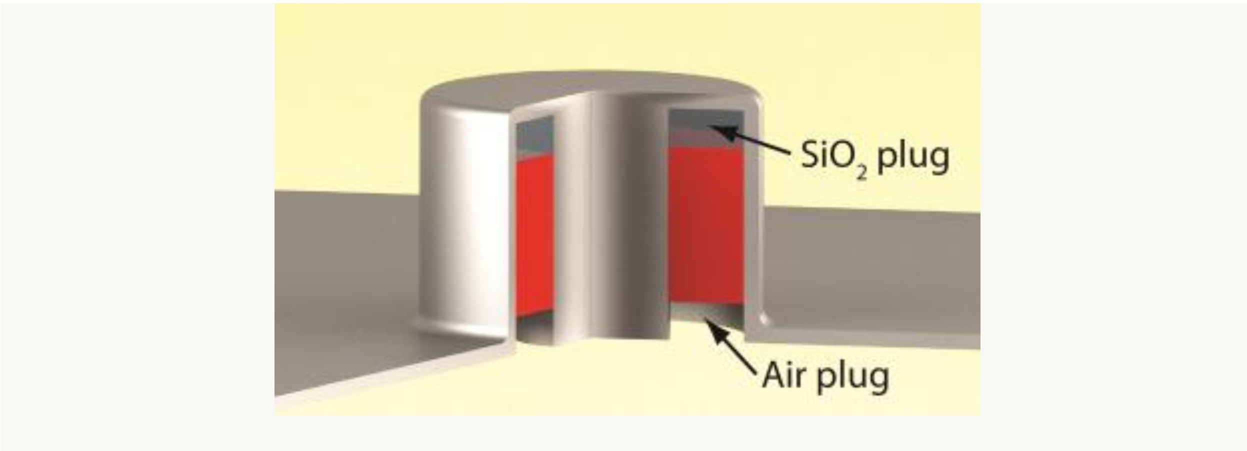
COAXIAL ‘CABLES’ MAKE GREAT LASERS, TOO

A coaxial cable plug. The coaxial nanolaser is more than 15,000 times smaller. Photo by mikemol via flickr.

When Oliver Heaviside invented the coaxial cable in 1880 he could not have foreseen the implications of his idea on modern nanotechnology. His coaxial cables consist of three layers: an inner metallic core, surrounded by an insulator, surrounded by a metallic layer on the outside. The benefit of this design is that the outer metallic layer shields the electrical signal through the cable from outside interference. This makes coaxial cables very useful for information transfer, and coax cables are used for TV antenna cables or some computer network cables. Mercedeh Khajavikhan,Yeshaiahu Fainman and colleagues from the University of California, San Diego now present a completely new application: they have fabricated coaxial lasers on the nanoscale that turn on without the usual minimum threshold power of usual lasers. To do this they had to shrink the coaxial cables first. These lasers are more than 15,000 times smaller than typical coaxial cables.



The nanoscale coaxial laser. Similar to coaxial cables it consists of an inner metal pillar and an outer metal shield. The structure is also protected from interference from the top. Inside is a semiconductor light emitter (red; insulated from the top metal through a SiO2 plug). The laser light exits through the hole in the substrate. Figure by Mercedeh Khajavikhan and Aleksandar Simic.

The benefit of a coaxial cable is that between the core and the outer metal layer well-defined and controlled electromagnetic waves can propagate shielded from any outside influence. Furthermore, shrinking such a device to the nanoscale – to length scales comparable to the light used – means that only the smallest optical beam pattern for the wavelength of light, known as the fundamental mode, fits into the small space between the metal structures. The other modes would be too large. If we now add a matching light-emitting semiconductor into the structure (see figure), light emission from this semiconductor is only possible if it emits light in the form of the fundamental mode. All other emission modes are forbidden because they are not sustained in this small space. Here, the coaxial structures have a diameter of about 300 nanometres, matched to the lasing wavelength of the InGaAsP semiconductor of about 1,400 nanometers.

The single mode has other implications, adds Khajavikhan, “by ensuring that cavity only supports one mode (the lasing mode) and all other channels for emission are absent, the emitters in the gain region only emit in the lasing mode thus resulting in thresholdless lasing.” Normally, when lasers are turned on they first need to overcome various internal losses before lasing can set it. But because there is only one emission channel that is furthermore shielded from outside losses, lasing sets in immediately.

As a proof of this principle, the authors fabricated two coaxial lasers. A large one in which several optical modes can exist, and a smaller one with only the fundamental optical mode. As expected, the larger structure only lases above a certain threshold whereas the smaller device starts lasing immediately. Xiang Zhang from the University of California, Berkeley, who works on nanoscale lasers, considers this a very interesting development, particularly for fundamental quantum physics research.

“The demonstrated nanoscale coaxial laser could be an interesting platform for the investigation of plasmon-based cavity quantum electrodynamics and quantum metamaterials.”

At the same time, Zhang cautions that there are still obstacles to overcome before coaxial lasers could complement the wide-spread use of coaxial cables. Low operating temperatures as well as the fact that these lasers are optically excited and not electrically need to be addressed in future work.

However, the practical potential is certainly clear, says Khajavikhan. “In the fabrication of these lasers we have used standard nanofabrication processes. More importantly, the lasers are batch fabricable, that is many of them can be fabricated at simultaneously and in the parallel way. […] No other nanolaser is so well adapted to the existing nano-fabrication tools.”

With their commercialization still a bit off, however, as Zhang suggests these lasers could be subject of plenty of fundamental research on quantum mechanical effects. And more possibilities will arise, adds Fainman. “We feel this is just a beginning of a new family of light emitters with superior characteristics and many advances in this new area is yet to come.”

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