Hot-hole photodetectors

By injecting high-energy charge carriers (dubbed 'hot holes') into a semiconductor, scientists have succeeded in realizing photodetectors capable of detecting ultralong wavelengths. Unil Perera from Georgia State University in the USA explains how the devices work and how they can be improved.

What was the motivation for your work?

Photodetection is the well-known process of converting light into an electrical signal. However, detection is usually restricted to a very limited wavelength range that is determined by the properties of the material used in the photodetector. For a long time, researchers have been seeking ways to extend the spectral range of operation, especially to enable the detection of long-wavelength, low-energy photons. In our work, we demonstrate a way around this problem that involves using a second light source to create high-energy charge carriers ('holes' in our case) in a semiconductor. These high-energy carriers, known as 'hot holes', absorb long-wavelength radiation far more effectively than conventional detectors. By exploiting this effect, we have achieved detection at wavelengths 20 times longer than is normally possible.

How does your device differ from conventional semiconductor detectors?

A conventional photodetector operates in a specific spectral range, and any photons detected must have energies higher than a characteristic energy associated with the material (for example, the semiconductor bandgap). This energy also determines the dark current, which is the current when no light is incident on the device and is mostly the result of thermal excitation. The dark current is one of the figures of merit used to evaluate the performance of a detector: the lower its value is the better, as it is considered to be a source of noise. Unfortunately, detection of long-wavelength radiation traditionally requires a low characteristic energy of the semiconductor, and this leads to a correspondingly high dark current. We have demonstrated that this restriction no longer holds. Our devices absorb not only high-energy photons (those with energies above the characteristic energy), but also low-energy photons; consequently, a broad spectral range of photons can be used to create photocarriers. Importantly though, the dark current is still determined by the high characteristic energy of the material. This gives rise to a drastically improved device performance. More generally, our approach will lead to new applications of conventional materials as a result of the extended spectral range, which is not restricted by the traditional bandgap limits. It will also allow dual- or multiband detectors to be developed, which could be used to reduce false positives when identifying, for example, toxic gases and materials.


U. PERERA

Unil Perera says that the 'hot-hole' semiconductor photodetectors developed by researchers at Georgia State University, USA, and University of Leeds, UK, can detect photons that have an energy around 20 times smaller than the bandgap of the photodetector material.

What is the longest wavelength you have been able to detect, and what limits the performance?

We have extended the response range of a detector, which has a conventional wavelength limit of 3.9 μm, up to an experimentally measurable limit of ~55 μm. A noisy signal beyond 55 μm is also seen up to about 100 μm, and our detector simulations provide evidence that suggests an extended wavelength range of up to 100 μm is possible. The present device utilizes a bulk semiconductor structure as the photon absorber. Compared to quantum structures, which incorporate wells or dots, the absorption efficiency is low, and hence there is scope for dramatic improvement. The energy transfer mechanism is based on carrier–carrier scattering processes and relaxation of the high-energy carriers — both of which are temperature dependent. Thus, the absorption efficiency and the operating temperature limit the spectral response of the present devices.

How could this response be improved even further?

We expect to be able to improve the performance by focusing on two areas: engineering the injection of highly energetic carriers and optimizing the absorber in the detector. For injection, we need to maximize the efficiency of energy transfer from the high-energy carriers to the low-energy carriers. This will require modifying the design of the structure, including the thickness, doping and potential gradient of the semiconductor layers. The resulting enhanced energy transfer efficiency will increase the number of carriers available for absorbing the long-wavelength radiation, and thus enhance the signal. For the absorber, we will consider using quantum wells or quantum dots. Owing to quantum confinement, this will enhance the absorption of light. Furthermore, we will utilize plasmon resonances to enhance the absorption. All these approaches are currently being studied at our laboratories.

What needs to happen for this approach to be turned into a commercial detector?

In our demonstration, we used an external light source to create hot holes, and operated the device at low temperatures. By integrating the detector with a light-emitting device, we will be able to realize a compact device without the need for an external light source. This is similar to previously demonstrated device integration for photon upconverters, and thus should be relatively straightforward to implement. For a practical commercial product, the operating temperature should be increased at least to the point where thermoelectric coolers can be used.

INTERVIEW BY OLIVER GRAYDON

Unil Perera and co-workers have an Article on long-wavelength photodetectors on page 412 of this issue.