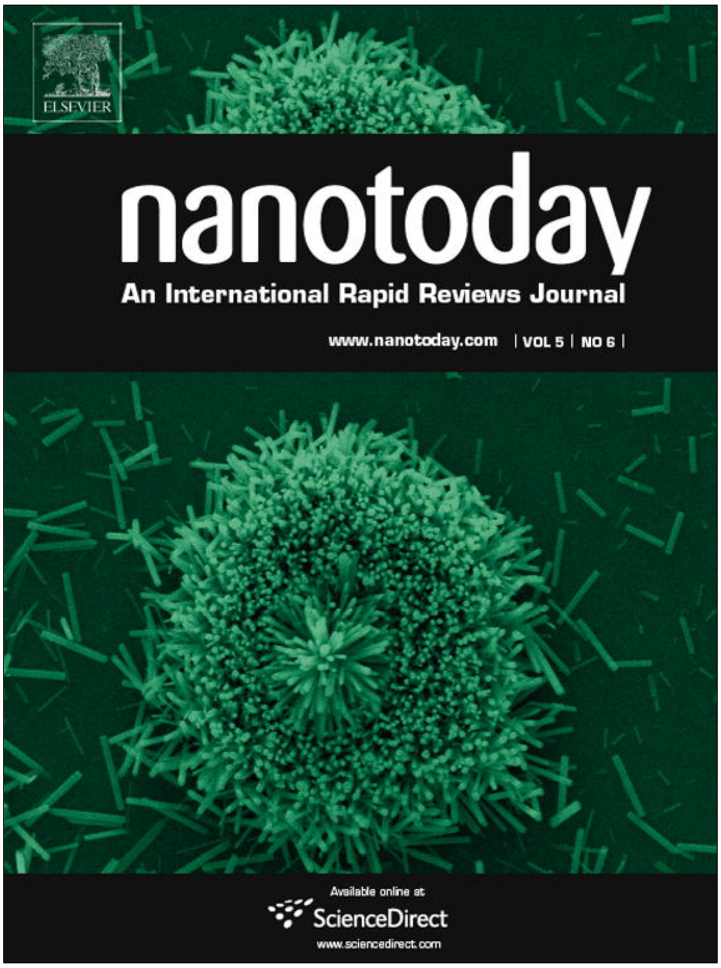
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NEWS AND OPINIONS

Toward self-powered sensor networks

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Nanogenerator;
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Summary The future of nanotechnology is likely to focus on the areas of integrating individual nanodevices into a nanosystem that acts like living specie with sensing, communicating, controlling and responding. A nanosystem requires a nano-power source to make the entire package extremely small and high performance. The goal is to make self-powered nanosystem that can operate wirelessly, independently and sustainably. The self-powering approach developed here is a new paradigm in nanotechnology for truly achieving sustainable self-sufficient micro/nano-systems, which are of critical importance for sensing, medical science, infrastructure/environmental monitoring, defense technology and even personal electronics.

A nanosystem is an integration of multi-functional nanodevices with the capability to sense, control, communicate and actuate/respond. Their low power consumption means it is possible to use the energy harvested from the environment to power such a system [1]. Power on the scale of microwatts is usually needed for independent, sustainable, maintain-free operations of implantable biosensors, remote and mobile environmental sensors, nanorobotics, microelectromechanical systems, and even portable/wearable personal electronics. A nanorobot, for example, could sense and adapt to the environment, manipulate objects, taking actions and perform complex functions, but a key challenge is to find a power source that can drive a nanorobot without adding too much weight. Self-powered sensors, meanwhile, are needed for monitoring oil/gas transportations line over long distances.

Self-powered sensors are a key component of the *defect tolerant sensor networks*, which use information sensing equipment such as radio frequency identification (RFID), sensors, global positioning systems (GPS) and laser scanners to connect objects with the internet to carry out communication, identification, positioning, tracking, monitoring and management. By replacing the traditional finite number of discrete sensors with a large number of independent and mobile sensors distributed in the field, a statistical analysis of the signals collected through the internet over the distributed sensors can give precise and reliable information. An internet of things that can correlate everyday objects and devices to large databases and networks (the internet) are the future of health care, medical monitoring, infrastructure/environment monitoring, product tracking, and smart home.

However, such a sensor network will be almost impractical if each sensor has to be powered by a battery because of the huge number and also environmental and health concerns. Therefore, new technologies that can harvest energy from the environment as *sustainable self-sufficient micro/nano-power* sources offer a possible of solution. But the mechanical energy available in our environment has a wide spectrum of frequencies and time-dependent amplitudes. This type of energy is called *random energy* and can come from irregular vibrations, light airflow, noise and human activity.

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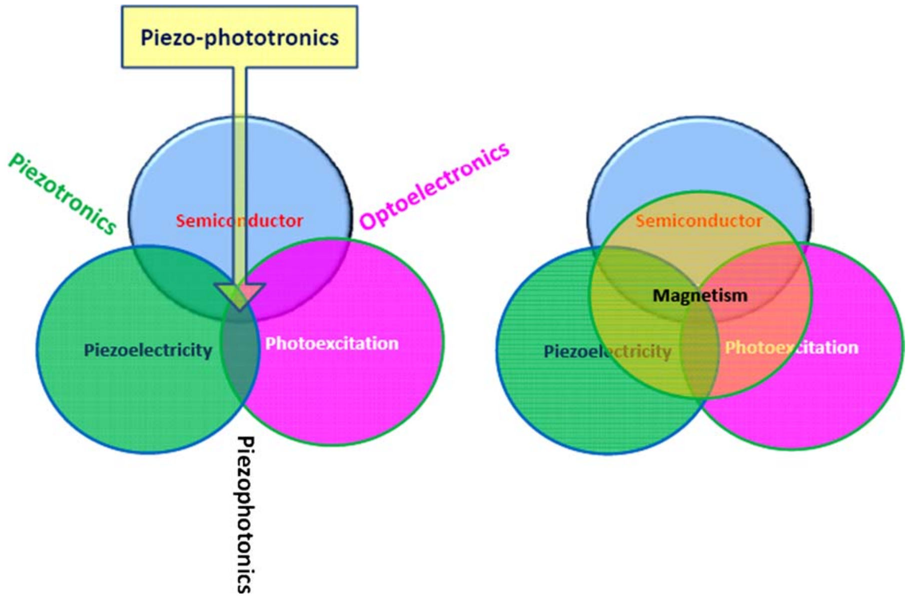

Fig. 1 Schematic diagram (left-hand side) showing the three-way coupling among piezoelectricity, photoexcitation and semiconductor, which is the basis of piezotronics (piezoelectricity—semiconductor coupling), piezophotonics (piezoelectric—photon excitation coupling), optoelectronics, and piezo—phototronics piezoelectricity—semiconductor—photoexcitation). The core of these coupling relies on the piezopotential created by the piezoelectric materials. Wurtzite structures with finite conductivity are ideal for these applications. By doping wurtzite materials with magnetic element, it is possible to achieve four-way coupling among piezoelectricity, photoexcitation, semiconductor and magnetism.

We have invented a nanogenerator for converting such random energy into electric energy using piezoelectric zinc oxide nanowire arrays [2,3]. The mechanism of the nanogenerator relies on the piezoelectric potential created in the nanowires by an external strain: a dynamic straining of the nanowire results in a transient flow of the electrons in the external load because of the driving force of the piezopotential. The advantage of using nanowires is that they can be triggered by tiny physical motions and the excitation frequency can be one Hz to thousands of Hz, which is ideal for harvesting random energy in the environment. By integrating the contribution from thousands of nanowires, a gentle straining can output 1.2—3 V, which can drive a self-powered pH and UV nanosensor [4], liquid crystal display and light emitting diode [5—7]. We believe this is a key step toward self-powered nanodevices.

The power generated by a nanogenerator may not be sufficient to continuously drive the operation of a device, but an accumulation of charges generated over a period of time is sufficient to drive the device for a few seconds. This could be of practical use for devices that have standby and active modes, such as glucose and blood pressure sensors, or even personal electronics such as blue tooth transmitters (driving power ~5 mW; data transmission rate ~500 kbits/s; power consumption 10 nW/bit), which are only required to be in active mode periodically. The energy generated when the device is in standby mode is likely to be sufficient to drive the device when it is in active mode.

Furthermore, the piezopotential created in a nanowire-based field-effect transistor (FET) can act as a gate voltage to tune/gate the transport process of the charge carriers in the nanowire, which is a gate-electrode free FET. Devices fabricated based on this principle are called *piezotronic* devices [8] (Fig. 1). *Piezo-phototronic* effect is about the tuning and controlling of electro-optical processes by strain-induced piezopotential [9]. Piezotronic, piezophotonic and pieozo-phototronic devices are focused on low frequency applications in areas involving mechanical actions, such as MEMS/NEMS, nanorobotics, sensors, actuators and triggers, which are likely to be new research directions in wurtzite structured nanomaterials.

The future of nanotechnology is likely to focus on the areas of integrating individual nanodevices into a nanosystem that acts like living specie with sensing, communicating, controlling and responding. A nanosystem requires a nanopower source to make the entire package extremely small and high performance. The goal is to make self-powered nanosystem that can operate wirelessly, independently and sustainably. The self-powering approach developed here is a new paradigm in nanotechnology for truly achieving sustainable self-sufficient micro/nano-systems, which are of critical importance for sensing, medical science, infrastructure/environmental monitoring, defense technology and even personal electronics.

References

[1] Z.L. Wang, Scientific American 298 (2008) 82—87; Z.L. Wang, Advanced Functional Materials 18 (2008) 3553—3567.
[2] Z.L. Wang, J.H. Song, Science 312 (2006) 242—246.
[3] R.S. Yang, Y. Qin, L.M. Dai, Z.L. Wang, Nature Nanotechnology 4 (2009) 34—39.
[4] S. Xu, Y. Qin, C. Xu, Y.G. Wei, R.S. Yang, Z.L. Wang, Nature Nanotechnology 5 (2010) 366.
[5] G. Zhu, R.S. Yang, S.H. Wang, Z.L. Wang, Nano Lett 10 (2010) 3151—3155.
[6] S. Xu, B.J. Hansen, Z.L. Wang, Nat. Commun, doi:10.1038/ncomms1098.

[7] Y.F. Hu, Y. Zhang, C. Xu, G. Zhu, Z.L. Wang, Nano Lett., submitted.
[8] Z.L. Wang, Advanced Materials 19 (2007) 889—992.
[9] Y.F. Hu, Y.L. Chang, P. Fei, R.L. Snyder, Z.L. Wang, ACS Nano 4 (2010) 1234—1240.

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