Novel nanostructures could make smartphones more efficient

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EU-funded researchers and partners are pushing the boundaries of the laws of physics, developing nanocomposite materials and nanoelectronic circuits to greatly improve energy, thermal and computing performance.

This could make smartphones and other electronics more efficient and boost the potential of solar power.

In today's world, nanomaterials play a crucial role in the emergence of intelligent devices and sensors, smart homes, autonomous devices, robotics, biotechnology and medicine.

But circuits have become so miniaturized and fast that they can no longer manage the heat generated during the processing of information.

"The standard ways of breaking this deadlock, such as by either generating less heat or removing it more effectively, are failing to keep pace," says Mimoun El Marssi of the Université de Picardie Jules Verne in France.

El Marssi is the coordinator of the EU-funded ENGIMA project, which tackles this very issue. It focuses on how to redistribute electricity efficiently at miniscule scales, harnessing nanotechnology breakthroughs that are opening up new possibilities and applications thought impossible until just a few years ago.

Making the impossible possible

A major challenge faced by ENGIMA researchers is the so-called Boltzmann tyranny problem in nanoelectronics.

It relates to one of the most basic concepts of electricity: capacitance, a quantity showing how much charge needs to be placed on a conductor in order to ensure a given voltage. The standard textbook definition states that capacitance is always positive. Therefore, the larger the voltage, the larger the stored charge, and, in turn, the more heat will be generated by a device.

In a breakthrough development, ENGIMA researchers in France and Russia working in collaboration with Valerii Vinokur of the US Department of Energy's Argonne National Laboratory developed a permanent static "negative capacitor," a device thought impossible until about a decade ago.

Previously proposed designs for negative capacitors worked on a temporary, transient basis but the ENGIMA-developed negative capacitor is the first to operate as a steady-state reversible device.

The proposed approach harnesses properties of ferroelectric materials, which possess spontaneous polarization that can be reversed by an external electric field. Increasing the charge on the positive capacitor increases the voltage. The reverse occurs with the negative capacitor—its voltage drops as the charge increases.

By pairing the two capacitors, the voltage of the positive capacitor can be locally increased to a point higher than the total system voltage. This enables electricity to be distributed to regions of the circuit requiring higher voltage while the entire circuit operates at a lower voltage.

This breakthrough will help reduce switching energy and operational voltage of electronic devices, thus cutting heat losses, notes Igor Lukyanchuk, ENGIMA's lead researcher.

"Negative capacitance is one of the most important recent developments in reducing the energy consumption of nanocircuits and solving overheating problems that limit the performance of conventional computing circuits," he says. "Building on this research, we are developing a practical platform for implementing ultra-low-power devices for information processing."

Toward battery-less smart devices

In practice, this would mean your smartphone, Internet of Things devices and numerous other electronic systems will become far more energy efficient. In combination with other work being conducted as part of ENGIMA, it could radically transform our experience of energy harnessing, consumption and storage.

Building on recent advances in photovoltaic technology and thin-film materials for solar energy conversion, ENGIMA research teams in France and Mexico are developing novel multifunctional super-lattice nanostructures finely tuned for optimized ferroelectric, structural and photovoltaic responses. The work promises an efficient way to design new nanostructures for future photovoltaic materials.

"These photovoltaic systems could become next-generation green energy sources as safe, reliable, environmentally friendly replacements for batteries in self-powered smart systems," El Marssi says.

Meanwhile, ENGIMA researchers in Slovenia, led by Zdravko Kutnjak at the Jožef Stefan Institute, are exploring other ways to overcome the "Boltzmann tyranny." They are exploiting the so-called electrocaloric effect that causes materials to show a reversible temperature change under an applied electric field. The team demonstrated for the first time that liquid crystals can be exploited as electrocaloric materials with large temperature changes.

Developments in this area have attracted huge interest from research and industrial communities since it suggests the efficient in-chip integration of coolers into nanoelectronic computing circuits, according to Kutnjak.

"We expect that the cooling temperature in prototypes of liquid crystal devices will be significantly enhanced compared to solid state systems," he adds. "Moreover, liquid crystal material can be used in any shape, and such devices will not be affected by fatigue problems caused by the cracking of materials."

The results emerging from ENGIMA promise to open significant new opportunities and possibilities for high-tech industries, particularly in addressing current energy consumption and harvesting issues, with applications across many fields.

"From this point of view, ENGIMA may improve the long-term quality of life and health of EU citizens. For example, by contributing to the development of different smart systems," El Marssi says. "It is also envisaged that ENGIMA will contribute to filling the gap in research activity on the application of multifunctional nanomaterials for computing and energy-consuming technologies between Europe and other countries."

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