nanomaterials news

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Ultraviolet LEDs from nanowires

US researchers have developed a way of making UV LEDs from semiconductor nanowires.

Researchers at the National Institute of Standards and Technology (NIST) in Maryland, US, together with scientists at the University of Maryland and Howard University in Washington DC, made the breakthrough.

UV diodes are required in applications such as data storage, sensors and optical communications, and the new nanowire LED fabrication technique is well-suited to industrial-scale production. This is in contrast to current nanowire LEDs, which are created using time-consuming nanowire manipulation methods that are unsuitable for commercial exploitation.

With photolithography, wet etching and metal deposition, the researchers align their nanowires using an electric field in a process known as dielectrophoresis. Each LED consists of an n-type gallium nitride nanowire deposited on the surface of a p-type gallium nitride thin film. Diodes with p-n junctions made from the same compound are more efficient than those of different materials, and so can operate at lower power.

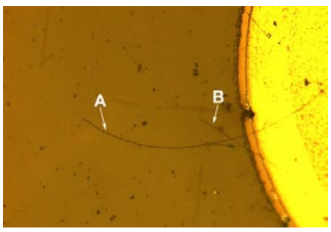
'We have demonstrated the proof-of concept by aligning nanowires on small areas,' says NIST scientist Abhishek Motayed. 'I do not see any problem scaling dielectrophoresis to full wafers. Higher control over the assembly can be achieved by optimising every aspect of the alignment process.'

More than 40 of these nanowire LEDs have been tested, and all show very similar emission properties. They are also thermally stable up to 750°C, and after two hours of continuous operation at room temperature show no signs of deterioration.

Motayed and his colleagues are planning to further develop the technique, and are looking to eventually incorporate nanowire devices with silicon microelectronics.

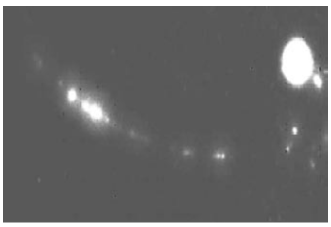
Andrei Kolmakov, a physicist at Southern Illinois University, comments: 'The work of NIST team on gallium nitride nanowire-based light-emitting diodes bridges the gap between current micro-technology and new nanoscopic elements in a very simple, cheap and elegant way. Technologically speaking, this is a ready-to-go nanowire device.'

Micrograph of a complete nanowire LED attached to its end contact. The long nanowire (A) is about 110 μm long, and a shorter nanowire (B) crosses it. The bright circular section is the metal post from which the nanowires are aligned



Source: NIST

Optical image of the same nanowire in action. Most of the light emitted from the device is in the ultraviolet portion of the spectrum, but enough visible light is generated to see it glowing



Source: NIST

Click here for more about the research

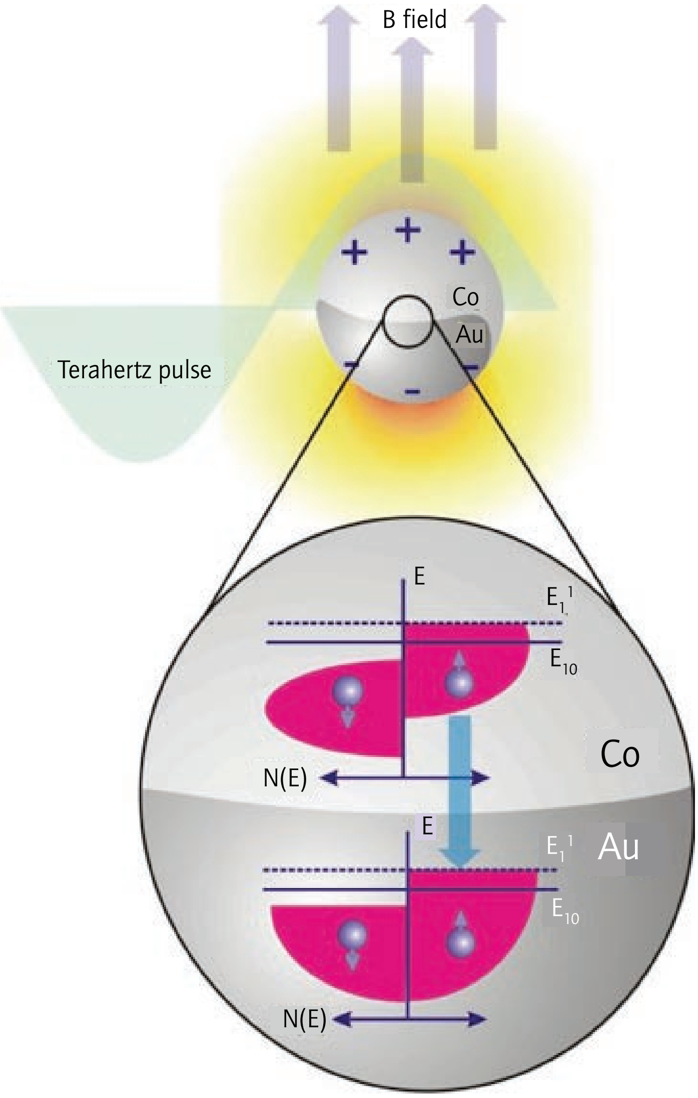
In this issue ...

Spinning out a new thread in nanotechnology

A team of Canadian researchers has combined two fields of nanotechnology, and expect that the new discipline will lead to revolutionary advances in electronics and other technology areas.

University of Alberta physicist Abdulhakem Elezzabi **has applied the principles of plasmonics to spintronics, and created a new way to control the quantum state of an electron's spin. The development – dubbed 'spinplasmonics' – is described in a recent issue of** *Physical Review Letters*, **and a patent has been filed on a number of applications already developed.**

Conceptual illustration of a non-resonant particle plasmon excited on a spintronic structure consisting of a sub-wavelength size ferromagnetic cobalt particle that has been coated with nonmagnetic gold layers



Source: Abdulhakem Elezzabi/University of Alberta

Plasmonics is concerned with the transfer of light energy into a tiny volume, and the phenomenon has led many scientists to rethink the laws of electromagnetism at the nanoscale. Spintronics is an emergent technology that exploits the spin states of electrons as well as their charge, thereby increasing the amount of information that the particles carry within circuits.

The aim of the researchers is to create efficient spin-based photonics devices which may in turn be used to build computers with extraordinary memory capabilities and very low power consumption. 'We are in the exploratory stage,' says Elezzabi. 'We are at a new cross point between various fields, and hope to find more interesting and possibly new physics.'

Elezzabi and his colleagues have demonstrated a device that switches a light on and off through the control of electron spins. They also confident that with a slight alteration to the gold and cobalt sample structure, the effect will be non-volatile, in which case the result will not depend on the presence of a power source.

'I'm sure we'll be busy for the next couple of years, but that's the fun part,' says Elezzabi. 'I have been approached by several investors, but have not taken any of them seriously as they are simply fishing for ideas. I will now consider demonstrating operational devices, and then possibly raise funds for research, development and commercialisation.'

Click here for more about the research

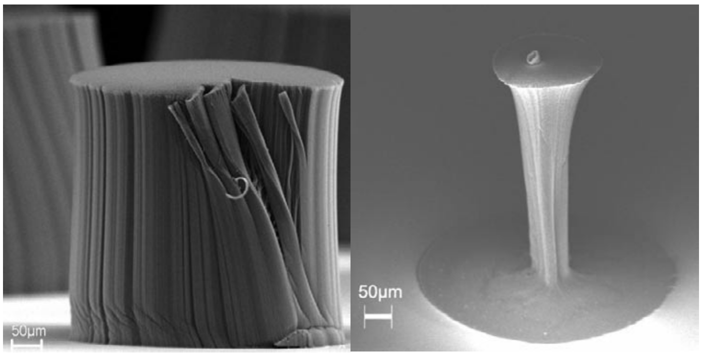
Bundling carbon nanotubes for microchip interconnects

Physicists at the Rensselaer Polytechnic Institute in New York, US, have devised a way of compacting carbon nanotubes into dense bundles that could eventually replace copper interconnects in microchips.

James Jian-Qiang Lu and his colleague Zhengchun Liu have shown that immersing vertically grown nanotube bundles in an organic solvent and allowing them to dry results in capillary action pulling the nanotubes together into a denser bundle. Molecular bonds then ensure that the nanotubes retain their tightly packed form.

Processing the nanotubes in this way boosts the density

Carbon nanotube bundles before and after densification



Source: James Lu/Rensselaer Polytechnic Institute

of the original bundles by up to 25 times, and the higher the density, the better the conductivity.

Factors that influence the density include nanotube height, diameter, spacing and synthesis method. And size is crucial. If the bundles are too short, they cannot be compacted; too tall and they collapse.

There is some way to go before the process can find practical application, but Lu is optimistic: 'We have to find ways to further process the nanotube bundles, such as metal/nanotube contact, placing it to the right locations ... It is very challenging, but we have some ideas, and are working on the implementation of densified carbon nanotubes as the basic building blocks for interconnects.'

The researchers are currently exploring various methods of further increasing the bundle density, and the quality of the nanotubes used. The eventual aim is to develop 3-D microchips in which the constituent devices are layered into vertical stacks, thereby dramatically shrinking the size of the chips.

Azad Naeemi, an electrical engineer at Georgia Tech, comments: 'Growth of densely packed carbon nanotube bundles is a grand challenge in fabricating nanotube interconnects. The 25-times increase in the density of nanotubes achieved by the Rensselaer researchers is very promising. More such out-of-the-box approaches are essential in circumventing the challenges facing nanotube interconnects.'

Click here for more about the research

Excitons play peek-a-boo on carbon nanotubes

In a recent issue of the journal *Science* researchers led by Rice University chemist Bruce Weisman and visiting French physicist Laurent Cognet from the University of Bordeaux describe a technique in which a fluorescence microscope is used to study in detail the behaviour of electrons and photons on individual carbon nanotubes.

The researchers are particularly interested in the short-lived entities known as excitons. An exciton is a quasi-particle formed when a photon strikes a semiconductor and raises an electron to a higher energy level, leaving behind a positively-charged 'hole'. The hole remains bound to the electron until the exciton vanishes with the emission of a photon.

By passing a light through nanotubes suspended in a soft gel, and observing the fluorescent glow with a time-lapse infrared camera, the researchers were able to observe reactions that quench in stepwise fashion any passing excitons.

Carbon nanotube fluorescence has a number of practical applications, one being the detection of acidity gradients in microfluidic channels and biological sensors.

'If the surrounding acidity were to vary along the length of the nanotube probe, then one would see corresponding differences in the up/down step ratio as a function of position,' says Weisman. 'From this, the pH gradient could be monitored with a spatial resolution of slightly less than a micron. Because of the high stability of single-walled carbon nanotubes, such a sensor could work for an extended period.'

Another potential application is related to the use of nanotubes in photodetectors. 'Our findings about the sensitivity of excitons to quenching sites on the nanotube sidewalls provide information that will be useful in that field,' says Weisman.

As well as research councils and not-for-profit foundations, the researchers received funding from scientific instrument specialists Applied NanoFluoresence.

Cognet, Weisman and their collaborators are about to submit another manuscript detailing an extension of the technique that will provide even more detailed information.

Atomic spectroscopy on a chip

Researchers at the University of California, Santa Cruz (UCSD) have for the first time combined atomic spectroscopy with integrated optics on a chip.

Conventional spectroscopic systems tend to be large, with many complex and costly components. Integrating all the necessary elements on a chip will allow, among other things, the mass production and deployment of distributed sensor systems for environmental monitoring. Other potential applications include frequency stabilisation for lasers, and quantum information processing.

In the June issue of *Nature Photonics*, UCSD physicists Wenge Yang and Holger Schmidt, together with Aaron Hawkins, Donald Conkey and John Hulbert at Brigham Young University in Utah, describe the first monolithically-integrated planar rubidium cell on a chip.

Central to the researchers' achievement is their development of hollow-core optical waveguides based on anti-resonant reflecting optical waveguide (ARROW) principles. To perform atomic spectroscopy, rubidium reservoirs were incorporated into a semiconductor chip, connecting vapour reservoirs to waveguides so that the optical beam path is filled with rubidium atoms.

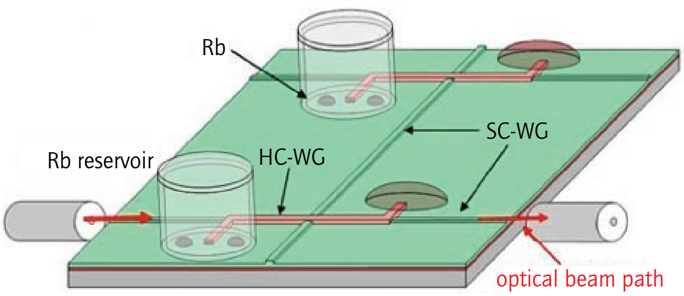
Gas sensors are a likely near-term commercial application of the technology, but they present some challenges, and the sensitivity must be exquisite, says Schmidt. 'We have already shown single molecule fluorescence sensitivity in liquid solution, as well as surface-enhanced Raman scattering, also with liquids in a chip. This indicates that both methods – fluorescence and Raman scattering – should be applicable to gas sensing.'

The researchers are currently working to improve the waveguides and cell lifetimes. They are also treating the surfaces of the channels to lessen the impact of collisions between rubidium atoms and the channel walls.

'Once that is possible, we can demonstrate effects based on electron coherence in rubidium,' says Schmidt. 'That will allow us to show slowed and stored light, as well as work towards parametric generation of correlated single photon pairs that can be used in quantum communication systems.'

Click here for more about the research

Schematic showing interconnected hollow-core (HC) and solid-core (SC) waveguides forming two independent vapour cells on a semiconductor chip. Sealed, rubidium-filled reservoir are attached to the open ends of the HC waveguides



Source: ***NPG clearance required.***

Designing practical spintronics circuits

Researchers at the University of California, San Diego, have developed the first practical design for a semiconductor circuit based on electron spin as well as charge.

Spintronics is an emergent technology which makes use of the quantum spin states of electrons as well as their charge, and in computing it will increase the amount of information that can be processed. For example, unlike conventional magnetic memory, in spintronics devices the spin state is built in, and is not erased when the device is switched off. Non-volatile memory is therefore a particularly promising application of new technology.

Spintronics is a term that is now fairly widely known, but there are as yet few applications that make use of the principle, and spintronics remains a largely experimental technology.

Lu Sham, Hanan Dery and their colleagues in San Diego have designed a device that employs a novel geometry to overcome the weakness of magnetic signals. This is currently the principal barrier to developing real-world spintronics devices.

The circuit in question is an interconnected series of logic gates, with each gate consisting of five magnetic contacts lying on top of a semiconductor layer. Operation of the circuit involves moving electrons between four of the magnetic contacts and the semiconductor, with the result read by the fifth contact.

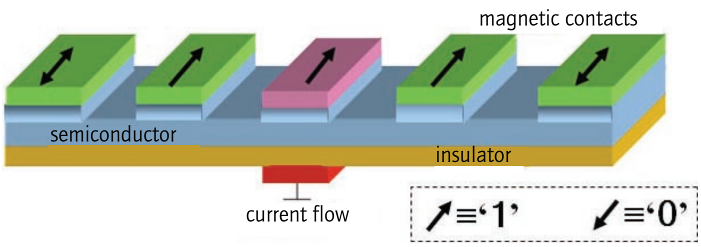
'In our proposal, the functions of the components have all been demonstrated to work in the laboratories at room temperature or at worst at liquid nitrogen temperature,' says Sham. 'The key component is the spin tie-in between the magnet and the electrons in the semiconductor, which has been demonstrated by others.'

Encouraging others to implement the design is the next step for the researchers, as is studying the detailed functionalities of the circuits.

Sham sees semiconductor spintronics building on CMOS technology for information processing, just as CMOS reaches its limitation. 'Commercialisation will follow when people start building such circuits and find functions to meet market needs.'

Click here for more about the research

Schematic of a proposed spintronics circuit



Source: Hanan Dery/UC San Diego

> 'The blown film technique opens a new chapter in nanowire and nanotube nanotechnology towards practical industrial applications'
>
> Zhong Lin Wang, materials scientist, Georgia Tech

Technology spotlight

From plastic bags to nanoelectronics with blown film extrusion

Researchers at Harvard University and the University of Hawaii have taken an established thin-film fabrication technology, and developed a way of aligning nanowires and nanotubes over areas 100-times larger than is possible with existing methods. The breakthrough paves the way for the mass production of nanoscale electronic devices.

Blown film extrusion is one of the most common methods for producing thin plastic films in the packaging industry, and is used, among other things, for producing cling film and supermarket carrier bags. The process involves extrusion of a molten polymer through a circular die, and expanding it with compressed air. The resulting bubbles can then be collapsed and slit to form continuous flat films with widths of more than a metre, and at rates of around 500 kg/hour.

This high volume and efficient manufacturing method has now been adapted by Harvard chemist Charles Lieber and his colleagues Guihua Yu and Anyuan Cao to produce films of aligned nanostructures that could be used for controlling pixels on flexible displays, and building sensors to detect chemicals, viruses and biomarkers for diseases.

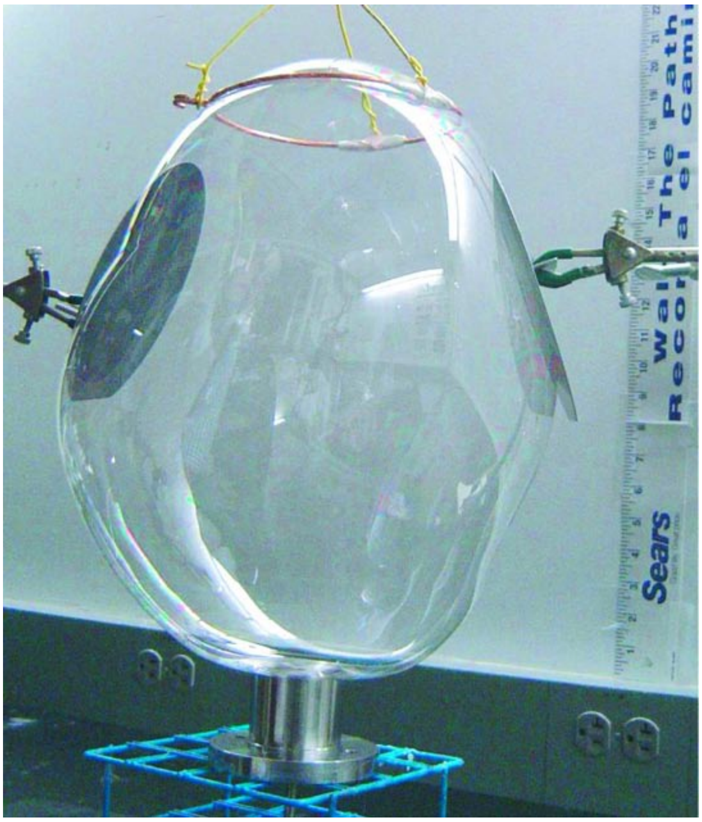
Other methods for preparing arrays of aligned nanowires and nanotubes are effective on small scales, but it is unclear whether they can be extended to large-scale assembly.

With the blown film technique, an epoxy polymer suspension of nanowires or nanotubes with a concentration of less than 1% is expanded with nitrogen gas to form a 25cm-wide and 50cm-tall bubble at a controlled pressure and expansion rate. A metal ring stabilises the bubble as it grows, and the polymer stretches to become a 200–500 nm thick film containing evenly spaced and aligned nanowires or nanotubes separated by around 2µm.

Studies show that 80–90% of transferred films are defect-free, and 90% of the structures are aligned to within 5° of the average direction. 'This transfer yield is sufficient for the successful fabrication of large arrays of silicon nanowire based transistors,' says Lieber. 'Both transfer yield and the degree of alignment can be further improved by, for example, automating the bubble expansion and film transfer. We believe that making the process more automated, together with a better understanding of the mechanism of nanostructure alignment during bubble expansion, will help to optimise and scale up the process.'

The researchers are now exploring several areas, including fabrication of nano-systems with distinct electrical or optical properties. They are also investigating the use of different polymers to facilitate device fabrication. 'For example, we have developed the bubble expansion and transfer process using the photopolymer PMMA (polymethylmethacrolate),' says Lieber. 'This enables our method to be integrated directly into a modern photolithography and fabrication process for defining electrodes and other circuit elements.' Other possibilities include three-dimensional structures based on the scrolling or folding of flexible films.

Directed bubble expansion at the final stage.



Source: Charles Lieber/Harvard University – adapted from Yu et al., Nature Nanotech. 2, 372 (2007).

Carbon nanohorns for hydrogen storage

A multinational team of researchers has developed a method for storing hydrogen gas based on single-walled carbon nanotubes with an irregular, horn-like shape.

Hydrogen has great potential as a carbon neutral and renewable energy source. Or at least it will have once the difficulties of storing the gas in a safe and cost-effective manner have been overcome.

Methods of storing hydrogen include uptake by metals and physical adsorption in porous materials. The latter is cheaper than using expensive metals, and 100% of the gas can be recovered for use. Another advantage is that the uptake-release process is recyclable.

Carbon nanotubes are promising candidates for adsorbent materials in hydrogen storage, but the weak interaction between molecular hydrogen and carbon means that the temperature must be kept below 200°C. This creates obvious practical difficulties.

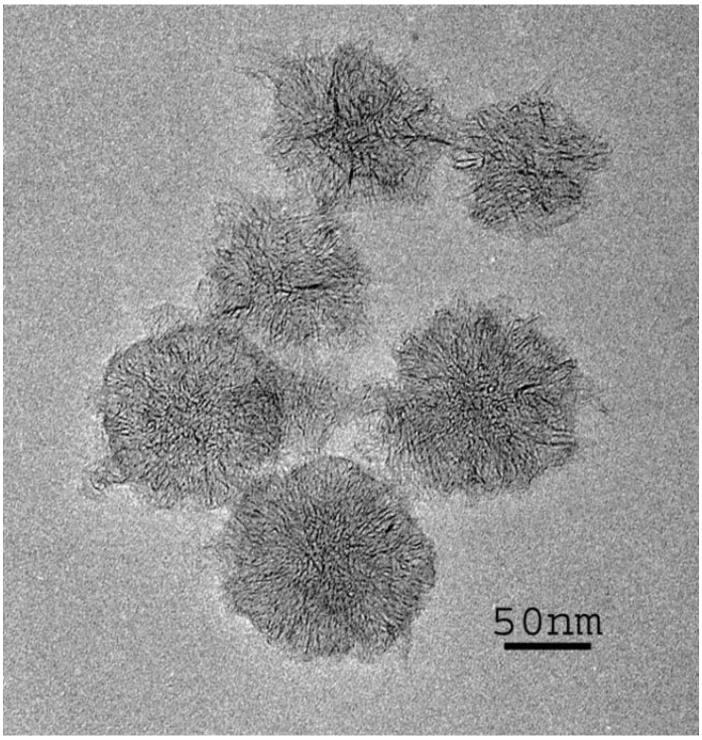
The researchers – based at the Rutherford Appleton Laboratory (UK), University of the Basque Country (Spain), MER Corporation (US) and CNRS (France) – propose instead to increase the binding energy by using 'nanohorns', the geometry of which is thought to lead to strong hydrogen-substrate interactions. Nanohorns have an average length of 2–3 nm, and adopt a horn shape 80–100 nm across at the bell end.

Neutron spectroscopy provides much detail on the mobility, energetics and geometry of the hydrogen-nanohorn complex. In their study, the researchers showed that at room temperature, most of the hydrogen remains firmly attached to the nanostructures.

Nanohorns are currently produced in small amounts by NEC in Japan, using laser ablation, and in the US by MER with an arc process. Both processes could be easily scaled up, says CNRS scientist Marie-Louise Saboungi.

Saboungi and her colleagues intend now to look at the effects of temperature on hydrogen storage, the reversibility of the process, and differences in the behaviour of single- and double-walled nanohorns. 'We would like to understand the basic differences of the interactions between carbon and hydrogen in different nanostructures of carbon.'

Image of carbon nanohorns



Source: CNRS

Hot developments in infrared photodetector technology

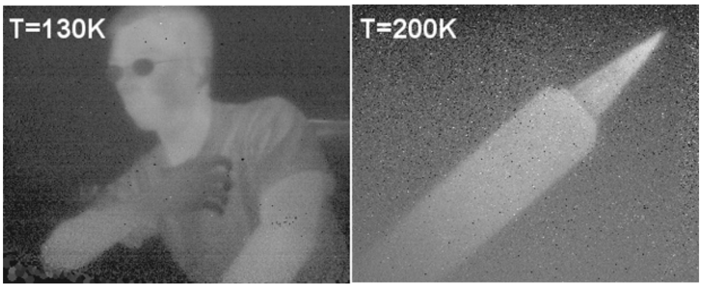
Researchers at Northwestern University, US, have made a significant advance in the development of infrared photodetectors that could lead to new imaging techniques for use in medicine, environmental monitoring, night vision and remote sensing from space.

Infrared detectors are highly sensitive to heat, and in order to minimise noise in the signal, detector hardware is typically cooled to 77 Kelvin, or around –200°C. The cryogenics required for achieving such low temperatures add significant costs, bulk and power consumption to the detectors, severely limiting their usability.

Quantum dots – also known as nanocrystals or 'artificial atoms' – display a number of interesting electronic and optical properties. With their small size the particles possess a physical property known as three-dimensional confinement, and this means they can operate at relatively high temperatures when used in infrared detectors.

The Northwestern researchers have developed quantum dot infrared photodetectors (QDIPs) based on a hybrid indium arsenide quantum dot and indium gallium arsenide quantum well structure grown on an indium phosphide substrate. The QDIPs can operate at room temperature, and have a maximum quantum

Focal plane array images taken at 130 and 200 Kelvin



Source: Manijeh Razeghi/Northwestern University

efficiency of 48%. An infrared camera incorporating the QDIPs was used to demonstrate thermal imaging at temperatures of up to 200 Kelvin.

'Our efficiency value is unprecedented for a quantum dot-based device, and shows the potential for quantum dots to overcome the low efficiency limitations of quantum well photodetectors,' says research leader Manijeh Razeghi.

In the short term, Razeghi and her colleagues hope to improve the performance of their photodetectors by reducing the operating bias. The longer term goal of the research is high performance and high operating temperatures through optimisation of the growth of the quantum dots.

Application development is currently focused on imaging arrays, and while the researchers are not looking at commercialising the technology themselves, they are open to doing so through industry collaborations.

Click here for more information

Long distance record for sending quantum keys

With the aid of nanotechnology-based detectors developed in Russia, Japanese and American researchers have sent photons serving as quantum encryption keys over a record-setting 200km optical link. The achievement opens up the possibility of making practical and secure terrestrial communications networks, together with long-range wireless systems using communication satellites.

Quantum Key Distribution systems transmit a stream of photons with their electric fields arranged in different orientations to represent digital 1s and 0s. Quantum encryption is essentially unbreakable – provided the systems are completely bug-free – because eavesdropping changes the state of the photons, alerting sender and receiver to the presence of an intruder on the line.

The record-breaking demonstration was carried out in a Stanford University lab with the optical fibre wound on a spool. Central to the experiment is the use of ultra-fast superconducting single-photon detectors developed at the Moscow State Pedagogical University, with packaging and cooling technology custom-made at the National Institute of Standards and Technology (NIST) in Boulder, Colorado. The results are detailed in the journal *Nature Photonics*.

Each detector consists of a single 100-nm long, 4-nm thick niobium nitride nanowire coupled to a 9-μm core single-mode fibre, and is housed in a closed-cycle, cryogen-free refrigerator with an operating temperature of 3 Kelvin (–270°C). According to NIST scientist Sae Woo Nam, the principal advantage of the Russian detector is single photon detection with very low jitter and usable sensitivity at near-infrared and visible wavelengths.

'We collaborated with BBN Technologies in Cambridge, Massachusetts, to develop packaging of the entire system so that it could be installed in a telecommunications closet,' says Nam. 'The biggest problem is building a classical control system that can handle the high clock rate at which the single photons are being generated and detected. There is a large classical communications overhead that must be implemented to generated secure key material from single photon detection.'

Click here for more about the research

> 'Japanese and American researchers have sent photons serving as quantum encryption keys over a record-setting 200km optical link'

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