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Integrated and free-space lasers with 2D materials on silicon nitride

Two-dimensional (2D) materials, such as transition metal dichalcogenides (TMDs), exhibit attractive optoelectronic properties. Here, we thoroughly explore their incorporation in silicon-on-insulator resonant structures and propose ultra-compact and efficient lasers for both integrated and free-space photonics.

The first example concerns a CW free-space laser exploiting a sharply-resonant metasurface based on silicon nitride [1], Fig. 1(b). We use an optically-pumped MoS_2/WSe_2 heterobilayer [Fig. 1(a)], which supports a long-lived interlayer exciton allowing for gain at room temperatures in the range 1100 nm-1300 nm, tunable by twist angle [2]. Following a meticulous design process, an ultralow threshold of $\sim$6 kW/cm^2 is achieved via enhanced coupling between the optical and matter states [1]. Thermal stability is investigated and stable operation with pump power densities up to a few MW/cm^2 (three orders of magnitude above the threshold) is predicted.

The second example concerns a *Q*-switched integrated laser based on an add-drop silicon nitride disk ($R = 1.5\ \mu\mathrm{m}$) [3], Fig. 1(c). A stack of 2D materials comprising the TMD bilayer, hBN, and graphene as the saturable absorber (SA) is overlaid on the cavity. Guided-wave pumping into a resonance of the disk is used to reduce the threshold to just 24 μW and improve practicality. The *Q*-switched laser delivers pulsed light inside an integrated bus waveguide with peak power up to 6 mW, pulse duration down to 4 ps, and repetition rates up to 40 GHz, depending on the pump power. Using different 2D materials for gain and SA (other TMDs, MXenes, TIs, BP, etc.) allows for obtaining a very broad range of pulse train metrics [4].

The design process has been greatly facilitated by developing a temporal coupled mode theory (CMT) framework extracted from the semiclassical Maxwell-Bloch equations and first-order perturbation theory [3,5,6]. Compared to other reduced-order models in the literature [7,8], it preserves phase information for the lasing mode, allows for resonant pumping, and allows for determining the lasing frequency when the cold cavity frequency and the atomic transition (peak of gain spectrum) are detuned. It is proven highly accurate, as verified by full-wave nonlinear simulations, Fig. 1(b). It can be readily expanded to other gain media and additional nonlinear effects.

References

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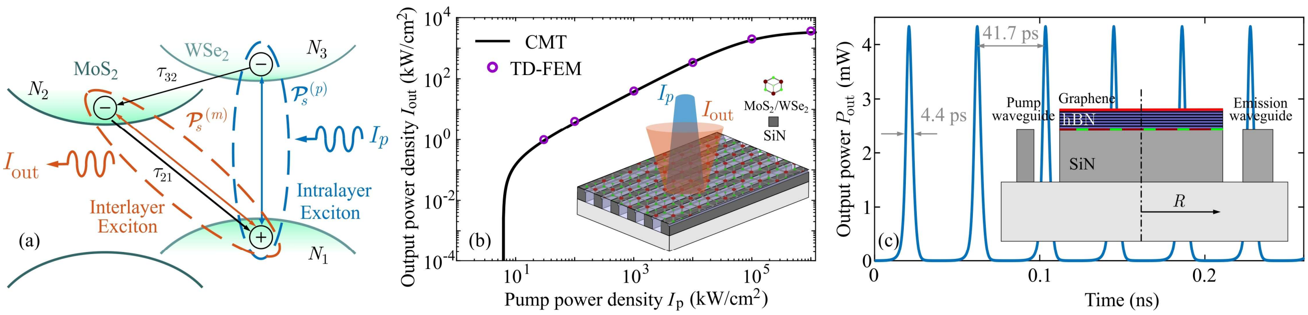

Figure 1: (a) Energy diagram of MoS_2/WSe_2 hetero-bilayer. (b) Free-space metasurface laser [1]. Low threshold of 6 kW/cm^2 and excellent agreement between CMT and full-wave time-domain simulations. (c) Integrated Q-switched laser using graphene as a saturable absorber [3]. Output pulse train collected in the emission waveguide when the pump power in the pump waveguide is 2 mW.