HIGH TEMPERATURE ELECTRONICS FOR FUTURE VENUS EXPLORATION.

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High temperature atmospheric environments are extremely difficult to measure in-situ. Up to now, large, massive, refrigerated spacecraft have been needed to conduct surface investigations of Venus, which has surface temperatures of 740 K. Autonomous in-situ exploration of the hotter temperatures (1000+ K) of volcanic vents has not been possible. The ability for mechanicals and instruments to comfortably function in these extreme temperature environments is essential to future exploration efforts.

Here we propose high-temperature capable microelectronics that are based upon arrays of carbon nanotubes (CNTs) which act as field emitters in the devices. Similar to their macroscopic counterparts, vacuum electronics, these CNT-based devices are immune to ionizing radiation and also exhibit nearly negligible changes in operating characteristics over an extremely wide temperature range, ~20K to ~900K, making them useful in digital as well as analog electronics. Furthermore, we have developed a method of growing these arrays in a planar geometry (Figure 1A) directly on a quartz wafer allowing for the parallel fabrication of robust high-temperature integrated circuits using proven microelectronic fabrication techniques.

We have performed preliminary experiments on first-generation CNT-diodes and CNT-triodes with prior NASA support showing proof-of-concept operation under a range of environmental conditions. The major accomplishments to date are:

- Room temperature to +600°C operation of CNT-diodes with little change in operating characteristics
- Room temperature triode operation showing effective gating
- Room temperature logic gate (OR) operation
- Room temperature and 400°C operation of a half-wave rectifier consisting of two CNT-diodes and COTS components

Such devices have the capability to expand present as well as enable entirely new mission profiles for future Venus exploration.

Another approach to high-temperature electronics is to develop wide-bandgap semiconductor-based transistors that can survive at the surface temperature of Venus. NASA has been supporting such research into SiC devices for a number of years at Glenn Research Center [1]-[3]. JHU/APL and the Kohn group at the University of Ulm have been investigating GaN as a high-temperature FET material [4]-[6]. The keys to the high-temperature operation of these devices are the InAlN/GaN heterostructure and the Mo gate. The InAlN/GaN heterostructure is a variation on the AlGaN/GaN heterstructure widely used in modern commercial RF power amplifiers. Unlike AlGaN, InAlN can be lattice-matched to the underlying GaN. This makes the heterostructure temperature-stable to well over 1600 °C. The refractory metal gate survives to a temperature over 1000 °C. In operation, devices have operated for 70 hours at a temperature over 1000 °C, and projections of the lifetime at 500 °C based on higher-temperature tests are in the range of 10s of thousands of hours.

Thus, InAlN/GaN device offer a promising path to an electronics package for a long-lived Venus lander. We envision a lander equipped with both a short-lived, insulated, instrument package and a long-lived, uninsulated simple sensor and electronics suite. The insulated core will provide sophisticated measurements like mass spectrometry and advanced imaging, but will only last a number of hours until its temperature rises above its operating range. The long-lived suite will last a Venus year, and will perform a variety of simple, low data rate measurements and transmit the results to an orbiting spacecraft for retransmission to Earth. These measurements could include wind, oxygen fugacity, seismicity, temperature, solar illumination, etc. The transduction and communications electronics for a simple sensor package like this could be made with of order 100 transistors, and enable time-series measurements of key Venus parameters of scientific interest.

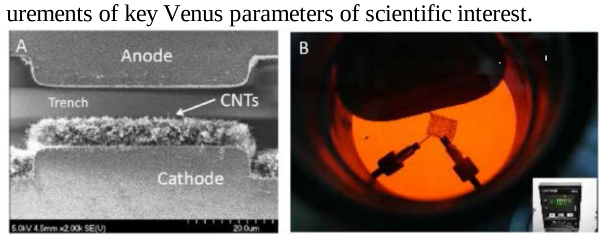

Figure 1: (A) SEM image of CNT diode (B) InAlN/GaN devices operating at 700 °C.

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