Amplified Thermionic Cooling Using Arrays of Nanowires

Cooling devices could be highly miniaturized.

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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 other-electric devices, that have previously been inaccessible for heat-removal purposes.

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.

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 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 nanotubes 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...
Delamination-Indicating Thermal Barrier Coatings
Luminescent sublayers reveal previously hidden coating damage.

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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 implemented 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.

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.

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 wavelength 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.

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 temperature in measurement was measured at the modulation frequency.

**Delamination-Indicating Thermal Barrier Coating**

Luminescence image is examined as (a) white-light image and (b) Eu²⁺ luminescence image. Enhanced Eu²⁺ 606 nm (red) luminescence detected from scratched region of TBC readily reveals subsurface delamination.