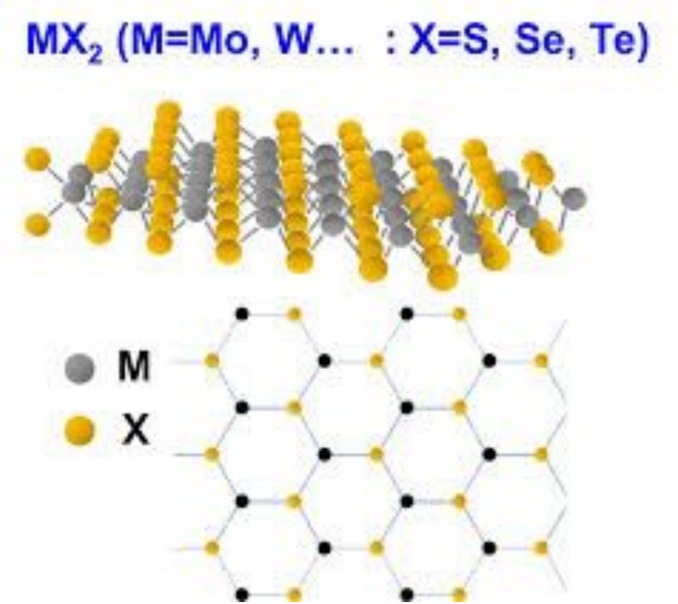
Determining the recombination rates and mobility of photoexcited charge carriers in 2D transition metal dichalcogenides

Chris Knotek and Akash Mullick

Introduction: 2D TMD Nanomaterials

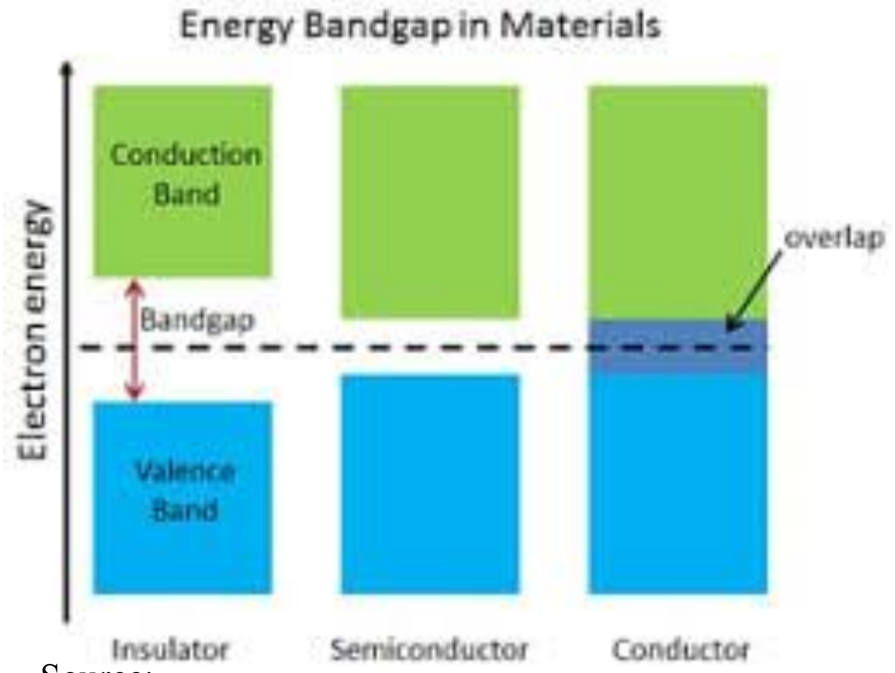


Source:
http://www.iae.kyoto-u.ac.jp/conv/en/research_matsuda_TMD.html

- Transition metal dichalcogenide monolayer (TMD) semiconductors
- Band gap in visible wavelength

Source: Jariwala, Deep, et al. *ACS Nano*, vol. 8, no. 2, 2014, pp. 1102–1120.,

Semiconductors Basics

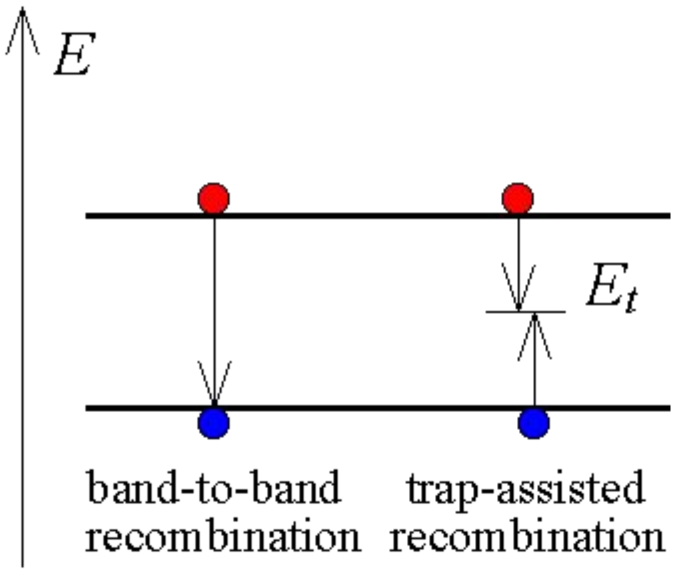


Source: https://www.mouser.com/applications/wide-bandgap-beyond-silicon/

- Semiconductors typically act as insulators
- Electrons can be moved to bands where mobility allows for conduction
- High mobility allows for faster transistor switching

Source: Jariwala, Deep, et al. *ACS Nano*, vol. 8, no. 2, 2014, pp. 1102–1120.,

Recombination and Carriers



- Both trap and non-trap assisted recombination can be radiative

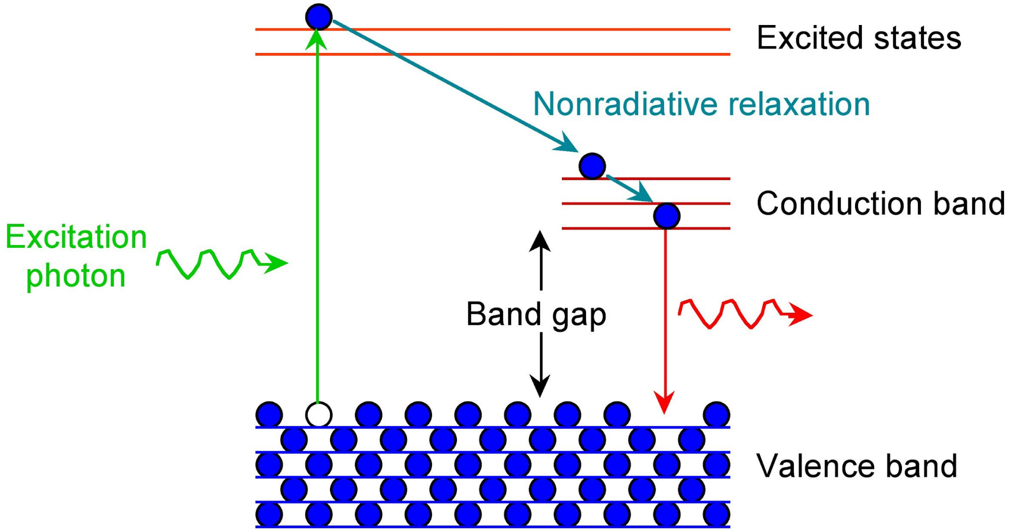
Source: https://ecee.colorado.edu/~bart/book/book/chapter2/ch2_8.htm

Goal

Characterize how charges move and lose energy through recombination in 2D TMDs

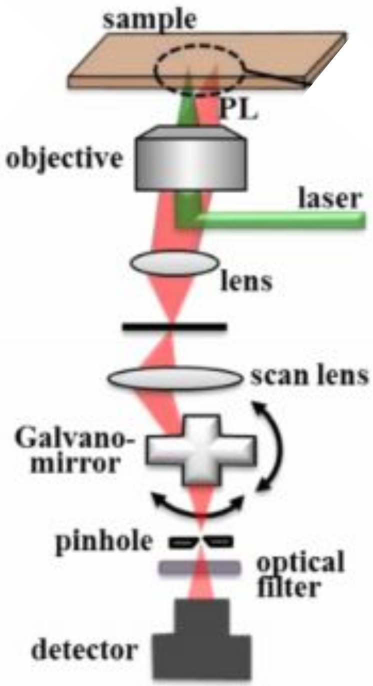
- Trap-assisted recombination
- Band-to-band recombination
- Diffusion

Methods/Actions #1



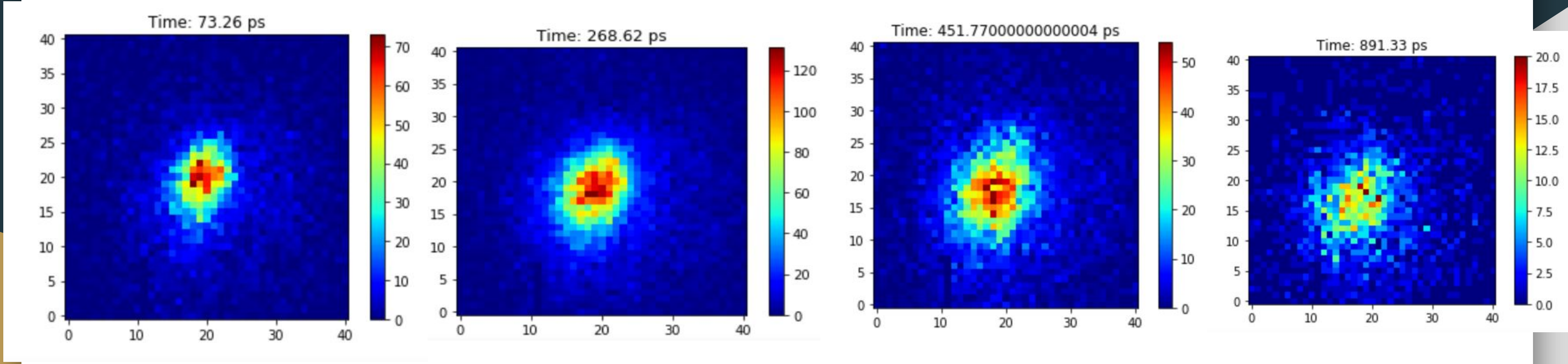
Source:
https://archive.cnx.org/resources/2b8da8e222954317cb6a8c2af9ecc7f2f899dab0/Object%2013c.jpg

Methods/Actions #2

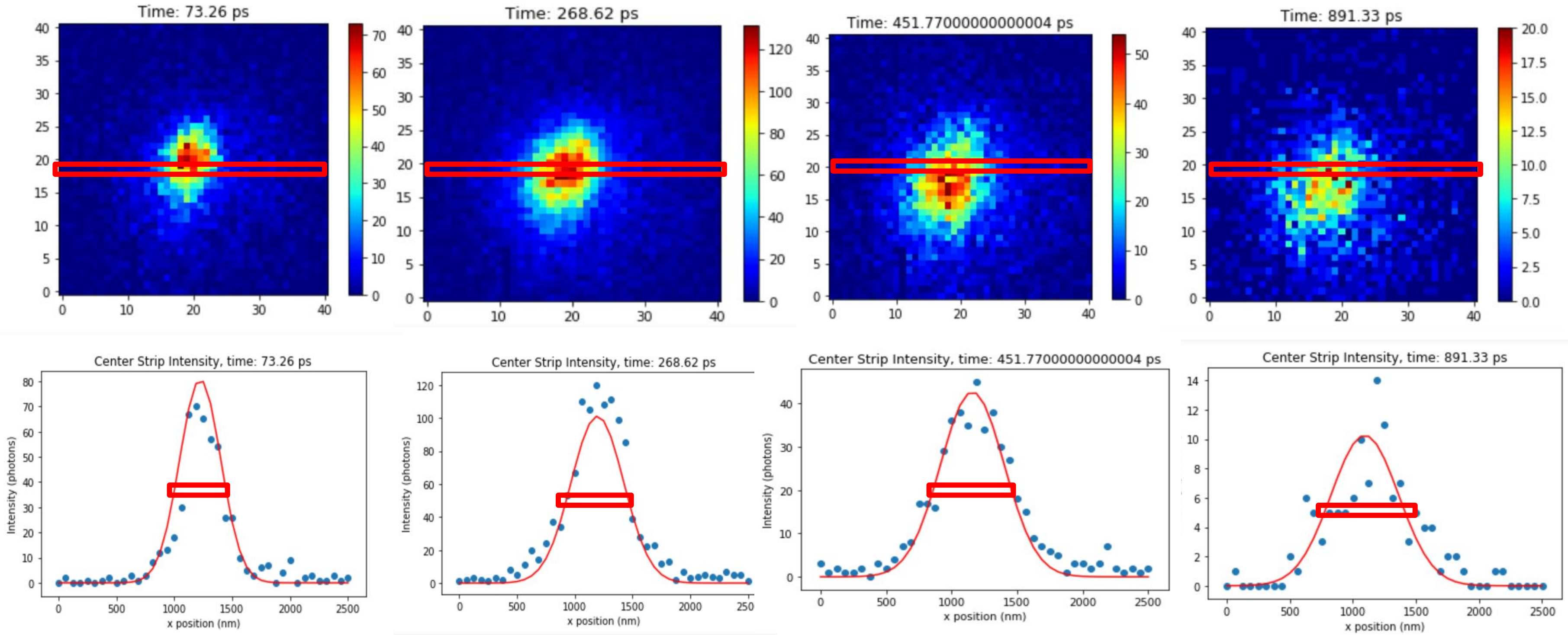


Source:
https://archive.cnx.org/contents/81bb0311-98ee-4cfc-b3c8-0eab6aeace37@2/photoluminescence-spectroscopy-and-its-applications

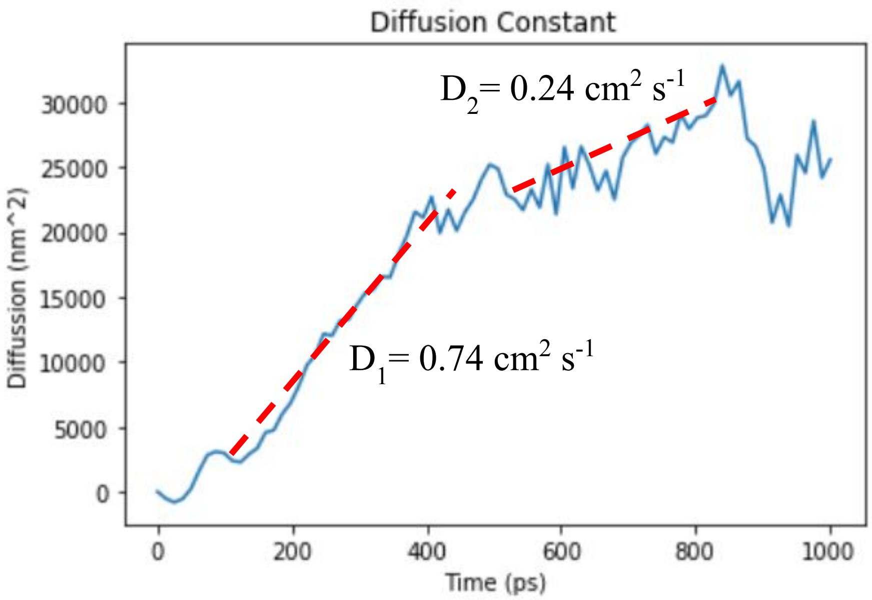
Diffusion over Time



Diffusion over Time

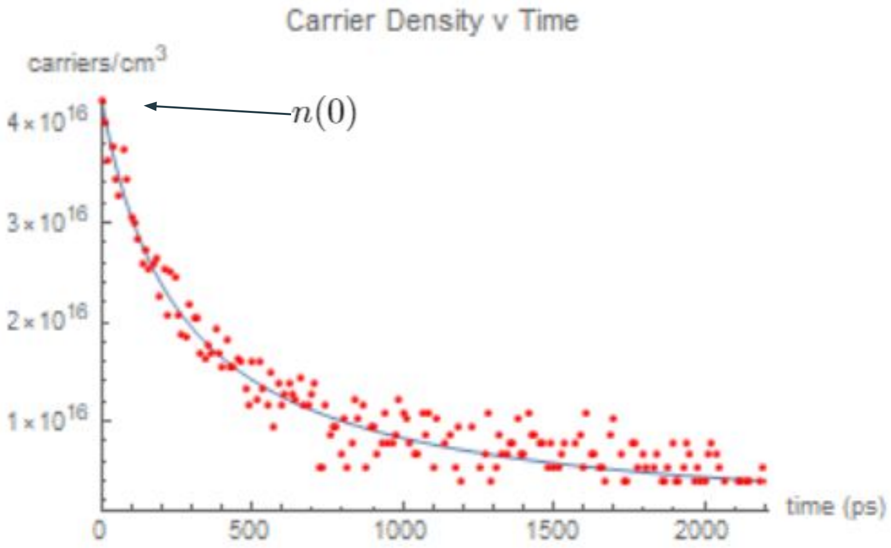


Diffusion over Time



- Modeled by width of gaussian curve
- $D_1 = 0.74$ cm^2 s^{-1}, t = (183, 400) ps
- $D_2 = 0.24$ cm^2 s^{-1}, t = (450, 830) ps

Intensity vs Time (Recombination Measurements)

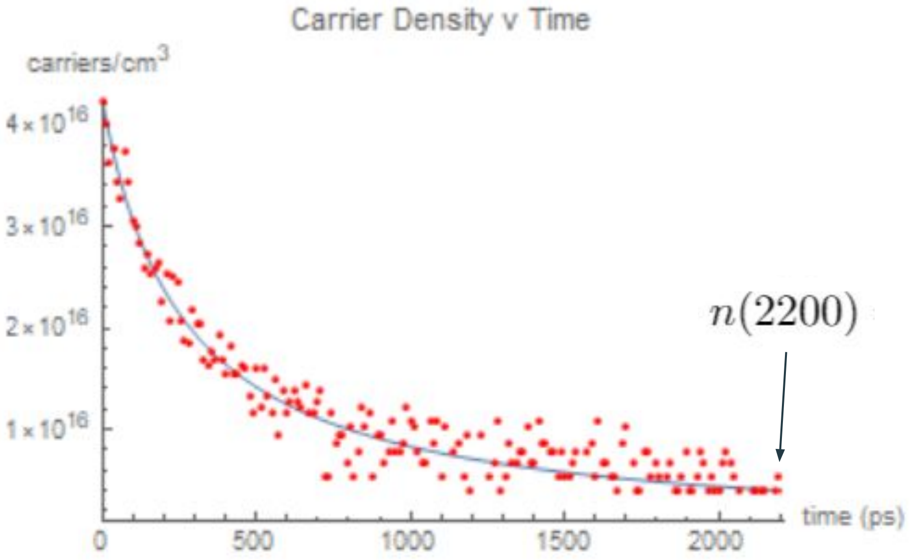


$$n'(t) = -a \cdot n(t) - b \cdot n(t)^2$$

$$a = 1.10 \cdot 10^{-4}\ \mathrm{ps}^{-1}$$
$$b = 8.87 \cdot 10^{-20}\ \frac{\mathrm{cm}^3}{\mathrm{carrier{\cdot}ps}}$$

$$b \cdot n(0) = 3.77 \cdot 10^{-3}\ \frac{\mathrm{carrier}}{\mathrm{cm}^3{\cdot}\mathrm{ps}}$$

Intensity vs Time (Recombination Measurements)

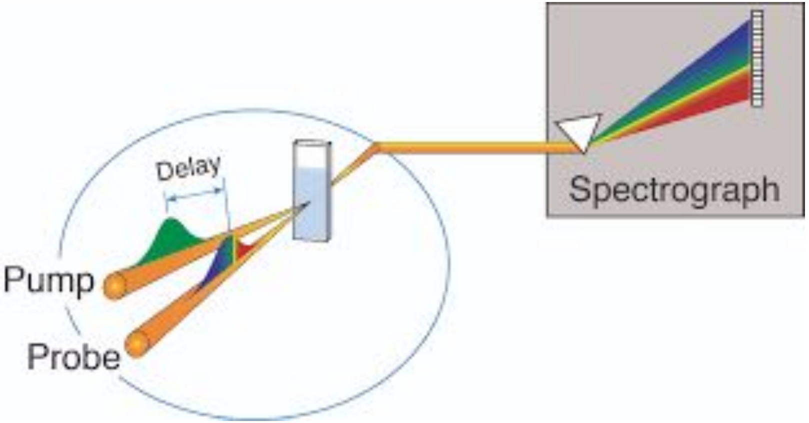


$$a = 1.10 \cdot 10^{-4}\ \mathrm{ps}^{-1}$$
$$b \cdot n(2200) = 3.42 \cdot 10^{-4}\ \frac{\mathrm{carrier}}{\mathrm{cm}^3 \cdot \mathrm{ps}}$$

Results

- Recombination: Band-to-band recombination has a 34.3 times larger effect than trap-assisted recombination initially, but decreases to 3.11 times larger
- Diffusion: The rate of diffusion decreases over time as carrier density decreases. $D_1 = 0.74\ cm^2\ s^{-1}$ over first ~400 ps, $D_2 = 0.24\ cm^2\ s^{-1}$ over next ~400ps

Future Work



Source:
https://www.google.com/url?sa=i&source=images&cd=&ved=2ahUKEwiYk9LT5L7jAhVPJt8KHWnwDNwQjRx6BAgBEAQ&url=https%3A%2F%2Fellesgroup.ku.edu%2Fta_spectroscopy&psig=AOvVaw2f8LIqJ0hHzpxtwtQNUFIw&ust=1563549065453525

Acknowledgements

We would like to thank Dr. Wu for his support, time, and lab space during the summer. We would also like to thank Dr. Bennett and Dr. Tang for their support and help on this project. Additionally we would like to thank Dr. Shoemaker, the NCSSM staff, the NCCU staff, the SNCURCS staff, the Carolina Livery drivers, and all those who helped contribute to making this project possible.