Optimized mapping of nanoscale heterogeneity in transition metal dichalcogenides enabled by sample design

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The optoelectronic properties of transition metal dichalcogenides (TMDs) are highly sensitive to a diverse range of internal and external perturbations, such as inhomogeneous dielectric environments [1], structural defects [2], and strain. Non-invasive nanoscale mapping of TMD optical response elucidates the causes of heterogeneity.
We demonstrate scanning-electron-microscope (SEM) cathodoluminescence (CL) hyperspectral mapping of the light emission from hBN-encapsulated TMDs [3] with minimal sample damage [4] and prompt transition between nano- and micro-scale fields of view. Both brightness and spatial resolution in TMD CL depend on the dynamics of electron-hole (e-h) pair generation and diffusion in the hBN encapsulation layers, which are typically significantly thicker than the optically active TMD layers. To date, there is no systematic understanding of hBN carrier dynamics.
Here, we show that hBN thickness controls the CL spatial resolution by acting on the effective diffusion length of the e-h pars generated in hBN. We provide a method to define the optimal working range of hBN thickness to obtain bright signal while maintaining sub-diffraction spatial resolution. We demonstrate the potential of TMD CL with high-resolution hyperspectral CL maps of TMD monolayers (fig. 1a) in which the combination of high spatial and spectral resolution can disentangle different forms of spectral disorder, leading to trion localization and peak energy shifts (fig. 1b).
Our study provides a practical strategy towards the full exploitation of CL to characterize the nanoscale fluctuations of TMD optical properties, which contribute to a robust understanding of TMD optical response for both fundamental and applied physics.

REFERENCES

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FIGURES

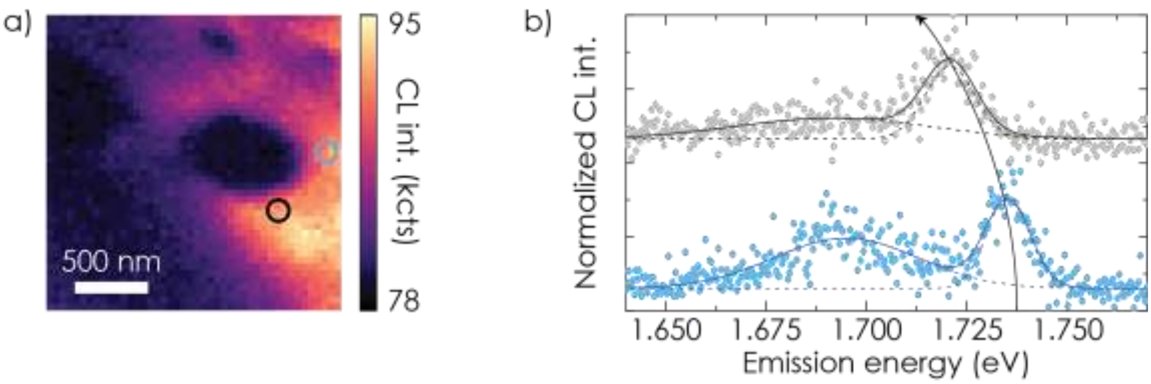

Figure 1: a) Hyperspectral CL map (1.65-1.75 eV shown) of a hBN-encapsulated WS2 monolayer at 15K. b) Spectra from the circled pixels in corresponding colors.