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To fit the laser in the microchip

Getting a silicon device to work as a laser would further shrink electronic components, says S.Ananthanarayanan.

The progress of miniaturization, which has been that the number of components on an electronic chip doubles every two years, is running into trouble because of physical limitations, of component sizes becoming comparable atoms and crystal structure. The other challenge is of creating high speed optical connections between components and to eliminate 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 which can work as a laser. Another tack is to use silicon itself as the laser material, using a process known as the ***Raman effect*** and use the silicon medium to amplify optical the signal. The trouble so far has been to miniaturise such devices to the micrometer scale and also to lower the minimum power that laser action calls for, from the current milli-watts 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 large-scale integration in photonic circuits.”

Raman Effect

Photons of light can be absorbed by atoms, when its 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 exciting 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 infra red or microware region.

When light is scattered, the scattered light contains a weak component of light just a little less or more energetic than original light. This change in frequency of scattered light is called the Raman effect, named after ***C V Raman***, who discovered the effect.. 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 the electronic properties of atoms interacting with light.

Lasers

The laser is an absorptio–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 which 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 synchronized. 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 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 centimeters, and they used heavy power, of the order of tens of milliwatts. What Takahashi and 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 nanometers, which is a tenth or a micron in size. But they needed to be arranged with great precision, so that they effectively reflect and prevent 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 energized by electrical stimulation. But the Raman laser needs optical powering. This would need 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 realization of compact photonic integrated circuit chips,” say the authors in their paper.