symmetric tensor representing the sum of the square power of the strain-rate tensor and the square power of the rotation tensor; and

- The magnitude of the vorticity vector.

The criteria associated with the first three quantities are those inside a vortex core, the discriminant is positive, the second invariant is positive, and the intermediate eigenvalue is negative, respectively. The fourth criterion — taking magnitude of the vorticity as an indication of vortical activity — might intuitively seem to be a good choice, but it is subjective rather than objective because it entails subjective selection of a threshold magnitude value for isolating flow structures of interest in high-vorticity regions.

These criteria were tested by use of a database generated in direct numerical simulations of high-pressure, binary-species-mixing flows undergoing transitions to turbulence. The quantities involved in the criteria were computed from the database, isosurfaces of these quantities were plotted, and plots were assessed with respect to utility in demarcating flow structures. Of the four criteria, that based on the second invariant was found to yield the most realistic plots of flow structures and to capture structures in all regions of the flow.

The figure presents plots of the second invariant isosurfaces showing vortical features from four of the simulations. The diversity of the features is noticeable and has been interpreted as boding well for the extraction of vortical features from visual data and enabling appropriate comparisons between experimental and computationally simulated flows.

This work was done by Josette Bellan and Nora Okong'o of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov

NPO-41932

Amplified Thermionic Cooling Using Arrays of Nanowires

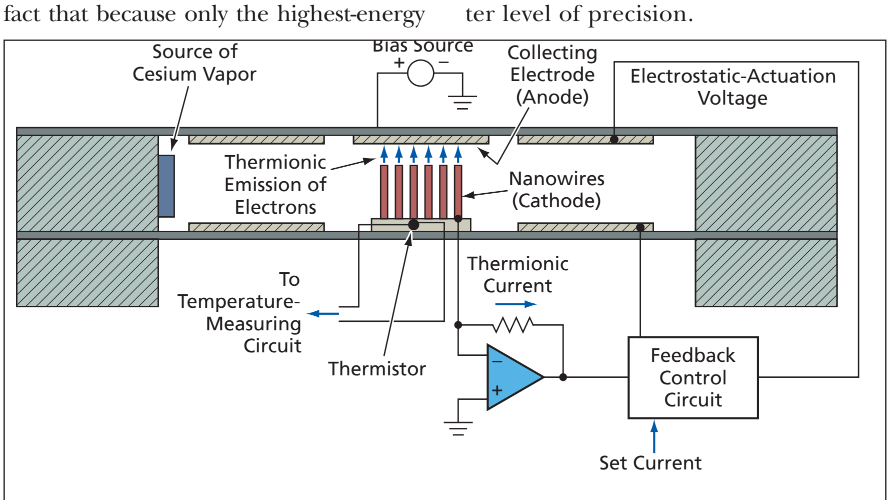
Cooling devices could be highly miniaturized.

NASA's Jet Propulsion Laboratory, Pasadena, California

A class of proposed thermionic cooling devices would incorporate precise arrays of metal nanowires as electron emitters. The proposed devices could be highly miniaturized, enabling removal of heat from locations, very close to electronic devices, that have previously been inaccessible for heat-removal purposes. The resulting enhancement of removal of heat would enable operation of the devices at higher power levels and higher clock speeds. Moreover, the mass, complexity, and bulk of electronic circuitry incorporating these highly miniaturized cooling devices could be considerably reduced, relative to otherwise equivalent circuitry cooled by conventional electromechanical, thermoelectric, and fluidic means.

In thermionic cooling, one exploits the fact that because only the highest-energy electrons are thermionically emitted, collecting those electrons to prevent their return to the emitting electrode results in the net removal of heat from that electrode. Collection is effected by applying an appropriate positive bias potential to another electrode placed near the emitting electrode.

The concept underlying the proposal is that the thermionic-emission current and, hence, the cooling effect attainable by use of an array of nanowires could be significantly greater than that attainable by use of a single emitting electrode or other electron-emitting surface. The wires in an array according to the proposal would protrude perpendicularly from a planar surface and their heights would be made uniform to within a sub-nanometer level of precision.



An **Array of Nanowires** would be coated with cesium and tested for effectiveness in thermionic cooling by use of an apparatus shown here in simplified schematic form.

A process of growing metal nanotubes in alumina nanopores has already been demonstrated and would be incorporated into the following process for fabricating an array according to the proposal:

1. An aluminum layer would be deposited on a silicon nitride membrane mesh substrate, the central portion of which would be covered with a silicon island.
2. The aluminum layer would be anodized to grow an alumina nanopore template on the silicon-island portion.
3. Metal nanowires would be grown inside the nanopores of the template by electrodeposition.
4. The exposed surface of the template and nanowires would be subjected to chemical-mechanical polishing.
5. The template would be etched away to expose the array of metal nanowires centered on the silicon island on the nitride membrane mesh substrate.

An experimental prototype array fabricated as described above would be further processed and tested as follows: A thermistor would be embedded in the island. The resulting assembly would be mounted in a vacuum chamber with electrical contacts to the array and the thermistor (see figure). In the vacuum chamber, cesium and/or other alkali metal(s) would be deposited on the nanowires to reduce their work function. The chamber would contain an upper membrane with metal-coated areas that would serve, respectively, as a collecting electrode (anode) and electrostatic-attraction electrodes. By means of electrostatic attraction with feedback control, this membrane would be pulled down to maintain a gap of the order of nanometers between the tips of the nanowires and the anode.

The bias potential would be applied to the anode and the temperature of the array (the cathode) would be measured by the thermistor. Because of the thermionic reduction of temperature is expected to be small in initial experiments, the sensitivity of measurement of this reduction would be enhanced by use of a lock-in technique in which the bias potential would be modulated and the variation in temperature measured at the modulation frequency.

This work was done by Eui-Hyeok Yang, Daniel Choi, Kirill Shcheglov, and Yoshikazu Hishinuma of Caltech for NASA's Jet Propulsion Laboratory. 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 this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-42101, volume and number of this NASA Tech Briefs *issue, and the page number.*

Delamination-Indicating Thermal Barrier Coatings

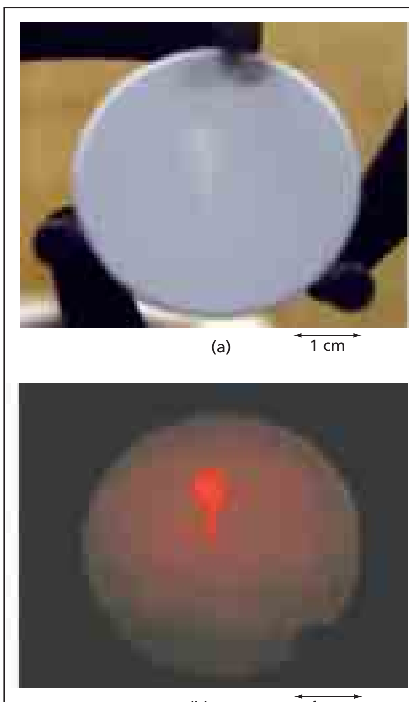
Luminescent sublayers reveal previously hidden coating damage.

John H. Glenn Research Center, Cleveland, Ohio

The risk of premature failure of thermal barrier coatings (TBCs), typically composed of yttria-stabilized zirconia (YSZ), compromises the reliability of TBCs used to provide thermal protection for turbine engine components. Unfortunately, TBC delamination proceeds well beneath the TBC surface and cannot be monitored by visible inspection. Nondestructive diagnostic tools that could reliably probe the subsurface damage state of TBCs would alleviate the risk of TBC premature failure by indicating when the TBC needs to be replaced before the level of TBC damage threatens engine performance or safety. To meet this need, a new coating design for thermal barrier coatings (TBCs) that are self-indicating for delamination has been successfully implemented by incorporating a europium-doped luminescent sublayer at the base of a TBC composed of YSZ. The luminescent sublayer has the same YSZ composition as the rest of the TBC except for the addition of low-level europium doping and therefore does not alter TBC performance.

The strategy for producing delamination-indicating TBCs relies on the enhanced luminescence produced by regions of the TBC where subsurface cracks are propagating. This enhanced luminescence is due to a large fraction of the excited luminescence that is incident upon the crack at an angle beyond the angle for total internal reflection. Deposition of 125-µm thick TBCs above a 7-µm thick europium-doped layer was performed in collaboration with Penn State University. These self-indicating TBCs were deposited by multiple-ingot electron-beam physical-vapor deposition without disrupting TBC growth so as not to alter the usual columnar growth that gives these TBCs many of their desirable properties. To demonstrate delamination indication, localized TBC delamination was induced by scratching the coating with a stylus.

While the delaminated region can be faintly discriminated in a standard white-light image [part (a) in the figure], the delaminated region stands out strongly in a luminescence image due to the greatly enhanced red emission originating from that area [part (b) in the figure]. The enhanced luminescence from the europium-doped sublayer was caused by total internal reflection of a large fraction of both the 532-nm excitation and the 606-nm emission wavelengths at the TBC/crack interface. Typically, luminescence is enhanced from delaminated regions by about a factor of three for electron-beam physical vapor deposited TBCs and by an incredible factor of about 100 for plasma-sprayed TBCs. Luminescence imaging was very simple to implement and can be achieved using only light-emitting-diode illumination source and a camera with a band-pass filter. High-resolution luminescence images were obtained within a few seconds that immediately identified regions of TBC delamination that would otherwise be difficult to detect, thereby showing great promise for routine inspection of TBCs.



Delamination-Indicating Thermal Barrier Coating is examined as (a) white-light image and (b) Eu^{3+} luminescence image. Enhanced Eu^{3+} 606 nm (red) luminescence detected from scratched region of TBC readily reveals subsurface delamination.

Future work will concentrate on developing delamination-indicating TBCs with near-infrared-luminescent sublayers. Because TBCs are much more transparent at near-infrared wavelengths than at visible wavelengths, luminescence can then be detected with less attenuation and from much greater coating depths. The prime candidate dopants for near-infrared luminescence are erbium and neodymium, which luminesce at 1.55- and 1.06-µm wavelength, respectively.

This work was done by Jeffrey I. Eldridge of Glenn Research Center. 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-17929-1/30-1.