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

### 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 shown in (top) a processing schematic for fabrication of the laser with integrated waveguide probe; and (bottom) in a waveguide mount with the integrated radial probe. The top half of the block is removed to show the QCL device inside the waveguide.
this is easily performed in a single photo-
lithographic 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-observation
and astrophysics community. The ap-
proach, which includes an integrated
probe on the QCL device in a waveguide
closure transitioning to a diagonal horn,
may lead to compact, coherent, con-
tinuous-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-
hital 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
instruments, security screening and il-
llicit 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 facil-
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-
reflect 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-
ated 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-
face 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
De Vries, and Paul Murphy of QED Technolo-
gies, Inc.; and Chris Brophy of Optical Engi-
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