# Laser in a microchip

GETTING A SILICON DEVICE TO WORK AS A LASER WOULD FURTHER SHRINK ELECTRONIC COMPONENTS, SAYS
**S ANANTHANARAYAN**

THE progress of miniaturisation — which involves the number of components on an electronic chip doubling every two years — is running into trouble because of physical limitations of component sizes becoming comparable atoms and crystal structures. The other challenge is of creating high-speed optical connections between components and eliminating the need to convert electronic signals to optical and back again.

Creating optical connections between components on a chip calls for laser sources built right inside the chip. One way is to bond silicon with another material that can work as a laser. Another tack is to use silicon itself as the laser material, employing a process known as the *Raman effect*, and use the silicon medium to amplify the optical signal. The trouble so far has been to miniaturise such devices to the micrometre scale and also to lower the minimum power that laser action calls for, from the current milliwatts to microwatts.

Yasushi Takahashi, Yoshitaka Inui, Masahiro Chihara, Takashi Asano, Ryo Terawaki and Susumu Noda, working in Osaka, Saitama and Kyoto in Japan, report in the journal *Nature* their success in creating a simple device based on a cavity less than 10 microns wide with sufficient power for "practical silicon lasers and amplifiers for largescale integration in photonic circuits".

Photons of light can be absorbed by atoms when their energy matches an energy step of an electron in orbit around the atomic nucleus. Or the photon could be reflected, without any absorption and emission. If it is reflected, there is no transformation of energy and the frequency of the reflected, or scattered, photon light is essentially the same as before. Except for a very tiny addition or subtraction of energy, not for any electronic exiting of the atom but just from the mechanical vibration or rotation of the atom system. Just as the energy levels of the orbiting electrons are arranged in steps, the vibration or rotation modes of molecules, or atoms in crystals, also change in steps, or quanta, of energy. But these steps are much smaller than the electron energy differences and are comparable to the lower energy of light in the infrared or microware region.

When light is scattered, it contains a weak component of light that is just a little less or more energetic than original light. This change in frequency of scattered light is called the Raman effect, named after CV Raman who discovered it. When the spectrum of the scattered light is viewed, there is the central line of light that is unchanged, with faint lines — the *Stokes line* and the *anti-Stokes line* — on either side, named after Sir George Stokes, who did important work in the field of scattering. Raman scattering is, thus, a case of mechanical, rather than electronic properties of atoms interacting with light.

**Lasers**

The laser is an absorption-emission system in which emission is delayed till a collection of emitters act together, resulting in a powerful burst of radiation. The usual arrangement is a cavity, like a tube with reflecting ends, or a piece of crystal whose opposite sides are ground to act as reflectors, where the light can reflect back and forth. The atoms of the gas within the tube or the material of the crystal get excited to a higher energy and then they de-excite. But a feature of the materials used is that while they de-excite, it is not back to the ground state but to an intermediate state that is a "little" stable, before they take the next step to the ground state. As atoms collect in this intermediate state, there are soon more atoms here than in the ground state. The reflecting photons are then more likely to cause a "stimulated emission", than be absorbed. The stimulated emission is of two photons together, which emerge with their vibration synchronised. The dimensions of the cavity are also "tuned" to match the frequency of the light and the result is a powerful burst of photons, with their vibration all *in phase*.

Laser light has qualities of being unidirectional and of a single colour, and laser light beyond the red end of the spectrum has been useful for communications, using optical fibres. Laser light is generated in a suitable unit and is switched on and off at gigabyte frequencies by electronic devices to carry information. But the laser unit has always been separate from the main electronics and is typically bulky and power-consuming. Hence, the interest in creating a miniature and low-power laser device within the microchip itself.

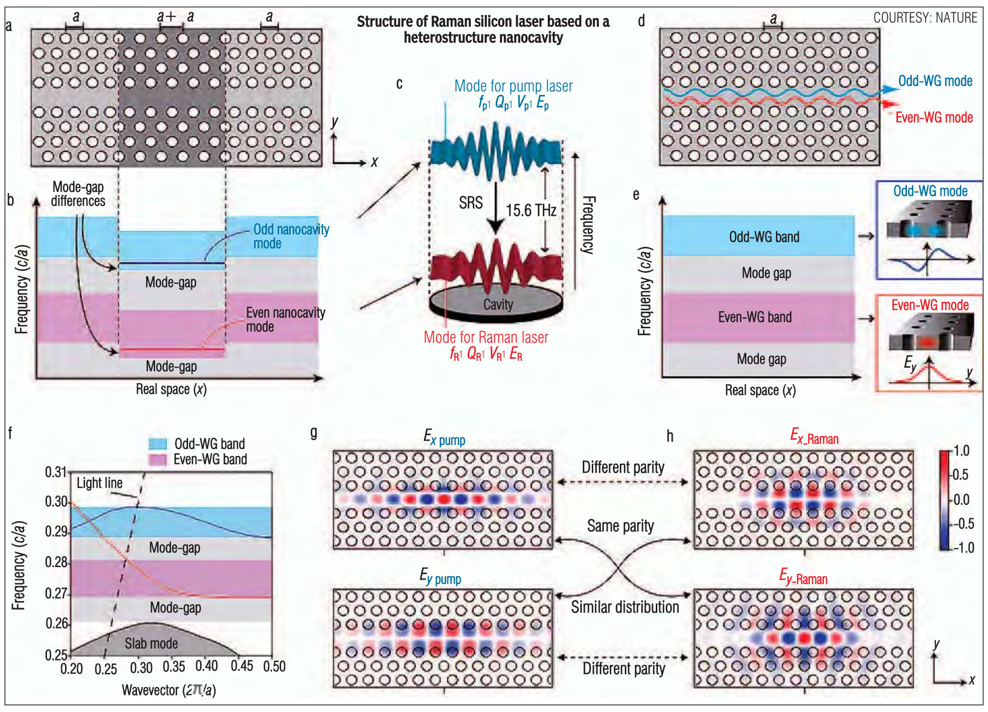
**Silicon photonics**

What has been done by the Japan group is to create resonating cavities within the silicon crystal of the microchip and bring about the laser effect, using not the electronic states of the material but the vibration modes of the crystal. The arrangement uses light of frequency 210 THz (tetra Hertz or a million million vibrations a second), which corresponds to the far infra-red. The silicon crystal has a step of vibration energy that corresponds to 15.6 THz. The light striking atoms in the crystal thus comes off with components that are at 15.6 THz more or less than the original radiation — the lesser frequency being dominant. This is then a case of Raman scattering and the objective is to create amplified and "in phase" radiation with the help of the crystal resonators.

The light within the crystal cavities is, thus, of two main frequencies, of 210 THz and 194.4 THz, which is 15.6 THz less. The light at these neighbouring frequencies interfere and result in "highs" and "lows", like the "beats" that a musician listens for while tuning an instrument, which have a frequency of 15.6 THz. This frequency matches the vibration frequency of the crystal structure and enhances the vibration, which results in a stronger Raman effect — and so on, leading to strong emission at the scattered, Stokes frequency of 194.4 THz, a Raman-silicon laser.

The Raman-silicon laser had already been developed but the dimensions were large, of the order of centimetres, and they used heavy power of the order of tens of milliwatts. What Takahashi and the others have done is to create the resonating cavity in the form of air-holes, like a Swiss cheese, within the silicon sliver. The holes were just 100 nanometres, which is a tenth or a micron in size. But they needed to be arranged with great precision so that they effectively reflected and prevented the escape of radiation for the two frequencies of interest.

With its compact size and low-power use, the device shows promise of practical application. The main challenge is the optical pumping arrangement to provide the 210 THz optical feed. Normal lasers are energised by electrical stimulation, but the Raman laser needs optical powering. This would need a redesign of the arrangement but is feasible in principle. What remains is to do it with little power loss and cost. "It will also be possible to make other Raman amplification devices based on photonic crystals using our design strategy. We believe that our device will stimulate silicon photonics research in a number of areas for the realisation of compact photonic integrated circuit chips," say the authors in their paper.




**a**, Schematic picture of the heterostructure nanocavity in the photonic crystal slab. The lattice constant at the centre of the cavity is slightly larger in the x direction. **b**, Band diagram of the nanocavity along the x direction, where **c** is the speed of light in vacuum. Two high-Q nanocavity modes originating from odd- and even-waveguide modes are formed in the heterostructure. **c**, Configuration of Raman silicon laser using a small cavity. The two nanocavity modes in **b** are used to confine pump light and Stokes-Raman-scattered light, respectively. SRS, stimulated Raman scattering. **d**, Line-defect waveguide formed by a missing row of air holes, in which two propagating waveguide modes are formed. WG, waveguide. **e**, Band diagram of the line-defect waveguide. The insets sketch the profiles of the propagating modes. **f**, Calculated band structure for the line-defect waveguide in k-space. **g**, **h**, Calculated electric field distributions for the odd nanocavity mode and the even nanocavity mode, respectively. The colour scale represents the intensity of the electric field.

THE WRITER CAN BE CONTACTED AT
simlescience@gmail.com

# PREDISPOSITION TO HEART ATTACKS

**TAPAN KUMAR MAITRA** focuses on a specific receptor and, as it turns out, a health issue that many of us are concerned about ~ the level of cholesterol in our blood

RECEPTOR Mediated Endocytosis is a highly efficient pathway for the uptake of specific macromolecules by eukaryotic cells. Many different kinds of macromolecules can be taken up by this means, each recognised by its own specific receptor on the plasma membrane of the appropriate cell types. If we consider the discovery of RME, however, we focus on a specific receptor — and, as it turns out, on a health issue that many of us are concerned about: the level of cholesterol in our blood.

One of the primary factors that predisposes a person to heart attacks is an abnormally high level of cholesterol in the blood serum, a condition called *hypercholesterolemia*. Because of its insolubility in the aqueous serum, cholesterol tends to be deposited on the inside walls of blood vessels. These deposits build up over time, forming the atherosclerotic plaques that cause atherosclerosis, commonly known as a hardening of the arteries.

Ultimately, the plaques may block the flow of blood through the vessels, causing strokes and heart attacks. Remember, however, that cholesterol is a normal component of healthy animal cell membranes — a moderate level of cholesterol is required for the maintenance of these membranes — and that the body will synthesise cholesterol if dietary amounts are inadequate.

Although a high blood cholesterol level is often linked to dietary intake of cholesterol and fatty acids, some people are genetically predisposed to high blood cholesterol levels and, hence, to atherosclerosis and heart disease. This hereditary predisposition, called *Familial Hypercholesterolemia*, is especially debilitating to homozygous individuals — that is, to those who inherited a defective FH gene from both parents. People with FH have grossly elevated levels of serum cholesterol (about 650-1,000 mg/100 mL of blood serum, compared with the normal range of about 130-200 mg/100 mL), and develop atherosclerosis early in life, often leading to death from heart disease before the age of 20. People who are heterozygous — those with one defective and one normal copy of the gene — are affected less severely, but they nonetheless have elevated serum cholesterol levels (about 250-500 mg/100 mL) and are at high risk for heart attacks in their 30s and 40s.

The link between FH and RME came about because of a study of FH by Michael Brown and Joseph Goldstein that was begun in 1972 and led not only to the discovery of RME but also to Nobel Prizes for both scientists in 1986. Brown and Goldstein began by culturing fibroblast cells from FH patients in the laboratory and showing that such cells synthesised cholesterol at abnormally high rates compared with normal cells. Their next key observation was that normal cells also synthesised cholesterol at abnormally high rates when they were deprived of the *Low-Density Lipoproteins* that were usually present in the culture medium. LDL is one form in which cholesterol is transported in the blood and taken up into cells.

Michael Brown and Joseph Goldstein

LDL is one of several classes of blood lipoproteins which are classified according to their density. Another class is the *High-Density Lipoproteins*, moderately high levels of which may be considered healthy. Basically, a lipoprotein particle consists of a monolayer of phospholipid and cholesterol molecules and one or more protein molecules, with the lipids oriented so that their polar head groups face the aqueous medium on the outside and their nonpolar tails extend into the interior of the particle. LDL is the class of lipoproteins with the highest cholesterol content: free cholesterol and cholesterol esters make up more than half of the LDL particle by weight.

The esterified form of cholesterol has a long-chain fatty acid linked to it, which makes it highly hydrophobic. Esterified cholesterol molecules (about 1,500 per particle) therefore cluster in the interior of the particle, whereas the free, or unesterified cholesterol molecules (about 500 per particle) are found mainly in the lipid monolayer.

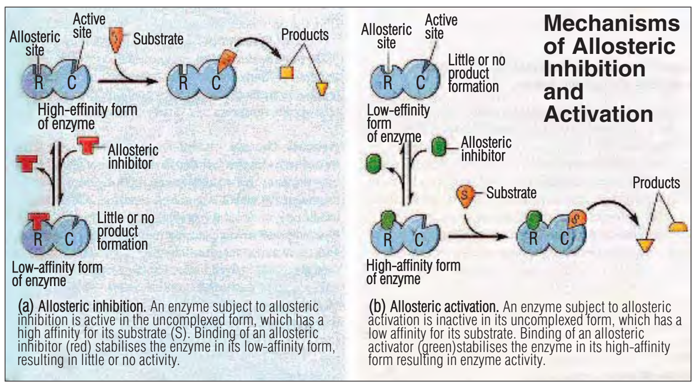
In addition to phospholipids and cholesterol, each LDL particle has a single molecule of a large protein called *apoprotein B-100* embedded in its lipid monolayer. This protein is crucial to our understanding of the difference in the response of FH cells and normal cells to the level of LDL in the medium. The ability of normal fibroblasts to maintain an appropriately low rate of cholesterol synthesis in the presence of LDL suggested to Brown and Goldstein that LDL was involved in the transport of cholesterol into the cell, where the cholesterol then regulated its own synthesis by allosteric (or feedback) inhibition. FH fibroblasts, on the other hand, synthesised cholesterol at a high rate, regardless of whether LDL was present in the medium, suggesting that these cells might be defective in LDL-dependent cholesterol uptake.

Based on their observations, Brown and Goldstein postulated that the uptake of cholesterol into cells required the action of a specific receptor on the cell surface and that this receptor was absent or defective in FH patients. In a brilliant series of experiments, these investigators and their colleagues demonstrated the existence of an LDL-specific membrane protein, called the *LDL receptor*, and showed that it recognised the apoprotein B-100 molecule that is present in every LDL particle. They also showed that the cells from FH patients either lacked this protein entirely or had receptor molecules that were defective in any of several ways.

To visualise the LDL particles, these scientists conjugated, or linked, these to molecules of *ferritin*, a protein that binds iron atoms. Because iron atoms are electron-dense, they appear as dark dots in the electron microscope. Using this technique, Brown and Goldstein showed that the ferritin-conjugated LDL particles bound to the surface of the cell and clustered at specific locations. I now recognise these sites as coated pits, localised regions of the plasma membrane characterised by the presence of clathrin on the cytoplasmic side of the membrane and by the accumulation of membrane-bound receptor-ligand complexes on the exterior of the membrane.

Dark dots were also seen on the inside of vesicles that formed by invagination and pinching off of coated pits. The receptors, in other words, not only bound the LDL on the cell surface but were also apparently involved in the internalisation of LDL within vesicles.

In short, these workers had discovered a new mechanism by which cells can take up macromolecules from their environment. And since it was an endocytic process involving specific receptors, Brown and Goldstein gave it the name by which we know it today — Receptor-Mediated Endocytosis.




THE WRITER IS ASSOCIATE PROFESSOR AND HEAD, DEPARTMENT OF BOTANY, ANANDA MOHAN COLLEGE, KOLKATA

## PLUS POINTS

### Coming up trumps

For Kolkata-born Rituparna Bose, research and endeavour have paid off handsomely. The 32-year-old, who now teaches at City University, New York, has developed mathematical algorithms that give the most specific estimates of biodiversity till date. She recently identified new fossil species in Michigan, a kind of ancient marine shell, and showed that the ancient biodiversity was underestimated. Her findings showed that a greater diversity of life had, in fact, existed in the past than had been previously appreciated.

"There are around five to 30 million species of plants and animals today. One reason for such ambiguity in biodiversity numbers is that organisms have been historically classified based on visual assessment of external morphology ever since the days of Carl Linnaeus (1735). Organisms that looked different were grouped differently, and that was fine till now," she said.

Bose's findings demonstrated the shortcomings of such visual classification and highlighted the need for classification based on objective quantitative algorithms. Part of her research was presented at the North American Paleontological Convention. This is especially significant as the United Nations has declared 2011-2020 the Decade of Biodiversity and she has subsequently been elected a Fellow of the Paleontological Society of India and the prestigious Geological Society of London.

Her findings were recently reported in *Historical Biology* and *Paläontologische Zeitschrift*, both journals on fossil science. Bose is also the editor of *Acta Palaeontogica Sinica*, the flagship journal of the Chinese Academy of Sciences, China's highest academic institution and provides scientific leadership on vital global issues. She also serves on the editorial board of a few famous scholarly journals, including the *Geological Journal* and *Bulletins of American Paleontology* (Paleontological Research Institute, Cornell University).

One of the exciting findings of her work, along with David Polly, was that scientists may have misestimated the number of species that existed in prehistoric times.

"My research has been published in several acclaimed palaeontology journals, including *Palaios*. My dissertation has also been selected for the best theses award by prominent publisher Springer and is being published in their 'best of the best theses' series," she said.

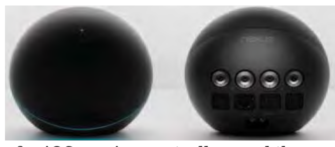
An alumnus of both Calcutta University and Jadavpur University, she is now an adjunct faculty at the Department of Earth and Atmospheric Sciences, City University, New York, and married to Arnab De, a microbiologist from Columbia University, who has also been her co- worker. De, too, is from Kolkata and had graduated from Presidency College.

INDIA BLOOMS NEWS SERVICE

## TIP TO PONDER

### Android-based console

Reports from the *Wall Street Journal* have revealed that Google is currently developing an Android-powered gaming console and smartwatch and it is believed that this is partly a pre-emptive measure intended to counter similar devices from Apple. Although there have so far only been suggestions that Apple might be entering the gaming market (these include patents



for iOS gaming controllers and the uptick in Apple TV's profitability), such rumours seem far more substantial if Google also believes in them.

Android-based gaming consoles have enjoyed great success over the past year with notable devices including the GameStick and Ouya. The latter, a £99 Kickstarter-funded console, was launched at the beginning of last week and managed to sell out through both Amazon US and UK stores, despite criticism for poor quality hardware.

Sources indicated that the company would be rebooting its Nexus Q device — a product described as "the first social streaming media player" but never released to the public.

THE INDEPENDENT