The 3D Silicon Leader

High performing wire bondable vertical Silicon Capacitors for RF power modules

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Who are we?

- Independent European High Tech Company
- Specialized in leading edge Integrated Passive Devices, world leader in 3D Silicon capacitors
- Operating own 10 000 m² Silicon wafer facility
- 25% of financial resources allocated to R&D
- 25% of sales in EU, 25% US, 50% Asia
- Technology adopted by 3 of the top 5 leaders in medical electronics as well as by key players in the semiconductor area and Hi-Rel industry
Introduction

- The need for high-power and high frequency transistors is increasing.
- GaN has progressed significantly over the last years.
- GaN device portfolio is covering a wide range of applications.
- LDMOS performance is continuously pushed to its limits.
Requirements for RF products:

- High efficiency
- High bandwidth and linearity
- High polarization voltage
- Low cost
- High reliability
- Smaller footprint
Value proposition of the 3D Si capacitors:

- Proper decoupling of the power supply: quick, smooth response to the large current demands of the output circuit.
- Low parasitic loss.
- High capacitance density with high voltage.
- Small footprint and low profile.
- High performance and power efficiency by using larger capacitor value in a small package.
- Cost saving due to the package size reduction.
3D Capacitor Technology

Capacitance
1.3nF/m² up to 900 nF/mm²
BV 450V down to 6v
3D Capacitor Technology

1.3nF/mm² up to 6nF/mm²
VBD = 450V down to 150V

A.R. ~ 1:20
ONO (Oxide – Nitride – Oxide)

20nF/mm² up to 900nF/mm²
VBD min = 100V down to 6V

A.R. ~ 1:60
Nitride Double stack

Design
Pores

Tripods
Vertical 3D Silicon Capacitors

Capacitance
6nF/m²  BV 150V
Vertical 3D Silicon Capacitors

Capacitance

20nF/m²  BV 100V
Low profile

Large range of die thickness from 100µm up to 400µm

100µm – 400µm

⇒ Selected thickness depends on the Backside Metallization and the package constraints
Capacitor strength comparison between Ceramic and Silicon cap

Results after bending strength 3 points

<table>
<thead>
<tr>
<th>LW</th>
<th>0.5×1.0mm</th>
<th>1.0×0.5mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>100um</td>
<td>100um</td>
</tr>
<tr>
<td>Ave.[N]</td>
<td>2.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Max.[N]</td>
<td>5.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Min.[N]</td>
<td>1.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

0402 100nF 100μm thick
Silicon Capacitor is stronger than Ceramic Capacitor
Topside and backside metallization

• Topside : 3 to 5µm
  – Pure Aluminum
  – AlSiCu
  – TiWAu
  – TiCuNiAu $T^\circ >150^\circ$ C, hermetic package

• Backside Metal : 3µm
  – Pure Au
  – TiNiAu
Wire bondable vertical Silicon Capacitor:

- **Wedge bonding**
  - Au wires
  - Al wires

- **Ball bonding**
  - Au wires
Wedge bonding – Aluminum wire:

Combination of aluminum wire with aluminum pad is recommended if $T > 150^\circ$ C to avoid Purple Plague issue!
Wedge bonding – Gold wire

Gold wire 20/25µm diameter

IPDiA capacitor with 1,5µm gold or 3µm aluminium pad finishing

Combination of gold wire with gold pad is recommended if $T > 150^\circ C$ to avoid Purple Plague issue!

<table>
<thead>
<tr>
<th>Bonding process: Wedge/Gold wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonder</td>
</tr>
<tr>
<td>Bonding Tool</td>
</tr>
<tr>
<td>Wire</td>
</tr>
<tr>
<td>US</td>
</tr>
<tr>
<td>Force</td>
</tr>
<tr>
<td>Bonding time</td>
</tr>
<tr>
<td>Deformation</td>
</tr>
<tr>
<td>Temperature</td>
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</tbody>
</table>
Ball bonding – Gold wire

Gold wire 20/25µm diameter

Combination of gold wire with gold pad is recommended if $T > 150^\circ C$ to avoid Purple Plague issue!

IPDiA capacitor with 1,5µm gold or 3µm aluminum pad finishing

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<td>Bonder</td>
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<tr>
<td>Bonding time</td>
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<tr>
<td>Temperature</td>
</tr>
</tbody>
</table>
RF performances
Temperature behaviour of Si Caps

Graph showing Capacitance vs Temperature with data points for Competitor and IPDiA.
DC leakage current at high Temperature
C = 100nF (Amps @ 3V)

I(120s) < 20pA @ 25°C
I(120s) < 2 nA @ 300°C
Capacitance dependence on DC bias and temperature

\[ V_{c1} = 1100 \text{ ppm/V} \]
\[ V_{c2} = -300 \text{ ppm/V}^2 \]
Performances

– Low leakage current <1nA/mm²
– Excellent temperature and voltage linearity
– High volume efficiency
– Low ESR, low ESL
IPDiA Capacitor failure mode

• Dielectric wear out accelerated under high voltage or high temperature conditions, getting visible by an increase of the leakage current to end up with a short.

• The main sensitivity or « degradation » factor is the increase of electrical field (voltage).

• There is no early failure

• The lifetime of 100 nF 0605 capacitor exceeds 18,000 hours at 200 °C.

• As a comparison, X8R capacitors show a useful life of 10,000 hours at 125 °C at the rated voltage.
Lifetime: Predictive models

\[ t_{bd} = A_0 \cdot \exp \left( \frac{E_{Ao}}{kT} \right) \cdot \exp \left( -\gamma \cdot E_{ox} \right) \]

→ \( A_0 \) = time constant
→ \( E_{Ao} \) = activation energy (eV) determined from the TDDB test
→ \( k \) = Boltzmann constant \((8.6 \times 10^{-5} \text{ eV/K})\)
→ \( \gamma \) = field acceleration factor
→ \( E_{ox} \) = field across the oxide given by the ratio of the applied voltage to thickness of the dielectric

PICSHV150

<table>
<thead>
<tr>
<th>Vg (V)</th>
<th>37°C</th>
<th>100°C</th>
<th>150°C</th>
<th>225°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>496676 years</td>
<td>36581 years</td>
<td>8022 years</td>
<td>1458 years</td>
</tr>
<tr>
<td>45</td>
<td>20090 years</td>
<td>1480 years</td>
<td>324 years</td>
<td>59 years</td>
</tr>
<tr>
<td>60</td>
<td>813 years</td>
<td>60 years</td>
<td>13 years</td>
<td>2.4 years</td>
</tr>
<tr>
<td>75</td>
<td>33 years</td>
<td>2.4 years</td>
<td>194 days</td>
<td>35 days</td>
</tr>
</tbody>
</table>

Lifetime predictions at different values of stress voltage and temperature using the TDDB E-model at 0.1% cumulative failure
Take away on reliability

• IPDiA technology is facing numerous success stories with the high reliability top players.

• This technology is featuring a composite ONO dielectric
  • Si3N4 boost capacitance density
  • Thermal oxide barriers enhance leakage and wear-out performance

• Wear out of the Capacitor is similar to CMOS
  • Failure mechanisms are similar to FET gate
  • Predictive reliability models (tddb) are available accounting for T and V derating

• EFR screening is part of the wafer test setup
  • Does not require component burn-in

• No ageing
• No catastrophic failures
• Not sensitive to moisture
## Reliability results

<table>
<thead>
<tr>
<th>Stress test</th>
<th>Abbr.</th>
<th>Stress Conditions</th>
<th>Stress Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life time at V use</td>
<td>TDDB</td>
<td>3T° &amp; 3 Voltages</td>
<td></td>
<td>&gt; 10 years @ 100°C</td>
</tr>
<tr>
<td>Failure in Time</td>
<td>FIT</td>
<td>150°C</td>
<td></td>
<td>&lt; 1 @225°C</td>
</tr>
<tr>
<td>High Temperature Operational Life</td>
<td>HTOL</td>
<td>150°C, Vuse</td>
<td>1008 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Thermo-mechanical cycling</td>
<td>TC</td>
<td>-65°C /+150°C</td>
<td>500 cycles</td>
<td>0 failures</td>
</tr>
<tr>
<td>High Temperature Storage Life</td>
<td>HTSL</td>
<td>150°C, unbiased</td>
<td>1008 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Unbiased Highly Accelerated Stress Test</td>
<td>UHAST</td>
<td>Preconditioning MSL3 260°C, 85% RH, unbiased</td>
<td>1056 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Temperature Humidity Bias Life Time</td>
<td>THB</td>
<td>85°C, 85% RH, V use</td>
<td>1008 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Metallization Stress voiding</td>
<td></td>
<td>200°C</td>
<td>168 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Stress Migration(stress induced voiding)</td>
<td></td>
<td>200°C</td>
<td>904 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Corrosion</td>
<td>THNB</td>
<td></td>
<td>168 hrs</td>
<td>0 failures</td>
</tr>
<tr>
<td>Passivation integrity</td>
<td></td>
<td>45°C, H3PO4 or electroless NiAu</td>
<td>40 mn</td>
<td>0 failures</td>
</tr>
</tbody>
</table>
Conclusion

• The need for high-power and high frequency transistors is increasing
• The miniaturization of the RF power modules is a must
• The WB Silicon Capacitor is providing perform miniaturization: a combination of high performance and power efficiency thanks to low parasitics and high capacitance in a very small package on top of an outstanding reliability.
Thank you for your attention!