RF MEMS Switch Packaging

IMAPS New England 44th Symposium & Expo, Boxboro, MA
Session: RF and Microwave - Innovations and Emerging Technologies

May 3, 2017
Agenda

- Introduction
- Packaging challenges
- Solutions
- Test Results
- Future Work
- Summary
What is GE Digital-Micro-Switch Technology?

A novel micro-mechanical switch architecture based on an ultra-reliable material set, incorporating new design and processing techniques.

Ohmic contact switch with cantilever beam and electrostatic actuation

Beam lifetime comparison under accelerated test conditions

Smart RF and Power relay systems
High-power, High-reliability

240V/10A AC/DC Relay
400V/2A RF Relay

Over 10+ years of development, over 40 patent families and know-how covering materials & fabrication processes, as well as system architecture, design, test

GE DMS technology can enable new, disruptive products:
High-power, High-reliability SMART RELAY SYSTEMS
The GE Approach

• GE approached MEMS reliability issues not as a semiconductor company, but with decades of experience in high-performance alloys

• GE’s breakthrough innovations in materials and processing enable true Product Development Platform:
  
  • **High-Reliability**: Shipping in production to a 3B cycles spec
  • **High-power capable**: Opens up new markets, larger TAM
  • **Simple design, <12 mask layers**: Can scale with volume to very low cost
  • **Simple design, wide design space**: Shorter design cycles = more products

![Diagram of GE engine and MEMS chip]
Digital-Micro-Switch Applications

Step function improvements in power handling and reliability

- Smaller size, higher power, higher frequency for RF switching
- Fast-switching, arc-free protection for Power switching

Benefits of micromechanical contact switch brought to many more applications
MEMS Product Portfolio - 2017

HV Switch Products

- **MM7100**
  - 9mm x 9mm LCC
  - WL bonded
  - 500V/1A <128MHz
  - **Target Markets:** MRI, general purpose HV switch

- **MM7110**
  - 6mm x 14mm SIP
  - 1000V/1A <128MHz
  - Integrated driver, passives

RF Switching Products

- **MM5120**
  - 5mm x 5mm QFN
  - SPDT, 25W/channel
  - DC-12GHz
  - Embedded controller with Vboost
  - Bare-die option to 18GHz+
  - **Target Market:** A/D, Test & Measurement, Wireless Infra.
  - **Target Applications:** Switched filters, switch matrix, high power RF switching, EM replacement

RF Tuning Products

- **MM3100**
  - 6mm x 6mm LGA / BGA
  - 6 channels, 25W/channel
  - DC to 3GHz
  - Embedded controller
  - **Target Markets:** A/D, Industrial
  - **Target Applications:** Tunable UHF/VHF/HF radios, general purpose EM relay replacement, WPT

Power Relay Products

- **Smart Power Relay Prototype**
  - 6" x 4" proto board
  - 200V/10A DC power relay
  - Integrated current sense
  - No heat sink
  - **Target Market:** Industrial, Test & Measurement

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**Summary**

- **HV Switch Products**
- **RF Switching Products**
- **RF Tuning Products**
- **Power Relay Products**

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[menlo micro logo]
RF Packaging Considerations

Package Design Considerations
- Maintain device hermeticity
- Compatible materials: Die attach films, mold compound, substrate
- Package geometry
- System-in-package component interaction

Package Design Approach
- Device-package co-design
- Design iteration
- Design for test
- Experimental validation
RF Package Design Case Study

MM3100 – 6 Channel SPST Digital Micro-switch

- **Hermetic 6mm x 6mm x 1.3mm LGA Package**
- **Integrated SPI Bus Gate Control**
- DC to >3 GHz Frequency Range
- 25 Watt (CW), 200W (Pulsed) Max Power Handling
- Low On-State Insertion Loss < 0.3 dB @ 3 GHz
- Low On-State Resistance < 0.75 Ω
- -25dB Isolation @ 3 GHz
- Maximum voltage (AC or DC): +200 Volt on RF Input
- < 10us On/Off Switching Time
- High Reliability > 3 Billion Switching Operations

6mm QFN/BGA

- Target Markets: A/D, Industrial
- Target Applications: Tunable UHF/VHF/HF radios, general purpose EM relay replacement, WPT
Wafer Level Packaging

(48) high reliability cantilever switches in a 3.6mm x 4mm die

Hermetic Cap sealed with glass frit

(6) Channels each capable of carrying 25W/Channel (1A)

MM3100

Device Substrate
Substrate Design Considerations

RF Simulation

Primary drivers
• Grounding
• Thickness
• Assembly constraints
  ✓ Pad size for wire-bonding
  ✓ Wire-bond keep out distance

Design changes improved performance
• Substrate material – FR4 (DK=4.3, tanδ=0.02)
• Thickness: 180 µm
• 2 metal layers
Stacked Die Considerations

- RF Implications – Isolation loss
- Wire sweep
- Keep out regions
Stacked Die Impact

Simulation Results

Insertion loss

Minimized Impact of die stacking with appropriate selection of:
- Die attach film
- Cap thickness
- Die thickness and placement location

Return loss

Impact of stacked die (3 wire bonds)
Impact of stacked die (2 wire bonds)
Encapsulant Effect

Simulation Results

Ch. 1

Lower insertion loss

Ch. 3

Lower insertion loss

Epoxy encapsulation

- Er: 3.5
- Tand: 0.012

Both Ch. 1 & Ch. 3 show improvement of insertion loss and return loss due to the better impedance matching from the dielectric loading of the encapsulant material.
RF Electrical Testing

- Simulation results match experimental data
- Low On-State Insertion Loss < 0.3 dB @ 3 GHz
RF Power Testing

Test conducted at -40C, 0C, RT, 70C, 85C
- With and without forced convection
- 25 Watt (CW), 200W (Pulsed) Max Power Handling
# Package Rel/Pre-Qual Test

<table>
<thead>
<tr>
<th>Stress Test Name</th>
<th>Code</th>
<th>Condition</th>
<th>Status</th>
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<tbody>
<tr>
<td>Life test (cold)</td>
<td>RTOL</td>
<td>&gt;10B* cycles @ RT</td>
<td>Pass</td>
</tr>
<tr>
<td>Temperature Humidity Bias</td>
<td>THB</td>
<td>85°C*/85%RH  Held closed Biased to failure taret 500hrs JESD22 A101</td>
<td>Pass</td>
</tr>
<tr>
<td>85°C/85%RH storage</td>
<td>85-85</td>
<td>85°C*/85%RH  1000 hours</td>
<td>Pass</td>
</tr>
<tr>
<td>Pressure pot unbiased (PPOT)</td>
<td>PPOT</td>
<td>121°C* @ 15PSIg* 168 hrs</td>
<td>Not started</td>
</tr>
<tr>
<td>Unbiased HAST</td>
<td>UHAST</td>
<td>130°C* @ 85%RH  100 hrs</td>
<td>Pass</td>
</tr>
<tr>
<td>Temperature Cycle (TMCL)</td>
<td>TMCL</td>
<td>-40C* to 125C*  1000x JESD22 A104 Cond.G</td>
<td>Pass</td>
</tr>
<tr>
<td>High temp storage (HTS)</td>
<td>HTS</td>
<td>125°C*/1000hrs</td>
<td>Pass</td>
</tr>
<tr>
<td>ESD</td>
<td>ESD</td>
<td>HBM Class 0</td>
<td>Pass</td>
</tr>
<tr>
<td>Solder shock</td>
<td>WAVE</td>
<td>260°C*/10 sec* dip</td>
<td>Pass</td>
</tr>
<tr>
<td>Preconditioning</td>
<td>MSL</td>
<td>MSL 3</td>
<td>Pass</td>
</tr>
<tr>
<td>Drop/Shock</td>
<td>DROP</td>
<td>JESD22 B111  1,500g (0.5ms)</td>
<td>Pass</td>
</tr>
<tr>
<td>Vibration</td>
<td>VIB</td>
<td>JESD22 B103B  Cond 1  20g*</td>
<td>Not started</td>
</tr>
<tr>
<td>Reworkability</td>
<td>REWORK</td>
<td>3x Pb-free SAC reflow</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Package Miniaturization

• Flip Chip assembly

• Metal seal for hermeticity
New Package Development

Today: Glass frit based hermetic package

- 500um wide glass frit

Future: Thru Glass Via (TGV) package

- Metal seal ring
- TGV IO’s: short trace lengths
- Very high package I/O density
- Low temp WLP process

Glass Frit Sealed Wafer Level Package
- Large die: needs escape routing past frit line
- Low package I/O density

TGV Package

<table>
<thead>
<tr>
<th></th>
<th>500um frit pkg  (Base line)</th>
<th>TGV capping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (L)</td>
<td>6mm</td>
<td>2mm</td>
</tr>
<tr>
<td>Package Height (H)</td>
<td>1.2mm</td>
<td>0.8mm</td>
</tr>
<tr>
<td>Insertion loss in dB @ (1, 10, 20GHz)</td>
<td>0.09, 0.56, 1.20</td>
<td>0.03, 0.26, 0.16</td>
</tr>
</tbody>
</table>
MEMS Packaging Roadmap

2014-2015
MM7100
WL Glass Cap in 9x9mm package

2016-2017
MM3100
WL Glass Cap in 6x6mm QFN

2018
WL Glass Cap w/TGV 4x4mm SiP

2019
WL Glass Cap w/TGV 1x1.3mm CSP

Continuous shrink of both die and package
Please contact us for more information:

sales@menlomicro.com

THANK YOU!