CVD low k Solutions for sub-0.18um Technology

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OUTLINE

Introduction:
• Materials World.
• Low k Roadmap.

Inorganic Low K Materials
• FSG
• Black Diamond

Barrier/Etch Stop Materials
• Copper Surface Treatment.
• BLOk.

CVD Remote Clean Technology
Summary
IC Manufacture/Equipment Industry Interaction

Each Transition is Characterized by Change Cycle

Source: Texas Instruments/Applied Materials
Driving Moore’s Law

Historically
- 90% Dimensional Improvements, 10% Material Changes
- Dimensional: Lithography and Etch
- Materials: PSG-BPSG, PVD - CVD W, WSi$_x$-TiSi-CoSi

Now
- 50% Dimensional Improvements, 50% Material Changes
- Dimensional: Lithography, Etch, Integration (T-Gate, Damascene)
- Materials: TaO, BST, Low K Dielectric, Copper

Future Beyond 0.1um - Trend Will Continue
- 30% Dimensional Improvements, 70% Material Changes

More Emphasis on Performance due to Materials, in addition to the traditional Focus on Lithography
• Dielectric constant range in Y2000 is 2.5-3.6, but expected to drop to <2.5 by 2002
• Expect another revision
HISTORY OF INDUSTRY LOW $\kappa$ DEVELOPMENT

- The need for Cu/Low $\kappa$ first introduced in 1994 NTRS
- First screening period (1995-1997) focused on $\kappa$ and thermal stability, since most initial candidates were organic SOD. Evaluation only involved 1 or 2 level metal damascene builds.
- Industry began to shift focus in 1998 to multi-level damascene integration compatibility. Thermal-mechanical properties become key criteria, which exposed deficiencies in many organic materials.
- Serious CVD options entered market in 1999 and continue to rapidly gained DTOR status. The majority of customers now looking at CVD carbon doped oxide as first viable $\kappa<3.0$ product.
RECENT INTERCONNECT CONFERENCE SUMMARY

Advanced Semiconductor Manufacturing Conference, Sept 99 in Boston, MA
• Documentation by Dataquest specifically revising their prediction 2 years ago of first generation $\kappa<3.0$ materials being SOD to CVD C-Doped Oxide materials.

Advanced Metallization Conference, Sept 99 in Orlando, FL
• First generation low $\kappa$ material will be FSG.
• Conference papers shows promising result of CVD Low $\kappa$, Carbon Doped Oxide.
• Key consensus from Panel Discussion:
  - CVD Low $\kappa$ provides better reliability than SOD.
  - Toughness, mechanical strength and adhesion of Low $\kappa$ are keys to success

<0.15$\mu$m Interconnect Materials Workshop, Nov 99 in Monterey, CA
• Oxide type of Low k materials is the most promising.
• Thermal-mechanical properties are the most crucial criteria for selection.
LOW κ MATERIALS FOR ADVANCED INTERCONNECTS

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Deposition Method</th>
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<tbody>
<tr>
<td>Inorganic</td>
<td>CVD</td>
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<tr>
<td></td>
<td>• FSG</td>
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<tr>
<td></td>
<td>• Black Diamond</td>
</tr>
<tr>
<td>Organic</td>
<td>Spin-on</td>
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<td></td>
<td>• Fox (HSQ)</td>
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<td></td>
<td>• MSQ</td>
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<td>• LOSP (T-23)</td>
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<td>• Nanoglass</td>
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<td>• a:FC</td>
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<td></td>
<td>• Parylene AF4</td>
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<td>• Copolymer</td>
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<tr>
<td></td>
<td>• Silk</td>
</tr>
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<td></td>
<td>• BCB</td>
</tr>
<tr>
<td></td>
<td>• Flare</td>
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<td>• PAE2</td>
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<td>• AS 418</td>
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**Inorganic CVD Low k:**
- Proven CVD deposition technology
- Oxide-like properties for ease of integration
Hardness Measurement of Different Low $\kappa$ Materials
(Nano Indentation Method)

- PETEOS USG: 8.50 GPa
- HDP-USG: 8.50 GPa
- HDP FSG: 7.50 GPa
- Black Diamond: 3.0 GPa
- C Based Spin On: 0.25 GPa
ULTIMA HDP-CVD™ FSG
Bulk Film Comparison vs. HSQ

**Thermal Conductivity**

<table>
<thead>
<tr>
<th></th>
<th>USG</th>
<th>FSG</th>
<th>HSQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>mW/cm°C</td>
<td>12.0</td>
<td>12.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

**Hardness**

<table>
<thead>
<tr>
<th></th>
<th>PE TEOS USG</th>
<th>HDP-USG</th>
<th>HDP-FSG</th>
<th>Spin-On Dielectrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (GPa)</td>
<td>8.5</td>
<td>8.5</td>
<td>7.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

- High thermal conductivity critical for heat dissipation
  - FSG provides equivalent thermal properties to conventional oxides
  - >3x thermal conductivity of Low κ spin-on dielectrics

- High hardness critical for electromigration resistance, mechanical stability during CMP
  - FSG provides equivalent hardness to conventional oxides
  - >20x hardness of Low κ SODs

**Oxide-Like Bulk Film Properties Contribute to Integration Ease, Device Reliability**
**ULTIMA HDP-CVD™**

**FSG and HSQ Dielectric Constant Comparison**

FSG $\kappa_{eff} \leq$ HSQ $\kappa_{eff}$ For Narrow Gaps

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**Graph:**

- $\kappa_{eff}$ as Function of Line-to-Line Spacing

  - HSQ+500Å Si-rich Liner
  - FSG bulk
  - Intra-metal FSG
  - HSQ bulk

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**Graph Notes:**

- FSG $\kappa$ decreases with smaller spacing due to higher F concentration between gaps

- Use of liner inhibits low dielectric constant for HSQ in smaller spaces

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**Image:**

- Full Flow FSG
- Embedded HSQ

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**Below 0.24µm spacing, FSG $\kappa_{eff}$ is lower than HSQ due to impact of USG liner on effective $\kappa$**
TDS Profile for $\kappa = 3.45$ HDP-FSG film

No desorption of any species at temperatures lower than 500°C.
F Stability for different Processes

SIMS of F outdiffusion.

HDP-FSG is more stable than PE SiH$_4$ FSG.

Annealed at 410°C for 6 cycles in an N$_2$ ambient with 30 minutes each cycle.
DIELECTRIC FILM REQUIREMENTS FOR DUAL DAMASCENE INTEGRATION

Films must be compatible with:
Etch, CMP, Photolithography, Metallization modules
BLACK DIAMOND™ LOW $\kappa$ FILM
($\kappa = 2.6-3.0$)

Simple Process Chemistry:
- Single wafer CVD reaction to form carbon doped oxide network
- Non-specialty chemicals as pre-cursors

Film Properties:
- Thermal and mechanical properties similar to silicon oxide

Integration:
- Silicon oxide like film properties simplify integration
- Compatible with copper/oxide damascene tool set
Black Diamond Film Composition (FTIR)
<table>
<thead>
<tr>
<th></th>
<th>Black Diamond</th>
<th>SiO$_2$</th>
<th>HSQ</th>
<th>Porous SiO$_2$</th>
<th>&gt;20 at.% SiOC</th>
<th>Organic Polymer</th>
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</thead>
<tbody>
<tr>
<td>Hardness (GPa)</td>
<td>1-3</td>
<td>7-8</td>
<td></td>
<td>0.4</td>
<td>0.1-0.3</td>
<td></td>
</tr>
<tr>
<td>CTE in plane (ppm/C)</td>
<td>5-15</td>
<td>~1.0</td>
<td>20</td>
<td>50-70</td>
<td>40-50</td>
<td>50-70</td>
</tr>
<tr>
<td>Biaxial E (Gpa)</td>
<td>10-15</td>
<td>70-80</td>
<td>5-10</td>
<td>2-3</td>
<td>5-7</td>
<td>2-3</td>
</tr>
<tr>
<td>Ther. Cond. (W/mC)</td>
<td>0.3-0.4</td>
<td>~1.0</td>
<td>0.05-0.07</td>
<td>&lt;0.2</td>
<td>&lt;0.1</td>
<td></td>
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**Black Diamond has the most similar thermal mechanical properties to SiO$_2$ for $\kappa < 3.0$ materials**
Issues for Organic and High C Content SiOC Films

- **Narrow process window for damascene etch**
  - Low etch rate and selectivity to SiN and photoresist

- **Poor ashing resistance**
  - Difficult sidewall polymer removal
  - Significant via sidewall pullback

- **Possible leakage due to silicon carbide or dangling Si bonds**

- **Poor thermal, mechanical properties**
  - Low hardness results in poor damascene structural integrity, incompatibility to CMP (peeling, scratches, etc.), Cu protrusions
  - High CTE and Low Young’s Modulus affected via integrity
  - Low thermal conductivity causes excess Joule heating, resulting in poor EM lifetime and Cu protrusions
(1) Plasma generates atomic hydrogen
(2) Hydrogen reacts with CuO to form H$_2$O / OH + Cu
(3) Cu rebonds to form high quality large grain structure
(4) H$_2$O is pumped out

Published Papers:
Cu DAMASCENE INTEGRATION
In Situ Plasma Treatment for Copper Oxide Removal

Oxygen Detection by ESCA/XPS

Wafer Without Treatment

500Å BLOK or Nitride
CMP Cu

Thin Cu Oxide layer interferes with adhesion
Stud Pull <1000PSI

Wafer with In Situ Plasma Treatment

500Å BLOK or Nitride
CMP Cu

Improves Adhesion
Stud Pull: >3000PSI *

In Situ Plasma Treatment Required for Good Cu/Barrier Adhesion

* Failed at epoxy/dielectric interface
** AMAT Electra Cu & Mirra Cu CMP + 500Å Barrier
** 10-30 sec. treatment
** BLOk Patent Pending

DIELECTRIC DEPOSITION SYSTEMS & MODULE PRODUCT GROUP
APPLIED MATERIALS®
Why is a low $\kappa$ barrier/etch stop necessary?

- Low $\kappa$ dielectric materials are required to reduce RC time delay in <0.25 micron metal interconnects.
- Low $\kappa$ barrier/etch stop has a significant impact on the effective $\kappa$ value of the damascene structure.
- The current barrier/etch stop candidate is SiN which has a $\kappa > 7$.
- Applied Materials has developed a barrier/etch stop candidate with $\kappa < 5.0$ (Barrier LOw $\kappa$).
BARRIER IMPACT ON EFFECTIVE DIELECTRIC CONSTANT

Use of BLOK Can Significantly Reduce Effective $\kappa$ Value

* Data obtained using Raphael™ simulation
PFCs and Global Warming Potential

- Global warming gases are causative agents*
- "The world's changing climatic conditions are more than the natural variability of weather."**

- 70 to 90% of PFC emissions from a semiconductor fab. are attributed to CVD chambers cleaning.
- The Semiconductor industry has taken a voluntary approach to reduce emissions.

- PFC gases have long lifetime and high global warming potential (GWP)

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**Contribution of the IPCC (Intergovernmental Panel on Climate Change) – First Conference of the Parties, Framework Convention on Climate Change, Berlin, 1995.
**In-Situ Clean versus Remote Clean™**

**In situ Clean**
- Results in corrosion of chamber components at high power density.
- Limited etch rate, longer clean time.
- Limited PFC Utilization Removal Efficiency (URE = 20-70%)

**Remote Clean™**
- Near complete Utilization Removal Efficiency of NF₃ (URE = 99%)
- High etch rate (20-60% reduction of clean time)
- No ion bombardment in main chamber ("soft" clean)
- Increased Mean Wafer Between Clean (3000 --> 5000 wafers)
- Global Warming emissions reduced by one to two order of magnitude (Carbon equivalent).
Results

GWP Equivalent Kg CO₂ Per Micron of TEOS Oxide Film

Awards

- The EPA honored Applied Materials with the 1999 Climate Protection Award for its Remote Clean™
- The Remote Clean™ received the prestigious R&D 100 Award sponsored by R&D Magazine
- Applied Materials Taiwan received the National Business Environmental Protection Award given by Taiwanese government.

* Based on initial investigation