Arizona State University demos room-temperature electrically powered nanolasers

Operating temperature has been raised by adjusting the SiN insulating layer thickness in sub-wavelength metallic-cavity laser.

Researchers at Arizona State University (ASU) have succeeded in developing electrically powered nano-scale lasers that operate effectively at room temperature – a step that could pave the way for their use in a variety of practical applications.

This is the latest development in the R&D group's long history of trying to make such a breakthrough. Previously, electrically powered nano-scale lasers could only be made to work at relatively low temperatures. Researchers in this field have been striving to enable them to perform reliably at room temperature.

Details of how the ASU researchers, led by Cun-Zheng Ning, made the room-temperature advance were published recently in the research journal Optics Express, vol. 21, issue 4, p4728 (2013).

Ning works as an electrical engineering professor in the university's School of Electrical, Computer and Energy Engineering, one of ASU's several Schools of Engineering, based in Phoenix. He has been among many groups of engineers and scientists worldwide trying to fabricate a workable nanolaser with a volume smaller than its wavelength cubed – which would be an intermediate step toward further miniaturization of lasers.

Miniaturizing lasers is crucial to making electronics smaller and better, and enabling them to operate faster. Being able to integrate more lasers onto a small microchip could hence make next-generation computers faster and smaller. The researchers say that wavelength scale is the next milestone to achieve in their overall effort to enable greater miniaturization.

Ning says that while other groups have developed extremely small and thin lasers, they always needed to be optically driven by a larger laser. Furthermore, existing electrically driven nanolasers can operate only at low temperatures and/or emit light only in short bursts or pulses.

To enable them to be useful in practical applications — particularly for improvements of electronic and photonic technologies — such lasers must possess three particular features: operate at room temperature without a refrigeration system; be powered by a simple battery instead of by another laser; and emit light continuously.

Ning commented, "This combination has long been the ultimate goal in the nanolaser research community." His team started looking for solutions in 2006, before he joined ASU, with his then postdoctoral assistant, Alex Maslov, who is currently a scientist working with Canon USA Inc.

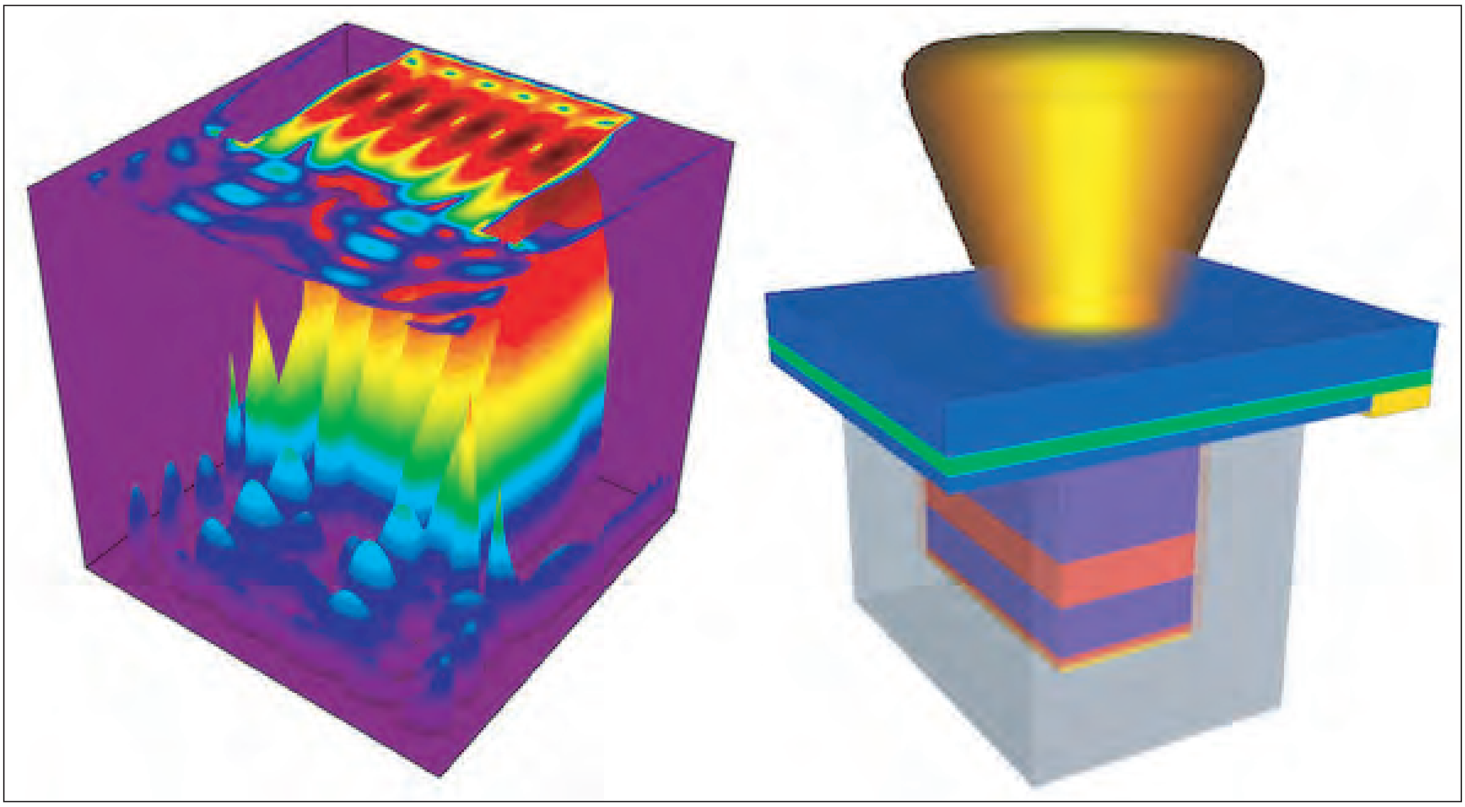
While working for the US National Aeronautics and Space Administration's Ames Research Center, they proposed a semiconductor wire coated with a silver shell and showed that such a core-shell structure was able to shrink the nanolaser to an incredibly small scale.

In 2011, working with Martin Hill, a former professor at Eindhoven University of Technology in the Netherlands, Ning's team then developed the thinnest nanolaser capable of operating at low temperatures. In 2011, with the aid of Ning's student, Kang Ding, they were able to raise the operating temperature to 260K (–13.2ºC /–8.3 ºF).

More recently, using an indium phosphide/indium gallium arsenide/indium phosphide (InP/InGaAs/InP) rectangular core and silicon nitride (SiN) insulating layer (encapsulated in a silver shell), the team demonstrated a nano-laser that could operate at room temperature, as reported in the journal Physical Review B, vol. 85, p041301(R) (2012). However, the overheating led to imperfect device operation and a conclusive demonstration of lasing remained elusive.

However, the latest results — obtained by using the same sub-wavelength metallic-cavity laser device structure but adjusting the thickness of the SiN layer and refining the fabrication process — have demonstrated an eight-fold improvement over previous results from a year ago. This finally provides an unambiguous demonstration of continuous electrically driven operation of a laser at room temperature, Ning says.

To explain the significance of such an advance, Ning says, "Imagine if computers had to be cooled down to



Left: variations in light intensity within a nanolaser. Right: nanolaser with a metallic cavity, where the center red region confines electrons and the grey enclosure is a silver cavity. The blue layer on top is the growth substrate. The orange-yellow color indicates the light emission.

–200ºC (73.2K /–350ºF) for our current information technology to work. If that were the case, we would not have the widespread usage of computers and social media."

Nanolasers that can operate at room temperature and be powered by a simple battery can be used to make computers operate faster, significantly broaden Internet bandwidth, and provide light sources for many computer-chip-based sensing and detection technologies.

Show-stopping advance

But the benefits of achieving continuous room-temperature operation go beyond the practical aspects. Ning commented, "In terms of fundamental science, it shows for the first time that metal heating loss is not an insurmountable barrier for room-temperature operation of a metallic cavity nanolaser under electrical injection. For a long time, many doubted if such operation is even possible."

"Unlike nanolasers driven by another laser, for which the driving laser can be chosen so that the heat generation is minimized, electrical injection by a battery produces more heat. In addition, typical metals can be heated quickly by the operation of the nanolasers. Thus, such elevated heat generation has been perceived as a show-stopper for such nanolasers."

He added, "More importantly, similar metal semiconductor structures used for nanolasers are also currently being explored for many other applications, such as being a building block for the formation of artificial materials that have remarkable properties. This demonstration is thus also important to the researchers working in those areas of materials science and engineering."

Ning says many challenges remain in efforts to integrate nanolasers into a photonic system on-chip platform, as well as to prolong the lifetime of laser operation, and to further develop the capabilities of such devices. In addition, the physical mechanisms involved in the interaction of photons with metallic structures on small scale are not yet fully understood, so there is still much research to be done in this area.

Ning concluded, "But thanks to the realization of room-temperature operation of nanolasers, all these goals can start to be more effectively explored."

Constructive collaboration

The breakthrough by Ning's team required nanofabrication and measurements, credited to several of his students, primarily Kang Ding, Leijun Yin, and Zhicheng Liu. Yin is pursuing his doctorate in physics. Ding and Liu are pursuing doctoral degrees in electrical engineering. ■

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By Matthew Peach, Contributing Editor