Packaging Technologies For 500°C SiC Electronics and Sensors
- Challenges in Material Science and Technology

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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 packaging systems
  – Challenges of thick-film/alumina systems
  – Co-fired alumina 32-I/O prototype packaging system and test results

• Dielectric performance of selected alumina substrates and HTCC alumina material at high temperatures

• Impurity effects on alumina dielectric performance and material requirements for packaging performance

• Summary and Challenges
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
- Packaging material issues

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

Co-fired Pt/alumina material system

- 32-I/O package and printed circuit board (PCB)
- Initial test results with SiC circuits at 500°C
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
# Au thick-film and 96% alumina packaging system

## 96% Alumina Chip-level Packages

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

- 50°F margin above 500°F

- pF
- μS
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
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

Chen, Beheim, Meredith, 2010 HiTEC
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 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
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.
Dielectric properties of packaging dielectric at elevated temperatures is critical to parasitic packaging effects

- Low dielectric constant
- Low parallel conductivity
- Low dissipation factor / high quality factor
- Stability with temperature increase
Compared with 96% alumina:

- Dielectric constants of 92% and 99.6% alumina are higher and increases more at 120Hz and 1kHz
- Dielectric constant of HTCC alumina is lower and increases less at 120Hz and 1kHz

Chen, 2012 HiTEC, 2007 ICEPT
Compared with 96% alumina:

- Dielectric constants of 92% and 99.6% alumina are higher and increase more at 10kHz, 100kHz, and 1 MHz

- Dielectric constant of HTCC alumina is lower and increases less at 10kHz, 100kHz, and 1MHz

Chen, 2012 HiTEC, 2007 ICEPT
Compared with 96% alumina:

- Conductivities of 92% and 99.6% alumina are higher at temperatures above 100°C at the frequencies of 120Hz and 1kHz
- Conductivity of HTCC alumina is ~ an order of magnitude lower at temperatures above 300°C at the frequencies of 120Hz and 1kHz

Chen, 2012 HiTEC, 2007 ICEPT
Compared with 96% alumina:

- Conductivities of 92% and 99.6% alumina are higher at temperatures above 200°C at the frequencies of 10kHz, 100kHz, 1MHz
- AC conductivity of HTCC alumina is always lower and increases less with T at 10kHz, 100kHz, and 1 MHz at T > 200°C

Chen, 2012 HiTEC, 2007 ICEPT
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

- 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
Challenges

Dielectric properties of alumina materials at elevated temperatures
- Overall 92% HTCC alumina the best
  - AC conductivity still increases with temperature
- 96% conventional alumina better than 92% and 99.6% alumina
  - Firing agents / impurities, and grain size
  - Chemical/electronic states of impurities at grain boundaries

Better packaging material systems at high temperatures
- For higher packaging density, higher operation frequency and temperature
- Understand impurity, grain size, process effects
- Design of new ceramic material with stable dielectric constant and lower dielectric loss at high temperatures
  - Co-fired process
  - CTE compatible to SiC – bigger die
- Metallization scheme for operation at 500°C and above
Acknowledgements

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