news & views

PHOTODETECTORS

A heated junction

Resonant photonic structures made of thermoelectric materials can convert light into electricity without wavelength limitations.

Ming Zhou and Zongfu Yu

Photodetection is an essential process in cameras, light sensors, solar cells and optical communications, covering a wide spectral range from the visible to the far infrared. Most conventional photodetectors use either semiconductors or resistive bolometers. Semiconductor photodetectors are fast and sensitive but are unresponsive to energies below the semiconductor bandgap. Below this cutoff wavelength, resistive bolometry is used, providing efficient photodetection, but with slow speed. Writing in *Nature Nanotechnology*, Mauser *et al.* now report a new type of photodetector that combines the thermoelectric (TE) effect and plasmonic resonance, potentially offering fast photodetection without a cutoff wavelength[1].

Figure 1 illustrates the structure of the resonant TE photodetector. The central nanowire made of bismuth telluride and antimony telluride is the photoactive region. This is connected to two metallic pads of p- and n-doped TE materials, acting as positive and negative electrodes, respectively. The nanowire is specifically designed to realize a unique thermophotonic function: it exploits the doped electrodes to form a TE junction in the middle; and, at the same time, it is shaped to support a guided optical resonance. When in operation, the optical resonance converts incident light into localized heat, which then drives the TE junction to produce an electrical signal.

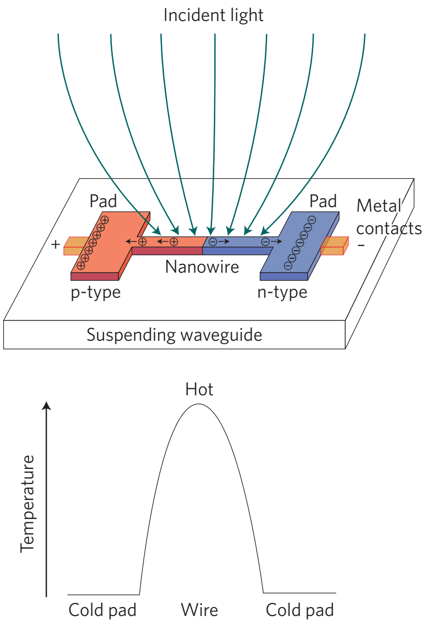

Figure 1 | Schematic of the resonant thermoelectric (TE) photodetector and its light-to-heat conversion mechanism. A nanowire made of TE p- and n-doped materials converts light into localized heat. The pads reflect most of the incident light and stay cool. The heat flow carries electrons to the n-doped pad and holes to the p-doped pad, generating an electrical voltage difference across the TE junction.

This occurs because a temperature gradient creates a heat flow that carries electrons and holes. In p-doped materials, the heat flow carries holes from the hot to cold region, whereas in n-doped materials, electrons move from the hot to the cold region. By using both n- and p-doped materials, the TE junction generates a voltage when the temperature in the middle is higher than that at the two ends (Fig. 1).

However, a TE junction is generally insensitive to incident light. To use a TE junction for photodetection, light must be first converted to localized heat. And this is where the optical properties of the nanowire come into play. The nanowire is a nanoscale resonator and can collect incident light from an area much larger than its geometrical cross section. Such a concentration effect, already exploited[2] in semiconductors for photodetectors, single molecule imaging and solar cells, is used by Mauser *et al.* in a metallic nanowire to convert light to heat through ohmic losses. The pads at the two ends of the device are highly reflective, and hence remain cool, creating a temperature gradient that drives the voltage across the TE junction.

This device offers a few advantages compared to conventional photodetectors. It can work over an extremely broad spectral regime from visible to infrared because the light-to-heat conversion process is not limited by a cutoff wavelength. The efficiency is comparable to that of state-of-art bolometers. The response speed can be almost 100 times higher than conventional TE detectors (thermopiles), because the resonant TE photodetector is much smaller in size. Lastly, the device offers built-in spectral selectivity, since the resonant absorption of the nanowire is narrow-band and can be configured to any wavelength through structural changes. In comparison, conventional photodetectors have to rely on colour filters for spectral selectivity.

Undeniably, though, there are still challenges to overcome before this technology is ready for practical applications. Although it can be made to operate at any wavelength, realizing broadband detection in a single device will be difficult because it relies on an optical resonance to generate and localize heat. In addition, while the efficiency of individual detectors is high, the total efficiency of the photodetector chip is still low, owing to a low filling factor of the photoactive region. Despite these challenges, the resonant TE nanophotonic platform proposed by Mauser *et al.* can be optimized for efficiency and speed, for example by increasing the optical cross section and reducing the junction volume.

It is usually thought that heat, with its high entropy, should be avoided when converting electromagnetic energy into electricity. In recent years, however, this idea has been challenged by the progress made in thermophotonic applications. In addition to the TE photodetector presented by Mauser *et al.*, other notable examples include thermophotovoltaic cells[3] and hot-carrier photodetectors[4]. In these cases, heat is the intermediate stage during energy conversion. By first converting light to heat, it is possible to overcome the fundamental bandgap limitation of semiconductor-based technologies. As new challenges arise in converting heat to electricity, sophisticated thermophotonic designs are expected to play an increasingly important role in advancing this technology. ❐

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References

1. Mauser, K. W. *et al. Nat. Nanotech.* http://dx.doi.org/10.1038/nnano.2017.87 (2017).
2. Cao, L. *et al. Nat. Mater.* **8,** 643–647 (2009).
3. Lenert, A. *et al. Nat. Nanotech.* **9,** 126–130 (2014).
4. Gabor, N. M. *et al. Science* **334,** 648–652 (2011).