THE MARS BOREHOLE IR SPECTROMETER. W. D. Smythe[1], M. Foote[1], E. Johnson[2], J. Daly[2], P.Loges[2], I. Puscasu[2], S. Gorevan[3], P. Chu[3], and J. Granahan[4], [1]JPL, MS 183-602, 4800 Oak Grove Drive, Pasadena, CA 91109 (wsmythe@jpl.nasa.gov),[2]Ion Optics Inc, 411 Waverley Oaks Road, Suite 144Waltham, MA 02452, [3]Honeybee Robotics, 460 W. 34th Street, New York, NY 10001, [4]SAIC, 4501 Daly Dr., Suite 400, Chantilly, VA 20151

Introduction: The best clues to Mars past may be hidden below the surface of Mars. Long exposure to the sun, high winds and dust storms, large diurnal temperature excursions, and eons of space weathering combine to render a greatly modified surface, in many instances remarkable for its appearance of uniform composition. Drilling can provide access to the layers in the caps, to the permafrost and possibly, to pristine crustal material. A remote drilling process is both complex and time intensive. It is prudent to monitor compositional changes down the borehole during the drilling process. This can be done through monitoring material brought up at the top of the drill, periodically removing the drill and measuring the borehole with some technique (such as fibers), or measuring the borehole from within the drill while drilling is active.

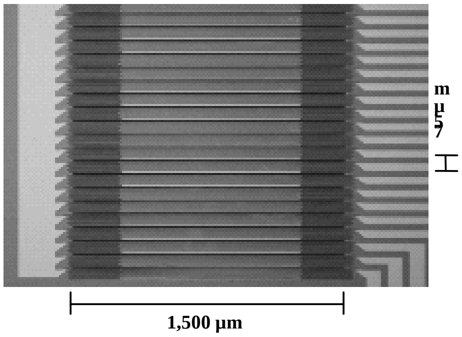

Figure 1. Picture of a developmental un-cooled microthermopile detector having high stability and detectivity. We use a smaller array with detector height of matching the waveguide and the number of elements matched to the desired spectral resolution.

The first approach has two major issues. There is a large lag between the time the material is cut and the time that it appears at the top of the drill – creating a very unresponsive feedback loop. Additionally, significant mixing can occur between material from the upper and lower walls of the borehole, making difficult to infer composition at the drill bit by monitoring material brought to the surface.

The second approach requires significant additional time (it can take longer to withdraw and re-insert the drill than to make the initial cut) and carries increased risk of sticking the drill or having the wall collapse (in unconsolidated material. Both of the first two approaches have additional liability if volatile is involved that may disappear if the time and/or distance to measurement is too great.

The third approach, measuring composition from within the drill during active drilling, does not have these challenges. The measurements can be contemporaneous, volatiles can be detected even if they evolve from the walls and mixing along the borehole is minimizes. This approach does have its challenges, however. The instrumentation must be small enough to fit within the drill stem (typically ~25 mm), it must be return data to the surface and, for optical instruments, it must provide its own illumination and its own environmental conditioning for the detector.

We are integrating an Ion-Optics solid-state IR spectrometer with their blackbody source and with microthermopiles developed by Marc Foote at JPL into a package to fit within a Honeybee Mars drill design. The borehole IR spectrometer is used to monitor facies encountered throughout the drilling process. The spectrometer/IR combination is used in reflectance spectrometer mode to monitor H_2O and CO_2 content, as well as iron and carbonate mineralogies.

The solid state spectrometer uses the index of refraction of silicon to achieve the required dispersion of infrared light in a very compact geometry. The silicon also serves as a waveguide to increase the throughput of the spectrometer. The layout is shown schematically in figure 2 for a prototype solid state spectrometer in an Ebert configuration. The solid state spectrometer

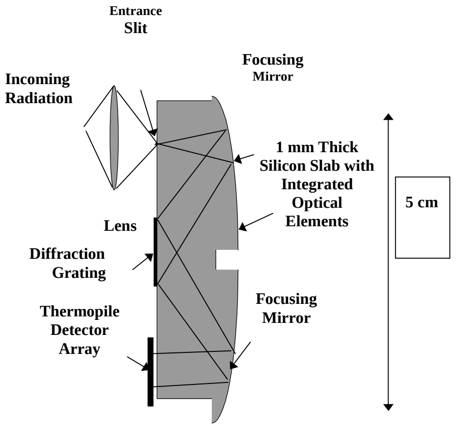

Figure 2 Schematic drawing of prototype 3 to 5.5 micron spectrometer. Infrared light from the target is focused onto a slit by an external lens. As the light enters the silicon waveguide, the angular spread is reduced due to the high index of refraction of silicon. Inside the silicon slab, light is reflected from a concave mirror, dispersed by a diffraction grating, and imaged with a second mirror. The dispersed light is detected by an external linear detector array.

has is small, lightweight due to minimal requirements for a supporting structure, and inherently rugged because the components are bonded into alignment. The solid state spectrometer has been modified to fit within the spatial constraint of the drill segment diameter. Changes included using a Littrow layout (more compact) and stacking the grating and detector on planar part of the optical bench to conform to the cylindrical geometry.

The illuminator is built a standard Ion Optics (Pulse-IR) infrared source. Illumination is a critical element for the borehole spectrometer, with the illumination and reflected signal sharing the same (small) window. We have demonstrated that the required throughput can be achieved and that windows can be obtained that do not scratch and provide diffuse self-illumination to the spectrometer.

The detector is a microthermopile array with sufficient number of elements to achieve the required spectral resolution. Figure 1 illustrates a prototypical microthermopile detector. The detector is an array of strips of thermally sensitive material on a silicon substrate. The detector dimensions can be adjusted to meet the resolution, sensitivity, and spatial requirements of the spectrometer. We use a microthermopile detector both because it has excellent drift characteristics and because it can operate in an ambient environment. The detector requires an associated multiplexer, which, together with the analog to digital converter, play a significant role in the noise performance of the focal plane array. The multiplexer used here is manufactured by Black Forest Engineering. A version of detector and its associated multiplexer is flying in the Mars MCS instrument. The detector is sensitive to its thermal environment – particularly convection currents. We have hermetically sealed the detector to improve the performance of the spectrometer system over a range of ambient atmospheric pressures.

We tested a variety of window materials and a range of techniques for mounting windows on the drill. It was determined that both sapphire and diamond windows have adequate performance and that both brazing and epoxy mounting provide satisfactory performance. A photograph of a test window on a drill segment is shown in figure 3. This particular test illustrated the importance of ensuring the window is flush with the surface to avoid accumulation near the window. We similarly tested the visibility through the window of the material moving up the drill flutes, using a (visible light) boroscope. The material, and its motion, was clearly visible through window while the hole was being drilled.

Data is sampled through the multiplexer then passed up the drill string utilizing a serial (CAN) protocol. The spectra are typically sampled tens of times per second. They may be summed to increase the signal-noise ratio.

The spectrometer being used for test is tuned for use in the wavelength range 3-5 microns. For silicon waveguides, the wavelength can span the transparent region for silicon – effectively one to six microns. Order-sorting filters, or separate spectrometers, must be used if the desired range includes multiple diffraction orders. Longer wavelength spectrometers can be achieved by using different material for the waveguide, such a germanium.

Figure 3. Test setup for assessing window durability, mounting techniques, and visibility of material. Visibility was checked utilizing a boroscope at visible wavelengths. The performance of both sapphire and diamond windows is excellent in this application. The samples, and changes to it during drilling, were clearly visible through the window.

This borehole spectrometer shows great promise for in situ measurements of the composition of borehole walls for planetary drills. The wavelength range of the silicon waveguide version is ideally suited for Mars drills, since it is an excellent wavelength region for detecting and quantifying soil compositions containing water, carbon dioxide, carbonates, sulfates, pyroxenes, and olivines. It is additionally an instrument that can greatly expedite the monitoring, control, and feedback for drill operations on the Martian surface.

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