VOLCANIC GAS TESTING OF A PROTOTYPE VENUS CHEMICAL SENSOR ARRAY USING SILICON CARBIDE ELECTRONICS. D. B. Makel1, A. G. Davies2, W. M. Moreland2, J. P. Makel1, K. H. Baines2, D. Pieri1, F. A. Wangberg1, T. Thordarson1, 1Makel Engineering, Inc., 1585 Marauder Street, Chico CA 95973; (dmakel@makelengineering.com). 2Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109. 3University of Iceland, Sæmundargata 2, 102 Reykjavík, Iceland.

Introduction: Field testing of high temperature silicon carbide (SiC) electronics combined with high temperature solid-state gas sensors has been done at 500 °C conditions on recent lava flows in Iceland. Chemical sensor instruments are of interest for in-situ measurements of trace atmospheric gases at the surface of Venus. Such chemical sensor arrays require both high temperature chemical sensor elements and suitable electronics which can operate uncooled at Venus surface conditions at temperatures in excess of 470 °C [1]. Application Specific Integrated Circuits (ASICs) using NASA Glenn Research Center n-channel SiC Junction Field Effect Transistors and Resistors (JFET-R) technology have been developed and combined with chemical microsensors previously developed for Venus atmospheric measurements [2]. Demonstration testing of the sensors and electronics has been conducted at the 2023 lava flows in the Fagradalsfjall region of the Reykjanes Peninsula, Iceland.

Objective: High temperature sensors have been developed for targeted trace species in the Venus atmosphere including SOx, CO, OCS, HF, O2, and H2O in prior work. In this project single chip ASICs were designed and fabricated by NASA GRC based on SiC electronics design demonstrated to operate at Venus surface conditions [3]. The ASICs provide multiple stages of amplification, required bias voltages, and signal transduction suitable for solid-state thick and thin film sensors with amperometric and potentiometric sensing principles. As part of the overall development of a compact, high temperature chemical sensor array instrument which could be used for extended duration (60 days) on the surface of Venus as a payload on a lander such as LLISSE and matured through several stages of work including testing at NASA GEER facility [4]. The objective of this field testing was to demonstrate operation of the electronics and sensors in probe configuration in at temperatures comparable to Venus surface temperature of 470 °C.

Results: The probe with the sensor mounted on alumina probe with the single chip ASIC mounted aft of the sensor is shown in Figure 1. The sensor shown is a single chip, potentiometric SOx sensor fabricated with thick film technology and using a high temperature electrolyte with working and reference electrodes screen printed on opposite ends in a planar configuration. Other sensor types including CO and CO2 sensors were included in the field testing. The sensor substrate has a thick film printed platinum heater and RTD on the backside and multiple sensors are mounted back-to-back in a single package. The sensor is suspended by platinum wires to gold traces on the alumina probe. The single chip ASIC is mounted on the opposite side of the core holder. The ASICs were fabricated with NASA JFET-R design rules on 4H-SiC wafers [5] and provide transduction and amplification of the low-level sensor signal to a high level signal which was cabled from the probe to an external, battery powered data acquisition system contained in Pelican cases which could be carried onto the lava fields. The sensor probe was housed in a stainless-steel probe and 2.5 cm diameter tube to allow the sensor and SiC ASIC to be lowered by a tripod into hot cracks in the lava flow. The gas temperature at the probe tip was measured with K-type thermocouple and the gas concentration measured with sensor/SiC ASIC was compared to gas samples pulled through 5 mm tube to external reference gas sensors using the same sensor types and silicon electronics. The voltage output of the ASIC and power to sensor heater (0-8 VDC) and ASIC power (+/-25 VDC) was cabled to support electronics located 5 m from the sample site.

Field work was conducted at two test sites on the 2023 Lítil Hrutur flows approximately three weeks following the end of the eruption. The location of the sample sites is shown in Figure 2. The highest temperature sample sites were found at site 2 closer to the vent of the volcanic fissure. Sample sites for gas measurement were found using a thermal mapping quadcopter system operated by the University of Iceland for detailed study of the lava flows. Realtime imaging from the FLIR mounted on the drone was used to survey the lava field and identify hot zones with a few meter resolution as shown in Figure 3. The final sensor probe sample location with lava surface temperature in excess of 520 °C
was determined using handheld FLIR camera and probes as shown Figure 4.

Figure 2. Location of sampling sites 1 and 2 on the 2023 Litli Hrutur flows (pink).

Figure 3. Drone thermal mapping of the field test site and deployment of equipment on lava flow.

Figure 4. Probe Location in Lava Surface Crack with Temperature of Excess of 520 °C.

The SO$_x$ gas measurement during insertion of the probe and during a 1-hour duration at depth is shown in Figure 5. The probe was suspended via the tripod to the maximum attainable depth (approximately 0.5 m) without being in contact with the lava surface. The maximum SO$_x$ reading depth was approximately 8 ppm which was confirmed with reference gas sensor used with the extractive gas samples pulled from the lava subsurface at the probe tip. The temperature of the ASIC was stable in the range of 470 °C with some variation due to high surface winds which induced some movement of the probe. Post field testing calibration and performance checks of the electronics and sensor showed good agreement with predeployment calibration and no degradation of sensors, SiC electronics or interconnections were detected.

Figure 5. SOx concentration during insertion to depth of approximately 0.5 m with lava surface temperature of 520 °C and gas temperature at probe tip of 470 °C.

**Acknowledgments:** The research described in this paper was funded by the NASA ROSES Program NNH16ZDA001N-HOTTCH. The authors would acknowledge the contributions of the SiC electronics team at NASA Glenn Research Center including Dr. Gary Hunter, Mr. Michael Krasowski and Dr. Phil Neudeck.

**References:**