HIGH TEMPERATURE ELECTRONICS, COMMUNICATIONS, AND SUPPORTING TECHNOLOGIES FOR VENUS MISSIONS

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SENSORS AND ELECTRONICS TECHNOLOGY BRANCH

SCOPE OF WORK

PHYSICAL SENSORS (T, Strain, Heat Flux)

CHEMICAL SENSORS

SILICON CARBIDE HIGH TEMP ELECTRONICS

MICRO-ELECTRO-MECHANICAL SYSTEMS

NANOTECHNOLOGY
NASA GRC: CUTTING EDGE DEVELOPMENT HARSH ENVIRONMENT SENSORS AND ELECTRONICS
HIGH TEMPERATURE ELECTRONICS AND SENSORS BENEFITS TO NASA MISSIONS

Intelligent Propulsion Systems

Space Exploration Vision PMAD

More Electric + Distributed Control Aircraft

Venus Exploration

Pillar Two: Revolutionary Technology Leaps
HARSH ENVIRONMENT VENUS MISSION REQUIREMENTS

• SURFACE CONDITIONS
  - TEMPERATURE: 450-500 C
  - PRESSURE: 90 bar PREDOMINATELY (~100 TIMES EARTH)
  - SULFURIC ACID PARTICLES IN CLOUD DECK
  - 96.5% CO2 and 3.5% N2; Trace Gases include H2O, SO2, CO, HCL, H2, and HF

• SOME PARAMETERS OF INTEREST: TEMPERATURE, PRESSURE, CHEMICAL SPECIES, FLOW (WIND)

• TEMPERATURE CONTROL INCREASES SYSTEM COMPLEXITY/RISK TO MISSION

• NEED TO SHIELD SYSTEM FROM EXTREME ENVIRONMENTS YIELDS INCREASE IN SIZE AND WEIGHT

• LIMITED INFORMATION AVAILABLE FROM IN-SITU SYSTEMS DUE TO HARSH ENVIRONMENTS INVOLVED

• SCIENTIFIC COMMUNITY: LACK OF VIABLE HARSH SENSOR SYSTEMS SENSORS AND ELECTRONICS FOR IN-SITU CHARACTERIZATION

• IN SOME AREAS, NASA GRC HAS ALREADY TECHNOLOGY SOLUTIONS ISSUES NEEDED BY SMD FOR HARSH ENVIRONMENT APPLICATIONS
HARSH ENVIRONMENT ELECTRONICS AND SENSORS APPLICATIONS

• NEEDS:
  - OPERATION IN HARSH ENVIRONMENTS
  - RANGE OF PHYSICAL AND CHEMICAL MEASUREMENTS
  - INCREASE DURABILITY, DECREASE THERMAL SHIELDING, IMPROVE IN-SITU OPERATION

• RESPONSE: UNIQUE RANGE OF HARSH ENVIRONMENT TECHNOLOGY AND CAPABILITIES
  - STANDARD 500C OPERATION BY MULTIPLE SYSTEMS
  - TEMPERATURE, PRESSURE, CHEMICAL SPECIES, WIND AVAILABLE
  - HIGH TEMPERATURE ELECTRONICS TO MAKE SMART SYSTEMS

• ALL-IN-ONE SHOP FOR HARSH ENVIRONMENT SYSTEM APPLICATIONS

• ENABLE EXPANDED MISSION PARAMETERS/IN-SITU MEASUREMENTS
VENUS SCIENTIFIC MISSIONS LIMITED BY AVAILABILITY OF HARSH ENVIRONMENT SENSORS AND ELECTRONICS

NASA GRC HAS VAST RANGE OF HIGH TEMPERATURE EXPERIENCE AND IS IN A POSITION TO PROVIDE NEEDED SOLUTIONS

HIGH TEMPERATURE ELECTRONIC NOSE

HIGH TEMPERATURE MICROELECTRONICS

HIGH TEMPERATURE PACKAGING

Hi-g SiC ACCELEROMETER

MULTIFUNCTIONAL PHYSICAL SENSOR ARRAY

600°C PRESSURE SENSOR

MICROENGINE, ACTUATORS, AND FUEL DELIVERY

Glen Research Center at Lewis Field
6H-SiC JFET NOR Gate

3 x 300 µm JFET’s

Unpackaged device tested for approx. 1 hour on prober with hot-chuck in 1997.

V_{DD} = 3.5 V
V_{SS} = 0 V
V_{substrate} = -1.8 V.

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T = 600 °C
NASA/GMI 6H-SiC JFET Amplifier Circuit
(Under Construction)
WORLD’S FIRST 500 HOUR 500 °C TRANSISTOR WITH VERY STABLE OPERATION

- 2000 hours of transistor operation achieved (some limited degradation)
- Device Operation Also Demonstrates Viability of Supporting Technologies
  - Packaging and ohmic contacts operated over 2000 hours at 500 °C without degradation.
- Strong Foundation for Improved Device Operation
  - Revised “junction gate” process should enable 2000 hours at 500 °C without transistor degradation.

![Graph showing transistor performance over time](image)

**Initial Characteristics at 500 °C**

- After 126 h 500 °C
- After 558 h 500 °C

Glenn Research Center at Lewis Field
High Temperature Wireless Development

OBJECTIVES:
• HIGH TEMPERATURE WIRELESS TELEMETRY, DISTRIBUTED ELECTRONICS OVER A BROAD OPERATING RANGE

TECHNICAL CHALLENGES:
– DEVELOPMENT OF RELIABLE HIGH TEMPERATURE TELEMETRY ELECTRONICS, POWER SOURCES, REMOTE COMMUNICATION ELECTRONICS, AND PACKAGING

GOALS SUPPORTED:
– ENHANCE PERFORMANCE
– SIGNIFICANTLY REDUCE COST

PROVIDE DATA TRANSFER IN HARSH ENVIRONMENTS IMPROVING RELIABILITY AND ENABLING NEW CAPABILITIES
Chip Level Packages for 500°C Application

- Three types of ceramic substrate and Au thick-film metallization based chip-level packages
- A compatible low resistance die-attach scheme tested for 1000hrs
- Compatible printed circuit board level interconnection system developed
Circuit Board Level Interconnection

Electronic Package for High Temperature Micro-Systems

- Three types of ceramic substrate and Au thick-film metallization based PCB
- Interconnection between chip-level packages and PCB
- 500 C technology
Demonstration of 500°C AC Amplifier Based on SiC MESFET and Ceramic Packaging – Test assembly 2006

Optical Picture of the Test Assembly

- The test assembly includes four testing circuit units
- Common - Source AC amplifier tested at 500 C for over 1100 hours
Atomically Flat SiC Mesas and Cantilevers

Defect-free areas large enough for prototype devices!

Top surface of mesa is atomically smooth completely free of steps. Surface can be enlarged by growing defect-free cantilevers.

Atomically Flat “Webbed Cantilevers”
Accomplishment: Growth of Improved GaN on SiC Films

Method: Growth of GaN (by US Naval Research Laboratory) on top of Atomically Flat SiC Mesa Arrays Grown by NASA GRC.

Transmission Electron Micrographs (from NRL) Comparing GaN on SiC Films

GaN grown on top of conventional SiC with surface steps

Defect Density $\sim 8 \times 10^9$ cm$^{-2}$

g=[2110]

GaN grown on top of NASA GRC SiC mesa free of surface steps

Defect Density $\sim 5 \times 10^7$ cm$^{-2}$

g=[0002]

GaN Dislocation Density Reduced by 100X!
SUMMARY
NASA GRC HAS THE TOOLS TO ENABLE NEW MISSIONS

EXAMPLE POSSIBLE MISSION: Venus Integrated Weather Sensor (VIWS) System
Sensor Suite to Monitor Venus Weather Conditions including: Data Processing and Communication, Wind Flow, Seismic, Pressure/Temperature/Heat Flux, Chemical Environment

- HIGH TEMPERATURE ELECTRONIC NOSE (Chemical Species)
- HOTProbe (Wind flow, Pressure, Temperature)
- MULTIFUNCTIONAL PHYSICAL SENSOR ARRAY (Temperature, Heat Flux)
- Hi-g SiC ACCELEROMETER (Seismic Activities)
- PRESSURE SENSOR (Pressure)
- SiC ELECTRONICS (Data Processing and Com)
BACK UP SLIDES
NASA Glenn Microsystem Development Facilities

- Significant In-House Capabilities for a Range of Micro/Nano Sensor and Electronics Development
- Capabilities Range From Semiconductor Material and Device Fabrication to Packaging and Testing
- State-Of-The-Art Facilities Leading to World Leading Technologies

SiC Chemical Vapor Deposition (CVD) Epitaxial Growth Laboratory

- Microsystems Fabrication Clean Room
- Microdevices Characterization Facilities

World’s Most up-to-date Facility of Its Type

3000 Square Foot Clean Room Space for Electronic-Grade Oxides and MEMS

A Range of Characterization and Testing Equipment For Device Development
SiC-BASED PRESSURE SENSORS

- SiC HAS EXCELLENT MECHANICAL PROPERTIES FOR USE AS A HARSH ENVIRONMENT PRESSURE SENSOR (T > 500 °C, SILICON UNDERGOES PLASTIC DEFORMATION)
- FORM DIAPHRAGM OF SiC AND INTEGRATE WITH ELECTRONICS
- WIDE RANGE OF APPLICATIONS
  - AERONAUTIC ENGINE APPLICATIONS
  - AUTOMOTIVE APPLICATIONS
  - MATERIAL PROCESSING
- ENGINE OPERATION DEMONSTRATED AT 500 °C
- CAN BE INTEGRATED WITH FLOW VELOCITY AND TEMPERATURE FOR A VENUS HIGH TEMPERATURE WEATHER MONITORING DEVICE

Real World Application: Pressure Sensor Installed in Engine Test

SiC High Operating Temp. Probe (HOTProbe): SiC chip to simultaneously measure flow velocity, pressure, and temperature;

Stainless Steel

Plug’n play pins
Thin Film Physical Sensors for High Temperature Applications

- Advantages for temperature, strain, heat flux, flow & pressure measurement:
  - Negligible mass & minimally intrusive (microns thick)
  - Applicable to all materials including ceramic based materials
  - Minimal structural disturbance
  - Intimate sensor to substrate contact & accurate placement
  - Multiple sensor fabrications, full-field measurement
  - High durability
  - Capable for operation to very high temperatures (> 1000°C)

- Multifunctional smart sensors being developed

- Can Be Used To Measure Venus Surface Conditions as well as Monitor Vehicle Conditions
HIGH TEMPERATURE GAS SENSOR ARRAY
HIGH TEMPERATURE ELECTRONIC NOSE

- High Temperature MEMS Based Gas Sensors Designed for Selective Detection
- Multiple Chemical Species Can Be Measured/Sensors Can Be Tailored for the Application
- Multiple Species of Interest To Venus Applications Can Be Detected

Automotive Engine Sensor Testing

Jet Engine Sensor Testing