commonly known as electrostatic precipitation, is a mature technology in air at one atmosphere. In this case, the high voltages required for the method to work can easily be achieved. However, in carbon dioxide at low pressures, such as those found on Mars, large voltages are not possible.

The innovation reported here consists of two concentric cylindrical electrodes set at specific potential difference that generate an electric field that produces a corona capable of imparting an electrostatic charge to the incoming dust particles. The strength of the field is carefully balanced so as to produce a stable charging corona at 5 to 10 mbars, and is also capable of imparting a force to the particles that drives them to the collecting electrode.

There are only two possible ways that dust can be removed from Martian atmospheric gas intakes: with this electrostatic precipitator design, and with the use of filters. However, filters require upstream compression of the gas to be treated because the atmospheric pressure on Mars is too close to vacuum to use a vacuum pump downstream to the filter to draw the gas through the filter. The electrostatic precipitator is the best and more efficient solution for this environment. No other precipitator designs have been developed for the environment of Mars due to the challenges of the low atmospheric pressure.

Dust particles are charged using corona generation around the high-voltage discharge electrode, which ionizes gas molecules. Since the atmospheric gas intakes for the ISRU processing chambers will likely be cylindrical, cylindrical precipitator geometry was chosen. The electrostatic precipitator design presented here removes simulated Martian dust particles in the required range in a simulated Martian atmospheric environment. The current-voltage (I-V) characteristic curves taken for the nine precipitator configurations at 9 mbars of pressure showed that a cylindrical collecting electrode 7.0 cm in diameter with a concentric positive high-voltage electrode 100 µm thick provides the best range of voltage and charging corona current. This precipitator design is effective for the size of the dust particles expected in the Martian atmosphere. Mass determination, as well as microscopic images and particle size distributions of dust collected on a silicon wafer placed directly below the precipitator with the field on and off, showed excellent initial results.

This work was done by Carlos Calle of Kennedy Space Center, and Sid Clements of the Appalachian State University Department of Physics and Astronomy. Further information is contained in a TSP (see page 1). KSC-13657

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**Terahertz Quantum Cascade Laser With Efficient Coupling and Beam Profile**

High-power QCLs can be used in medical instruments, security screening equipment, and illicit material detection.

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

Quantum cascade lasers (QCLs) are unipolar semiconductor lasers, where the wavelength of emitted radiation is determined by the engineering of quantum states within the conduction band in coupled multiple-quantum-well heterostructures to have the desired energy separation. The recent development of terahertz QCLs has provided a new generation of solid-state sources for radiation in the terahertz frequency range. Terahertz QCLs have been demonstrated from 0.84 to 5.0 THz both in pulsed mode and continuous wave mode (CW mode).

A 2.7-THz QCL structure uses a metal-metal waveguide QCL with multiple-quantum-well cascade medium to provide terahertz gain for subbands engineered to have the desired energy separation. The approach employs a resonant-phonon depopulation concept. The metal-metal (MM) waveguide fabrication is performed using Cu-Cu thermo-compression bonding to bond the GaAs/AlGaAs epitaxial layer to a GaAs receptor wafer. A laterally corrugated distributed feedback (DFB) grating is etched into a MM waveguide, as

![MM-Waveguide QCL Laser](https://ntrs.nasa.gov/search.jsp?R=20120011902)
this is easily performed in a single photo- 
tolithographic and etch step. Extended 
modeling is done for both the DFB cav- 
ity and the coupling with the waveguide 
via the integrated probe. The DFB struc-
ture QCL has an integrated waveguide 
probe suitable for mounting in a ma-
chined waveguide block. Following fab-
rication of the MM-waveguide, the wafer 
can be mounted top-down on a tempo-
rary support wafer, and the GaAs recep-
tor substrate is thinned to a membrane 
with the assistance of an etch-stop layer. 

Development of a demonstrator horn-
antenna coupled QCL at 2.7 THz with 
Gaussian output beam profile and high 
coupling efficiency capable of effectively 
pumping mixers at these frequencies is a 
major breakthrough in the spectro-
scopic studies for the Earth-observa-
tion and astrophysics community. The 
approach, which includes an integrated 
probe on the QCL device in a waveguide 
enclosure transitioning to a diagonal 
horn, may lead to compact, coherent, 
continuous-wave solid-state sources. 

A phase-locked terahertz QCL source 
with high-quality beam profile and ex-
cellent output coupling efficiency oper-
ating at or above liquid nitrogen temper-
atures will be of great strategic 
importance for NASA’s astrophysics, 
Earth, and planetary mission capabili-
ties. This will make these QCLs the local 
oscillator source of choice for the future 
NASA and European suborbital and or-
bital terahertz instruments for astro-
physics missions such as the interfero-
metric (ESPRIT) and other single- and 
multi-pixel heterodyne spectroscopic 
missions, as well as for Earth observing 
and planetary missions. A high-power 
QCL with good beam profile can also be 
used in biological and medical science 
instrument, security screening and il-
illicit material detection, and nondestruc-
tive evaluation applications. 

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Measurement Via Optical Near-Nulling and 
Subaperture Stitching 

This simple and universal technique uses adjustable corrective optics. 

Goddard Space Flight Center, Greenbelt, Maryland

A subaperture stitching interferome-
ter system provides near-nulling of a sub-
aperture wavefront reflected from an ob-
ject of interest over a portion of a 
surface of the object. A variable optical 
 element located in the radiation path 
adjustably provides near-nulling to facili-
tate stitching of subaperture interfero-
grams, creating an interferogram repre-
sentative of the entire surface of 
interest. This enables testing of aspheric 
surfaces without null optics customized 
for each surface prescription. 

The surface shapes of objects such as 
lenses and other precision components 
are often measured with interferometry. 
However, interferometers have a limited 
capture range, and thus the test wave-
front cannot be too different from the 
reference or the interference cannot be 
analyzed. Furthermore, the performance 
of the interferometer is usually best 
when the test and reference wavefronts 
are nearly identical (referred to as a 
"null" condition). Thus, it is necessary 
when performing such measurements to 
correct for known variations in shape to 
ensure that unintended variations are 
within the capture range of the interfer-
ometer and accurately measured. 

This invention is a system for near-
nulling within a subaperture stitching in-
terferometer, although in principle, the 
concept can be employed by wavefront-
measuring gauges other than interferom-
eters. The system employs a light source 
for providing coherent radiation of a sub-
aperture extent. An object of interest is 
placed to modify the radiation (e.g., to re-
fect or pass the radiation), and a variable 
optical element is located to interact 
with, and nearly null, the affected radia-
tion. A detector or imaging device is situ-
at ed to obtain interference patterns in 
the modified radiation. Multiple subaper-
ture interferograms are taken and are 
"stitched," or joined, to provide an inter-
ferogram representative of the entire sur-
f ace of the object of interest. 

The primary aspect of the invention is 
the use of adjustable corrective optics in 
the context of subaperture stitching 
near-nulling interferometry, wherein a 
complex surface is analyzed via multiple, 
separate, overlapping interferograms. 
For complex surfaces, the problem of 
managing the identification and place-
ment of corrective optics becomes even 
more pronounced, to the extent that in 
most cases the null corrector optics are 
specific to the particular asphere pre-
scription and no others (i.e. another as-
phere requires completely different null 
correction optics). In principle, the 
near-nulling technique does not require 
subaperture stitching at all. 

Building a near-null system that is 
practically useful relies on two key fea-
tures: simplicity and universality. If the 
system is too complex, it will be diffi-
cult to calibrate and model its manu-
facturing errors, rendering it useless as 
a precision metrology tool and/or pro-
hibitively expensive. If the system is 
not applicable to a wide range of test 
parts, then it does not provide signifi-
cant value over conventional null-cor-
rection technology. Subaperture stitch-
ing enables simpler and more 
universal near-null systems to be effec-
tive, because a fraction of a surface is 
necessarily less complex than the 
whole surface (excepting the extreme 
case of a fractal surface description). 
The technique of near-nulling can sig-
nificantly enhance aspheric subaper-
ture stitching capability by allowing 
the interferometer to capture a wider 
range of aspheres. Moreover, subaper-
ture stitching is essential to a truly ef-
fective near-nulling system, since look-
 ing at a fraction of the surface keeps 
the wavefront complexity within the 
capability of a relatively simple near-
null apparatus. Furthermore, by reduc-
ing the subaperture size, the complex-
ity of the measured wavefront can be 
reduced until it is within the capability 
of the near-null design. 

This work was done by Greg Forbes, Gary 
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gies, Inc.; and Chris Brophy of Optical Engi-
neering Services for Goddard Space Flight 
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