Researchers demonstrate new concepts for heat management

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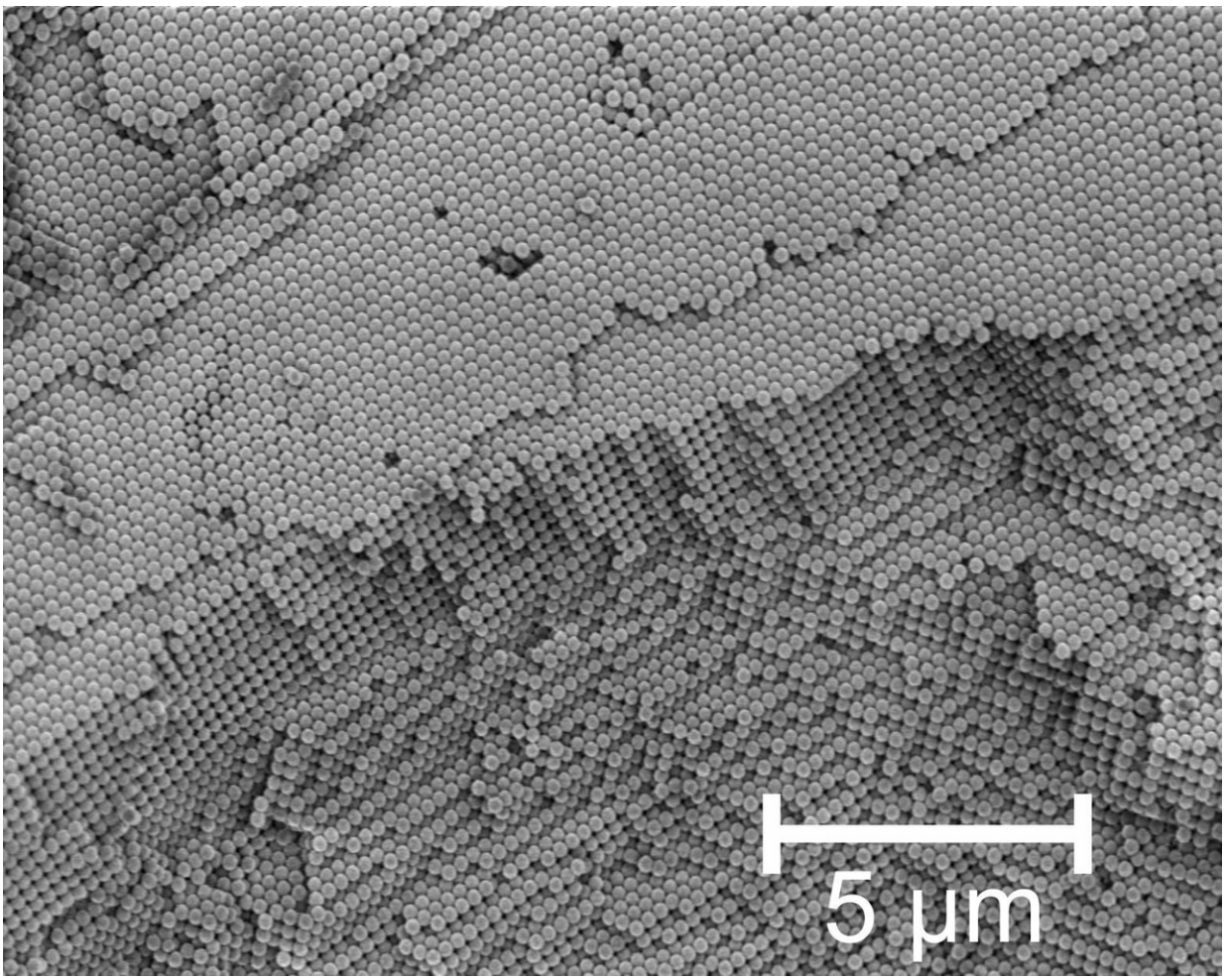

An electron microscope image displaying the regular nanostructure of a photonic crystal. Scale bar: 5 micrometres = 0.005 millimetres. Credit: Markus Retsch

For the first time, Prof. Dr. Markus Retsch and his research group at the University of Bayreuth have succeeded in precisely controlling temperature-dependent thermal conductivity with the help of polymer materials. These advanced functional materials – initially produced for laboratory experiments – have now been presented in the journal *Science Advances*. The findings are of great relevance to the development of new concepts of thermal insulation.

From butterfly wings to new functional materials

The polymer materials that allow thermal conductivity to be controlled are photonic crystals. They often give butterflies, beetles, and other insects dazzling colours and have mainly been investigated due to their optical effects. Prof. Dr. Markus Retsch, Lichtenberg Junior Professor of Polymer Systems, and his doctoral student Fabian Nutz (M.Sc.) have developed four different methods to control temperature-dependent heat transfer in such photonic crystals.

These methods exploit the fact that polymer nanomaterials become more heat-permeable once they lose their nanostructure by crossing a certain temperature threshold. That is when the thermal conductivity of the photonic crystals skyrockets to a level that is two or three times as high as it was before. On this basis, clearly defined effects on thermal transfer can be achieved via changes in the nanostructure of the crystals.

Film formation increases thermal conductivity

The research of the scientists in Bayreuth has shown that the temperature at which thermal conductivity jumps to a higher level depends crucially on the composition of the nanoparticles that make up the photonic crystals. This temperature can be precisely adjusted by incorporating a plasticizer into the polymer structure. Whether thermal conductivity

changes within a wide or narrow temperature range when the temperature rises can also be precisely controlled: doing so only requires nanoparticles which are similar in size but which differ with regard to plasticizer content to be equally mixed. This leads to a gradual loss of the nanostructure across a wide temperature range. Consequently, the increase in thermal conductivity also spans a larger temperature range.

In addition, by using a layered structure, the researchers also managed to transform the continuous increase into a multi-level increase in conductivity. By adjusting the thickness of individual crystal layers, one can also precisely influence the conductivity level that is reached at the respective level.

Potential for energy technology and thermal management

"These research findings demonstrate that it is possible in principle to regulate thermal conductivity in nanostructured materials with a high degree of precision. However, developing materials that enable thermal transfer to be precisely controlled is only the beginning. Our findings to date are very encouraging and have revealed interesting concepts for constructing more energy efficient insulation materials. In the long term, these concepts could be valuable for the development of thermal transistors or diodes," Prof. Retsch explained.

He did, however, point to one obstacle that must still be overcome: the increase in thermal conductivity – as regulated in the four methods developed by the team – is irreversible. This means that the conductivity remains at the level that is reached even when the temperature sinks again. "Constructing nanosystems that enable thermal transfer to be reversibly controlled is a difficult yet exciting and central task for further research in this field," said Prof. Retsch.

More information: Fabian A. Nutz et al. Tailor-made temperature-dependent thermal conductivity via interparticle constriction, *Science Advances* (2017). DOI: 10.1126/sciadv.aao5238

Provided by University of Bayreuth