Healthcare, Drug development, Diagnostics

Intracellular heat diffusion measured by newly developed quantum nano sensors

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Abstract

Biological thermogenesis is observed in mammals, birds, insects, and plants. Understanding the mechanism of thermogenesis is one of the major targets in biology and physiology. However, there are very few knowledge about how the heat diffuses from intracellular heat sources through the intracellular space. This is due to the technical difficulties in measuring and manipulating the temperature at the small scale such as a cell. Here, we newly developed a method to determine the physical parameter for the heat diffusion (thermal conductivity) using a nanoparticle called a quantum nano sensor, and successfully applied the method to intracellular measurements.

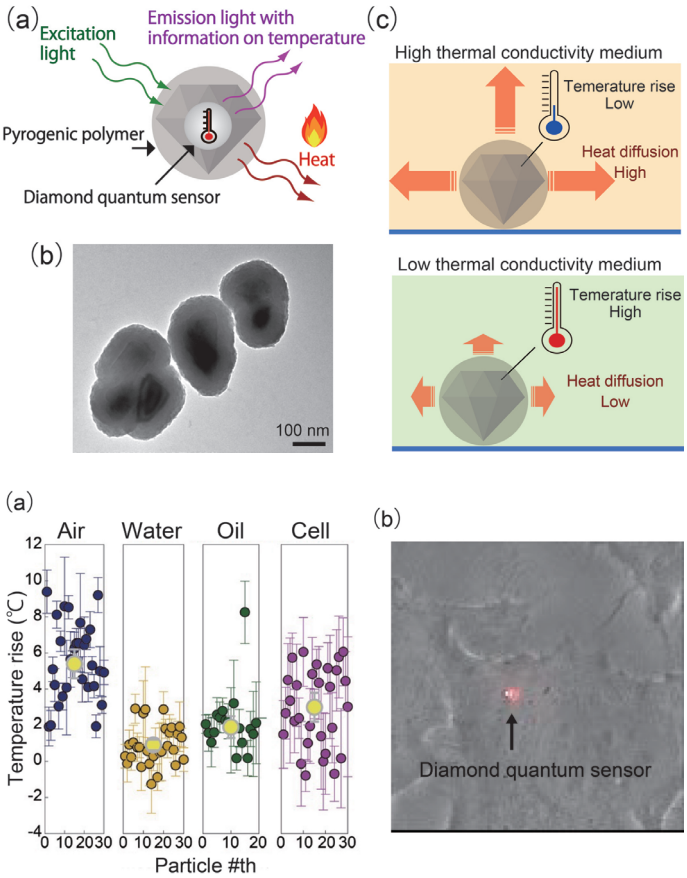
Background & Results

The quantum nano sensor is a diamond nanoparticle. Due to the impurity in the lattice of carbon atoms, those nanodiamonds become fluorescent. From the temperature dependent fluorescence signal, we can determine the temperature changes in the nanodiamond. Individual nanodiamonds were coated with a polymer that releases heat upon light illumination. Thus, a heater-thermometer nanohybrid was developed with which we can determine the thermal conductivity at the nanoscale.

We confirmed the accuracy of the new methodology using air, water and oil with known values of thermal conductivities, followed by the measurements in cells. It has been considered that the intracellular thermal conductivity is similar to that of water, and that the value is homogeneous within a cell. However, our measurements revealed that those considerations were wrong; the intracellular value is about one sixth of that of water, and the value deviates around the mean significantly. Furthermore, according to the calculations using the measured values, there can be localized temperature rises that are high enough to accelerate enzymatic activities and to thermally modulate biological molecules in a cell.

Significance of the research and Future perspective

Accurate measurement of thermal properties is the important first step towards the understanding of thermogenesis at the cellular scale. For example, the hot spot where the thermal conductivity is lower can maintain higher temperature than other locations in a cell. The high temperature can accelerate the enzymatic activities around the heat source such as transcriptions and ATP synthesis. It can also change the dynamics of lipid bilayers. If there are cells with lower thermal conductivity, these cells can elevate the temperature higher than other cells. Our studies contribute the progress of basic biology and medical biology, but can also promote the development of anti-obesity treatments and novel methods of hyperthermia using artificial tiny heat sources.



Patent	Japanese Patent No.6919923, WO2017-073728
Treatise	Sotoma, S. et al. *In situ* measurements of intracellular thermal conductivity using heater-thermometer hybrid diamond nanosensors. Science Advances. 2021; 7(3), eabd7888. doi: 10.1126/sciadv.abd7888 Suzuki, M; Plakhotnik, T. Opportunities for hybrid diamond nanosensors targeting photothermal applicatoins in biological systems. Applied Physics Letters. 2021; 119: 190502. doi: 10.1063/5.0063089 Plakhotnik, T; Suzuki, M. Backstage of rising body temperature: Advances in research on intracellular heat diffusion. Temperature. 2021; 8(4): 303-305. doi: 10.1080/23328940.2021.1982363
URL	https://resou.osaka-u.ac.jp/en/research/2021/20210116_1 https://www.scientificamerican.com/article/mysterious-heat-spikes-inside-cells-are-probed-with-tiny-diamonds/ https://physicsworld.com/a/nanodiamonds-measure-thermal-conductivity-in-living-cells/
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