Mechanism behind capacitor's high-speed energy storage discovered

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Researchers at North Carolina State University have discovered the means by which a polymer known as PVDF enables capacitors to store and release large amounts of energy quickly. Their findings could lead to much more powerful and efficient electric cars.

Capacitors are like batteries in that they store and release energy. However, capacitors use separated electrical charges, rather than chemical reactions, to store energy. The charged particles enable energy to be stored and released very quickly. Imagine an electric vehicle that can accelerate from zero to 60 miles per hour at the same rate as a gasoline-powered sports car. There are no batteries that can power that type of acceleration because they release their energy too slowly. Capacitors, however, could be up to the job – if they contained the right materials.

NC State physicist Dr. Vivek Ranjan had previously found that capacitors which contained the polymer polyvinylidene fluoride, or PVDF, in combination with another polymer called CTFE, were able to store up to seven times more energy than those currently in use.

"We knew that this material makes an efficient capacitor, but wanted to understand the mechanism behind its storage capabilities," Ranjan says.

In research published in Physical Review Letters, Ranjan, fellow NC State physicist Dr. Jerzy Bernholc and Dr. Marco Buongiorno-Nardelli from the University of North Texas, did computer simulations to see how the atomic structure within the polymer changed when an electric field was applied. Applying an electric field to the polymer causes atoms within it to polarize, which enables the capacitor to store and release energy quickly. They found that when an electrical field was applied to the PVDF mixture, the atoms performed a synchronized dance, flipping from a non-polar to a polar state simultaneously, and requiring a very small electrical charge to do so.

"Usually when materials change from a polar to non-polar state it's a chain reaction – starting in one place and then moving outward," Ranjan explains. "In terms of creating an efficient capacitor, this type of movement doesn't work well – it requires a large amount of energy to get the atoms to switch phases, and you don't get out much more energy than you put into the system.

"In the case of the PVDF mixture, the atoms change their state all at once, which means that you get a large amount of energy out of the system at very little cost in terms of what you need to put into it. Hopefully these findings will bring us even closer to developing capacitors that will give electric vehicles the same acceleration capabilities as gasoline engines."

More information: "Electric Field Induced Phase Transitions in Polymers: a Novel Mechanism for High Speed Energy Storage" by V. Ranjan, M. Buongiorno Nardelli and J. Bernholc, Center for High Performance Simulation and Department of Physics, North Carolina State University, Published online in *Physical Review Letters*.

Abstract
Using first-principles simulations, we identify the microscopic origin of the non-linear dielectric response and high energy density of PVDF-based polymers as a cooperative transition path that connects non-polar and polar phases of the system. This path explores a complex torsional

and rotational manifold and is thermodynamically and kinetically accessible at relatively low temperatures. Furthermore, the introduction of suitable copolymers significantly alters the energy barriers between phases providing tunability of both the energy density and the critical fields.

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