The Development of a High TemperatureVenus Seismometer

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Introduction: Venus exploration has gained considerable interest and relevance in recent years. Venus has significant similarities to Earth in terms of size, initial composition, and solar-radiative influences. However, its present planetary conditions contrast drastically from that of Earth with a significant greenhouse effect [1]. Venus has a very hostile environment with an average surface temperature of 462° C, an atmospheric pressure of 90 atm on the surface, and an atmosphere comprised primarily of CO_2. Missions that have landed on the surface of Venus have typically lasted on the order of hours due to the high temperatures and harsh conditions. Further, the measurement of Venus planetary conditions has generally been limited by the lack of sensor and instrument systems that can operate long term in the harsh Venus environment.

One set of measurements identified as having significant scientific interest in understanding Venus planetary conditions and history is seismometry [1]. Seismometry can determine the activity of the interior of Venus and provide clues related to its history and evolution. A regional or global network of seismometers could answer several important questions related to Venus seismic activity and subsurface structure. Wireless communication may also be an asset, as it would allow the seismometer to be deployed at some distance from the parent lander, partially decoupling the seismometer from oscillations created on the main lander. However, there is a fundamental question as to whether such seismic measurements can be performed given the high temperature, harsh environment of Venus.

This paper describes efforts to design, fabricate, and demonstrate a proof-of-concept seismometer operating at Venus temperatures. The approach of this work is to show operation of a basic seismometer system laying the foundation for more complex instruments. Seismometer design and fabrication are discussed, as well as preliminary results.

Technical Barriers: A high temperature Venus seismometer does not exist at this time. This is predominantly due to the nature of seismometer measurements, which require operation of the measurement system directly in the harsh Venus environment. In order to produce such a seismometer operating in-situ in the Venus environment, a range of high temperature operable technologies are necessary. These include the seismic measuring instrument itself (mechanical structure), a position transducer, and associated signal processsing electronics. Conventional seismometer technologies are not functional in Venus-relevant environments. For example, silicon (Si) based electronics on which standard conventional seismometers are based, do not operate at Venus temperatures [2]. This implies the use of wide bandgap electronics, such as silicon carbide (SiC), or other high temperature electronic systems. Similarly, transducer technology and other components of the seismometer mechanical structure are challenged by Venus operational conditions.

Seismometer Design Approach: The development of a proof-of-concept high temperature Venus seismometer operational at temperatures up to 500° C and responsive to seismic vibrations from 1-30 Hz is on-going. The seismometer system has a mechanical structure with a transducer to interface with the planetary environment, as well as signal conditioning and wireless communications electronics [3]. The mechanical structure and transducer are designed for harsh environment operation at 500 ºC. The signal conditioning and wireless electronics are based on high-temperature-operable silicon carbide (SiC) electronics.

A high temperature seismometer utilizing a vertical pendulum design has been fabricated and is shown in Figure 1. A leaf-spring seismometer design is used [4]. A seismic mass on a boom supported by crossed hinges is counterbalanced with a leaf spring. A novel thermal expansion compensation mechanism is employed to maintain the boom orientation despite temperature induced changes in the Young's modulus of the spring. Vertical seismic vibrations cause the boom to oscillate, and motion of the boom is sensed using a variable inductance position transducer. A coil is fixed to the seismometer frame and a specialized aluminum probe, mounted on the seismometer boom, is positioned on the inside of the inductor coil, such that a movement of the boom changes the axial position of the probe in the coil and causes the inductance to change.

Silicon carbide electronics are used to enable this seismometer design. Specialized SiC electronic circuits designed for high temperature operation have shown the capability to operate at Venus relevant temperatures for extended periods of time [5-7]. A simple signal conditioning circuit is employed in which the variable inductance transducer is used in an oscillator circuit to convert the sensed boom position to an electrical frequency which is transmitted wirelessly by an antenna. The oscillator is based on a Clapp-type design and presently uses a commercial SiC MESFET (metal semiconductor field effect transistor) [3]. Although the MESFET is not designed for operation at extremely high temperatures we have found that it provides sufficient reliability at temperatures up to 475 °C to demonstrate the viability of this approach. Thin film capacitors and inductors capable of 500ºC operation are included in the oscillator circuit. The oscillator as presently designed operates at 100 kHz, which, as necessary, is less than the 600 kHz self-resonant frequency of the transducer coil.

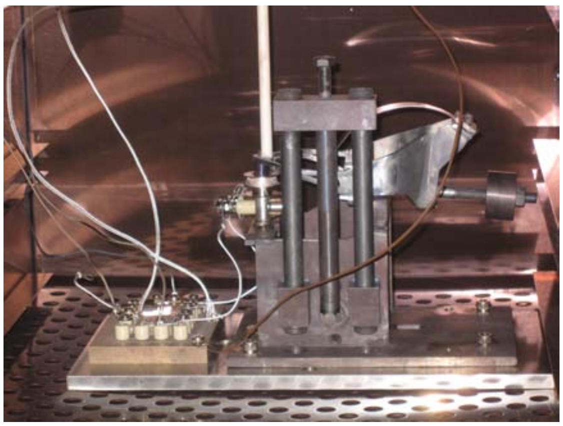

Fig. 1. Photograph of the wireless seismometer mechanism and circuit in an oven.

Preliminary Data: Preliminary testing of the seismoter has been performed over the temperature range from 425 ºC to 475 ºC. For this measurement, the seismic mass is adjusted to lift the probe to its maximum height, and a ceramic rod attached to a micromanipulator is used to lower the aluminum probe in a controlled, stepwise manner. Figure 2 shows the measured spectra of the signals wirelessly transmitted as a function of probe position. The seismometer with electronics is at 426° C and there is a 1 m distance between transmitting and receiving antennas. The oscillator frequency is wirelessly transmitted as the position of the probe is varied from 1-11 mm. As can be seen in Figure 2, the signal strength is 40 dB above the noise floor at 426°C, and changes in oscillator frequency are measured with changing probe position.

Subsequent data show the seismometer/oscillator system operated stably for 73 hours at 475°C, although subsequent degradation of the oscillator circuit occurs. The seismometer mechanism is still operational after this testing. Future generations of this system will use more durable SiC JFETs (junction gate field-effect transistor) [5-7], rather than commercial MESFETs. In addition, specialized high-temperature on-chip metallization and packaging will be employed.

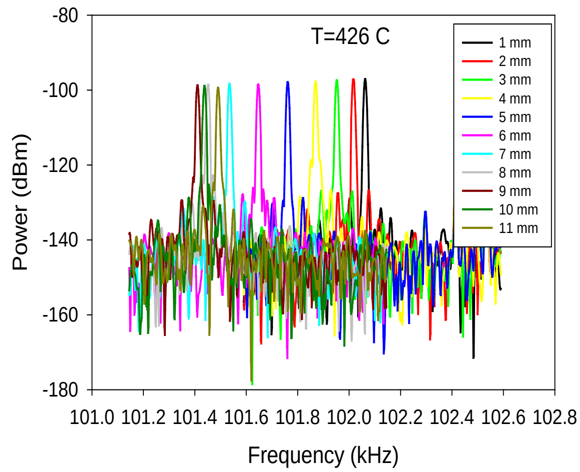

Fig. 2. Measured spectra of the received signal from the wireless seismometer for probe positions from 1 to 11 mm, at 426° C.

Future Development: Continued development is targeted to demonstrate a complete proof-of-concept seismometer to show the potential viability of an operating seismometer at Venus relevant temperatures for a number of days. This includes longer term testing and characterization of a range of parameters associated with the instrument operation. This proof-of-concept seismometer is designed to demonstrate operation in an important seismic frequency subrange providing the core for a wider frequency range seismometer system operating at 500 ºC. This seismometer is a first generation prototype to demonstrate seismic sensing at extremely high temperatures. Further refinements, e.g. miniaturization and insertion in a vacuum chamber, will be required to produce a seismometer suitable for use on Venus.

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