MATERIALS SCIENCE

Flexible self-powered biosensors

Current biological sensors require bulky external power sources. Ultrathin solar cells have now been fabricated that can power flexible, wearable sensors for the precise and continuous monitoring of biological signals. SEE LETTER P.516

SHIMING ZHANG & FABIO CICOIRA

Flexible electronic devices are emerging as powerful tools for measuring biological signals, such as a person's heart rate or blood pressure. This is because these devices are lightweight, can bind to human skin and can tolerate mechanical deformation[1,2]. However, although various flexible biosensors have already been demonstrated, most of them rely on large external power sources to operate. On page 516, Park *et al.*[3] report ultraflexible biosensors, used to monitor heart rate, that are powered by ultrathin solar cells. The integration of ultraflexible power sources and sensors has the potential to revolutionize the technology of self-powered conformable biosensors for applications in wearable electronics and diagnostics.

Park and colleagues achieved this feat by combining solar cells, known as organic photovoltaic (OPV) cells[4], with electronic devices called organic electrochemical transistors (OECTs)[5,6]. The authors fabricated the OPV cells and OECTs on an ultrathin substrate, which was made of a type of plastic known as parylene. The OPV cells could convert up to 10.5% of the energy received from light into electricity — which is among the highest reported values of power-conversion efficiency for ultraflexible devices.

Flexible OPV cells are normally less efficient than their rigid counterparts, which use more-established fabrication processes. Park *et al.* overcame this limitation by introducing zinc oxide structures into the OPV cells. These structures consisted of nanometre-scale patterns that facilitated electron transport in the OPV cells, maximizing their efficiency.

Park and co-workers produced the nanopatterns using a blank DVD, which has these patterns on its surface to store information. The authors first replicated the DVD's nanopatterns onto an elastic stamp. They then used this stamp to generate nanopatterns on the OPV cells by a fabrication technique known as soft lithography[7].

Another key advantage of Park and colleagues' OPV cells over rigid solar cells is that the power-conversion efficiency is insensitive to the angle at which the cells are illuminated by light. In conventional solar cells, light that comes in at a greater angle to the surface of the cells undergoes more reflection, leading to a lower efficiency. But in the authors' devices, the nanopatterns minimize the reflection of incoming light, regardless of the illumination angle. As a result, the efficiency of these devices is unaffected by movement, which is a desirable property for wearable biosensors.

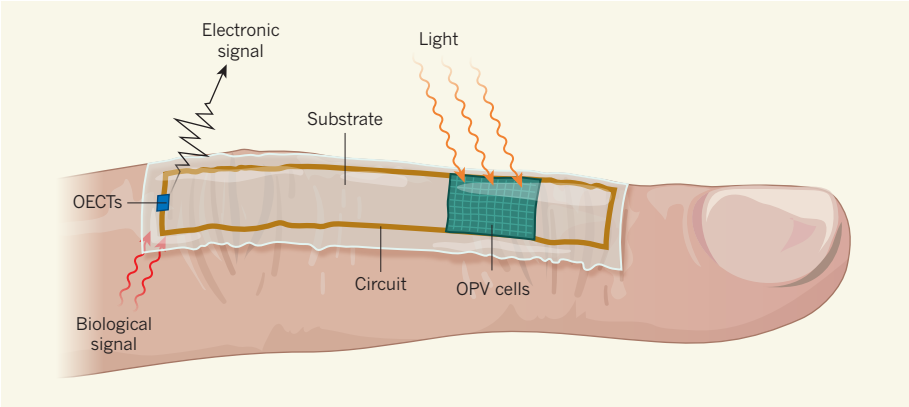

Figure 1 | A self-powered ultraflexible biosensor. Park *et al.*[3] demonstrate a platform for capturing biological signals and converting them into electronic signals, which can then be analysed. The platform is ultraflexible, and does not require external power connections. It consists of electronic devices known as organic electrochemical transistors (OECTs) and solar cells called organic photovoltaic (OPV) cells. These components are connected by an electric circuit and are contained on an ultrathin plastic substrate. The platform is powered by the electrical energy produced when the OPV cells are irradiated with light. The authors attached the platform to a person's finger and a gel electrode to the person's chest (not shown), and found that the platform could be used to monitor the person's heart rate.

The interest in using flexible OPV cells to power flexible sensors naturally calls for stable electrical performance under mechanical deformation. Conventional flexible OPV cells do not meet this requirement because they are comprised of thick, rigid materials, which make the devices fragile. Park *et al.* took advantage of the ultrathin nature of their nanopatterned OPV cells and laminated the devices on a pre-stretched elastomer[8] (a rubber-like material). They found that the resulting devices could not only be laid on curved surfaces, but could also be stretched to twice their initial length (a mechanical strain of 200%) and still maintain high power-conversion efficiency. Even after 900 cycles of stretching and releasing the devices, the efficiency dropped to only about 75% of its initial value.

Park and colleagues used the nanopatterned OPV cells to drive OECTs, which acted as sensitive and flexible biosensors. Such OECTs are able to work using a low voltage (about 1 volt; ref. 9), which is well within the powering capacity of the OPV cells. Furthermore, the OECTs can be powered by standard room lighting.

The authors demonstrated that their self-powered OPV–OECT sensing platform can detect biological signals (Fig. 1). They attached the platform to a person's finger and a gel electrode to the person's chest. Every heartbeat produced a voltage difference between the electrode and the platform, because of the movement of ions through the person's body. Such a difference is normally too small to be detected, but was measurable here owing to the high signal amplification achievable with the OECTs.

Park *et al.* found that, under a constant illumination from light-emitting diodes, the platform recorded clear heart-rate signals. The recording sensitivity was about three times higher than that of OECTs powered by conventional power sources[10]. This is because the absence of external power connections reduced signal fluctuations.

The authors validated the reliability of their approach *in vivo* by attaching the sensing platform to the exposed surface of a rat's heart. They successfully measured the animal's heart rate, proving the efficacy of the platform for monitoring biological signals.

However, before Park and co-workers' OPV cells can be fully integrated into wearable devices, several optimizations are needed. The transmission of electronic signals from the platform is still based on conventional rigid silicon-based electronics that are powered by external sources. In addition, the OPV cells produce only low output power, so it will be challenging to drive sensing systems that are complicated or that have high power consumption.

Nevertheless, the OPV cells are a milestone in the production of ultrathin and highly efficient solar cells for self-powering applications. Moreover, the devices pave the way for the development of ultraflexible, stretchable and even healable[11,12] self-powered biosensors[13] for the precise, sensitive and continuous measurement of biological signals. ■

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CELL BIOLOGY

A core problem in nuclear assembly

Chromosomes can exist outside the nucleus in rupture-prone structures called micronuclei. It emerges that micronuclei are fragile because their outer layer lacks some nuclear-envelope components. SEE LETTER P.551

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The genome sequencing of some cancer cells revealed the occurrence of large-scale DNA rearrangements that are characteristic of a single catastrophic event[1]. This type of genetic abnormality is termed chromothripsis. It occurs in many types of human cancer, and is thought to drive tumour formation[2]. Chromothripsis can arise as a result of cell division if individual chromosomes do not join the other chromosomes within the newly formed nuclei but instead form rupture-prone structures called micronuclei[3,4]. Liu *et al.*[5] report on page 551 that the nuclear-envelope structure that encloses a micronucleus lacks some of the components of the nuclear envelope that surrounds a nucleus. They propose a mechanism for how this might occur, and how it might account for micronuclear fragility.

In the cells of organisms such as animals and plants, the genome is stored in a nucleus. This is surrounded by a nuclear envelope[6] composed of lipid membranes, proteins, and multi-protein structures termed nuclear-pore complexes, which provide a route for the transport of materials between the nucleus and the cytoplasm. During cell division, the nuclear envelope disassembles, and the replicated chromosomes bind to a structure called the spindle, which is made of protein filaments called microtubules. The chromosomes align on the spindle at the centre of the cell, and the two copies of each chromosome then separate and move away from the middle of the cell. At a later stage of cell division termed telophase, a nuclear envelope reassembles around the chromosomes to form a nucleus in each daughter cell.

However, if any chromosomes lag behind the rest and are still in the middle of the dividing cell during telophase, they become isolated and can form a separate small nucleus called a micronucleus. Micronuclei often rupture spontaneously[7], resulting in substantial damage to DNA and chromothripsis[3,4]. The basis for micronuclear fragility was unclear.

Studying cell division in human cells grown *in vitro*, Liu *et al.* found that lagging chromosomes formed micronuclei that lacked certain components of the nuclear envelope, such as proteins from the nuclear-pore complex and proteins called B-type lamins that are necessary for nuclear-envelope integrity. Indeed, deficiencies in B-type lamins were previously shown to trigger micronuclear fragility[7]. Deficiencies in the formation of nuclear-pore complexes in the nuclear envelope that surrounds a micronucleus might hinder the entry of the proteins needed for successful repair of DNA damage and for stabilization of the nuclear envelope, which might explain why micronuclei are prone to rupture[7] and chromothripsis[3,4].

When normal nuclear assembly occurs around the end of cell division, part of the emerging nucleus is in close contact with the spindle, where the local density of microtubules is high. This part of the emerging nucleus is referred to as a region that contains 'core' nuclear-envelope components (Fig. 1). The part of the nucleus that emerges in areas with low microtubule density is known as the region that contains 'non-core' nuclear-envelope

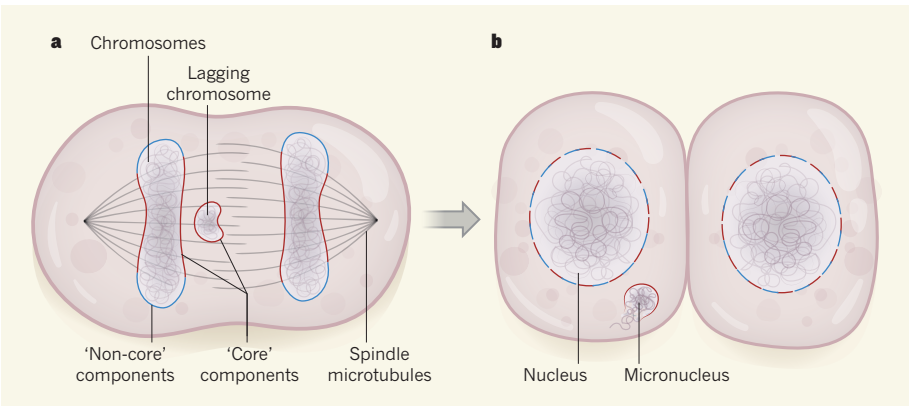

Figure 1 | The formation of a micronucleus. During cell division, chromosomes align in the middle of the cell on the spindle, which is made of protein filaments called microtubules. **a**, When chromosomes then move away from the middle of the dividing cell, a lagging chromosome might remain stranded in the centre of the cell, owing to a cell-division error. As cell division nears completion, the chromosomes become surrounded by what is termed nuclear-envelope material. 'Core' components of the nuclear-envelope material reassemble around chromosomes in spindle regions that have a high density of microtubules, and 'non-core' components reassemble in regions with a low density of microtubules. Liu *et al.*[5] analysed cell division in human cells grown *in vitro*. They report that the high density of microtubules surrounding lagging chromosomes prevents the binding of non-core components of the nuclear envelope. **b**, When nuclear-envelope assembly is completed, the core and non-core materials become interspersed in the nuclear envelope. When nuclear-envelope material reassembles around a lagging chromosome, the result is a rupture-prone structure termed a micronucleus that can undergo large-scale DNA damage and is linked to cancer[2–4].