Pure silicon laser debuts

By Eric Smalley, Technology Research News

Researchers from the University of California at Los Angeles have made a prototype laser from the stuff of computer chips -- silicon. The laser is tunable, meaning it can lase in a range of wavelengths, or colors, and it works at room temperature.

The silicon laser could be used to provide optical wireless communications at a wavelength that is optimal for transmission through air and even fog, to detect chemicals and biological molecules, and to provide an infrared countermeasure capable of jamming heat-seeking missiles, said Bahram Jalali, a professor of electrical engineering at UCLA.

The device promises to be compatible with today's silicon manufacturing processes because it amplifies light using the natural atomic vibrations of silicon rather than a mix of materials or a particular nanoscale physical structure, said Jalali. "This is significant because no special impurity or complicated device structure is needed, and hence the technology is 100 percent compatible with silicon chip manufacturing," he said.

This makes silicon lasers potentially inexpensive. "Silicon is the bread and butter material of the... electronics industry," Jalali. "Ideally everything should be made in silicon because its combination of technology and economics cannot be matched," he said.

The researchers' prototype consists of a fiber-optic loop containing a silicon waveguide. A standard laser pumps energy into the loop. A tap channels five percent of the output light from the loop to a detector. The remaining light remains in the loop where it is amplified by the silicon. When the pump laser produces 9 watts or more of power, the prototype produces a laser beam.

A laser, short for light amplification by stimulated emission of radiation, works by electrically or optically energizing matter. An atom's electrons occupy discrete energy levels, and when an atom absorbs energy its electrons move to higher energy levels around the atom's nucleus.

When an electron falls back to a lower energy level, the atom emits energy in the form of a photon. This is the natural process of spontaneous light emission. If an atom is already at a higher energy level when it absorbs energy, however, an electron releases two photons as it returns to its low energy level, or ground state. This stimulated emission is the basis of lasing.

The basic components of a laser are a gain medium -- atoms that emit photons -- contained in a resonator cavity, and an energy source. The cavity can be a pair of parallel mirrors that bounce photons back and forth, or, in the case of the researchers' prototype, a fiber-optic loop that channels emitted photons back into the gain medium. The energy source -- electricity or another laser -- energizes the atoms, and the resonator cavity causes photons produced by spontaneous emission to be resorbed by the atoms. When more atoms emit photons through stimulated rather than spontaneous emission, the laser produces an intense beam of light at a single wavelength, or color. The wavelength of the beam is determined by the type of gain medium.

Ordinarily silicon makes a poor gain medium because when its electrons drop to the ground state more energy is channeled into the material as vibrations or heat than is emitted as light. The researchers got around this problem by taking advantage of the Raman effect.

When photons strike atoms, many are absorbed and some scatter. The scattered photons gain or lose energy depending on whether the atoms they struck are in a high or low energy state. The energy change causes the photons' wavelength to shift. The amount of wavelength shift, or color change, is determined by the type of atom. This effect is commonly used to identify materials.

When a powerful enough laser strikes a material, the scattered photons induce lasing at the Raman-shifted wavelength. Raman lasers made from glass optical fiber are common. The researchers found that silicon works much better than glass as a Raman gain medium because silicon's atomic structure is well ordered, which increases photon scattering. The Raman effect is 10,000 times stronger in silicon than in optical fiber, Jalali said.

The researchers' silicon Raman laser shifts 1,540-nanometer wavelengths to 1,675-nanometer light, which is in the near- to mid-infrared range.

The silicon laser could be a cheaper alternative to the fiber-optic Raman lasers currently used to provide light for telecommunication networks, said Jalali. "The silicon Raman laser would be for more compact [and] much lower cost," he said.

The silicon laser could also be used in optical wireless communications devices, which require a wavelength that is optimal for transmission through air and fog, said Jalali. "Existing communication lasers emit at a wavelength that are ideal for transmission to an optical fiber" rather than through air, he said.

The device's ability to lase in the mid-infrared range is also useful. Lasers that emit mid-infrared wavelengths are used to detect chemicals and biomolecules. "Most molecules have very strong vibrational signals in the mid-infrared spectrum," Jalali said. The only other lasers that emit mid-infrared wavelengths either require cryogenic cooling or consist of expensive materials. The silicon laser would make for a much cheaper room-temperature alternative, said Jalali.

The laser can also produce extremely short pulses on the order of femtoseconds, or million billionths of a second, which is useful for data transmission through fog and scientific imaging of fast-moving phenomena.

The researchers are working on the next generation of the prototype, which uses a silicon optical resonator rather than a waveguide. An optical resonator is a tiny disk that acts like an echo chamber for light. They are also working on making a silicon laser that puts out continuous beams of light, which would allow it to operate in telecommunications networks.

A practical silicon Raman laser could be ready in two years, said Jalali.

Jalali's research colleague was Ozdal Boyraz. The work appeared in the October 18, 2004 issue of *Optics Express*. The research was funded by the Defense Advanced Research Projects Agency (DARPA).