800 °C Demonstrated kHz SiC IC Electronics and Pressure Sensors as Technical Foundation for Realizing MHz DARPA HOTS Goals

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DARPA BAA: "The HOTS program will develop a technology for high-bandwidth, high-dynamic-range sensing at high temperature. Performance will be validated through the development and demonstration of a pressure sensor module (i.e., integrated transducer and signal-conditioning microelectronics) achieving the following performance goals:"

NASA Glenn has already demonstrated SiC-based ICs & pressure sensors meeting these HOTS goals.

Table 1 HOTS high-temperature microelectronic pressure sensor module goals

Operating Temperature: 800 °C	**Dynamic Range**: > 90 dB*
Operating Lifetime at Temperature: > 1 hour	**Bandwidth**: > 1 MHz
No Active Cooling	

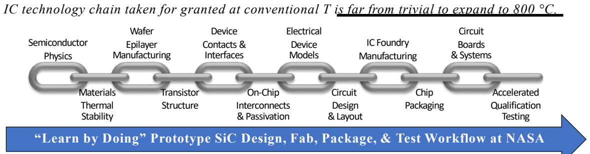
*Pressure resolution: < 1 Pa

However, these are further hard development challenges to be overcome during DARPA HOTS.

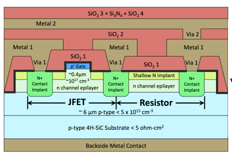
Technical foundations of 800 °C operation from decades of "learn by doing" NASA Glenn SiC development (Significant risk reduction ahead of addressing DARPA HOTS challenging goals within 36 months)

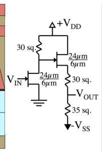
SiC Integrated Circuit Electronics

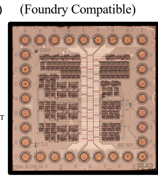
IC technology chain taken for granted at conventional T is far from trivial to expand to 800 °C.

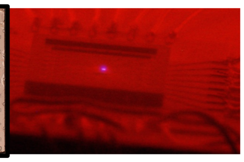


SiC JFET-R IC Topology (pn homojunction durability, L_G = 6μm) | **Ratio Design** (-190 to +800 °C) | **ASIC Fabrication** (Foundry Compatible) | **Packaging & Oven Testing** (ICs exposed to air atmosphere)



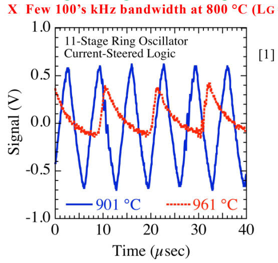




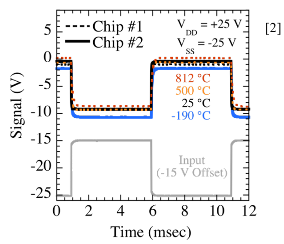


- ✓ T ≥ 800 °C IC demonstrated > 1 hour in air
- ✓ T = 500 °C ICs demonstrated > 1 year in air
- ✓ Packaged testing with no cooling
- X Few 100's kHz bandwidth at 800 °C (L_G = 6 μm)

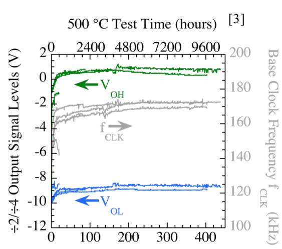
- ✓ Demonstrated -190 °C to + 812 °C logic operation without changing signal or supply voltages
- ✓ Analog ICs (Op amps, 8-bit ADCs) tested to +500 °C
- X Limited chip complexity (LSI) and power (< 1 A)



Measured oven-test waveforms from packaged SiC JFET-R ring oscillator prototype chip.



SiC JFET-R NOT gate waveforms measured during cold-chamber and hot-chamber testing.



Change in signal voltages measured during over a year of 500 °C testing of SiC JFET-R clock chips.

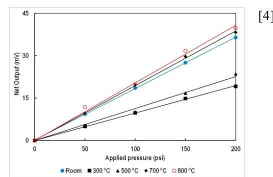
Candidate NASA electronics contributions to HOTS:

- Electronics integration with pressure sensors
  - Separate chips or monolithic?
- Increase 800 °C electronics bandwidth > 1 MHz
  - SiC BJT inherently higher-f, less mature
  - SiC JFET* most durable, more proven/developed
  - III-N inherently higher-f, less durable
- SiC prototype chip design, fabrication & testing
  - Tech transfer (including to customer fab)
  - Prototype ASIC fab (including at external fab)
    - GE partial fab of NASA IC Gen. 12 wafers
  - Process development
  - Ceramic packaging (wire bond or flip-chip)
  - Circuit design and modeling

* f_T > 100 MHz, 1 MHz system at 800 °C is achievable in 4H-SiC JFET with L_G = 1μm. See [2,9,10].

SiC Pressure Sensors

Piezoresistive bridge & diaphragm approach fabricated via dry etch patterning of 4H-SiC

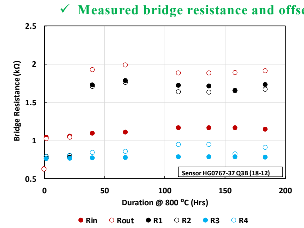


Net output voltage versus pressure at various temperatures. Note output increase at 800 °C.

Packaged high temperature pressure sensor.

Demonstrations of NASA Glenn SiC Pressure Sensors at 800 °C in Air

✓ Measured bridge resistance and offset voltage stable through 200 hours at 800 °C



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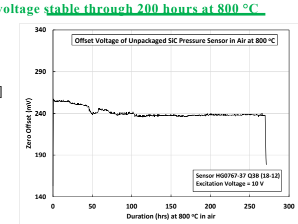
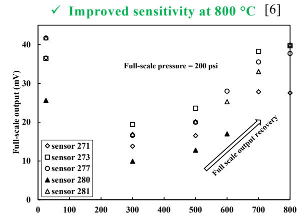
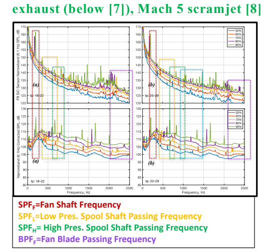


✓ Improved sensitivity at 800 °C [6]



Full-scale output as function of temperature up to 800 °C shows the five sensors with characteristic upward swing beyond 400 °C and reaching near or above the room temperature values at 800 °C.

✓ Field validation tests including 600 °C turbofan exhaust (below [7]), Mach 5 scramjet [8]



(Top Row) SiC sensor response at key frequencies of interest were in good agreement with externally located conventional pressure sensors (Bottom Row)

Key Pressure Sensor Takeaways

- ✓ SiC pressure sensors demonstrated reference offset voltage stability at 800 °C in air well beyond 1 hr. Stable offset voltage is the perquisite for reliable post-calibration measurement.
- ✓ Demonstrated high sensitivity at 800 °C, providing good S/N and dynamic range.
- ✓ Validated sensor kHz frequency response up to in relevant operational environment up to 600 °C, including hypersonic speed regime.
- Frequency response at 1 MHz (800 °C) is achievable with sensor geometry reconfiguration.

NASA Glenn has unique technology experience in extreme environment pressure sensors & IC electronics, including at 800 °C in air, providing significant risk reduction in meeting DARPA HOTS goals

- Appropriate partnership and tech transfer should accelerate realization of DARPA HOTS hard technical challenges
- NASA-patented technology available for no-cost "Government Use" licensing by DARPA HOTS awardees (after project selection)

References

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