Packaging Technology for 500^{o}C SiC Microsystems

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Outline

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

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Background

- 500^{o}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^{o}C, most in test probe station
  - Systematically validated packaging technology for T > 350^{o}C not available
- 500^{o}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
  - 500ºC operable substrates
    - Ceramics: Al_2O_3 and AlN
  - 500ºC 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

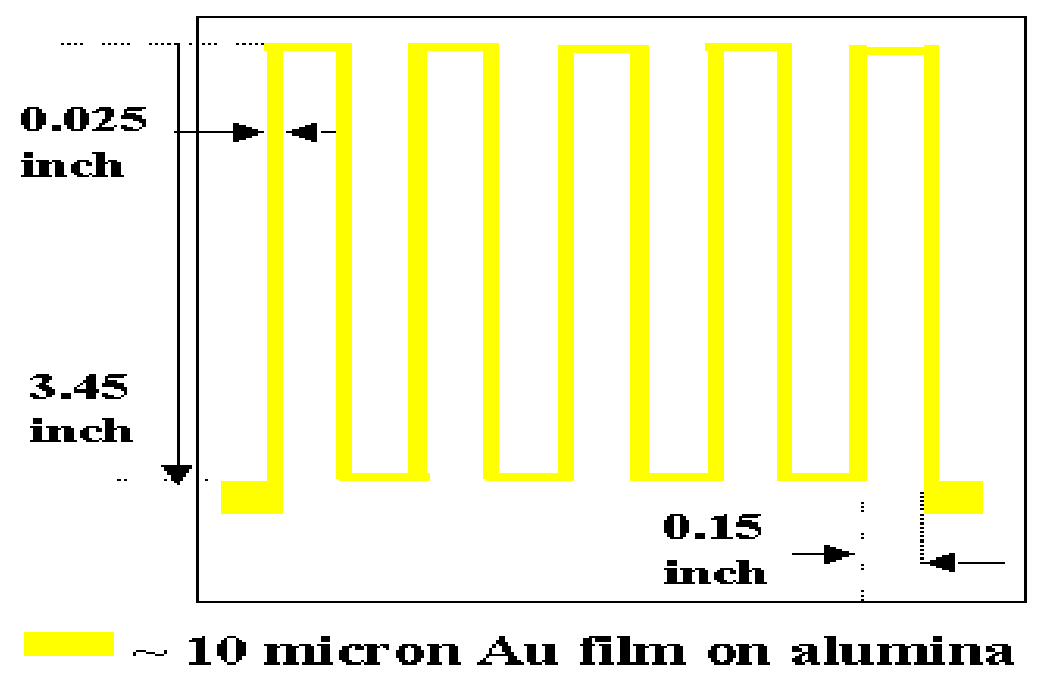
Test Facilities

- Testing systems for 500ºC 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 – 500ºC) and die tensile (T_R)
    - Wire loop test (T_R, 500ºC 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 500ºC with electrical bias

Thick Film Based Interconnections



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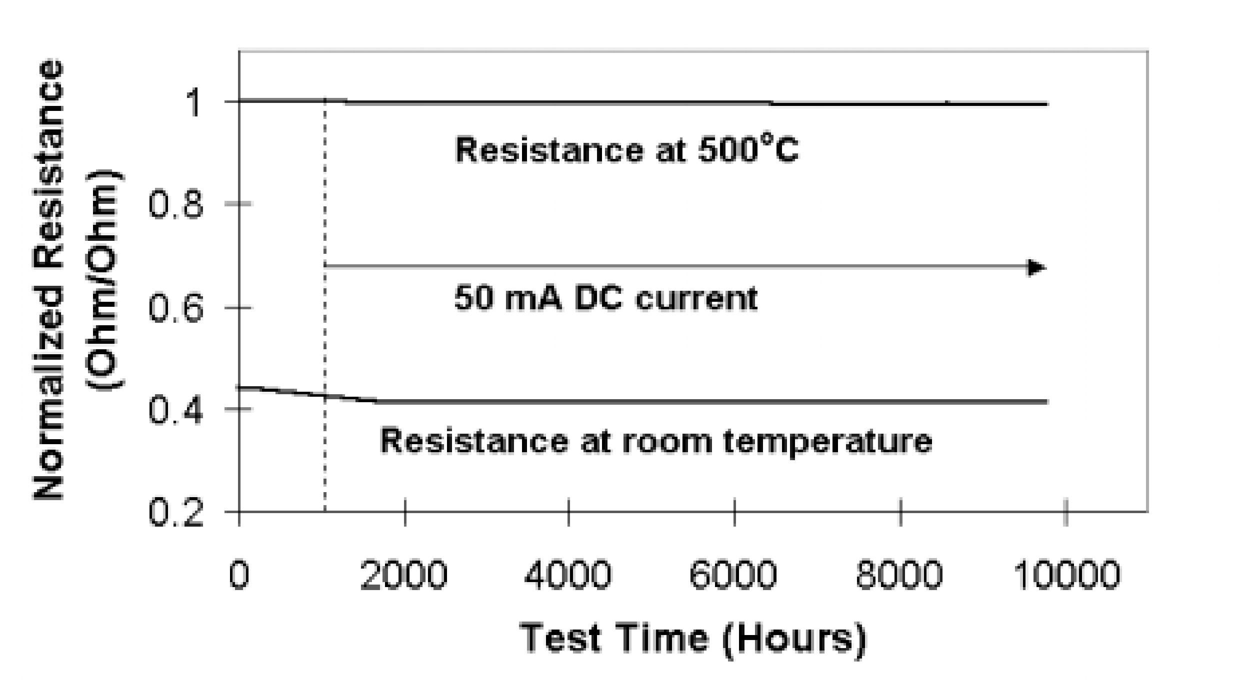
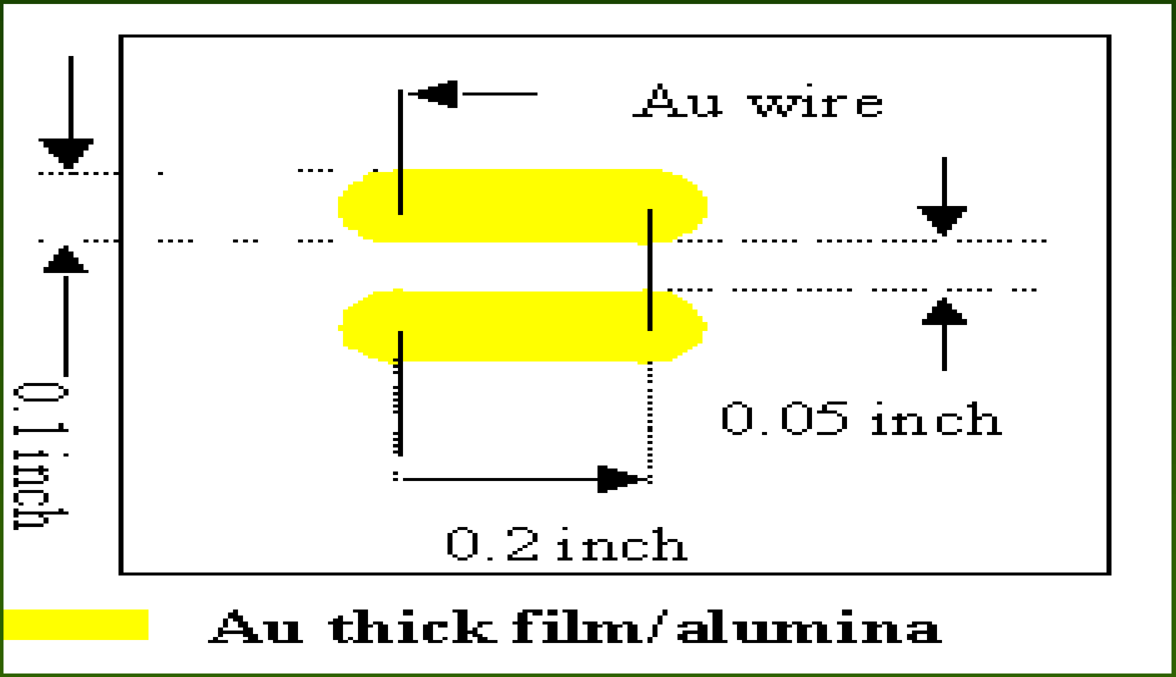
Thick Film Printed Wire



Thick Film Based Interconnections



Unit Circuit

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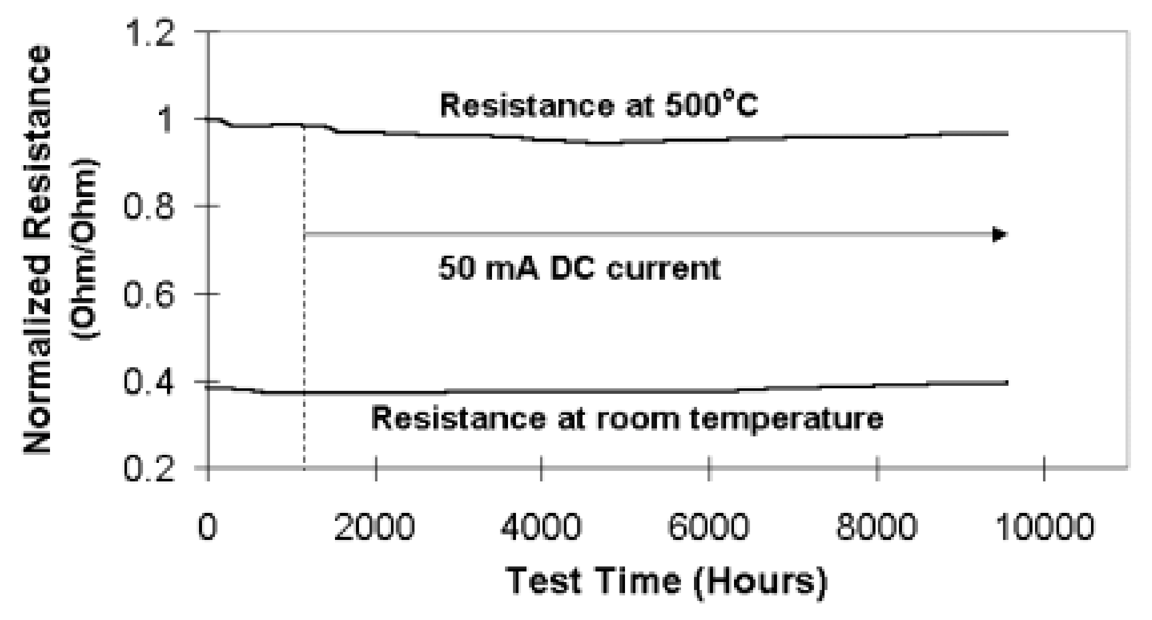
Thick-Film Metallization Based Au Wirebond



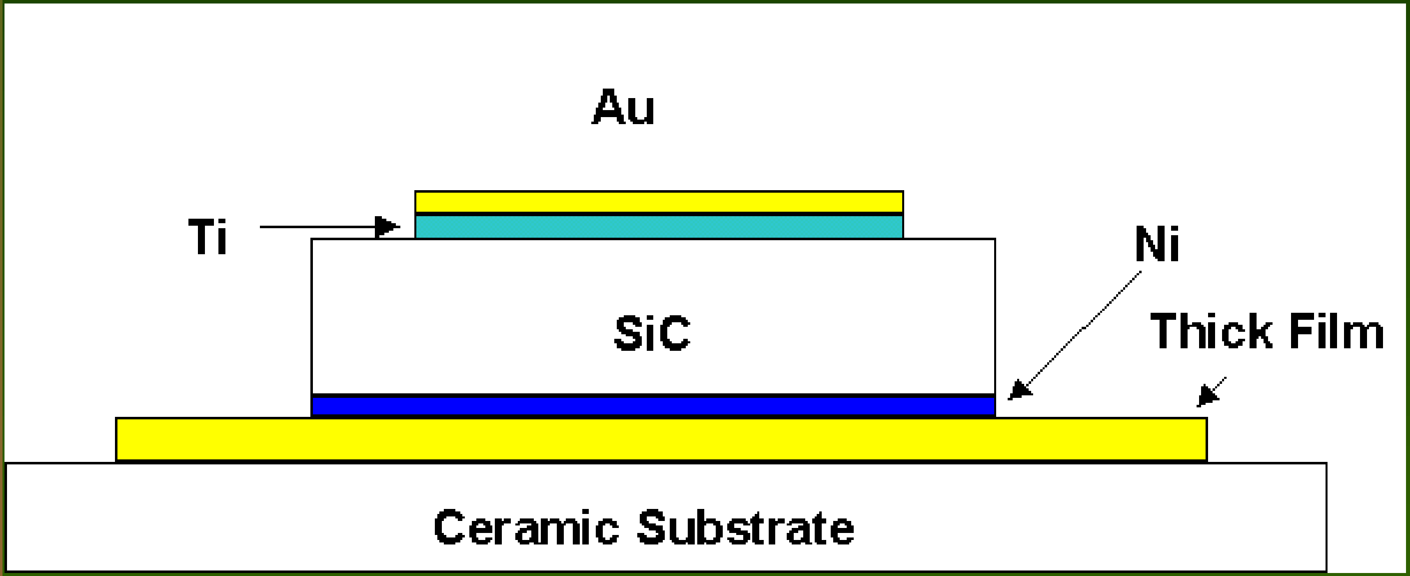
Conductive Die-attach

- SiC test device
  - Backside: Ni/4H-SiC ohmic contact after annealing at high temperature in Ar
  - Front-side: Au/Ti/4H-SiC **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 850ºC
  - Best bonding to ceramic substrates
- 850ºC 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



Two-Step Thick Film Process

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

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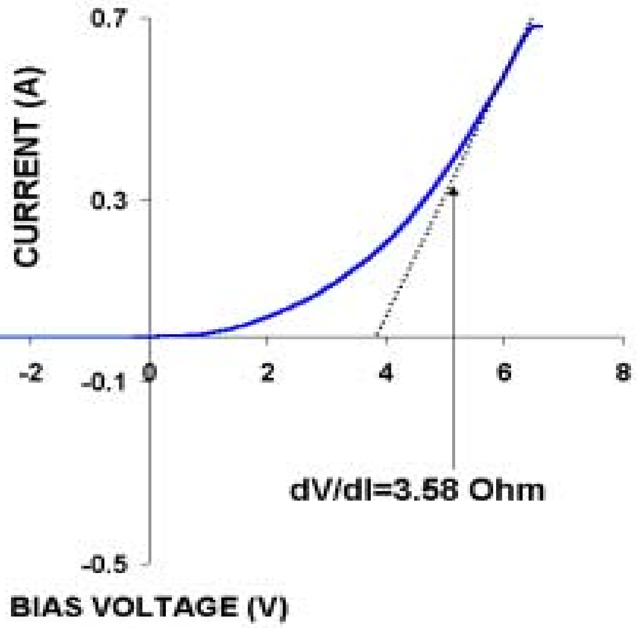
I-V Curve of an Attached SiC Diode at 500ºC

T=500ºC

t=1000 hours

In Air



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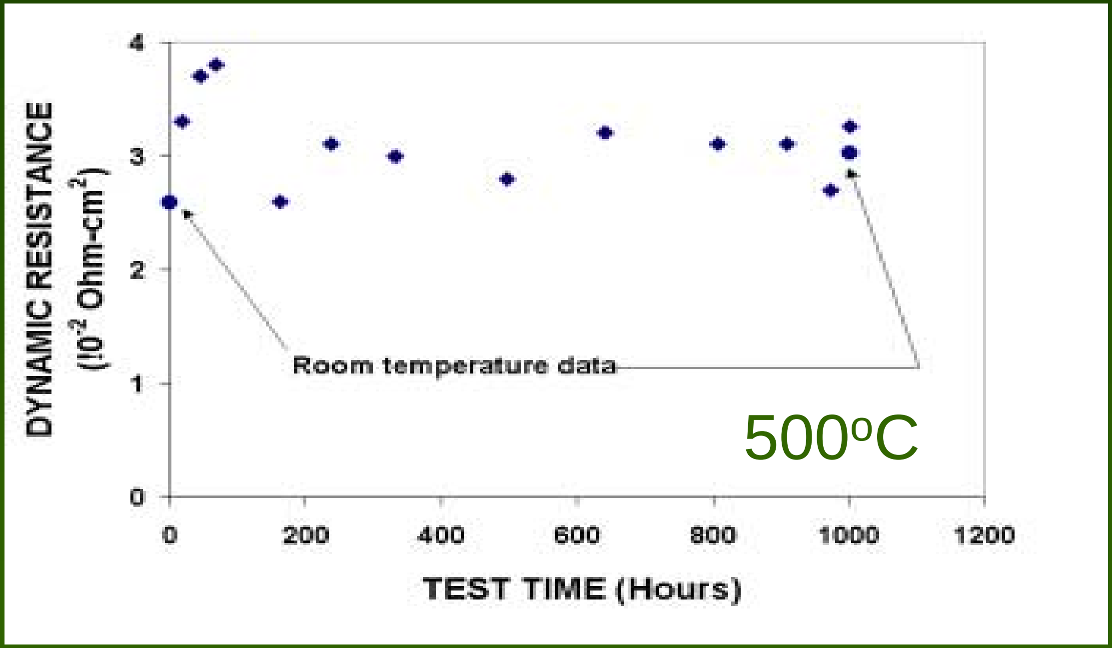
Dynamic Resistance of Attached SiC Diode



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Test Results

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

500^{o}C Chip Level Package

- AlN and Al_2O_3 substrates
- Au thick-film metallization based wire-bond
- Au thick-film based low resistance conductive SiC die – attach scheme
- T_R - 500^{o}C operable
- Tested in oxidizing environment
- Basic elements electrically tested at T_R - 500^{o}C for ~10000 hours
- Packaging HT SiC sensors and circuits

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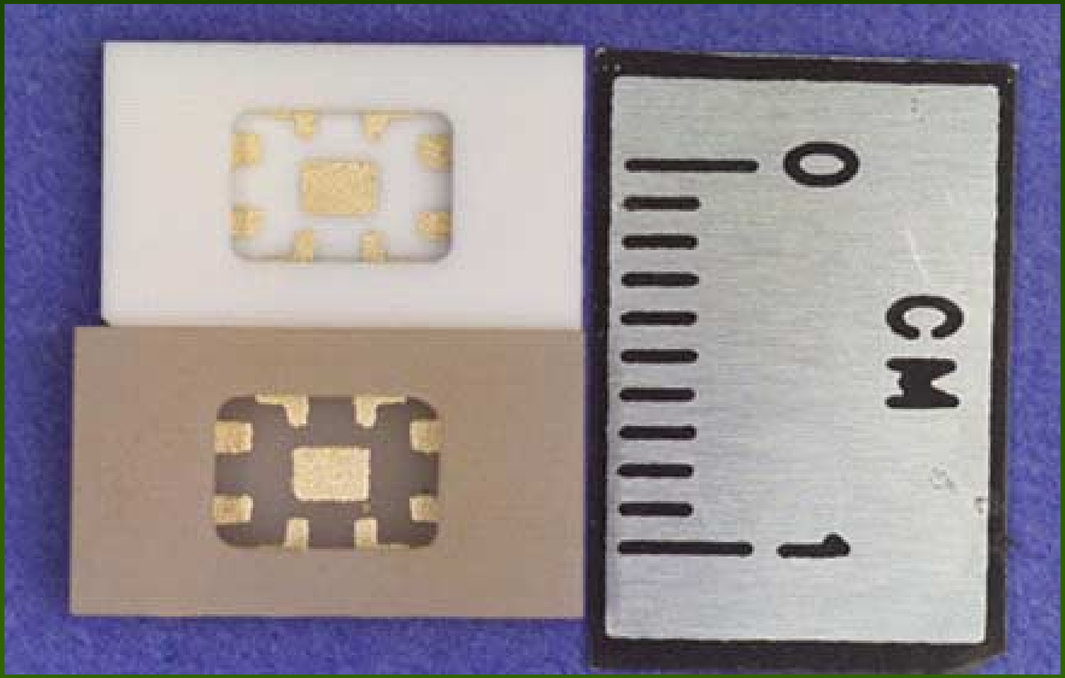
High Temperature Chip Level Package

Al_2O_3 based

AlN based



Summary

- AlN and 96% Al_2O_3 selected as substrates
- Au thick-film based interconnections validated at T_R and 500°C for ~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 – 500ºC
- 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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Acknowledgements

- 2nd NEPP Annual Conference Committee
- Thick-film test samples fabricated in Case Western Reserve University
- Jih-Fen Lei and Lawrence G. Matus at GRC
- The technical support team at GRC
- Phillip J. Zulueta and David Mih at JPL
- High temperature SiC device packaging efforts at GRC are currently supported by NEPP and GMI