Packaging Technology for 500°C SiC Microsystems

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Outline

- Background: motivations
- Electrical and mechanical characterization facilities
- Thick-film metallization based electrical interconnections
  - Validation results
- 500°C operable low electrical resistance die-attach
  - Method and evaluation results
- Summary
- High temperature MEMS packaging
  - Thermal mechanical stability of die-attach
- Acknowledgements
Background

- 500°C operable sensors/electronics have many applications in NASA aerospace missions
  - Sensors/electronics for combustion monitoring and control
    - Pressure sensor, gas chemical sensor, and flow sensor for aeronautic engine diagnosis and control
  - Sensors/electronics for space probes to inner solar planets
    - Atmosphere profile for Venus
- SiC - excellent high temperature semiconductor
- SiC electronic devices/sensors/MEMS demonstrated ~ 600°C, most in test probe station
  - Systematically validated packaging technology for T > 350°C not available
- 500°C device packaging technology needed
  - In situ device testing and commercialization
NEPP High Temperature SiC Packaging Project

- Collaborating efforts between NASA, industry, university
  - GRC: Material selection, package design and fabrication, testing, SiC device
  - JPL: NDE of die-attach
  - MSFC: Engine test
  - UTRC: Dynamic thermal environment tests, FEA evaluation
  - CWRU: Assistance in fabrication
High Temperature SiC Microsystem Packaging

- Electrical interconnection system
  - 500°C operable substrates
    - Ceramics: Al₂O₃ and AlN
  - 500°C operable electrical interconnection
    - Precious metal thick-film metallization
    - Au wire-bond
  - Conductive die-attach
    - Conductive, low electrical resistance
    - Thermal mechanical stability

- Mechanical system
  - Thermal mechanical reliability of die-attach
Test Facilities

- Testing systems for 500°C packaging materials/components tests
  - Electrical/electronic tests
    - Computerized
    - Simultaneous measurement of multi-parameters for multi-samples
    - Temperature programming
  - Mechanical/materials tests
    - Die shear ($T_R - 500^\circ C$) and die tensile ($T_R$)
    - Wire loop test ($T_R$, 500°C later this year)
Au Thick-film Based Interconnections

- Au based thick film metallization
  - Screen-printed thick-film wire/pads
  - Good adhesion to various ceramic substrates
  - Stable in corrosive ambience at high temperatures
  - Au thin wire-bond

- Printed thick-film wire/pad and Au wire-bond
- Tested at 500°C with electrical bias
Thick Film Based Interconnections

- 0.025 inch
- 3.45 inch
- 0.15 inch

~ 10 micron Au film on alumina
Thick Film Printed Wire
Thick Film Based Interconnections

Unit Circuit
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Thick-Film Metallization Based Au Wirebond
Conductive Die-attach

- SiC test device
  - Backside: Ni/4H-SiC ohmic contact after annealing at high temperature in Ar
  - Front-side: Au/Ti/4H-SiC \textit{rectifying} contact
- Au thick-film used as conductive attaching material
  - Two steps process allowing low curing temperature
- AlN substrate: high thermal conductivity and a CTE matches SiC
Optimized Die-Attach Process

- Thick film suggested be cured at 850°C
  - Best bonding to ceramic substrates
- 850°C may not be comfortable to die
- Optimize thick-film process for die-attach
- Scanning Electron Microscopy (SEM) and Auger Electron Spectroscopy (AES) were used to study the thick film surfaces cured at various temperatures
Conductive Die-attach Structure

Diagram showing a conductive die-attach structure with layers labeled as Au, Ti, Ni, SiC, and a ceramic substrate.
Two-Step Thick Film Process

- AES results indicate
  - High curing temperature (~ 850°C) preferred for binder migration to Au/ceramic interface
- SEM results indicate
  - Coherent thick film formation at ≥ 600°C
- Best adhesion and low temperature exposure to die
  - First screen-printed layer cured at 850°C
  - Die attached at 600°C with minimal amount of thick film materials
I-V Curve of an Attached SiC Diode at 500°C

T=500°C
t=1000 hours
In Air
Dynamic Resistance of Attached SiC Diode

![Graph showing dynamic resistance over test time at 500°C](image)
Test Results

- Attached SiC test chip
  - Diode I-V curves characterized at both $T_R$ and 500°C
  - Dynamic resistance of I-V curves indicated die-attach resistance less than $3.5 \times 10^{-2} \, \Omega \, \text{cm}^2$ at $T_R$ and 500°C tested for over 1000 hours
  - Sufficient shear strength measured at $T_R$
- Thick-film based interconnections validated at 500°C
  - Thick film printed wires stable at $T_R$ - 500°C, with/without 50mA DC, for $\sim 10000$ hours.
  - Thick film metallization based wire bond stable at $T_R$ - 500°C, with/without 50 mA DC, for $\sim 10000$ hours.
500°C Chip Level Package

- AlN and Al$_2$O$_3$ substrates
- Au thick-film metallization based wire-bond
- Au thick-film based low resistance conductive SiC die – attach scheme
- $T_R$ - 500°C operable
- Tested in oxidizing environment
- Basic elements electrically tested at $T_R$ - 500°C for ~10000 hours
- Packaging HT SiC sensors and circuits
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High Temperature Chip Level Package

Al$_2$O$_3$ based

AlN based
Summary

- AlN and 96% Al$_2$O$_3$ selected as substrates
- Au thick-film based interconnections validated at $T_R$ and 500°C for $\sim$10000 hours with/without DC bias
- Au thick-film based conductive SiC die-attach scheme evaluated for 500°C operation
- Attached SiC diode electrically tested at 500°C for $>1000$ hours in oxidizing environment
  - The upper limit of die-attach resistance $< 3.5 \times 10^{-2} \Omega\text{-cm}^2$ at both $T_R$ and 500°C
High Temperature MEMS Packaging

- Wide operation temperature range
  - $T_R - 500^\circ$C
- MEMS devices are sensitive to thermal mechanical stress
  - Device mechanical operation
  - CTE mismatch of die-attach materials
- Non-electrical interactions between the device and environment
  - Chemical, mechanical, magnetic, optical
- Thermal mechanical optimization of die-attach is critical to the reliability of packaged devices
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