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Quantum Dots as Tiny Thermometers

by Michael A. Greenwood

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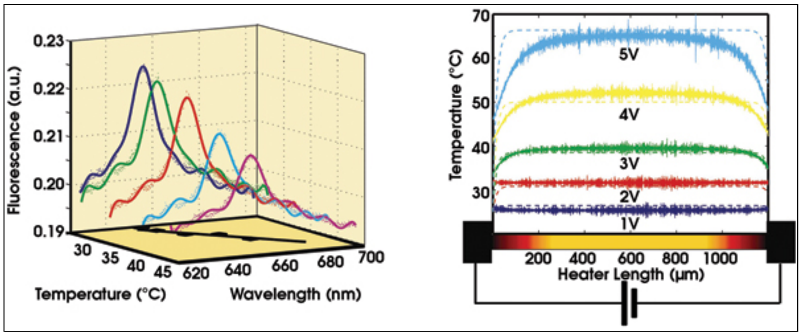
As technology gets smaller and smaller, it is becoming increasingly difficult to take accurate temperature readings in systems that are measured in the micro- and nanometer ranges.

Researchers from the University of California, Berkeley, and from the Lawrence Berkeley National Laboratory believe that a single quantum dot — a semiconductor device measuring □10 nm in diameter — could be the tiny scientific thermometer of the future.

Such highly specific readings currently are acquired with IR cameras and other approaches, but the results are limited by spatial resolution and temperature ranges.



The temperature-dependent fluorescence spectra from a representative single quantum dot shows a redshift as temperature increases from 24.4 to 43.6 °C (left). The figure on the right shows the temperature profile along a fabricated aluminum microheater under various voltage inputs. Both quantum dot spectral shift measurements (solid lines) and calculations from an analytical model (dashes) show a temperature increase from the ends to the center of the heated device. Reprinted with permission of Nano Letters.

Quantum dots, by virtue of their small size and high photostability, appear to be well suited for taking temperature readings in a noncontact mode, said researcher Jui-Ming Yang. Potential applications for the technique include measuring the temperature of an individual cell and estimating for thermal stress patterns associated with temperature changes in microelectromechanical systems (MEMS) devices.

The researchers used the wavelength shifts of a single CdSe quantum dot to sense temperature variations and to report these changes through an optical readout. The quantum dots, which had an emission maximum of 655 nm, were encapsulated by a ZnS shell, coated with an organic polymer and conjugated with streptavidin.

They placed the samples between glass coverslips and used a 532-nm CW Coherent laser to excite the quantum dots through an Olympus microscope. They collected the emission of each quantum dot using a Chroma dichroic mirror and imaged the samples using a Photometrics' intensified camera.

To calibrate the spectral shift of a single quantum dot and to eliminate the blinking effect, the researchers took 100 frames, each with a 2-s exposure time, at temperature increments of roughly 5 °C. The temperature of the substrate gradually was increased from 24.4 to 43.6 °C during the experiment.

The investigators found that, as the temperature rose, the quantum dots exhibited a redshift and that the temperature sensitivity was □0.1 nm/°C.

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To further test the technique, they applied multiple quantum dots over the surface area of a MEMS microheater measuring 1200 × 40 × 0.1 µm and adjusted the device’s temperature by applying from 1 to 5 V. The technique successfully reconstructed the temperature profiles of the microheater.

One problem with the method is that the peak emission wavelength varies from quantum dot to quantum dot. Even particles with the same peak emission wavelength can exhibit different temperature-sensing behavior. The researchers said that the likely explanation is that, when quantum dots are synthesized by wet chemistry, their size and shape are not uniform. Because of this, it is advisable to measure relative temperatures and not absolute temperature change.

Yang said that the team plans to apply the technique to measuring the temperature of individual cells.

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