cm²

Cut off at 2.5e20 atoms/cm³
Using $B_{36}$ or $C_{16}+B_{36}$ one can get to low sheet resistance with millisecond anneal with $X_j < 10\text{nm}$.
Using $B_{36}$ only without any PAI

$X_j \approx 7.3$ nm.

$R_s \approx 965$ Ohm/sq
Lower dose provides better Rs. (Formation of Boron complex ending up in deactivation due to higher available concentration)
C_{16} + B_{36} – 200eV, C_{16–3keV}

Flash Anneal

Anneal EFFECT

Higher Rs after impulse spike and flash anneal.

<table>
<thead>
<tr>
<th>Species</th>
<th>fRTP 1250°C</th>
<th>iRTP 1000°C + fRTP 1250°C</th>
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<tbody>
<tr>
<td>200eV_1e15</td>
<td>1072</td>
<td>1300</td>
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Summary

- Molecular implant has many unique features which provide process solutions for current challenges
  - Amorphization with high productivity
  - Elimination of EOR damage for low leakage junctions
  - Diffusion control for advanced junctions
- ClusterBoron implant enables advanced USJ for 22nm and beyond