Center for Energy Efficient Electronics Science

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Optical Characterization of WSe_2 Monolayers

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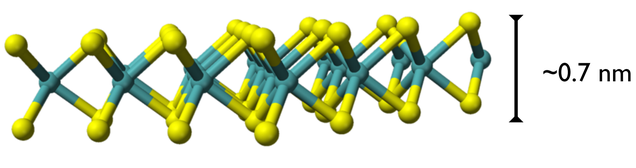
Abstract

The realization of feasible optical interconnect technology demands an efficient nanoscale light emitter. Increasing the efficiency of nanoLEDs requires (1) enhancing radiative recombination rates in semiconductor materials and (2) lowering non-radiative recombination rates in those materials. Although optical antennas are potential solutions to the first problem, the second also deserves attention. Here, we investigate the optical performance of WSe_2 at different feature sizes, performing photoluminescence (PL) and lifetime measurements to characterize the non-radiative edge recombination behavior in this 2D semiconductor material. With the results, we model the edge recombination characteristics of WSe_2 and use this model to discuss the potential of WSe_2 for use as the light emitting material in nanoLEDs.

Transition Metal Dichalcogenides (TMDs)



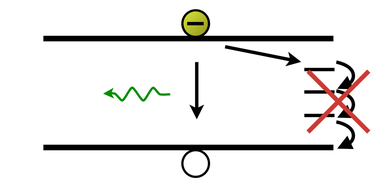
Monolayers have a direct band gap ⟶ Efficient emission

Fewer dangling bonds ⟶ Better Surfaces

QE of WSe_2 ⟶ ~ 5%

Image: Ben Mills, Wikipedia Commons

Recombination Rates and Edge Recombination



Comparison of radiative and edge recombination

$$\frac{1}{\tau} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{bulk}} + \frac{1}{\tau_{edge}}$$

enhance radiative recombination

limit non-radiative recombination

Quantum Efficiency

$$\eta = \frac{1/\tau_{rad}}{1/\tau_{rad} + 1/\tau_{nonrad}}$$

Edge Recombination Model †

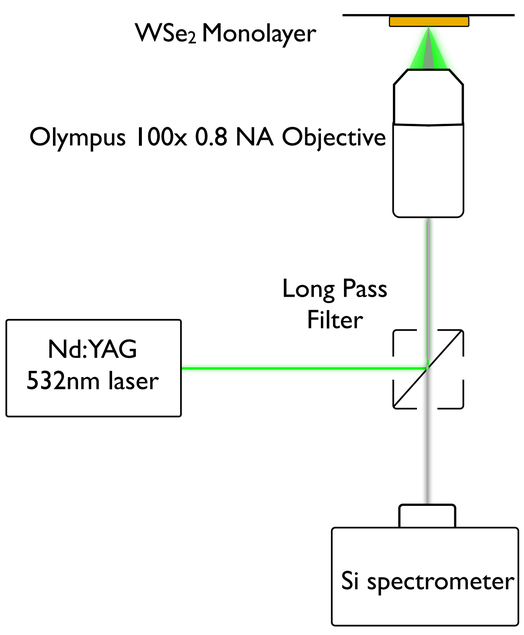
$$\tau_{edge} \cong \frac{W}{2v_e} + \frac{1}{D}\left(\frac{W}{\pi}\right)^2$$

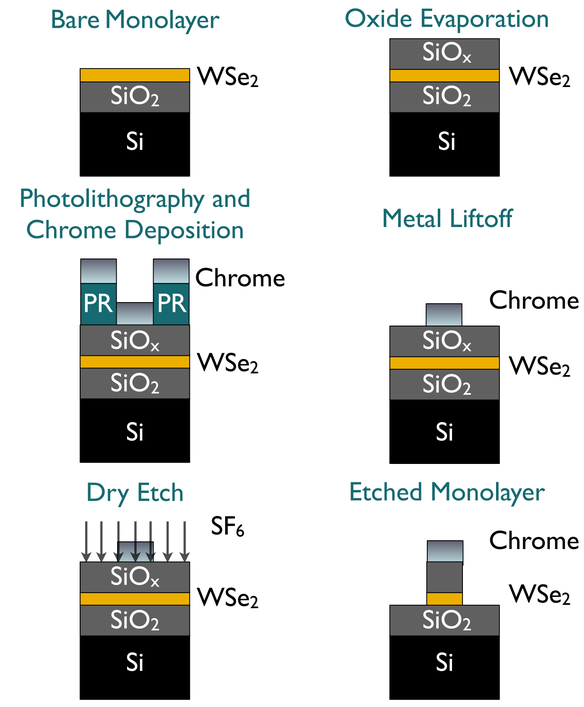
W: feature size

D: diffusion coefficient

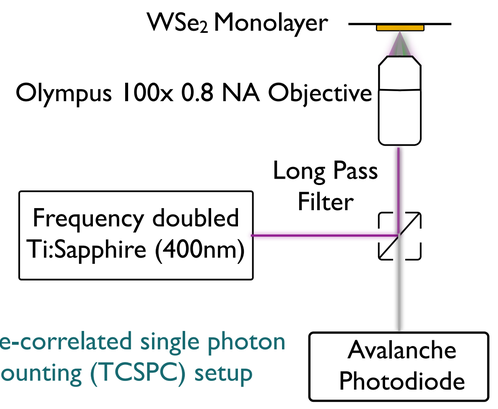
v_s: surface recombination velocity

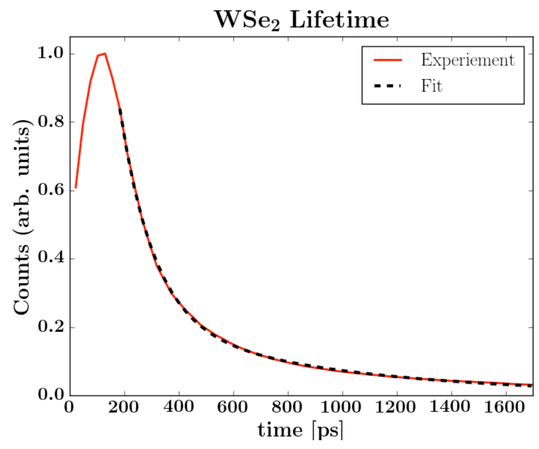
PL Measurement Setup and Process Flow





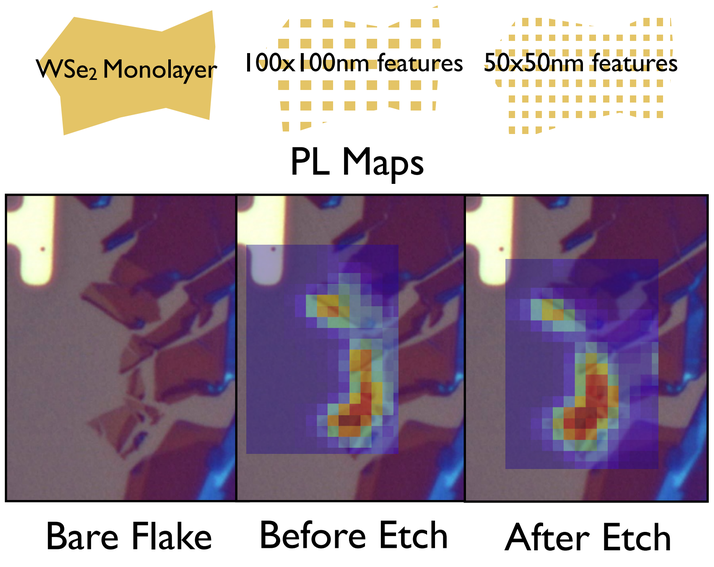
Lifetime Measurement of Bare Monolayer

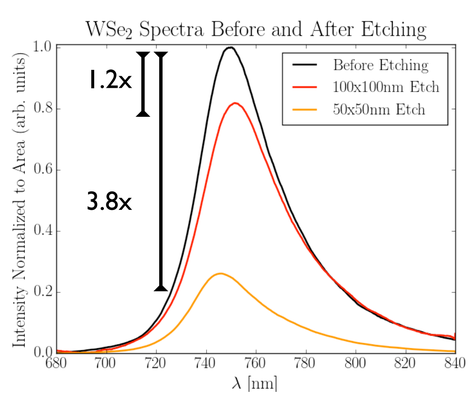


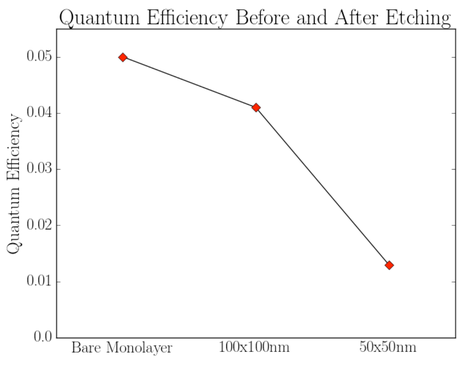


Measured lifetime of WSe_2 = 130 ps

PL Measurements of Bare and Etched Monolayers

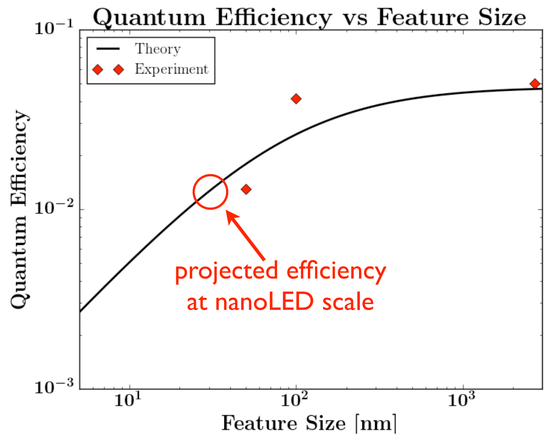






Only a small drop in quantum efficiency at small feature sizes

Results



- WSe_2 maintains a decent efficiency at smaller feature sizes
- Simple edge recombination model allows for geometry-based efficiency estimates

Theory predicts a quantum efficiency of ~1% at 30nm—the scale of nanoLEDs.

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† Sproul, A. B.. "Dimensionless solution of the equation describing the effect of surface recombination on carrier decay in semiconductors." *Journal of Applied Physics*: 2851.

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