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RESEARCH HIGHLIGHT

# Two-dimensional material nanowatt threshold lasing

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Wu *et al.*[1] demonstrated a two-dimensional (2D) material-based laser that required only $1\,\mathrm{W\,cm^{-2}}$ of pump power to reach the threshold limit. This value is low enough to be optically driven by a regular household light bulb! Reducing the power level for the onset of lasing action is a desirable goal in laser science. A series of design choices led to this breakthrough: (1) the 2D gain material exhibited high conversion efficiencies; and (2) the laser cavity —a photonic crystal cavity (PCC)—had a high quality factor (Figure 1).

Although the choice of PCCs for miniaturized lasers is well established,[2] the significance of the study by Wu *et al.* was how it showed lasing action with an atom-thin 2D gain material. Success was possible by careful photon management, that is, the efficient build-up of a sufficiently high photon density to enter the regime of stimulated emission characterized by a high $\beta$-factor. The $\beta$-value of 19% for this 2D laser,[1] although high, can actually approach unity for plasmon lasers.[3] The cavity quality ($Q$) and the effective cavity mode volume ($V_{cav}$) are proportional to the so-called Purcell factor,[4] and, fundamentally, high photon utilization is possible when $Q/V_{cav}$ is enhanced. Wu *et al.* followed the high-$Q$ approach and maintained $V_{cav}$ at about the diffraction limit; however, high-$Q$ devices bear technological challenges, such as long photon lifetimes for direct modulation and high drive power because heating pads are often needed for resonance stabilization.

It is key to spatially and spectrally align the gain emitter to the feedback-providing cavity for a high-$Q$ laser. 2D materials may offer advantages by providing deterministic cavity alignment and fabrication, which is currently a challenge for quantum-dot lasers. In addition, their permittivities are tunable by electrostatic doping, and a wide selection of direct bandgaps is available. However, the modal overlap of the subnanometer-thin 2D gain material in PCC mode is fundamentally low and may be a reason for the low external conversion efficiency.[1]

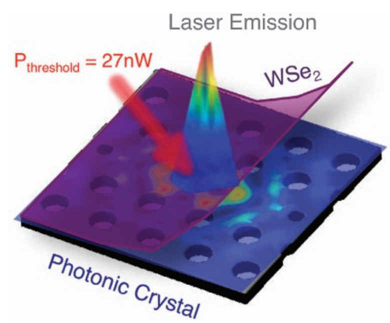


**Figure 1** A photonic crystal cavity provides strong feedback for the atom-thin $WSe_2$ gain layer.[1] This demonstration illustrates the potential for nanowatt-low threshold lasing enabled by the high-$Q$ factor of the selected cavity and efficient photon utilization (that is, high Purcell factor).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

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

In conclusion, with the nanowatt thresholds having been demonstrated, the question that arises is: how low can the threshold be? Enhancing the Purcell factor by further increasing $Q$ is unlikely to be an option due to broadening effects.[5] Alternatively, one can match $V_{cav}$ with the scale length of the 2D material by deploying nano-optics methods, provided that losses are manageable. By achieving this concept for 2D lasers,[1] these light sources may have an important role in the looming flexible-electronics revolution.

## CONFLICT OF INTEREST

The author declares no conflict of interest.

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