JSR Spin-on dielectrics

JSR LKD-5109

Low k Challenges Beyond 100 nm
NCAVS-TFUG

October 16, 2002
Contents

- Roadmap
- Properties of JSR LKD-5109
- Integration of LKD-5109
  - Challenges
  - ISMT product line
  - ISMT result highlights
- Summary
Low-k Challenges for CMP

Crystal ball beyond 100 nm (k= 1.9 - 2.5)

- Does conventional abrasive-based CMP work?
  Yes, and it requires **only process optimization**
  Reduced head pressure (1-3 psi)
  Optimized head design, **pad, slurry**, ...

- Why so?
  CMP is not the only process requiring mechanical integrity of low-k
  *containment of copper migration under heat and current*
  *stress caused by the packaging and application of chips*
Slipping roadmap for low-k

<table>
<thead>
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<td>3.0 - 4.1</td>
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October 13, 2002
# Classification of Low k Dielectrics

<table>
<thead>
<tr>
<th>Material</th>
<th>k=4.1</th>
<th>k=3.5</th>
<th>k=2.6 - 3.2</th>
<th>k=2.0 - 2.5</th>
<th>Process</th>
<th>Vendor</th>
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<tr>
<td>Inorganic</td>
<td>SiO2</td>
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<td>CVD</td>
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<td>LKD-2020</td>
<td>LKD-5109</td>
<td>Spin-on</td>
<td>Dow Corning</td>
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<td>IPS2.5</td>
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<td>uPLK</td>
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<td>HOSP</td>
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<td>PPSZ-M</td>
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<td>ALCAP-S</td>
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<td>Hybrid</td>
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<td>POLA</td>
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<td>Clariant</td>
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<td>BlackDiamond 2</td>
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<td>Spin-on</td>
<td>Tokyo Ohka</td>
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<td>Spin-on</td>
<td>Honeywell</td>
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From JSR Seminar, 2001 December
Typical Curing Sequence of JSR LKD

<table>
<thead>
<tr>
<th>Tool</th>
<th>Process</th>
<th>Condition</th>
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<tbody>
<tr>
<td>SOD Coater</td>
<td>Spin Coat</td>
<td>2000 - 3000 rpm</td>
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<tr>
<td>SOD HP</td>
<td>Prebake</td>
<td>Evaporation of solvent 80°C x 60 sec in Air</td>
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<tr>
<td>SOD HP</td>
<td>Softbake</td>
<td>Crosslink of polymer 200°C x 60 sec in Air</td>
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<tr>
<td>Vertical Furnace</td>
<td>Final Cure</td>
<td>420°C x 30 min Ambient Pressure in N₂</td>
</tr>
</tbody>
</table>
Conventional method of p-MSQ

Silica Precursor

Sacrificial Compound

Coating

Silica-Organic Hybrid

Decomposition of organic compound

Curing

Porous Silica

Control of k value

Sacrificial content ↔ Porosity of Silica film

Schematics of P-MSQ

- Doneness of cure depends on residual free Si-OH
- Correct indicators of cure need to be chosen. Detect residual Si-OH groups and moisture uptake. \( \Leftrightarrow n, k, IR, \) outgassing, etc.

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Concept of JSR LKD (Polymer Design)

Precursor (Soluble)
- SiO: Partially crosslinked silsesquioxane (High heat resistance)
- OH: Heat-curable group
- R: Hydrophobic group (Methyl, Phenyl, etc)

Low k Film (Insoluble)
- Fully crosslinked silsesquioxane without hydroxyl group

Control of k value \leftrightarrow Density of Silica film

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LKD-5109 offers …

- Superior material properties
  Low dielectric constant, high modulus, Small CTE, ...

- Successful integration
  Baseline process information through industry consortium
    *Sematech, IMEC, Selete, Leti, ...

  Commercial Cu/LKD-5109 sample availability
    *Sematech wafer service

- Readiness for the commercial use

- Extendibility of ILD technology
  Keeping eye also on k < 2.0 ranges
JSR Research Activity toward Ultra Low-k

![Graph showing Elastic modulus vs. Dielectric constant for LKD-6103, LKD-5109, LKD-5115, and LKD-2020. Prototypes and Products are indicated.]
# JSR LKD Line Up

<table>
<thead>
<tr>
<th></th>
<th>ULK</th>
<th>ELK</th>
<th>VLK</th>
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<tr>
<td><strong>Cure method</strong></td>
<td>Thermal</td>
<td>Thermal</td>
<td>Thermal</td>
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<tr>
<td><strong>Product name</strong></td>
<td>LKD-6103</td>
<td>LKD-6102</td>
<td>LKD-5109</td>
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<tr>
<td><strong>Product stage</strong></td>
<td>R&amp;D</td>
<td>R&amp;D</td>
<td>Product</td>
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<tr>
<td><strong>Final Cure Temp.</strong></td>
<td>420°C</td>
<td>350°C</td>
<td>420°C</td>
</tr>
<tr>
<td><strong>Dielectric constant: K</strong></td>
<td>1.91</td>
<td>2.01</td>
<td>2.20</td>
</tr>
<tr>
<td><strong>Refractive index</strong></td>
<td>2.01</td>
<td>1.226</td>
<td>1.248</td>
</tr>
<tr>
<td><strong>Modulus: E (GPa)</strong></td>
<td>2.1</td>
<td>5.4</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Thermal conductivity</strong></td>
<td></td>
<td></td>
<td>0.235</td>
</tr>
<tr>
<td><strong>Specific Gravity</strong></td>
<td>0.82</td>
<td>0.90</td>
<td>0.93</td>
</tr>
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</table>

Sematech/IMEC focus on LKD5109

All of these JSR LKD products can be described generically as (porous-)MSQ material

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IITC 2002 poster

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CTE Advantage

LKD-5109 (MSQ based Low-k) has CTE comparable to Copper

MSQ = Inorganic back bone polymer
### Chemical Compatibility of JSR LKD

<table>
<thead>
<tr>
<th>Chemical</th>
<th>pH</th>
<th>Etch Rate (nm/h)</th>
<th>Si-CH3 Retation %</th>
<th>k value increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>0.05%</td>
<td>&lt;1.0</td>
<td>-16</td>
<td>99</td>
</tr>
<tr>
<td>Etch Clean A</td>
<td>NH4F base</td>
<td>1.0</td>
<td>-24</td>
<td>99</td>
</tr>
<tr>
<td>Etch Clean B</td>
<td>Organic acid base</td>
<td>1.0</td>
<td>-8</td>
<td>100</td>
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<tr>
<td>CMP Slurry A</td>
<td>Neutral</td>
<td>6.0</td>
<td>-11</td>
<td>102</td>
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<td>Etch Clean C</td>
<td>Solvent base</td>
<td>6.6</td>
<td>-3</td>
<td>100</td>
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<tr>
<td>CMP Slurry B</td>
<td>Amine base</td>
<td>10.4</td>
<td>-8</td>
<td>100</td>
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<td>Etch Clean D</td>
<td>Organic amine base</td>
<td>12.4</td>
<td>-7</td>
<td>100</td>
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<tr>
<td>HA</td>
<td>PR Devloper</td>
<td>13.4</td>
<td>0</td>
<td>80</td>
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**Exposure:** 25°C/20 min

JSR LKD have a good chemical compatibility over a wide range of pH. Incompatibility can be seen in HF base solutions and Hydroxyamine base solutions.
FT-IR Spectra
Hydrophobicity

- Why we measure it?
  Degradation of k value
  Blistering etc during heat cycle

- How we measure?
  Screening test can use:
    \( FTIR \)

  Success criteria should include:
    \[ k \text{ value and } \Delta k = k(25C) - k(200C) \]
    \( TDS \text{ (MS)} \)
TDS Fragment
Cure Temp. Dependency

Mass Fragment @ 200°C

Mass Fragment @ 300°C

Cure : 350°C 30m

Cure : 400°C 30m

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k measurement at 200 °C is to eliminate moisture effect in k value.
Cure Temperature Dependency of $k$ and $\Delta k$
in JSR LKD-5109

Increase in $k$ value as lowering cure temperature is mostly
due to moisture absorption.
TEM Observation of LKD-5109

k=2.2 Low k

No pore structure is observed. Low density film structure.

5 nm

5 nm
Pore Size Distribution & Porosity of LKD5109
Sample: Powder

Micropore (Ar)

Mesopore (N2)

Pore Size of Max Probability
13.6 Å

Average Pore Diameter
4V/A
19.1 Å

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Integration Challenges of JSR LKD

Known integration issues for JSR LKD

- Side wall damage (Etch / Ash)
  Degas, Increase dielectric constant.
  Adhesion to BM.
- Void formation
- Chemical Corrosion (Stripper)
- Photoresist poisoning
- Delamination, scratch, ... (CMP)
Possible Integration Interactions of JSR LKD

After Patterning, Etch, Ash, ...

Ash damage and Photoresist poisoning can be avoided by dual H.M. scheme. Etch and Dep. damages are still present even with dual H.M. scheme.
ISMT LKD Test Wafer with 800AZ Mask
ISMT LKD Test Wafer with 800AZ Mask

Metal 1 Copper CMP Test Wafer
Dual Damascene Cross-Section

* Not to scale

Example of available structure (Source www.sematech.org)
ISMT LKD Test Wafer with 800AZ Mask

Metal 2 Copper CMP Test Wafer
Dual Damascene Cross-Section

* Not to scale

Example of available structure (Source www.sematech.org)

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ATDF Baseline
JSR LKD5109
Collaboration with Sematech Activity

Interconnect Structure

Electrical/Reliability Characterization, Package Assessment, High Frequency Characterization

Fabrication of 1LM, 2LM and >2LM Cu/low-k Dual Damascene Interconnects

Module Integration

- Low-k Dielectrics
  - Material Properties
  - Low k Deposition
  - Etch stop/ Caps
  - Module Screening
- Metallization
  - New Barriers
  - Cu Seed/Repair
  - Cu Plating Tools
  - Cu Plating Baths
- Etch
  - Etch Tools/ Processes
  - Ash/ Capes
- Lift
  - Low k – 157nm resist interaction

Octobe
Integration Issues: Strength/Adhesion

- Low strength and adhesion challenge CMP
- Cap loss must be avoided with porous low-k
- Alternatives to CMP
- Tiling

![Graph showing Young's Modulus and Hardness of low-k dielectrics]

Young's Modulus of Dielectric < 3 GPa

Low-k Dielectrics

- No delamination of blanket layers
- Special CMP techniques needed

Units GPa

CVD1, CVD3, CVD5, SOD1, SOD3, SOD5, SOD6, SOD8, SOD10, SOD12, SOD14
3LM Lot; 0.3 μm Via Chain

Structure to support packaging activity to mimic real-world integration.

M3 was patterned with M2 (775 level) mask in ATDF with good overlay.

(K. Mosig)
M2 Long Serpentine/Comb Structure

M1 comb runs parallel to the picture surface
Package Results; Gold Wirebond II

Successful wire bonding and solder bumping (high yield and pull/shear strengths).

(M. Rasco)
Summary

- Momentum for the spin-on low-k material is building up rapidly.
  - Publication
    - *IITC 2002 and Semicon/West 2002 coming*
  - Commercial sample availability
    - *JSR for liquid and ISMT for wafer*
- JSR LKD-5109 technology has demonstrated extendibility beyond K < 1.9
- JSR LKD-5109 is accumulating integration knowledge at the device manufactures, tool vendors, and research consortiums.