ENERGETIC MATERIALS

# Flexible approach pays off

Researchers have managed to extract electrical energy from environmental noise by exploiting the piezoelectric properties of zinc oxide nanowires with a device that could herald a new generation of local power sources.

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Despite rapid advances in the design and fabrication of miniaturized sensors and devices, their practical applications have been impeded by the lack of suitably miniscule sources of electrical power. Indeed, the generation and storage of electrical energy for mobile devices and systems is one of the most urgent challenges in science and engineering today. Micro- and nanoscale devices — such as ultrasensitive chemical and biomolecular sensors, nanorobotics, microelectromechanical systems (MEMS), environmental sensors and other personal electronic devices — have energy requirements that are not fully met by available technologies such as batteries.

Although the energy requirements of these micro- and nanoscale devices are rather small, they still require a power source that is compact, fully mobile, robust and sustainable over extended periods of time. Converting these devices into completely autonomous and self-powered units will therefore remain an elusive goal until we are able to develop scalable power generators that can scavenge energy from ambient sources such as mechanical vibrations, acoustic energy, thermal gradients and electromagnetic waves (including light). One possible solution would be a miniaturized power source that literally harvests energy directly from low-frequency environmental vibrations[1–3]. Writing in *Nature*, Yong Qin, Xudong Wang and Zhong Lin Wang of the Georgia Institute of Technology demonstrate such a device, which offers the prospect of being able to scavenge enough energy from ambient motion to power nanoscale systems without the need for batteries[4].

Last year the Georgia Tech team demonstrated a d.c. nanogenerator that was driven by ultrasonic waves[5]. This nanogenerator consisted of an array of vertically aligned zinc oxide nanowires that was similar to a bed of nails, with a specially designed metal electrode floating on the top. The ZnO nanowires are piezoelectric materials, and they become electrically polarized when they are bent by an external force. The team used ultrasonic waves to move the electrode up and down, bending the nanowires in the process. The resulting electrical polarization of ZnO was converted into electricity through a combination of piezotronic effects[6] and the piezoelectric–semiconducting coupling process[7]. Although this work demonstrated the potential of piezoelectric nanowires, a useful device obviously needs to work in the absence of the ultrasound source (which required it own power source).

The group's latest generator builds on the d.c. nanogenerator through an ingenious design that increases the number of individual nanowires and the number of electrical contacts and also, crucially, exploits soft materials to capture energy directly from low-frequency mechanical vibrations. The essential building block of the new generator is a Kevlar microfibre onto which the ZnO nanowires have been grown radially, creating a microscale 'bottle brush' that contains billions of nanoscale ZnO bristles. One microfibre–nanowire structure is coated with gold (to serve as the electrode) and is then entangled with an uncoated brush to ensure intimate contact between the two (Fig. 1).

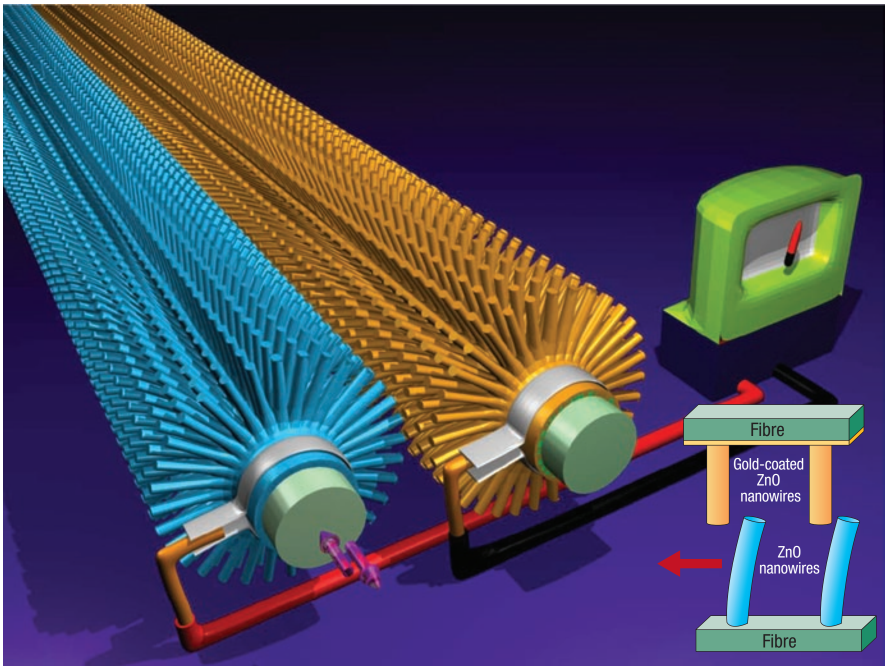


**Figure 1** When ambient vibrations move a microfibre covered with zinc oxide nanowires (blue) back and forth with respect to a similar fibre that has been coated with gold (orange), electrical energy is produced because ZnO is a piezoelectric material.

As low-frequency ambient vibrations move the brushes back and forth relative to each other, the resulting bending of the nanowires is converted into electrical energy. The approach offers a novel, adaptable, mobile and cost-effective technical platform for harvesting energy from the environment, and could have applications in powering a wide range of nanodevices and nanosystems, especially networks of sensors that are distributed over a large (and sometimes remote or hostile) geographic area[8]. There will also be applications in the defence industry because military sensors and surveillance devices generally need to remain hidden and often have to be located in unfavourable (for example, dirty, wet or subterranean) environments that are unsuited to alternative approaches such as solar energy. Another promising application area is in the emerging field of implantable biosensors with telemetry for continuous monitoring of various medical conditions. Although nanosensors that could be implanted in the body are already available, their utility is limited by the lack of miniature power sources that have practical lifetimes and do not contain toxic chemicals.

So what is the next step forward for this area? Increasing the efficacy of energy conversion is a must for practical applications. Integration into micro- and nanosystems, and harvesting sufficient power without increasing the overall size will also pose engineering challenges. However, the self-powered energy-harvesting strategy being pioneered by the Georgia Tech group is an important step forward in the effort to make such devices a practical reality.


## References

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NANOCRYSTALS

# Shedding new light on silicon


Experiments in magnetic fields suggest that defects are responsible for light emission from silicon nanocrystals. However, when these defects are passivated with hydrogen, quantum effects become responsible for the emission.



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Silicon is the material on which the numerous electronic gadgets that dominate our lives — from laptop computers to iPhones — are based. Even though silicon has wonderful electronic properties, and has even been labelled as 'God's material', it has poor optical properties, which is why other semiconductors are preferred for devices such as light-emitting diodes and lasers. Unlike bulk silicon, however, nanostructured silicon can actually emit light with reasonable efficiency, although the origins of this photoluminescence have been the subject of intense debate for almost two decades. This debate has focused on whether the quantum confinement of electrons and holes in structures that measure just a few nanometres is responsible for the light emission, or if atomic-scale defects at the surfaces of the nanocrystals are responsible[1].

On page 174 of this issue Manus Hayne and co-workers[2] report on measurements in high magnetic fields that allow them to distinguish between these two different mechanisms. As often happens in life they find that both processes play a role, depending on the treatment of the nanocrystals. Moreover, they show that it is possible to make one mechanism, and then the other, the dominant source of light in these materials.

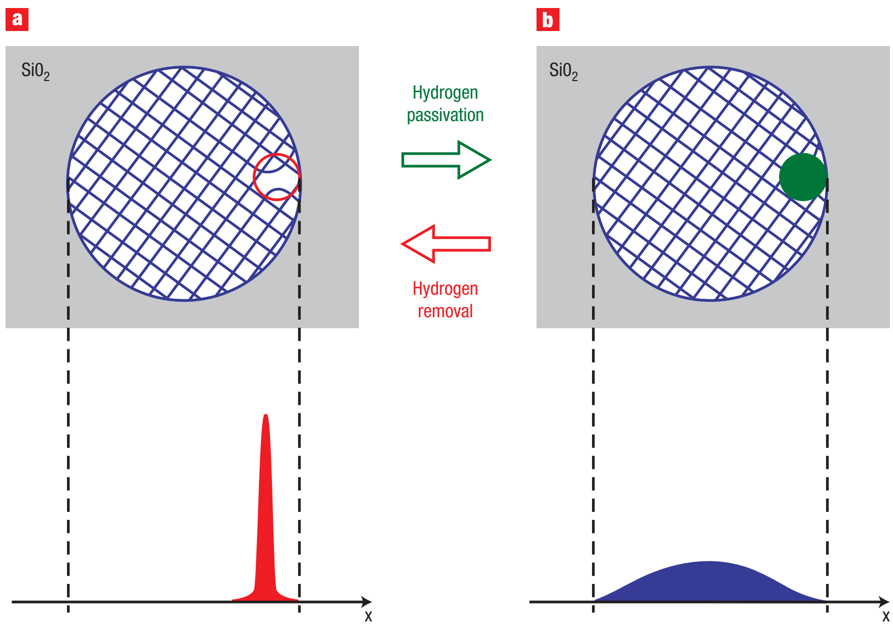


**Figure 1** Photoluminescence from silicon nanocrystals embedded in silicon dioxide. **a**, The presence of a defect (circled in red) near the surface of the nanocrystal results in excited electrons being localized in space (bottom). **b**, After hydrogen passivation is used to make the defect electronically inactive, the electrons are no longer localized by the defect, but quantum effects confine them within the nanocrystal (bottom). Ultraviolet radiation can be used to remove the hydrogen, causing the electrons to be localized at the defect again.

The specific spatial arrangement of silicon atoms, and the resulting electronic band structure, prevents efficient light emission from bulk silicon crystals. When an electron in an excited energy state falls back to its ground state, it cannot simply lose