

microwave power and, thus, in the VCSEL wavelength. It is possible to choose a set of design and operational parameters (most importantly, the electronic part of the loop gain) such that the OEO stabilizes itself in the sense that an increase in circulating microwave power causes the VCSEL wavelength to change in a direction that results in an increase in optical absorption and thus a decrease in circulating microwave power. Typically, such an appropriate choice of opera-

tional parameters involves setting the nominal VCSEL wavelength to a point on the shorter-wavelength wing of an absorption spectral line.

*This work was done by Dmitry Strelakov, Andrey Matsko, Nan Yu, Anatoliy Savchenkov, and Lute Maleki of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to*

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*Innovative Technology Assets Management  
JPL*

*Mail Stop 202-233  
4800 Oak Grove Drive  
Pasadena, CA 91109-8099  
(818) 354-2240*

*E-mail: iaoffice@jpl.nasa.gov*

*Refer to NPO-43751, volume and number of this NASA Tech Briefs issue, and the page number.*

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## Internal Water Vapor Photoacoustic Calibration

*John H. Glenn Research Center, Cleveland, Ohio*

Water vapor absorption is ubiquitous in the infrared wavelength range where photoacoustic trace gas detectors operate. This technique allows for discontinuous wavelength tuning by temperature-jumping a laser diode from one range to another within a time span suitable for photoacoustic

calibration. The use of an internal calibration eliminates the need for external calibrated reference gases. Commercial applications include an improvement of photoacoustic spectrometers in all fields of use.

*This work was done by Jeffrey S. Pilgrim of Vista Photonics, Inc. for Glenn Research Cen-*

*ter. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18417-1*

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## Mid-Infrared Reflectance Imaging of Thermal-Barrier Coatings Apparatus successfully monitors extent of hidden subsurface delamination.

*John H. Glenn Research Center, Cleveland, Ohio*

An apparatus for mid-infrared reflectance imaging has been developed as means of inspecting for subsurface damage in thermal-barrier coatings (TBCs). The apparatus is designed, more specifically, for imaging the progression of buried delamination cracks in plasma-sprayed yttria-stabilized zirconia coatings on turbine-engine components. Progression of TBC delamination occurs by the formation of buried cracks that grow and then link together to produce eventual TBC spallation. The mid-infrared reflectance imaging system described here makes it possible to see delamination progression that is invisible to the unaided eye, and therefore give sufficiently advanced warning before delamination progression adversely affects engine performance and safety.

The apparatus (see figure) includes a commercial mid-infrared camera that contains a liquid-nitrogen-cooled focal-plane indium antimonide photodetector array, and imaging is restricted by a nar-

row bandpass centered at wavelength of 4  $\mu\text{m}$ . This narrow wavelength range centered at 4  $\mu\text{m}$  was chosen because (1) it enables avoidance of interfering absorptions by atmospheric OH and CO<sub>2</sub> at 3 and 4.25  $\mu\text{m}$ , respectively; and (2) the coating material exhibits maximum transparency in this wavelength range. Delamination contrast is produced in the mid-infrared reflectance images because the introduction of cracks into the TBC creates an internal TBC/air-gap interface with a high diffuse reflectivity of 0.81, resulting in substantially higher reflectance of mid-infrared radiation in regions that contain buried delamination cracks.

The camera is positioned a short distance ( $\approx 12$  cm) from the specimen. The mid-infrared illumination is generated by a 50-watt silicon carbide source positioned to the side of the mid-infrared camera, and the illumination is collimated and reflected onto the specimen by a 6.35-cm-diameter off-axis paraboloidal mirror. Because the collected images are of a steady-state reflected inten-

sity (in contrast to the transient thermal response observed in infrared thermography), collection times can be lengthened to whatever extent needed to achieve desired signal-to-noise ratios.

Each image is digitized, and the resulting data are processed in several steps to obtain a true mid-infrared reflectance image. The raw image includes thermal radiation emitted by the specimen in addition to the desired reflected radiation. The thermal-radiation contribution is eliminated by subtracting the image obtained with the illumination off from the image obtained with the illumination on. A flat-field correction is then made to remove the effects of non-uniformities in the illumination level and pixel-to-pixel variations in sensitivity. This correction is performed by normalizing to an image of a standard object that has a known reflectance at a wavelength of 4  $\mu\text{m}$ . After correction, each pixel value is proportional to the reflectance (at a wavelength of 4- $\mu\text{m}$ ) at the corresponding location on the specimen.