

the issue that gave rise to the prior abandonment of complex compound sorption heat pumps, the primary accomplishment of the present development program thus far has been the characterization of many candidate sorption media, leading to large increases in achievable heat- and mass-transfer rates. In particular, two complex compounds (called "CC260-1260" and "CC260-2000") were found to be capable of functioning over the temperature range of interest for the lunar-habitat applica-

tion and to offer heat- and mass-transfer rates and a temperature-lift capability adequate for that application.

Regarding the temperature range: A heat pump based on either of these compounds is capable of providing a 95-K lift from a habitable temperature to a heat-rejection (radiator) temperature when driven by waste heat at an input temperature  $\geq 500$  K. Regarding the heat- and mass-transfer rates or, more precisely, the power densities made possible by these rates: Power densities ob-

served in tests were 0.3 kilowatt of cooling per kilogram of sorbent and 2 kilowatts of heating per kilogram of sorbent. A prototype 1-kilowatt heat pump based on CC260-2000 has been built and demonstrated to function successfully.

*This work was done by Uwe Rockefeller, Lance Kiroi, and Kaveh Khalili of Rocky Research for Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-22952*

## Improved Refractometer for Measuring Temperatures of Drops

The task of upgrading PDPA hardware for measurement of temperature is simplified.

*Marshall Space Flight Center, Alabama*

The Dual Rainbow refractometer is an enhanced version of the Rainbow refractometer, which is added to, and extends the capabilities of, a phase Doppler particle analyzer (PDPA). A PDPA utilizes pairs of laser beams to measure individual components of velocity and sizes of drops in a spray. The Rainbow-refractometer addition measures the temperatures of individual drops. The designs of prior versions of the Rainbow refractometer have required substantial modifications of PDPA transmitting optics, plus dedicated lasers as sources of illumination separate from, and in addition to, those needed for PDPA measurements. The enhancement embodied in the Dual Rainbow refractometer eliminates the need for a dedicated laser and confers other advantages as described below.

A dedicated laser is no longer needed

because the Dual Rainbow refractometer utilizes one of the pairs of laser beams already present in a PDPA. Hence, the design of the Dual Rainbow refractometer simplifies the task of upgrading PDPA hardware to enable measurement of temperature. Furthermore, in a PDPA/Dual-Rainbow refractometer system, a single argon-ion laser with three main wavelengths can be used to measure the temperatures, sizes, and all three components of velocity (in contradistinction to only two components of velocity in a prior PDPA/Rainbow-refractometer system).

In order to enable the Dual Rainbow refractometer to utilize a pair of PDPA laser beams, it was necessary to (1) find a location for the refractometer receiver, such that the combined rainbow patterns of two laser beams amount to a pattern identical to that of a single beam, (2) ad-

just the polarization of the two beams to obtain the strongest rainbow pattern, and (3) find a location for the PDPA receiver to obtain a linear relationship between the measured phase shift and drop size.

*This work was done by Amir A. Naqwi of Aerometrics/TSI, Inc. for Marshall Space Flight Center. For further information, contact the Company at (651) 490-3836.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to Aerometrics/TSI, Inc.*

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*Refer to MFS-31531, volume and number of this NASA Tech Briefs issue, and the page number.*

## Semiconductor Lasers Containing Quantum Wells in Junctions

Additional design degrees of freedom are available for improving performance.

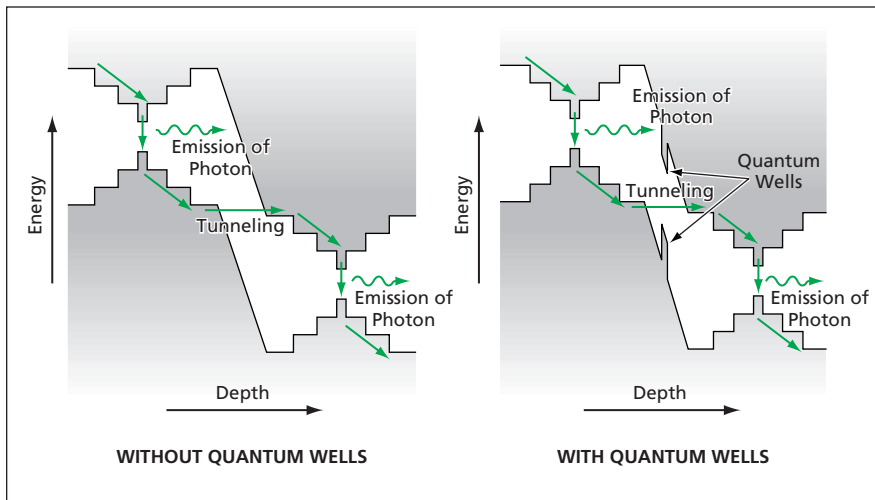
*NASA's Jet Propulsion Laboratory, Pasadena, California*

In a recent improvement upon  $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{InP}$  semiconductor lasers of the bipolar cascade type, quantum wells are added to Esaki tunnel junctions, which are standard parts of such lasers. The energy depths and the geometric locations and thicknesses of the wells are tailored to exploit quantum tunneling such that, as described below, electrical resistances of junctions and concentrations of dopants can be reduced while laser performances can be improved.

$\text{In}_x\text{Ga}_{1-x}\text{As}/\text{InP}$  bipolar cascade lasers have been investigated as sources of near-infrared radiation (specifically, at wavelengths of about 980 and 1,550 nm) for photonic communication systems. The Esaki tunnel junctions in these lasers have been used to connect adjacent cascade stages and to enable transport of charge carriers between them. Typically, large concentrations of both n (electron-donor) and p (electron-ac-

ceptor) dopants have been necessary to impart low electrical resistances to Esaki tunnel junctions. Unfortunately, high doping contributes free-carrier absorption, thereby contributing to optical loss and thereby, further, degrading laser performance.

In accordance with the present innovation, quantum wells are incorporated into the Esaki tunnel junctions so that the effective heights of barriers to quantum tunneling are reduced (see figure).



These Schematic Energy-Band Profiles are typical of a bipolar cascade laser.

Inasmuch as the tunneling current is approximately inversely proportional to the exponential of the barrier height, the introduction of quantum wells into the Esaki tunnel junction can significantly reduce the electrical resistance of the junction and thereby reduce the amounts of dopants needed. Further-

more, the numbers and shapes of the quantum wells constitute additional degrees of freedom in design that can be used to tailor carrier-transport and potential profiles to optimize laser performance.

Going beyond bipolar cascade lasers, the present innovation could also be

beneficial in some light-emitting diodes and single-stage semiconductor lasers that contain Esaki tunnel junctions. For example, quantum wells could be incorporated into vertical-cavity surface-emitting lasers, wherein Esaki tunnel junctions are used to connect n-doped mirrors to avoid the use of p-doped resistive mirrors.

*This work was done by Rui Q. Yang and Yueming Qiu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

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## Phytoplankton-Fluorescence-Lifetime Vertical Profiler

**A compact, battery-powered instrument measures marine chlorophyll fluorescence at depths  $\leq 300$  m.**

*Stennis Space Center, Mississippi*

A battery-operated optoelectronic instrument is designed to be lowered into the ocean to measure the intensity and lifetime of fluorescence of chlorophyll A in marine phytoplankton as a function of depth from 0 to 300 m. Fluorescence lifetimes are especially useful as robust measures of photosynthetic productivity of phytoplankton and of physical and chemical mechanisms that affect photosynthesis. The knowledge of photosynthesis in phytoplankton gained by use of this and related instruments is expected to contribute to understanding of global processes that control the time-varying fluxes of carbon and associated biogenic elements in the ocean.

The concentration of chlorophyll in the ocean presents a major detection challenge because in order to obtain accurate values of photosynthetic parameters, the intensity of light used to excite fluorescence must be kept very low so as not to disturb the photosynthetic system. Several innovations in fluorometric instrumentation were made in order to make it possible to reach the required

low detection limit. These innovations include a highly efficient optical assembly with an integrated flow-through sample interface, and a high-gain, low-noise electronic detection subsystem. The instrument also incorporates means for self-calibration during operation, and electronic hardware and software for control, acquisition and analysis of data, and communications. The electronic circuitry is highly miniaturized and designed to minimize power demand. The instrument is housed in a package that can withstand the water pressure at the maximum depth of 300 m.

A light-emitting diode excites fluorescence in the sample flow cell, which is placed at one focal point of an ellipsoidal reflector. A photomultiplier tube is placed at the other focal point. This optical arrangement enables highly efficient collection of fluorescence emitted over all polar directions. Fluorescence lifetime is measured indirectly, by use of a technique based on the same principle as the one described in "Fluorometer for Analysis of Photosynthesis in Phyto-

plankton" (SSC-00110), *NASA Tech Briefs*, Vol. 24, No. 1 (November 2000), page 79. The excitation is modulated at a frequency of 70 MHz, and the phase shift between the excitation light and the emitted fluorescence is measured by a detection method in which the 70-MHz signal is down-converted to a 400-Hz signal. The fluorescence lifetime can be computed from the known relationship among the fluorescence lifetime, phase shift, and modulation frequency.

In operation, the instrument measures fluorescence intensity and lifetime repeatedly, according to a schedule established during an instrument set-up process, in which the instrument is connected to a host computer. Once programmed, the instrument is disconnected from the computer and remains in a quiescent state as it is placed in the ocean. The measurement process is started by use of a magnetically actuated switch. Measurements taken by the instrument are recorded in a memory module that can hold the data from more than 28,000 measurements. The