‘Properly tuned polymer capacitors could eventually replace batteries as we know them’

Technology spotlight

Ferroelectric polymers for high-density energy storage

Battery technology has improved much in recent years. Almost all of us today carry mobile phones, some of which boast standby times of several days, and the more advanced laptop computers can run for four or more hours on a single charge. We are beginning to take high-capacity rechargeable cells for granted, and expect battery technology to keep up with the ever increasing power requirements of our mobile devices.

Nanotechnology has played a key role in the development of the metal hydride and lithium polymer cells currently used in mobile phones and laptops. But while we may describe the latest batteries as high capacity, the amount of energy they store is often less than that needed for devices which can power, say, all-electric vehicles for an entire day on the road. Either that, or they take an unfeasibly long time to charge. Research engineers are continually improving materials and devices, but with polymers and ceramics falling significantly short of rising energy demands, the need is for new materials with superior electrical energy capacities.

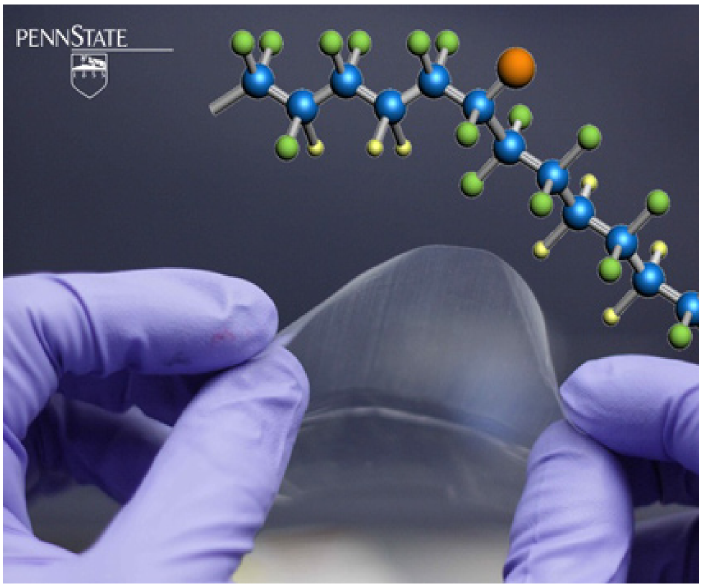
Tunable polymer capacitors

Materials scientists led by Qing Wang at Penn State University in the US reported in August to a meeting of the American Chemical Society in Philadelphia on their development of power density tuneable polymers and polymer ceramic nanocomposites as electric storage materials for capacitors. Power conditioning is currently carried out by capacitors, but Wang says that properly tuned polymer capacitors could eventually replace batteries as we know them.

Together with postdoc Yingying Lu and graduate students Jason Claude and Junjun Li, Wang has developed a ferroelectric polymer of poly(vinylidene fluoride) and trifluoroethylene which, with the addition of chlorotrifluoroethylene, displays a very high dielectric permittivity at room temperature. Permittivity is a measure of how much charge is stored in a material for a given electric field. The researchers found that they could tune the energy density of the material by altering the amounts of various chemical components of the polymer mix.

Mixing up to 10% by volume of titanium dioxide nanoparticles into a ferroelectric polymer matrix significantly increases the electrical energy capacity of the material.

The nanocomposite could form the basis of high-power batteries for electric vehicles and other power-hungry machinery



Source: Qing Wang/Penn State University

The key here is the introduction of nanoparticulate ceramics into the polymer matrix to improve the energy density. Combining large permittivity ceramics with highly insulating polymers could lead to impressive energy storage capacities, as energy density is proportional to the product of permittivity and the square of the electric field.

Another advantage of polymer-based dielectric materials is that the mechanical flexibility they provide is useful when it comes to building

> ‘Based on the results of this study, we are also able to select polymers to address the requirements of different applications and operational temperatures’

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real-world devices with optimised volume and weight. ‘Compared with ceramics, polymers have inherent advantages including flexibility and light weight,’ says Wang. ‘Over the last few years, this field has experienced unprecedented growth as the promise of flexible electronics with reduced size and weight has been realised through development of polymeric material-based devices for storing and processing electrons.’

Challenges

In practice, however, mixing ceramic nanoparticles with polymers is a challenge as the tendency of the particles is to clump and aggregate. If the materials are not evenly mixed, the interface between them will break down in the presence of high electric fields, and the ability of the composites to store energy will decrease rather than increase. For Wang and his team the way around this problem is to add functionalised groups to the materials in order to match them electrically. They also control the mixing so that the nanoparticles are spread evenly throughout the polymer matrix.

‘The surfaces of the nanoparticles are modified with organic ligands such as phosphonic acids and ethylene amines,’ says Wang. ‘This gives the particles a greatly enhanced dispersibility in the organic solvents used in film processing, and in turn a homogeneous distribution in the polymer matrix. The functionalised nanoparticles can be prepared by ball-milling – an industry-friendly process – with organic ligands. The polymers are then added to the respective nanoparticle dispersions to yield well-dispersed polymer-nanoparticle nanocomposites.’

Choosing the right fillers

As for the ceramics used, lead-based titanates such as PZT and PMNT have been popular choices as fillers in dielectric nanocomposites owing to their high permittivities. But selecting nanoparticles with permittivities up to hundreds of times those of the polymers into which they are embedded does not lead to a proportional increase in energy density of the composite material. The reason for this is that an increase in effective permittivity arises from

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a greater average electric field in the polymer matrix, with relatively little contribution from the high-permittivity filler phase. In addition, the presence of widely differing permittivities between the two materials results in a highly inhomogeneous electric field, and thus a significantly reduced effective electrical breakdown strength of the composite.

Wang and his colleagues opted for rod-shaped nanocrystals of titanium dioxide (TiO_2) as dopants in their ferroelectric polymer, known as poly(vinylidene fluoride-ter-trifluoroethylene-ter-chlorotrifluoroethylene) [P(VDF-TrFE-CTFE)]. Here the polymer matrix and filler have comparable permittivities of 42 and 47Fm^{-1}, respectively. The dielectric performance of the nanocomposite as a whole derives from the large enhancement in polarisation response at high electric fields, and changes in polymer microstructure induced by the filler.

Regarding the choice of polymer, the researchers prepared a library of around 50 polymers with controlled chemical compositions. ‘The

