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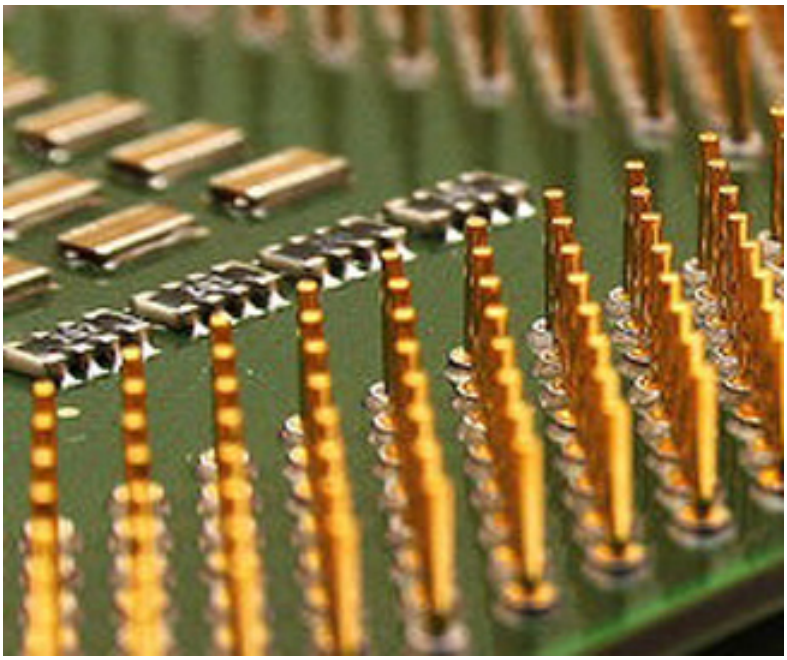
More efficient thermoelectric devices



A joint research carried out by the Group of Nanomaterials and Microsystems and the Group of Statistical Physics of the UAB Department of Physics, as well as by the Laboratory of Molecular Beam Epitaxy belonging to ICMAB-CSIC, has developed a material based on germanium nanostructures that presents a significant reduction in thermal conductivity and therefore could be a potential candidate in the development of thermoelectric systems compatible with silicon.

In the past few years, the design and manufacturing of circuits at nanoscopic scale for integrated devices has become one of the frontier fields in new material science and technology. The significant reduction achieved in these devices often is accompanied by new discoveries in how they behave precisely when the systems are of extremely small dimensions. Understanding this new physics at nanoscopic scale at the same time has enabled researchers to study the possibility of designing new materials with innovative characteristics.

One of the most crucial properties to take into account when designing chips is the thermal conductivity of the devices integrated in the chip, i.e. their capacity to remove or accumulate energy. This property is essential to control the heating of micro-sized circuits, which represents one of the current physical limitations to computing potential. Combining heat and electricity creates thermoelectric effects which would allow circuits to cool down and would increase the power of computing. Until now, no material has contained the properties needed to be efficient enough in terms of thermoelectric behaviour. This is why obtaining materials at nanometric scale can be useful for the improvement of thermoelectric properties, since these materials can achieve a significant reduction in thermal conductivity as well as maintain a high level of electrical conductivity, which is needed to obtain high thermoelectric efficiency.

Figure 1. *Sketch of the samples containing ordered and disordered nanocrystal structures. The represented materials are silicon (blue), germanium (orange), and carbon (black).*

In this project, researchers of the UAB Department of Physics and the Barcelona Institute of Materials Science (ICMAB-CSIC) have worked together to develop a new material based on supernets formed with two alternative layers, one made of silicon (Si) and the other of germanium (Ge) nanocrystals (quantum dots). In comparison to previous improvements, this project proposes to place the quantum dots in an uncorrelated fashion on consecutive layers. In other words, the dots on one layer would not be vertically aligned with those of the lower layer. This is achieved by introducing a small sub-layer of carbon between each layer of silicon and Ge nanodots, which hides the information of the quantum dots found on the lower levels. The main result of the uncorrelation between consecutive layers is the reduction in thermal conductivity, since it becomes more difficult to transport heat perpendicularly from the multilayers. Researchers were able to prove that this reduction reached a factor in excess of 2 when compared to structures with a vertical correlation of dots. This could greatly influence the design of new materials with improved thermoelectric characteristics and pave the way for the creation of nanofridges for common semiconductor devices, given that the structure is compatible with silicon technology.

Figure 2.*Thermal conductivity for the ordered sample (blue) and for the disordered one (red). Straight line corresponds to the computation following the theoretical model. The one the right corresponds to the acoustic phonons Raman spectrum, that take part on the heat transportation, measured on the same samples.*

Ge-based structures also could be used in high-temperature applications, such as in recovering heat generated in combustion processes and converting it to electrical energy.

A second and important aspect of this project is the theoretic study of the thermal properties this new material contains through a simple model based on the modification of the Fourier heat equation, which can predict its behaviour according to the dimensions of its characteristics. Thus with the help of results from previous studies, researchers were able to understand the theoretical foundations of thermal behaviour of this nanostructured material.

The research was coordinated by Javier Rodríguez, professor at the UAB Department of Physics, with the participation of Jaime Álvarez, Xavier Álvarez and David Jou, also from the UAB Department of Physics, as well as the collaboration of CSIC researchers Paul Lacharmoise,

Alessandro Bernardi, Isabel Alonso, and ICREA researcher Alejandro Goñi. Part of the research was carried out at the Nanotechnology Lab of the MATGAS research centre located at the UAB Research Park. The research paper was recently published in Applied Physics Letters and research members are now working to develop a material with a good level of electric conductivity through controlled doping of the structure.

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References

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