Australian National Fabrication Facility
ACT Node & WA Node
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Small lasers a big topic in nano-photonics

In recent years there have been significant advances in the size and characteristics of small lasers, i.e. lasers with dimensions or modes sizes close to, or smaller than, the wavelength of emitted light. This work has primarily been led by innovative use of new materials and cavity designs.

In a recently published review article in the journal Nature Photonics [1] Martin Hill (University of Western Australia) and Malte Gather (University of St Andrews) analysed the progress that has been made over the last few decades in the development of small lasers. Both the development time scales and size scales for the various laser types are shown, put in context and compared, in order to clarify how the magnitude and speed of miniaturisation in lasers is occurring.

December 2014 cover of Nature Photonics showing SiN coated InP/InGaAs pillars approximately 200nm in diameter, after they have had their gold encapsulation removed. The semiconductor heterostructure in the pillar and gold encapsulation form a metallic nano-cavity which supports the lasing of the smallest electrically pumped lasers ever made. Journal cover reprinted by permission from Macmillan Publishers Ltd: Nature Photonics, copyright 2014.

The most dramatic progress has been in the emergence of lasers made from small metallic structures, as well as refinements in dielectric cavity lasers and the beginning of their penetration into new areas such as biology. Via the use of a simple laser model, it can be seen that small lasers based on dielectric and metallic cavities use different strategies to reduce the size of lasers.

In general, small dielectric lasers employ cavities with long photon lifetimes to reduce demands on the laser gain medium. In contrast, metallic cavities typically have much shorter photon lifetimes, often due to absorption in the metal. Increased confinement of the optical mode to the gain medium does however provide a design window in which lasing can occur in the metallic structures, though the gain medium is still often pushed to its limit.

By analysing results from many publications on small lasers, Hill and Gather showed that, typically, dielectric small lasers have cavities with dimensions and volumes greater than the wavelength of light, and quality factors greater than 1,000 whereas the cavities of metal based small lasers can be smaller than the wavelength of light, and have quality factors less than 1,000.

Besides providing tight confinement, the metal structures in metallic and plasmonic lasers also provide good heat-sinking and a pathway for electrical pumping, which has contributed to the rapid development of electrically pumped devices operating at room temperature. Additionally, the ever smaller lasers have stimulated useful debate in the following areas:

- *Propagation of light and gain in small, lossy dispersive structures;*
- *Spontaneous vs stimulated emission and the characteristics of lasers with cavity sizes well below the diffraction limit;*
- *Increasing the maximum optical gain available from various gain media.*

A key issue to be solved for very small dielectric and metallic lasers will be device lifetime. The small gain regions in these devices have large surface to volume ratios and their fabrication often involves etching which can introduce surface defects and surface recombination that accelerate device aging. Small metallic and plasmonic lasers also require substantial improvement in room temperature threshold current and efficient out-coupling of light or plasmons into either free space or a (plasmonic) waveguide.

"We are employing the microelectronic fabrication facilities at the West Australian node of the ANFF, in particular Reactive Ion Etching, Plasma Enhanced Chemical Vapour Deposition, and metal deposition equipment, to produce new plasmonic laser structures which, in theory, address the above mentioned issues." Hill said.

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Interest in making lasers smaller does not seem to have been discouraged when established laser concepts approached the conventional diffraction limit; on the contrary, recent years have clearly seen a very significant interest in making ever smaller and lower power lasers.

Concrete, high-impact applications where small size and low power are of key importance are starting to emerge, particularly in short distance communications. To lay the groundwork for additional applications, continued research will be necessary in small lasers, in their fundamental properties and constituent materials, and in related research areas that depend on small lasers and optical amplifiers such as plasmonics and nanophotonics. Having access to facilities provided by the ANFF will play a vital role in the development of this work.

[1] M.T. Hill, M. C. Gather, "Advances in small lasers," Nature Photonics, vol. 8, no. 12, pp. 908-918, (2014).

Edited from an article supplied courtesy of Martin Hill, Electronic and Computer Engineering, UWA.

ANFF 2025 - Future Capabilities Consultation

Nearly 3,000 users are forecast to access ANFF facilities to create new products, new companies, and world-class scientific advances this year. The ANFF 2025 - Future Capabilities Consultation is an opportunity to examine the fabrication challenges that the Australian R&D community will tackle over the next 7 – 10 years.

- *What will be the impact of this work?*
- *What will be the new scientific and commercial outcomes?*
- *What are the barriers to our success?*

Based on the themes identified in the 2012 National Nanotechnology Strategy released by the Australian Academy of Science, sessions will be held covering:

- *Photonics;*
- *Nanoelectronics and nanomagnetics;*
- *Nano-materials; and*
- *Nanobio and nanomedicine.*

More than 20 people attended the first session of the ANFF 2025 - Future Capabilities Consultation forum on photonics held in the Finkel Theatre at the John Curtin School of Medical Research, ANU on 24 February 2015. A similar event was held in Adelaide on 26 February. Everyone is welcome to participate, including existing and future ANFF users from universities, publicly funded research agencies and industry. Come and tell us your vision for nanofabrication in Australia. Further events to be held around Australia include:

- *Melbourne - 10 March;*
- *Sydney - 17 March;*
- *Brisbane & Perth dates to be advised.*

So get in quick! For venues, detailed program information and registration, see the ANFFL website: - http://www.anff.org.au/anff-2025-future-capabilities-consultation.html.

We are pleased to welcome the newest recruit to the ACT Node - Mark Lockrey (see photo left). Mark joined the Australian National University (ANU) in late January 2015 as the new Micronalysis Research Officer and SEM Process Engineer and operates the newly installed FEI FESEM-CL system reported on in our December newsletter.

Mark received his PhD in Physics at the University of Technology, Sydney in 2015, where his PhD studies focused on cathodluminescence (CL) analysis of III-nitride materials.

Mark's research interests include electron-beam processing of materials, CL analysis of nanomaterials and characterisation III-V semiconductors.

He certainly hit the ground running too! After arriving and settling in he was straight into advanced training with the FEI engineers on the new tools and has begun training users themselves. In February he trained over 20 people with more sessions planned - so if this tool is for you contact Mark and book in for a session.

We also have another feature article on a recent Nature Photonics paper - from the WA Node this time (see main story). We have featured three Nature papers recently, so the ANFF is certainly a valuable resource for researchers for building on existing work and developing new advances. In fact, we have just added over 50 journal & conference papers to our 'Publications' web page for 2014 - have a look and you'll see what the ACT Node alone is assisting reseachers to achieve.

And, if you want to help with the future of the ANFF's direction you can have your voice heard at the ANFF 2025 - Future Capabilities Consultation sessions - but get in quick as there are only four sessions to go - see left. (JK)

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