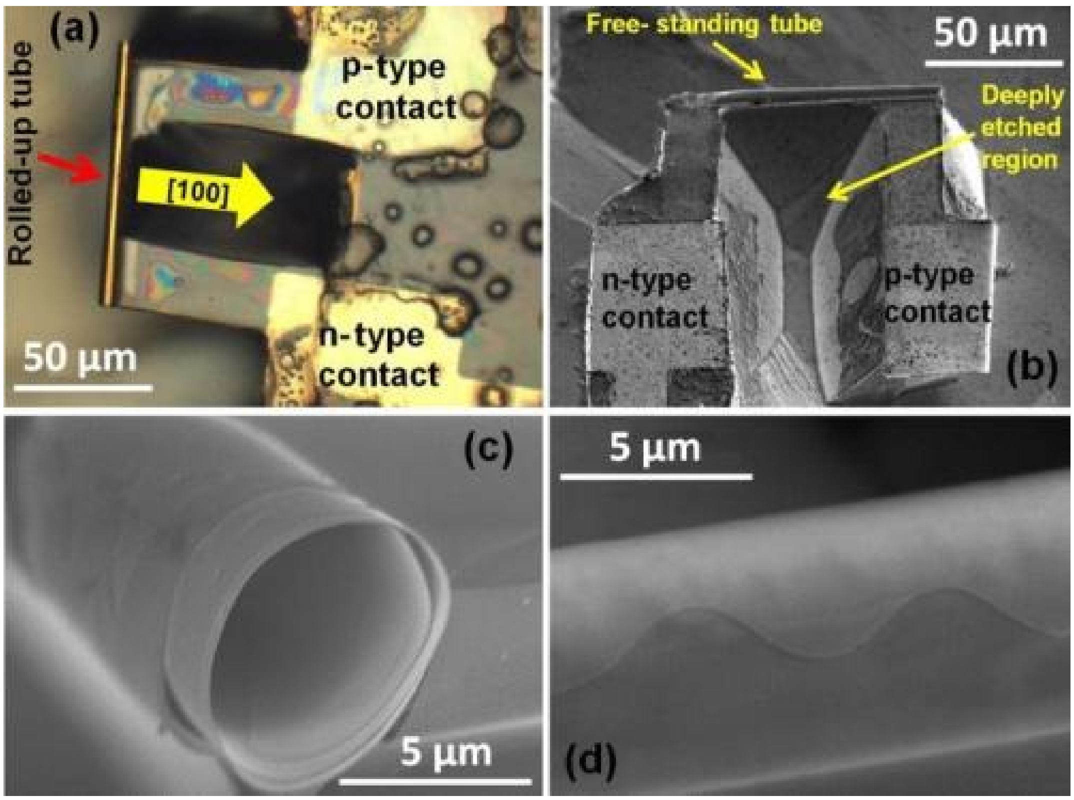
First-of-its-kind tube laser created for on-chip optical communications

January 23 2015, by Lisa Zyga



(a) Optical microscope image of the free-standing rolled-up tube laser positioned on top of two electrodes. (b, c, d) Scanning electron microscope images of different views of the laser. Surface corrugations for axial mode confinement can be seen in (d). Credit: M. H. T. Dastjerdi, et al. ©2015 AIP Publishing

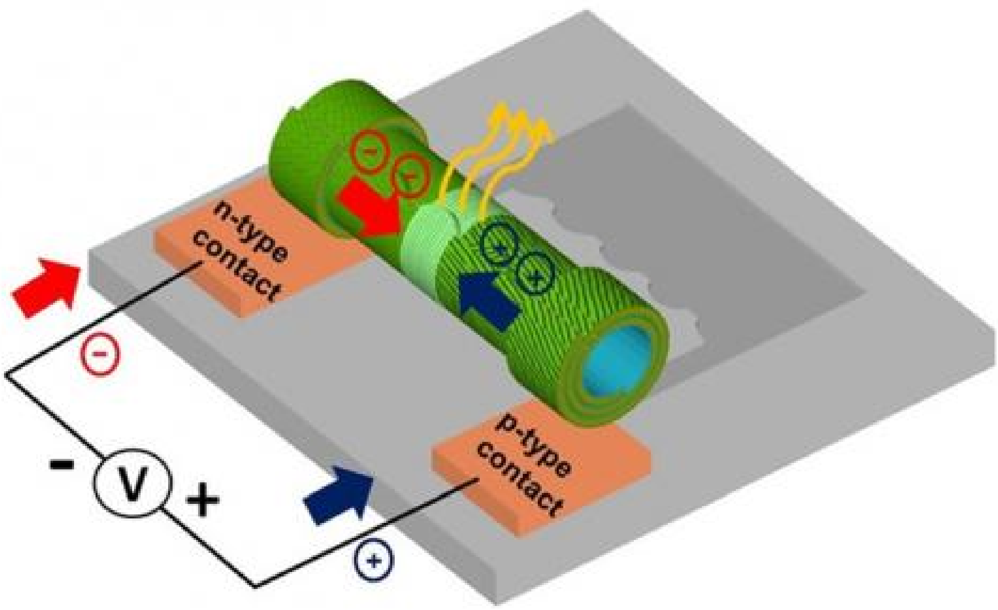
(Phys.org)—Nanophotonics, which takes advantage of the much faster speed of light compared with electrons, could potentially lead to future optical computers that transmit large amounts of data at very high speeds. Working toward this goal, researchers in a new study have developed a tiny laser 100 micrometers long and 5 micrometers in diameter—right at the limit of what the unaided human eye can see. As the first rolled-up semiconductor tube laser that is electrically powered, it can fit on an optical chip and serve as the light source for future optical communications technology.

A team of engineers, M. H. T. Dastjerdi, et al., at McGill University in Montreal have reported their development of the tiny laser in a recent issue of *Applied Physics Letters*.

Future optical chips will require many vital components, such as modulators (which convert electrical signals into optical ones), photodetectors (which do the reverse), and waveguides (which control the path of light). Another essential requirement is, of course, the light itself, which may come from a micro- or nano-scale laser that can be integrated with the other components onto a silicon (Si) platform.

Although many different types of micro-sized lasers have been studied over the past several years, one promising candidate is a laser made from rolled-up semiconductor tubes. These lasers are fabricated by straining 2D nanomembranes on a substrate, and then selectively releasing parts of the nanomembranes so that they roll up into tiny tubes that act as optical cavities. The rolled-up tube lasers have an advantage over most other types of small lasers in that their optical emission characteristics can be precisely tailored using standard photolithography processes. They can also be easily transferred onto a Si platform, allowing for seamless integration with other chip components.

So far, the only rolled-up tube lasers that have been demonstrated have been powered optically, not electrically, which have certain disadvantages.



Schematic of the electrically injected free-standing rolled-up tube laser, showing light emission from the center of the laser. Credit: M. H. T. Dastjerdi, et al. ©2015 AIP Publishing

"In contrast to electrically injected devices, optically pumped devices require additional light sources (lasers, LEDs) to operate that take additional space on the chip and add a significant level of complexity," Zetian Mi, Associate Professor at McGill University, told *Phys.org*. "Therefore, optically pumped light sources are not practical for integrated chip-level optical communication systems."

As the researchers explain, fabricating electrically powered rolled-up tube lasers is difficult because the very thin nanomembranes make the process of injecting charge carriers into the laser very inefficient. To overcome this problem, the researchers designed the laser to lie horizontally on top of two supporting pieces connected to the electrodes in a U-shaped mesa design. In this formation, charge carriers are injected into the laser cavity from the sides. By circumventing the thin membrane walls, this lateral carrier injection scheme emits light from the center of the tube laser, significantly increasing injection efficiency.

"The U-shaped mesa design allows the efficient injection of charge carriers into the center region of the tube, and thereby light emission from this region," Mi said. "However, to achieve lasing, optical confinement in both the axial direction (along the tube) and azimuthal direction are required. The azimuthal confinement is achieved by the free-standing tube itself. The axial confinement is offered by the surface corrugations. The surface corrugations are introduced by modulating the inner edge of the U-shaped mesa during the device fabrication process. It leads to an effective change of the refractive index along the tube direction, which can strongly confine light."

The new rolled-up tube laser is made of the commonly used semiconductor material InGaAsP (indium gallium arsenide phosphide), interspersed with two InGaAs quantum well layers. At just 7 nm thick, the quantum wells confine light in very small areas, contributing to efficient photoluminescence. The laser's light emission peaks in the telecom wavelength range at about 1.5 micrometers. The laser also operates with very low threshold current, which improves efficiency and is essential for chip-scale applications.

"Practical light sources for chip-level communication systems require electrically-injected light sources," Mi said. "To date, the most efficient light sources are made of III-V semiconductors (GaAs, InP, etc.). The monolithic integration of such III-V light sources onto a Si platform has been fundamentally limited by the large lattice mismatch, large thermal coefficient difference, and polar/nonpolar incompatibility between III-V materials and Si, leading to poor performance and extremely short lifetime. The greatest significance of our work is that the electrically injected free-standing semiconductor tube lasers can be transferred directly onto a Si platform, and the device performance is no longer limited by these [three] fundamental issues."

In the future, the researchers plan to integrate the lasers onto chips, taking an important step toward applications.

"Future plans include the achievement of electrically injected semiconductor tube lasers at room-temperature and direct integration with waveguides and other components on a Si-chip," Mi said. "It is worth mentioning that we have previously demonstrated the integration of such devices with Si-waveguides on a Si platform under optical pumping. Therefore we do not foresee any fundamental roadblocks for semiconductor tube lasers to emerge as a viable light source for Si photonics."

More information: M. H. T. Dastjerdi, et al. "An electrically injected rolled-up semiconductor tube laser." *Applied Physics Letters*. DOI: 10.1063/1.4906238