

2D Material Nanowatt Threshold Lasing

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Wu et al.¹ demonstrate a 2D material-based laser only requiring 1 W/cm² 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 led 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 established², 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 $\beta=19\%$ for the 2D laser¹, while high, can actually approach unity for plasmon lasers³. 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 efficiency¹.

The technological usefulness of on-chip lasers depends on both the device performance (i.e. deliverable light output, electrical drive power, stable 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 in 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 effects⁵. 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 achieved¹, these light sources may play an important role in the looming flexible-electronics revolution.

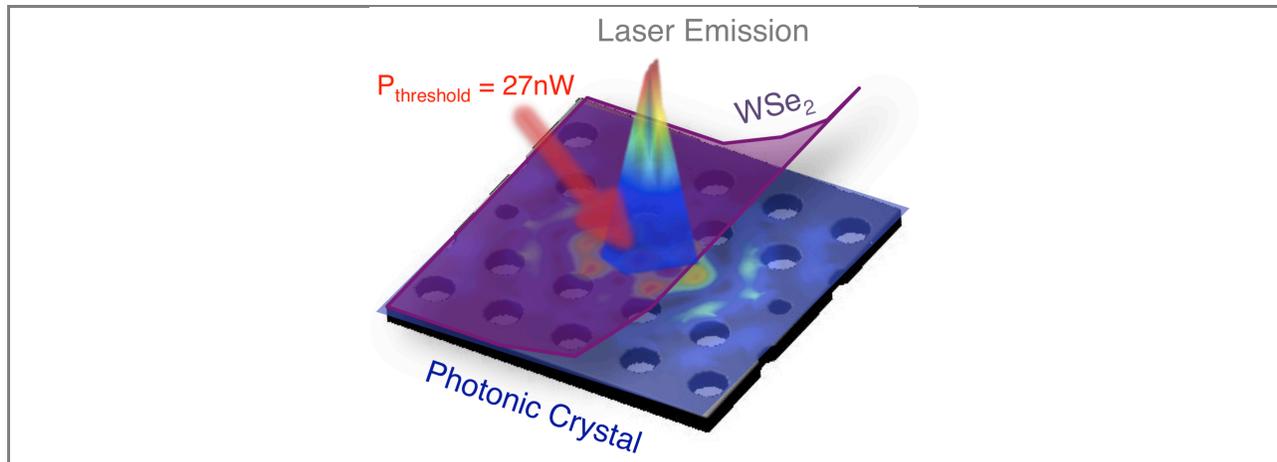


Figure 1. A photonic crystal cavity provides strong feedback for the atom-thin WSe₂ gain layer.¹ This demonstration indicates the potential for nanowatt-low threshold lasing enabled by the high-Q factor of the selected cavity, and efficient photon utilization (i.e. high Purcell factor). It is intriguing 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

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