Digital Batteries

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One of the biggest problems in using alternative sources of power is energy storage. Currently most energy produced by solar panels is stored in lead acid batteries; solar panels are environmentally friendly, but lead acid batteries are not. Capacitors could store energy much more efficiently and would be environmentally friendly. However, their storage capacity is very small. The energy density in capacitors is limited by dielectric break-through.

Chemical systems also store energy as electrostatic energy, but the limiting electric fields are much higher because quantization phenomena prevent dielectric break-through. For instance, when the electron of a hydrogen atom is lifted from the ground state to the first excited state, energy is stored in the system. The ratio between the stored energy and the volume of the atom is several orders of magnitude above the maximum energy density in a capacitor. Because the excited state of hydrogen atoms is short lived, hydrogen atoms cannot be used for long term energy storage. What about using molecular hydrogen or carbohydrates for energy storage? Unfortunately, molecular hydrogen is hard to store and the energy retrieval from hydrogen in fuel cells is slow and inefficient. And energy retrieval from carbohydrates produces carbon dioxide, a pollutant.

Living organisms use charge separation at the nano level for energy storage in photosynthetic macromolecules and across cell membranes. For instance, electric eels store enough energy across cell membranes that, it when discharged, can electrocute their prey. Ion pumps across cell membranes generate this charge separation.

Could one use nano capacitors for energy storage, where dielectric break-through is prevented by quantization phenomena? This is an exciting prospect.

The theoretical limit for electrostatic energy storage in quantum devices is very high. The energy density in heavy atoms, i.e. the ratio between the stored energy and atomic volume for an excitation from the ground state of heavy metal ions is 10,000 times higher than in hydrogen atoms. Based on this theoretical limit, the maximum density of retrievable energy in nano capacitors is comparable with the density of retrievable energy from nuclear reactions.

However, there may be other limitations to the energy density in a nano capacitor, for instance, tunneling and large tensions which may fracture the material. Such unforeseen hurdles may delay but hopefully not prevent researchers from building prototypes of nano capacitors with energy densities close to the theoretical limit.

The rapid energy release of nano capacitors discharged by an electrical short makes them potent explosives, potentially exceeding the power of any chemical explosive. In contrast to nuclear explosives, the production of nano capacitors requires not radioactive substances but common, nonpoisonous, environmentally friendly chemicals. Without electrical charge, nano capacitors have no explosive power. In contrast to both nuclear and chemical explosives, simply using nano capacitors as batteries and slowly removing their charge as electrical current could easily and safely discharge them. In the discharged state, they could be shipped without safety concerns. At their destination they could be easily charged with

DOI 10.1002/cplx.20275
Published online 15 December 2008 in Wiley InterScience
(www.interscience.wiley.com)

electrical current. Even if an explosion were to occur, it would produce no radioactive waste, no long term radiation, and probably could be designed to produce no chemicals.

Technology to produce nano capacitors may already exist because similar quantum effects are used to keep charge separated in MTJ capacitors (used in MRAM), in flash drives and in laser diodes. In laser diodes, the recombination of electrons and holes is a forbidden transition. Therefore, the holes are long lived even if they are very close to the electrons. This leads to large electric fields. Literature data suggest that in standard laser diodes the electric field is above the breakthrough field of regular capacitors, and could be much larger. Conceivably, conventional flash drives could be used for energy storage, but they are not designed for this purpose: the substrates are thick and the energy to weight ratio is small. One could design large arrays of individually connected nano capacitors, to be charged and discharged one-by-one, similar to flash drives. In contrast to regular batteries, the output voltage would remain constant until the last nano capacitor is discharged. One could call these arrays of nano capacitors digital batteries. A digital battery's stable output voltage is of key importance for sensors and other sensitive devices. However, the high energy density of such devices may pose a challenge in terms of safety. Charged digital batteries could explode if all nano capacitors were shorted simultaneously. In the electrically discharged state digital batteries probably pose no safety hazard whatsoever.

As an inexpensive and environmentally friendly alternative to both chemical batteries and nuclear explosives, digital batteries may prove to be a great asset. It could trigger economic growth and shift the power balance in the world. The introduction of digital batteries could spark an exciting transition from the nuclear age to a quantum engineering age.

DOI 10.1002/cplx