2D Material Nanowatt Threshold Lasing

Volker J. Sorger[1*]

[1]Department of Electrical and Computer Engineering, School of Engineering and Applied Science, George Washington University, Washington, DC 20052
[*]Corresponding author: sorger@gwu.edu

Wu et al.[1] demonstrate a 2D material-based laser only requiring 1 W/cm^2 of pump power to reach threshold – a value low enough to be optically driven by a regular household light bulb! Reducing the power-level for the onset of the lasing action is a worthy goal in laser science. A series of design choices have lead to this breakthrough; 1) the 2D gain material exhibits high conversion efficiencies; 2) the laser cavity - a photonic crystal cavity (PCC) - has a high quality factor.

While choosing PCCs for miniaturized lasers is well established[2], the significance of Wu's work is to show lasing action with an atom-thin 2D gain material. Success was possible by careful photon management; the efficient built-up of a sufficiently-high photon density to enter the regime of stimulated emission as characterized by a high β-factor. The β=19% for the 2D laser[1], while high, can actually approach unity for plasmon lasers[3]. Fundamentally, high photon utilization is possible when Q/V_{cav} is enhanced relating the cavity quality (Q) with the effective cavity mode volume (V_{cav}) a value proportional to the so-called Purcell factor.[4] While Wu followed the high-Q approach and keeping V_{cav} at the diffraction limit, high-Q devices bear technological challenges such as long photon lifetimes for direct modulation and high drive power since heating pads are often needed for resonance stabilization.

Key for a high-Q laser is to spatially and spectrally align the gain emitter to the feedback-providing cavity. 2D materials may offer advantages by providing deterministic cavity alignment and fabrication – a challenge for quantum-dot lasers still today. In addition, their permittivities are tunable via electrostatic doping and a wide selection of direct bandgaps are available. However, the modal overlap of the sub nanometer-thin 2D gain material with the PCC mode is rather low, and could be a reason for the low external conversion efficiency[1].

The technological usefulness of on-chip lasers depends on both the device performance (i.e. deliverable light output, electrical drive power, stabile room temperature operation) and the ease-of-integration (i.e. small footprint, efficient waveguide out-coupling, low cost). The functionality of 2D materials is not clear yet, since the nanoscale gain volume leads to tiny output levels, diffraction-limited PCC do not scale down is size, and the emission couples out vertically from the chip.

In conclusion, with demonstrated nanowatt thresholds the intriguing question arises: how low can we go? Enhancing the Purcell factor by increasing Q further is likely not an option due to broadening effects[5]. Alternatively, one can match V_{cav} with the length scale of the 2D material by deploying nano-optics approaches, provided losses are manageable. With the concept for 2D lasers achieved[1], these light sources may play an important role in the looming flexible-electronics revolution.

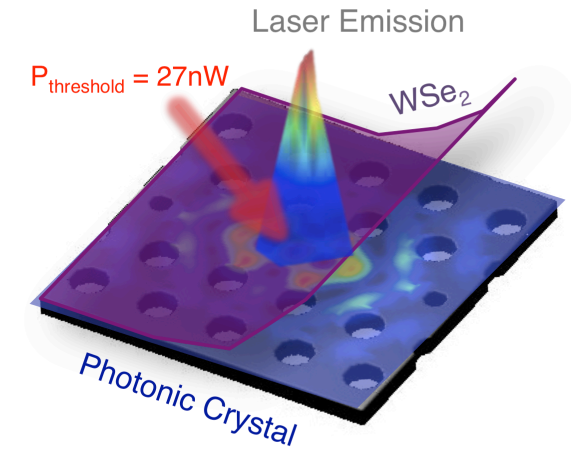

Figure 1. A photonic crystal cavity provides strong feedback for the atom-thin WSe_2 gain layer.[1] This demonstration indicates the potential for nanowatt-low threshold lasing enabled by the high-Q factor of the selected cavity, and efficient photon utilization (i.e. high Purcell factor). It is intriguing to ask what the ultimate lowest limit for a laser threshold is, and what technological role 2D material-based lasers might play in the near future.

References

[1] Wu, S., Buckley, S., Schaibley, J. R., Feng, L., Yan, J., Mandrus, D. G., Hatami, F., Yao, W., Vučković, J., Majumdar, A. & Xu, X. Monolayer semiconductor nanocavity lasers with ultralow thresholds. *Nature* **520**, 69-73 (2015).

[2] Altug, H., Englund, D. & Vučković, J. Ultrafast photonic crystal nanocavity laser. *Nature Physics* **2**, 484-488 (2006).

[3] Oulton, R. F., Sorger, V. J., Zentgraf, T., Ma, R.-M., Gladden, C., Dai, L., Bartal, G. & Zhang, X. Plasmon lasers at deep subwavelength scale. *Nature* **461**, 629–632 (2009).

[4] Sorger, V. J. Nano-optics gets practical: Plasmon Modulators. *Nat. Nanotech.* **10**, 11-15 (2015).

[5] Gu, Q., Slutsky, B., Vallini, F., Smalley, J. S. T., Nezhad, M. P., Erateschi, N. C. & Fainman, Y. Purcell effect in sub-wavelength semiconductor lasers. *Opt. Exp.* **21**, - (2013).