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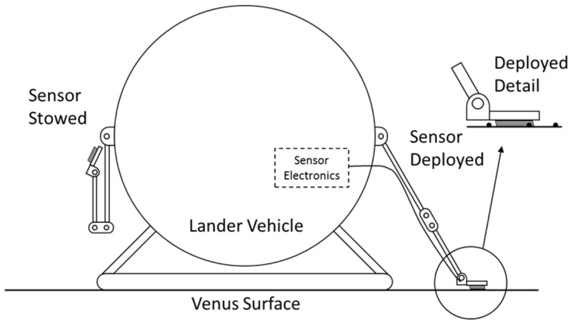
Introduction: We are developing an instrument that would help illuminate the evolutionary path that has brought Venus to its unique state today by measuring the heat loss from its interior at the surface. Knowledge of the present day heat flow would allow us to provide an estimate of the lithospheric thickness, the current level of geologic activity, and distinguish between various hypotheses of planetary evolution. Numerous models of Venus' thermal evolution exist. A very low heat flow (<20 mW/m^2) would indicate that either a recent stagnant lid or a very late stage of episodic global overturn is operating [1]. An intermediate value of heat flow (20-40 mW/m^2) would be consistent with a stagnant lid modulated by convective heat flux [2]. High values (> 40 mW/m^2) would indicate a thinner lithosphere and possibly a long period of mantle heating due to the effect of an insulating stagnant lid [3]. The predicted heat flow today is a function of the assumed concentration of radiogenic material, heat of accretion, and most importantly, the style of geologic activity.

Heat flow measurements for Earth, the Moon, and those scheduled for Mars (InSight mission) are based on subsurface temperature measurements below their diurnal and annual variations. On Venus, access to the subsurface is not necessary because there are essentially no diurnal or annual temperature variations due to the thermal stability of its dense lower atmosphere. The surface flux measurement approach described here is possible on Venus because the surface diurnal or annual temperature changes are small ~1 K; [4] and occur at much longer time scales than the time required to measure the surface flux.

Objectives: Our objective is to develop robust a instrument for rapidly measuring heat flow at the Venus surface over the range of 10 to 100+ mW/m^2 with an accuracy of ±5 mW/m^2. This level of accuracy is sufficient to determine whether the interior Venus heat flux is low, intermediate or high.

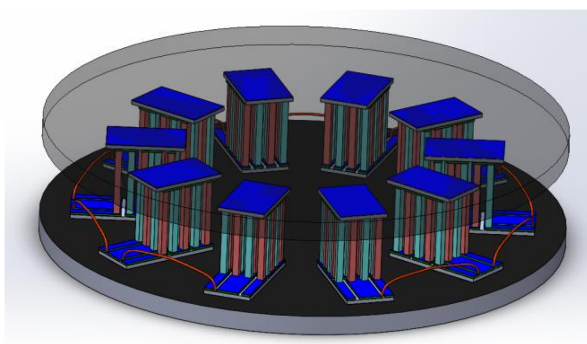
Configuration: The heat flux sensor would be externally deployed from a lander vehicle as shown in the figure below. The sensor would be located on the end of a boom that places it on the surface. During operation the sensor generates a voltage proportional to the heat flux flowing through it. The electronics located within the lander vehicle measure the generated voltage signal.



Heat flux sensor instrument shown on a Venus lander vehicle.

Prototype: The heat flux sensor uses the thermoelectric effect of specific semiconductor materials to measure heat flow. Thermoelectric material pairs produce a voltage when they are subjected to temperature gradients. This principle is used by thermocouples to measure temperature.

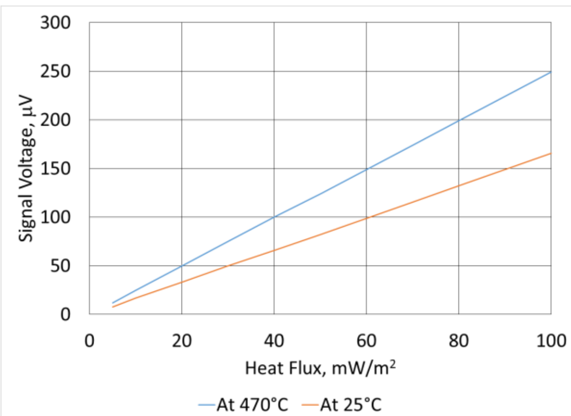
The sensor, shown in the figure below, has a graphite disk base. Heat flow from the Venus surface would flow into the base, through the thermopiles and then through the top graphite disk. Between the graphite disks are ten thermopiles each with 10-pairs of thermoelectric element (TE) legs. One leg of each thermoelectric pair is an n-type skutterudite semiconductor and the other leg is a p-type. The top of the thermopiles are bonded to a graphite disk that rejects heat by convection and radiation to the ambient environment.



A CAD rendering of the prototype Venus surface heat flux sensor.

Analysis: An analytical model of the heat flux sensor has been developed to understand the performance and capability of the heat flux sensor and to guide the development of a prototype sensor. The analysis was performed using finite element modeling with COMSOL Multiphysics. Parametric studies of device geometry, effects of conjugate heat transfer, and assumed heat flux from the surface were carried out. The thermoelectric device-based sensor design constitutes a geometry that analytically satisfies the requirements for measuring the surface heat flux in the range of 10 to 100+ mW/m^2 with a resolution of $5mW/m^2$.

For the selected n- and p-type semiconductors the Seebeck coefficient is 340 μVolts/K at 750K, Venus' surface temperature. This produces a voltage of 0.12 μVolts per element pair and for an array of 100 elements, the total voltage generated is 12 μVolts for the 5 mW/m^2 heat flux resolution. A plot of the predicted sensor output voltage as a function of input heat flux is shown below at Venus temperature and at ambient temperature.



Predicted performance of the Venus heat flux sensor.

References: [1] Parmentier, E. M., and Hess P. C., (1992) *Geophys. Res. Lett., 19*, 2015-2018. [2] Phillips, R.J et al. (1997) in *Venus II*, Univ. Arizona Press. [3] Smrekar, S. E. and Sotin, C. (2012) *Icarus*. [4] Dobrovolskis, A.R. (1993) *Icarus* 103, 276-289.