



## Multi-Pass Quadrupole Mass Analyzer

**The technology will enhance the resolving power of small QMA instruments and simplify the electronics package for ground and space instruments.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Analysis of the composition of planetary atmospheres is one of the most important and fundamental measurements in planetary robotic exploration. Quadrupole mass analyzers (QMAs) are the primary tool used to execute these investigations, but reductions in size of these instruments has sacrificed mass resolving power so that the best present-day QMA devices are still large, expensive, and do not deliver performance of laboratory instruments.

An ultra-high-resolution QMA was developed to resolve  $N_2^+/CO^+$  by trapping ions in a linear trap quadrupole filter. Because  $N_2$  and  $CO$  are resolved, gas chromatography columns used to separate species before analysis are eliminated, greatly simplifying gas analysis instrumentation. For highest performance, the ion trap mode is used. High-resolution (or narrow-band) mass selection is carried out in the central region, but near the DC electrodes at each end, RF/DC field settings are adjusted to allow broadband ion passage. This is to prevent ion loss during ion "reflection" at each end. Ions are created inside the trap so that low-energy particles are selected by low-voltage settings on the end electrodes. This is beneficial to good mass resolution since low-energy particles traverse many cycles of the RF filter-

ing fields. Through Monte Carlo simulations, it is shown that ions are reflected at each end many tens of times, each time being sent back through the central section of the quadrupole where ultrahigh mass filtering is carried out. An analyzer was produced with electrical length orders of magnitude longer than its physical length. Since the selector fields are sized as in conventional devices, the loss of sensitivity inherent in miniaturizing quadrupole instruments is avoided. The no-loss, multi-pass QMA architecture will improve mass resolution of planetary QMA instruments while reducing demands on the RF electronics for high-voltage/high-frequency production since ion transit time is no longer limited to a single pass. The QMA-based instrument will thus give way to substantial reductions of the mass of flight instruments. Advantages of the multi-pass quadrupole mass analyzer include:

- Provides ultra-high-resolution mass analysis to resolve  $N_2^+/CO^+$  and  $Ne^+/Ar^{++}$ .
- Multiple passes through QMA region.
- Very slow ions can be created inside the trap compared to beam injection into conventional QMA.
- Low-risk, high-resolution performance sufficient to resolve  $N_2^+/CO^+$  has already been demonstrated. This work will improve signal efficiency by 100-fold.

- Discovery, MIDEX, and all planetary science will advance by use of multi-pass QMA instrument development.
- Eliminates trade-off between high-voltage and high-frequency RF mass selector fields.
- Both high mass operation and high resolution are achievable in the multi-pass QMA.
- Mass range to over 1,000 Daltons will be provided.
- Recycling ion passage through mass selector fields, filtering length is orders of magnitude longer than physical length, matching resolution of the best ground-based instruments.
- This technique can be applied to improve mass resolution of ultra-miniature QMA devices.
- This approach reduces the risk and loss of resolution typically encountered in miniaturization of a quadrupole gas analyzer since the QMA device uses conventional-sized quadrupole filtering fields, acceptance angles, etc. as currently used in planetary instruments.

The pre-analysis provided by gas chromatography columns will not be required.

*This work was done by John D. Prestage of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47277*

## Lunar Sulfur Capture System

**The process substantially reduces the need for Earth-supplied consumables.**

*John F. Kennedy Space Center, Florida*

The Lunar Sulfur Capture System (LSCS) protects in situ resource utilization (ISRU) hardware from corrosion, and reduces contaminant levels in water condensed for electrolysis. The LSCS uses a lunar soil sorbent to trap over 98 percent of sulfur gases and about two-thirds of halide gases evolved during hydrogen reduction of lunar soils. LSCS soil sorbent is based on lunar minerals

containing iron and calcium compounds that trap sulfur and halide gas contaminants in a fixed-bed reactor held at temperatures between 250 and 400 °C, allowing moisture produced during reduction to pass through in vapor phase. Small amounts of Earth-based polishing sorbents consisting of zinc oxide and sodium aluminate are used to reduce contaminant concentrations to

one ppm or less. The preferred LSCS configuration employs lunar soil beneficiation to boost concentrations of reactive sorbent minerals.

Lunar soils contain sulfur in concentrations of about 0.1 percent, and halogen compounds including chlorine and fluorine in concentrations of about 0.01 percent. These contaminants are released as gases such as  $H_2S$ ,  $COS$ ,  $CS_2$ ,

HCl, and HF during thermal ISRU processing with hydrogen or other reducing gases. Removal of contaminant gases is required during ISRU processing to prevent hardware corrosion, electrolyzer damage, and catalyst poisoning. The use of Earth-supplied, single-use consumables to entirely remove contaminants at the levels existing in lunar soils would make many ISRU processes unattractive due to the large mass of consumables relative to the mass of oxygen produced. The LSCS concept of using a primary sorbent prepared from lunar soil was identified as a method by which the ma-

ajority of contaminants could be removed from process gas streams, thereby substantially reducing the required mass of Earth-supplied consumables.

The LSCS takes advantage of minerals containing iron and calcium compounds that are present in lunar soil to trap sulfur and halide gases in a fixed-bed reactor downstream of an in-ISRU process such as hydrogen reduction. The lunar-soil-sorbent trap is held at a temperature significantly lower than the operating temperature of the hydrogen reduction or other ISRU process in order to maximize capture of

contaminants, but is held at a high enough temperature to allow moisture to pass through without condensing. The lunar soil benefits from physical beneficiation to remove ultrafine particles (to reduce pressure drop through a fixed bed reactor) and to upgrade concentrations of iron and/or calcium compounds (to improve reactivity with gaseous contaminants).

*This work was done by Mark Berggren, Robert Zubrin, and Emily Bostwick-White of Pioneer Astronautics for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13233/615*

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## Environmental Qualification of a Single-Crystal Silicon Mirror for Spaceflight Use

*Goddard Space Flight Center, Greenbelt, Maryland*

This innovation is the environmental qualification of a single-crystal silicon mirror for spaceflight use. The single-crystal silicon mirror technology is a previous innovation, but until now, a mirror of this type has not been qualified for spaceflight use. The qualification steps included mounting, gravity change measurements, vibration testing, vibration-induced change measurements, thermal cycling, and testing at the cold operational temperature of 225 K.

Typical mirrors used for cold applications for spaceflight instruments include aluminum, beryllium, glasses, and glass-like ceramics. These materials show less than ideal behavior after cool-down. Single-crystal silicon has been demonstrated to have the smallest change due to temperature change, but has not been spaceflight-qualified for use. The advantage of using a silicon substrate is with temperature stability, since it is formed from a stress-free sin-

gle crystal. This has been shown in previous testing. Mounting and environmental qualification have not been shown until this testing.

*This work was done by John Hagopian, John Chambers, Scott Rohrback, Vincent Bly, Armando Morell, and Jason Budinoff of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16473-1*

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## Planar Superconducting Millimeter-Wave/Terahertz Channelizing Filter

**The design enables multiple-octave operation with no spurious harmonic response.**

*Goddard Space Flight Center, Greenbelt, Maryland*

This innovation is a compact, superconducting, channelizing bandpass filter on a single-crystal (0.45  $\mu\text{m}$  thick) silicon substrate, which operates from 300 to 600 GHz. This device consists of four channels with center frequencies of 310, 380, 460, and 550 GHz, with approximately 50-GHz bandwidth per channel. The filter concept is inspired by the mammalian cochlea, which is a channelizing filter that covers three decades of bandwidth and 3,000 channels in a very small physical space. By using a simplified physical cochlear model, and its electrical analog of a channelizing filter covering multiple octaves bandwidth, a large number of out-

put channels with high inter-channel isolation and high-order upper stop-band response can be designed.

A channelizing filter is a critical component used in spectrometer instruments that measure the intensity of light at various frequencies. This embodiment was designed for MicroSpec in order to increase the resolution of the instrument (with four channels, the resolution will be increased by a factor of four). MicroSpec is a revolutionary wafer-scale spectrometer that is intended for the SPICA (Space Infrared Telescope for Cosmology and Astrophysics) Mission. In addition to being a vital component of MicroSpec, the chan-

nelizing filter itself is a low-resolution spectrometer when integrated with only an antenna at its input, and a detector at each channel's output.

During the design process for this filter, the available characteristic impedances, possible lumped element ranges, and fabrication tolerances were identified for design on a very thin silicon substrate. Iterations between full-wave and lumped-element circuit simulations were performed. Each channel's circuit was designed based on the availability of characteristic impedances and lumped element ranges.

This design was based on a tabular type bandpass filter with no spurious har-