High Temperature Pt/Alumina Co-fired System for 500°C Electronic Packaging Applications

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Outline

• Background
  – 500°C SiC electronics and sensors
  – 96% alumina and thick-film metallization based packaging system for 500°C applications
  – Quick review of Au thick-film/alumina material systems
  – Challenges of thick-film/alumina systems

• Dielectric performance of selected HTCC alumina at high temperature
• Pt/alumina co-fired systems for high temperature applications
• Prototype 32-pin low power package and PCB
• Summary
Background

500°C SiC electronics and MEMS sensors have been demonstrated

- JFETs and JFETs based circuits demonstrated at NASA GRC
- MEMS based pressure sensors and Schottky diode based gas chemical sensors developed at NASA GRC
- Applications include aerospace engine control and long term Venus probes

96% alumina and thick-film metallization based prototype packaging system for 500°C SiC electronics and sensors

- 96% alumina provides acceptable electric/dielectric properties at high temperatures up to 550°C
- The system composed of chip-level package, printed circuit board (PCB), and edge-connector
Au thick-film and 96% alumina packaging system

Ceramic Chip-level Packages and PCBs

• Three types of ceramics and Au thick-film metallization based chip-level packages and printed circuit boards (PCBs)
• Chip-level packages characterized between room temperature and 500°C
• An edge connector in development for PCB – PCB (subsystem-level) interconnection
• 96% alumina provides best electrical performance at high temperatures

Chen and Hunter, 2005 HiTEN
### Parasitic Capacitance and Conductance of Neighboring I/Os

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Usable for packaging of many envisioned low power 500°C devices/circuits

> 50°C margin above 500°C

Chen and Hunter, 2005 HiTEN
Au thick-film and 96% alumina packaging system

Static Thermal Test

- 96% alumina packaging system – chip-level packages and PCB
- less than 7% change in the JFET characteristics in first 6000 hours
- Tested at 500°C for over 10,000 hrs
- Demonstrated for long term operation at 500°C for the first time
**Au thick-film/96% alumina system for pressure sensor packaging**

**Spark - Plug Type Package for High Temperature Capacitive Pressure Sensors**

- 96% alumina substrate with Au thick-film metallization
- Four 10 mil diameter Au wires (I/Os) attached
- Au wires extended by four Pd wires
- Pd wires sealed in a commercial SS high temperature gland
- The gland operable up to 8000 psi
- Electrically characterized between RT and 500°C
- Low parasitic effects
- May apply to other micro-fabricated solid sensors

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Chen, Beheim, Meredith, 2010 HiTEC
Spark-plug Type Package for High Temperature Capacitive Pressure Sensors

- Stainless steel sealing gland with LAVA seal
- Wiring configuration: two signal wires with third wire for “shield”
- Low parasitic capacitance at high frequencies > 10 kHz
- No direct impact on capacitance measurement results from parasitic conductance
- Usable for packaging some envisioned high temperature sensors
Spark-plug Type Package for High Temperature Capacitive Pressure Sensors

- Capacitive SiC pressure sensor with four polycrystalline SiC diaphragms electrically connected in parallel
- Measured at 100 kHz
- Packaging parasitic effects subtracted
- Parasitic conductance to be further reduced for packaging other sensors
HTCC Alumina for High Temperature Packaging

HTCC Pt/Alumina for High Temperature Packaging

• Au thick-film/96% alumina based packaging system
  – Prototype package and PCB long-term tested at 500°C with SiC circuits
  – Packages assembled in a research lab – a non-mass-production step
  – Thermal dynamic stability issue of Au thick-film materials at elevated temperatures

• High temperature co-fired (HTCC) alumina
  – Co-fired at T >1500°C
  – A few percent of glass used in co-fired alumina systems
  – Dielectric performance at high temperatures tested
  – Pt metallization
    – Chemically stable at high temperatures
    – Low CTE (8.8x10^{-6}/C°)
    – Aluminum oxide for binder - Thermal dynamically stable
    – Alloy with Au, Au is always surface rich at elevated temperatures
Compared with 96% alumina:

- Dielectric constant of HTCC alumina is lower and increases less at 120Hz and 1kHz, compared with 96% alumina at low frequencies

Chen, 2012 HiTEC
Compared with 96% alumina:
• Dielectric constant of HTCC alumina is always lower and increases less with T at high frequencies

Chen, 2012 HiTEC
Compared with 96% alumina:

- Conductivity of HTCC alumina is ~ an order of magnitude lower compared with 96% alumina at temperatures above 300°C at the frequencies of 120Hz and 1kHz

Chen, 2012 HiTEC
Compared with 96% alumina:
• AC conductivity of HTCC alumina is always lower and increases less with $T$ at 10kHz, 100kHz, and 1 MHz at $T > 200^\circ C$

Chen, 2012 HiTEC
Compared with 96% alumina

- Dielectric constant of HTCC alumina is slightly lower and it increases less with temperature. AC conductivity of this material is also lower than that of 96% alumina at temperatures above 200°C
- Dissipation factor of HTCC alumina is always lower compared with that of 96% alumina at temperatures above 250°C
- HTCC alumina parts can be hermetic sealed
- Alumina based binders used for HTCC thick-film materials are expected to be thermal dynamically stable in a wide temperature range
Pt/HTCC Alumina Prototype Package

- Pt/HTCC alumina
- 32-IOs
- For low power circuits
- Via connecting pads
- 1 inch x 1 inch package
- Surface mount
- Preliminarily tested with SiC high temperature ICs
- In characterization/testing process
Pt/HTCC alumina PCBs, 2 inch x 2 inch, preliminarily tested with SiC circuits
Pt/HTCC Alumina Prototype Package and PCB

- SiC RAM decoder waveforms
- With 32-IOs HTCC package and PCB
- Initial test data recorded at 501°C

- SiC D/A convertor
- With 32-IOs HTCC package and PCB
- Initial test data recorded at 500°C

G.W. Hunter, P.G. Neudeck, D.J. Spry, G.E. Ponchak, G.M. Beheim et al, Venus Science Priorities for Laboratory Measurements Workshop, April, 2015, Hampton, VA.
Summary

96% alumina substrate and thick-film metallization based packaging systems demonstrated at 500°C

- Au thick-film/alumina chip-level packages and PCBs
- Static thermal test of packaged SiC JFET circuits successfully at 500°C for over 10,000 hours
- Thermal dynamic stability issue of thick-film binders at elevated temperatures
- Laboratory step involved on package assemble
  - Chip - level packages not fully commercially fabricated

Pt/HTCC alumina system

- Dielectric properties of selected HTCC alumina tested up to 550°C
- Better dielectric performance
- Co-fire process more suitable for large scale commercialization
- Alumina binder for Pt metallization more stable at high temperatures
- Dielectric performance of 32-IOs co-fired packages in evaluation
- Prototype package initially tested with SiC circuits at 500°C
- Further development needed
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