New diamond and gold-based techniques let scientists measure and control the temperature inside living cells

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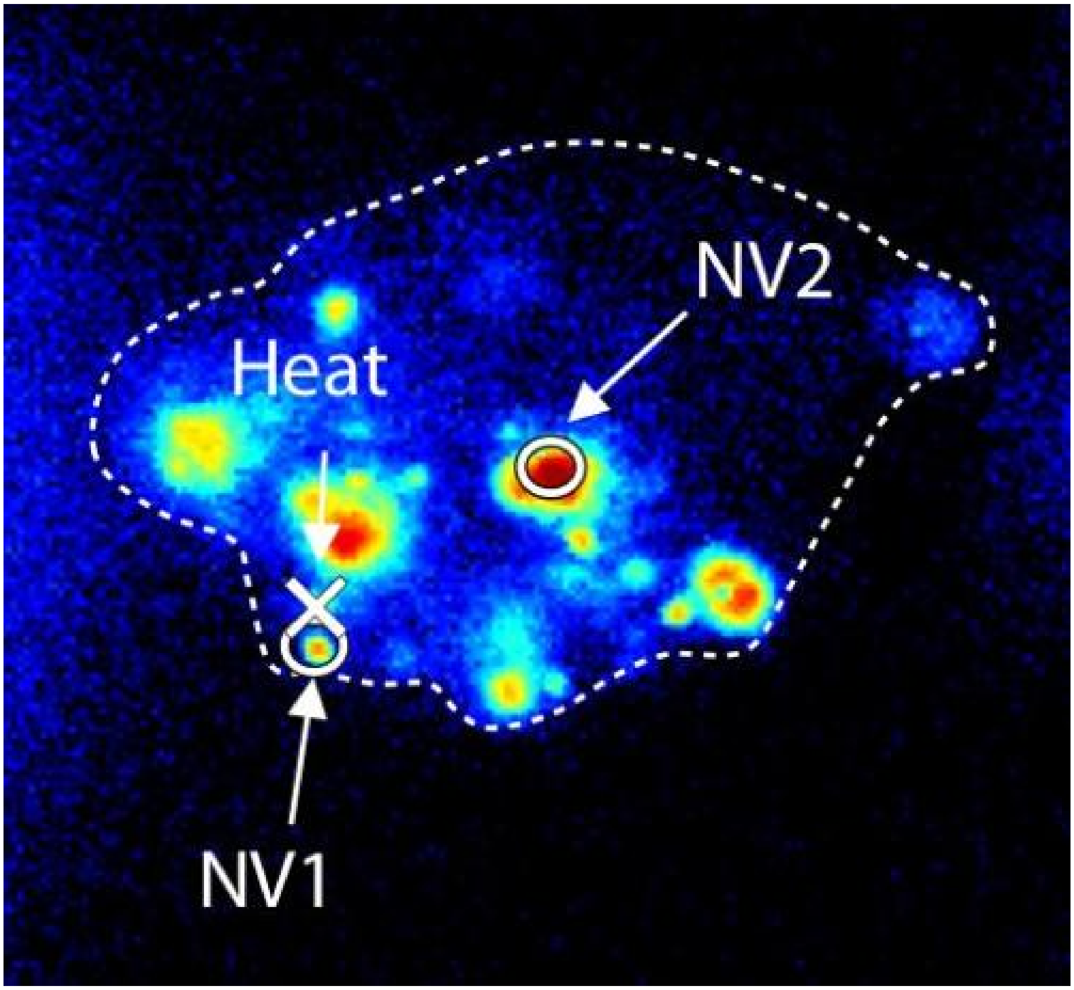
Artist's concept of researchers heating gold nanoparticles inside of a cell with a laser and monitoring diamond sensors to measure temperature. This image is not to scale. Credit: Steven H. Lee (graphiko.com)

How do you take the temperature of a cell? The familiar thermometer from a doctor's office is slightly too big considering the average human skin cell is only 30 millionths of a meter wide. But the capability is significant; developing the right technology to gauge and control the internal temperatures of cells and other nanospaces might open the door to a number of defense and medical applications: better thermal management of electronics, monitoring the structural integrity of high-performance materials, cell-specific treatment of disease and new tools for medical research.

A team of researchers working on DARPA's Quantum-Assisted Sensing and Readout (QuASAR) program recently demonstrated sub-degree temperature measurement and control at the nanometer scale inside living cells. The QuASAR team, led by researchers from Harvard University, described its techniques in a *Nature* paper titled "Nanometer scale quantum thermometry in a living cell."

To measure temperature, the researchers used imperfections engineered into diamond, known as nitrogen-vacancy (NV) color centers, as nanoscale thermometers. Each NV center can capture an electron, such that the center behaves like an isolated atom trapped in the solid diamond. Changes in temperature cause the lattice structure of the diamond to expand or contract, similar to the way the surface of a bridge does when exposed to hot or cold weather. These shifts in the lattice induce changes in the spin properties of the trapped atoms, which researchers measure using a laser-based technique. The result is that scientists can now monitor sub-degree variations over a large range of temperatures in both organic and inorganic systems at length scales as low as 200 nanometers. For a sense of scale, see: learn.genetics.utah.edu/content/begin/cells/scale/.



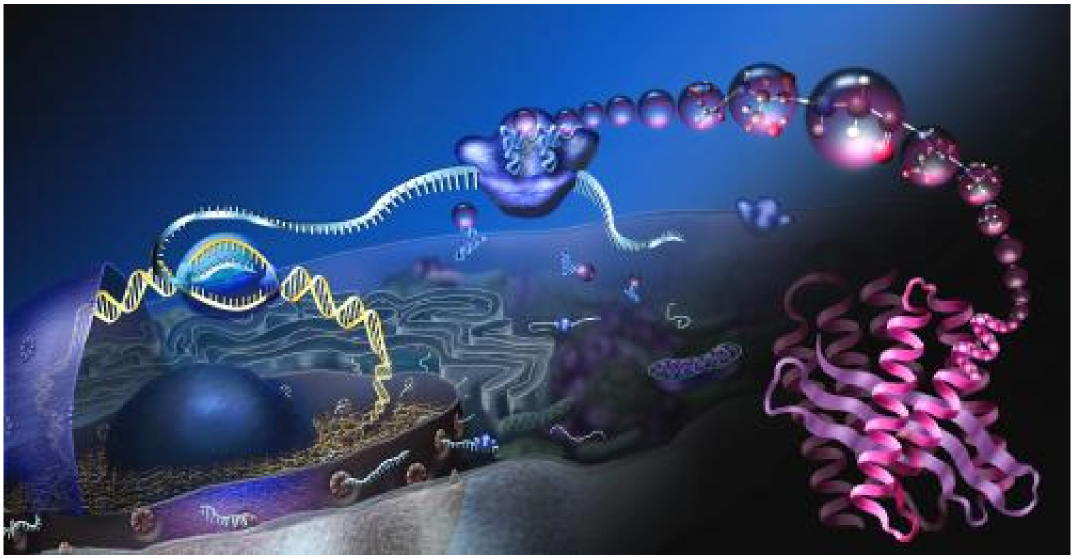
Confocal scan of a single cell. The white cross corresponds to the position of the gold nanoparticle used for heating, while the red and blue circles represent the location of diamond sensors used for thermometry. The dotted white line outlines the cell membrane.

The diamond sensors are themselves only 100 nanometers in diameter. Each one contains multiple NV centers (the QuASAR team engineered 500 NV centers into each), and multiple sensors can be embedded in a single cell using nanowires. Given the extremely small size of the diamond sensors and their temperature sensitivity, researchers can accurately measure temperature within areas smaller than one percent of the total area of a cell.

The QuASAR team also demonstrated control and mapping of temperature gradients at the subcellular level by implanting gold nanoparticles into a human cell alongside the diamond sensors. The 100-nanometer-diameter nanoparticles were then heated using a separate laser. By varying the power of the heating laser and the concentration of gold nanoparticles, the researchers were able to modify and characterize (using the diamond sensors) the local thermal environment around the cell. In particular, they were able to verify that the heating was localized near the gold nanoparticles and that the cell did not experience an overall ambient rise in temperature.

The team's findings have several potential applications and could lead to additional areas of study:

- The temperature-measurement technique could provide insight into organic and inorganic systems, informing subjects like heat dissipation in integrated circuits and thermal properties of musculoskeletal restoration or inflammation following physical exertion;
- Because the techniques have been shown to be effective up to temperatures of 600 degrees Kelvin, they could allow for monitoring of nanoscale cracking and degradation caused by temperature gradients in materials and components operating at high temperatures;
- The intrinsic chemical inertness of diamond may allow for direct microscopic monitoring and control of chemical reactions.



Although the cell is the smallest unit of life, it is by no means simple. The human body is made up of tens of trillions of cells like this one, that have developed a highly synchronized set of components to carry out the processes that keep the organism alive, allow it to reproduce and adapt to changing environments. Credit: National Science Foundation

"This research provides another example of how the extreme precision and control of atomic physics techniques can impact sensing applications. It demonstrates that the novel measurement tools being developed under QuASAR can provide new capabilities to the Department of Defense and the broader scientific community at scales that have not previously been possible," said Jamil Abo-Shaeer, DARPA program manager for QuASAR. "We plan to keep exploring applications for quantum sensors for the measurement of temperature, magnetic and electric fields, and the development of compact optical atomic clocks. We see this work as a jumping off point for whole new areas of research and development."

More information: www.nature.com/nature/journal/ … ull/nature12373.html

Provided by DARPA

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