PULSION® HP: Tunable, High Productivity Plasma Doping

S.B. Felch, F. Torregrosa, H. Etienne, Y. Spiegel, L. Roux, and D. Turnbaugh

Ion Beam Services, Peynier, France

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Introduction

- Plasma doping in R&D for over 2 decades
  - Ultra-shallow junctions
  - Conformal doping of trenches and fins
- In production today for two very high dose, DRAM applications
  - Polysilicon gate counter-doping
  - Contact doping
- Parasitic effects due to reactive plasma at wafer surface
  - Etching of surface materials
  - Enhanced oxidation
  - Deposition of films
- Key features of PULSION® HP
  - Dual Region Chamber© design that enables a high density plasma with low chamber pressure
    - Minimizes undesired side effects
    - Enables wide process space
    - Low gas flow rates
  - Special chamber and wafer electrode designs that optimize doping uniformity
Unique Features of PULSION HP®

- Continuous or pulsed plasma
- High Pressure, very high density plasma: Remote ICP plasma source
- Dual Region Chamber Design (DRC)
- Low Pressure, high density plasma
- Rotating chuck for better uniformity
- Adjustable Wafer/Source Offset
- Plasma Sheath
- Features to Improve Uniformity
- Longer distance to improve homogeneity

- ON
- OFF

- O
- HV
Independent Tuning of BF$_3$ Plasma Density and Chamber Pressure

- Adjustable pressure differential of \( \leq 2 \) orders of magnitude between plasma source and process chamber
- Plasma source RF power is primary control of plasma creation and density and implant current
- Chamber pressure can be independently varied to achieve desired chemistry effects at the wafer surface
Conformal Doping with Boron Plasma Implant

- Conformal doping of 3D structures requires dominance of deposition and implant
- Equal thicknesses of all doped regions
- Actual doping of fin Si, since no change in fin dimensions
- No evidence of corner rounding or fin erosion
DRAM contact doping requires implantation with balance of minimal etching, sputtering, and deposition

Can vary B surface concentration and implanted dose while keeping junction depth constant - ideal to reduce contact resistance

See Poster P2-41
**BF₃ Dose Response for Typical Poly Counter-Doping**

- As dose increases, all points in SIMS profile increase
- Different behavior than B₂H₆

See Poster P2-41
Minimal Si Etching: HRTEM Implanted / Unimplanted Samples

BF$_3$ 4kV, 1.5E16 atoms/cm$^2$

Unimplanted

Implanted

Si (15 nm)

SiN (4 nm)

Si Substrate

Implanted structure

+-1 nm Oxide Growth

See Poster P1-33
**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
PULSION® n-Type Doping
Shallow Implant Depth Capability

PULSION AsH$_3$ As-Implanted profiles

- As 1keV $2\times10^{15}$/cm$^2$
- As 3keV $4\times10^{15}$/cm$^2$

concentration (at/cm$^3$) vs. depth (nm)
**Arsenic USJ with Flash Anneal**

- 300 V As, 2E14 cm\(^{-2}\)
- 1200C flash anneal

![Graphs showing arsenic concentration and silicon counts versus depth](image-url)
**PULSION® HP Uniformity Advantages**

- Tall chamber design
  - Longer distance between source and wafer
  - Improves uniformity of plasma flow
- Adjustable wafer/plasma source offset
- Rotating wafer
  - Enhances implant uniformity at wafer level
$R_s$ Uniformity and Repeatability

<table>
<thead>
<tr>
<th>Mean $Rs$ (ohms/sq.)</th>
<th>Uniformity ($%$, 1$\sigma$)</th>
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</thead>
<tbody>
<tr>
<td>162.55</td>
<td>0.828</td>
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<tr>
<td>161.19</td>
<td>0.780</td>
</tr>
<tr>
<td>160.17</td>
<td>0.787</td>
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<tr>
<td>157.96</td>
<td>0.777</td>
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<tr>
<td>158.66</td>
<td>0.840</td>
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</tbody>
</table>

PULSION Repeatability Test

- Uniformity (1$\sigma$) < 1%
- Repeatability (1 sigma) = 1.16%

- Typical poly counter-doping process
  - BF$_3$, 6.5 kV, 7E16 cm$^{-2}$
  - HF strip before anneal
  - 1000C, 10 sec anneal
PULSION HP® – Max 4 Chambers, >100 WPH (Poly Counter-Doping)
Summary

- Dual Region Chamber® design of PULSION HP® enables a high density plasma with variable, low chamber pressure
  - Allows customer choice of dominant process mechanism: deposition, implant, or etch
  - Minimizes undesired side effects
- Special chamber and wafer electrode designs
  - Optimized doping uniformity
  - Wide process space
- High wafer throughputs necessary for high-volume production
  - High plasma density
  - Platform with up to four plasma doping chambers