Understanding Carrier Density and Electric Field Effects on Valley Dynamics in 2D Transition Metal Dichalcogenides

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Valleytronics is an emerging field of electronics and optoelectronics that aims to store information by manipulating the valley degree of freedom. Within this field, 2D transition metal dichalcogenides (TMDCs) are attracting much attention due to their unique properties that may aid in developing valleytronic devices. Currently, a major limitation of valleytronics remains its short valley polarization lifetime, or the amount of time that information can be stored [1]. Understanding the mechanism behind valley polarization is a major step towards overcoming this hurdle. In this study, we applied an out-of-plane electric field while changing carrier density as well as isolating the effect of the out-of-plane electric field. Previous attempts at investigating valleys in TMDCs have dealt with defect engineering, creation of heterostructures between two different TMDCs, and application of an out-of-plane magnetic field [2,3]. However, the carrier density and electric field effects have yet to be extensively studied experimentally, though theory has been proposed [4,5]. For testing both carrier density and electric field effects we used a WSe_2 monolayer placed between hBN and graphene on gold. To isolate the electric field effect, we used another device where we completely encapsulated a WSe_2 monolayer with hBN on gold, using graphene again to connect the electrodes. Optical measurements were carried out at low temperatures, as it has been reported that valley polarization is more pronounced [5]. We will report on the results of this experiment and its repercussions. Our research is an important step towards laying a foundation for realizing modern valleytronic applications.

[1] J.R. Schaibley *et al.* Nature Rev. Mat. **1**, 16055 (2016).
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[5] Y. Miyauchi *et al.* Nat. Commun. **9**, 2598 (2018).

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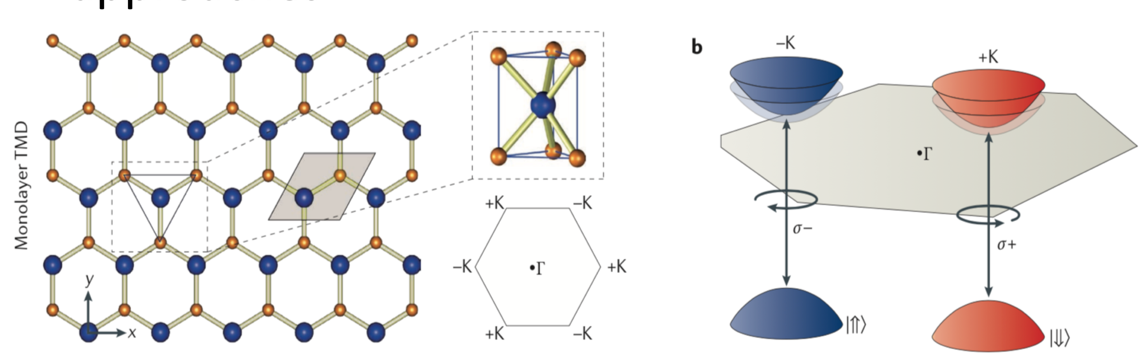
Beyond Silicon

Valleytronics is a new field of optoelectronics:[1]

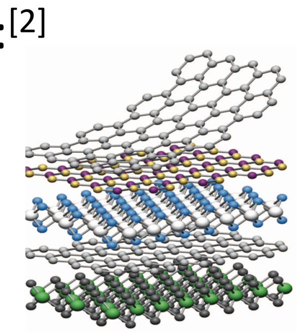
- +K and –K are analogous to 0 and 1 in binary
- Limited by the amount of time we can store information (valley polarization) $\rho = \dfrac{I_{\sigma^+} - I_{\sigma^-}}{I_{\sigma^+} + I_{\sigma^-}}$
- Faster and more efficient than conventional approaches



Momentum Space Depiction of Valleytronics in TMDCs[1]

2D TMDs can help enable Valleytronics:[2]

- Stronger coulomb interactions
- Heterostructures
- Longer valley polarization
- Tunable valley effects


2D Stacking[2]

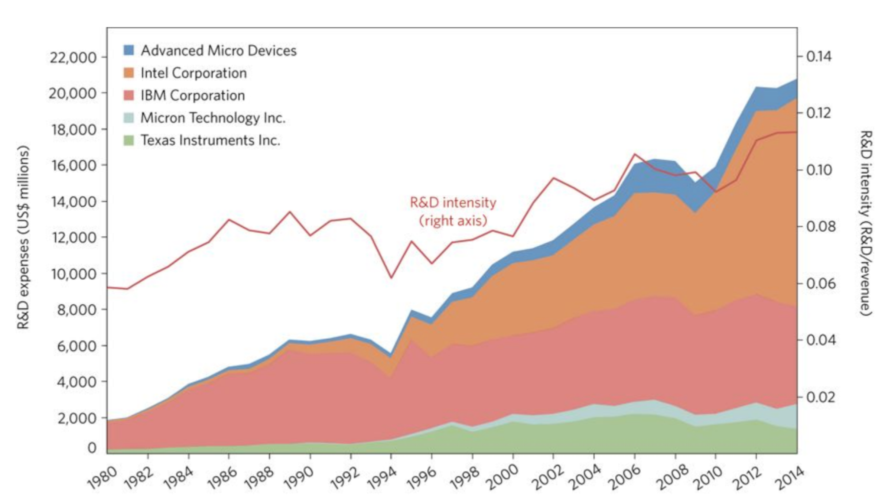
Research Question

How can we utilize electric field and carrier density (number of electrons) effects to manipulate valley dynamics in TMDCs?

Entering Quantum Regime

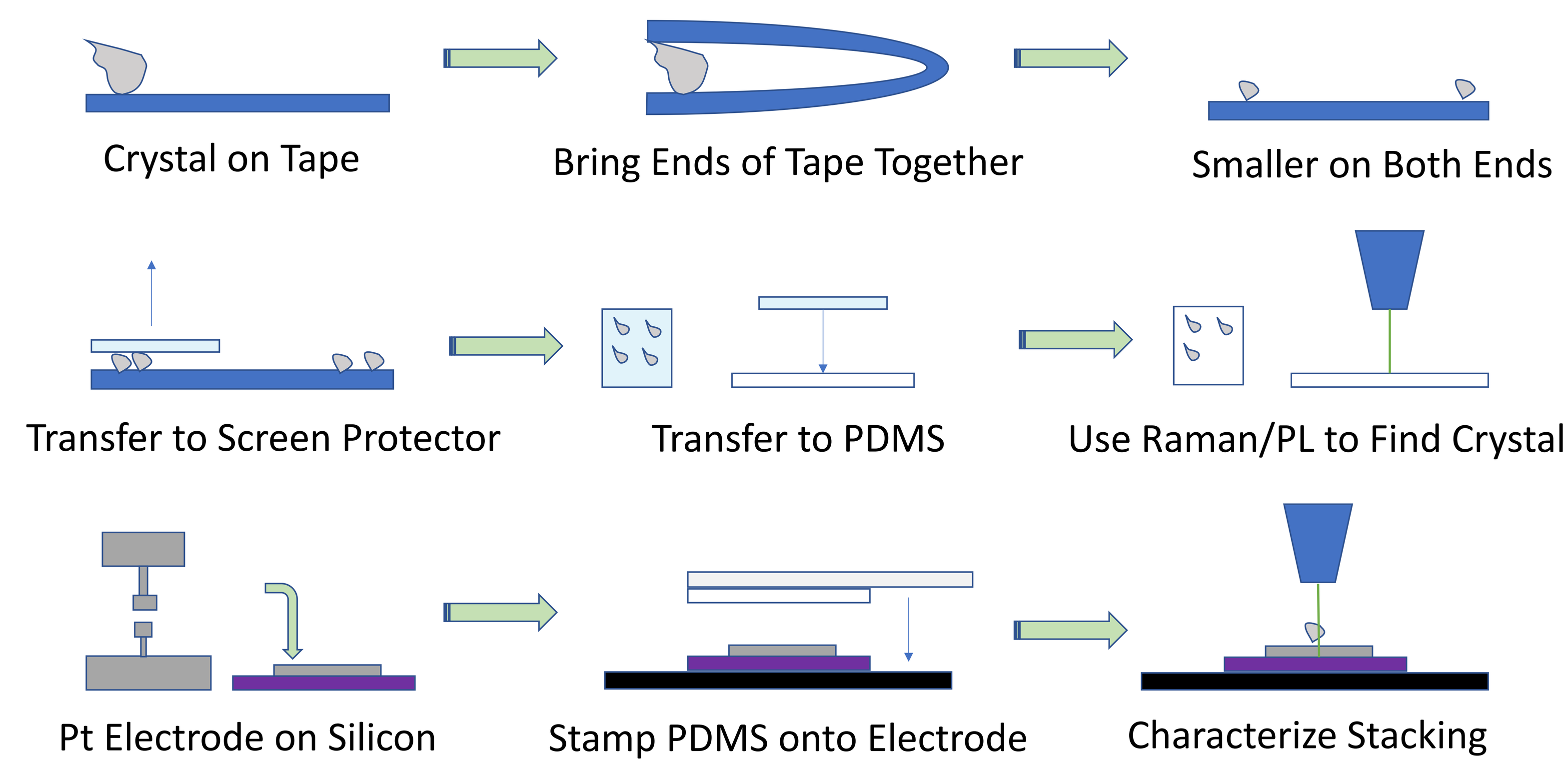
Nearing the end of Moore's Law:

- Encounter immense heating and electron leakage as we experience quantum effects
- Current Solutions: 3D chip sets, parallel processing[3]
- We need **ALTERNATIVES** to Silicon

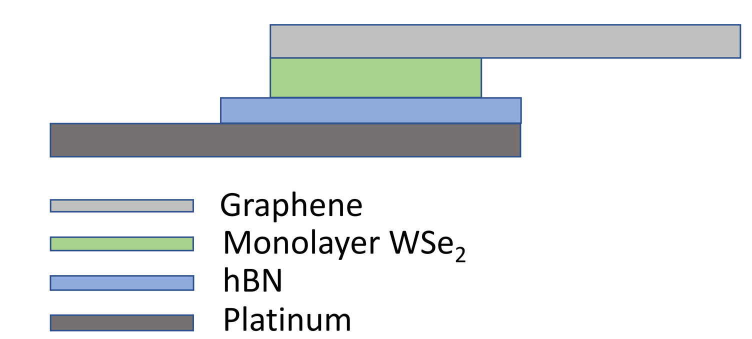


Acceleration of R&D costs as manufacturing firms face new challenges[3]

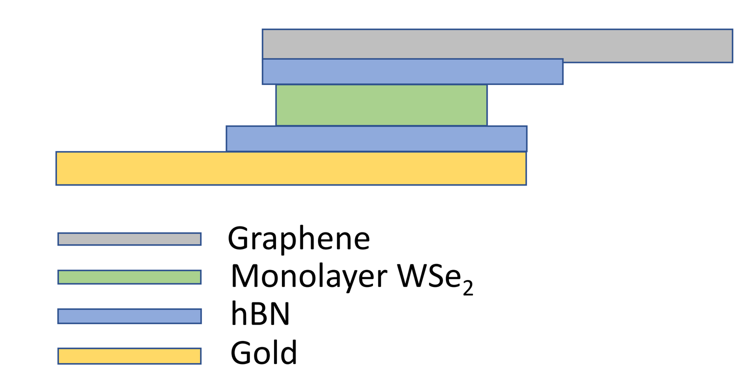
Device Fabrication



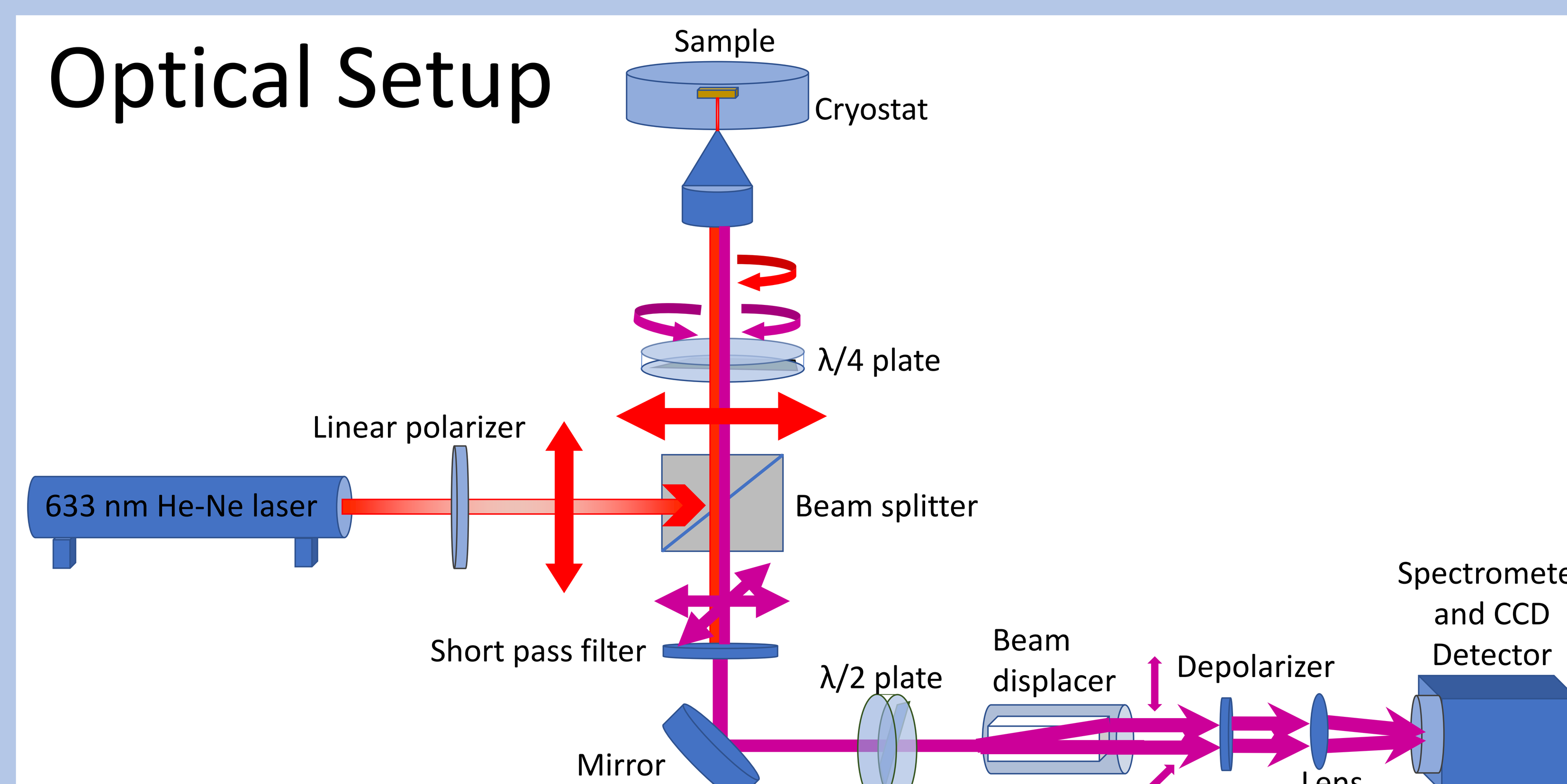
Carrier Density & Electric Field Device



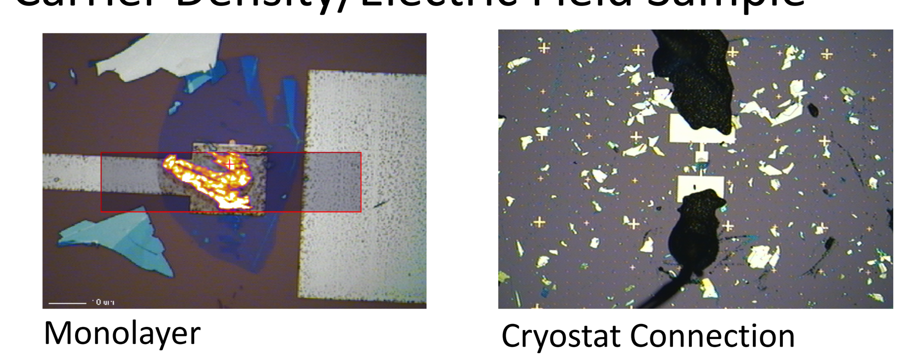
Electric Field Device



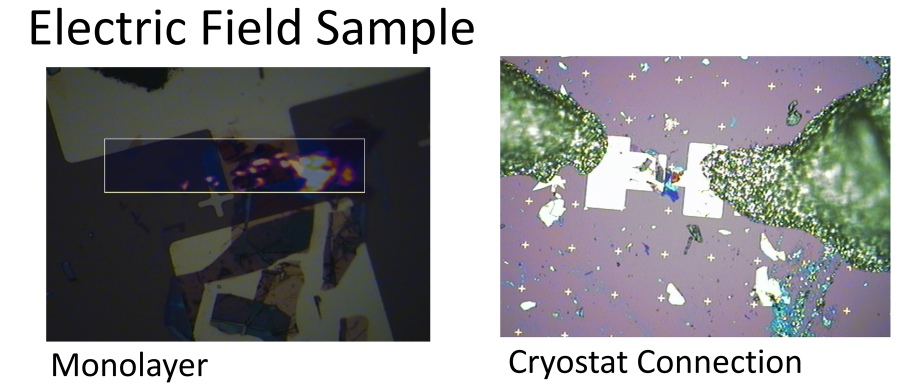
Optical Setup



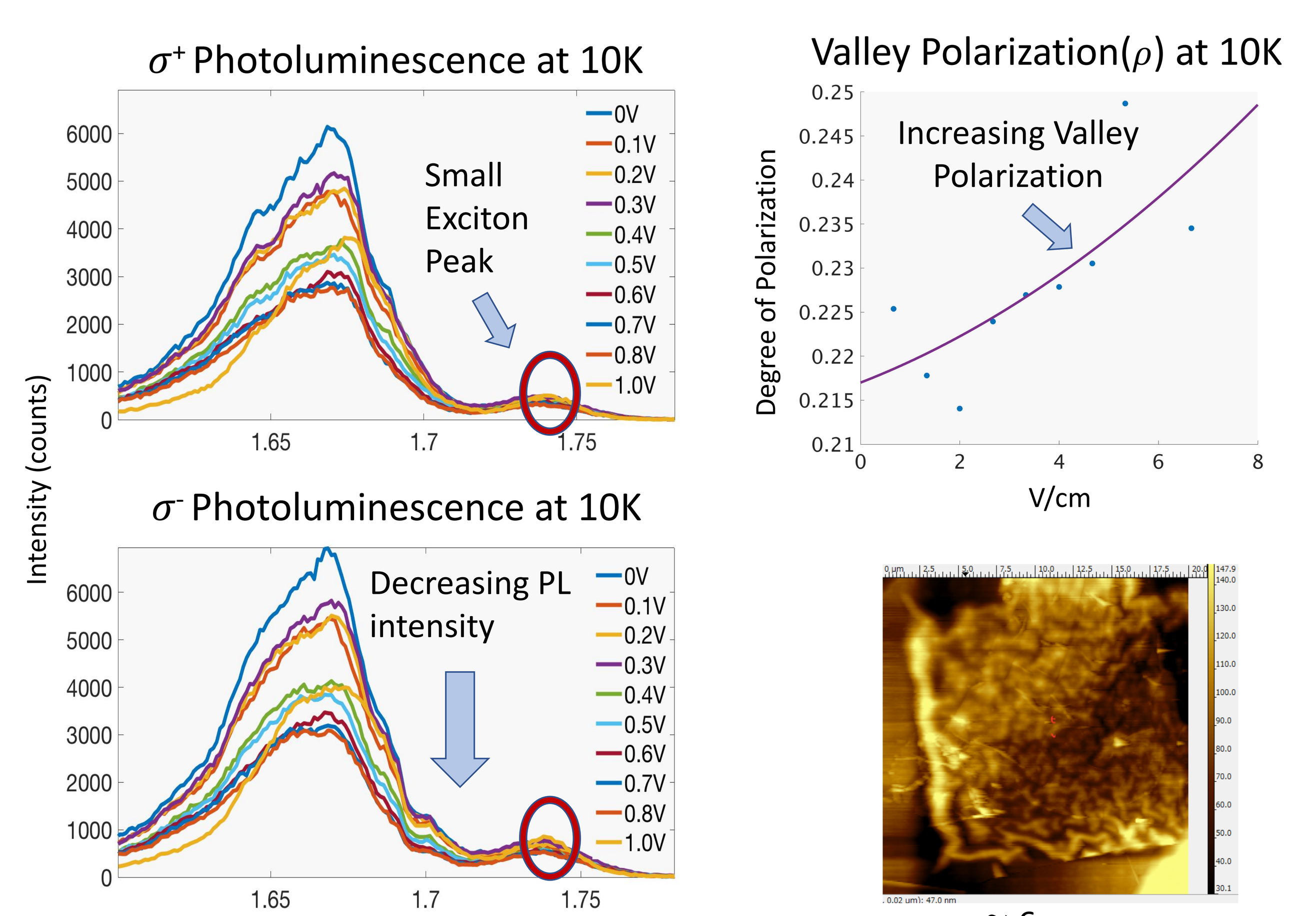
Carrier Density/Electric Field Sample



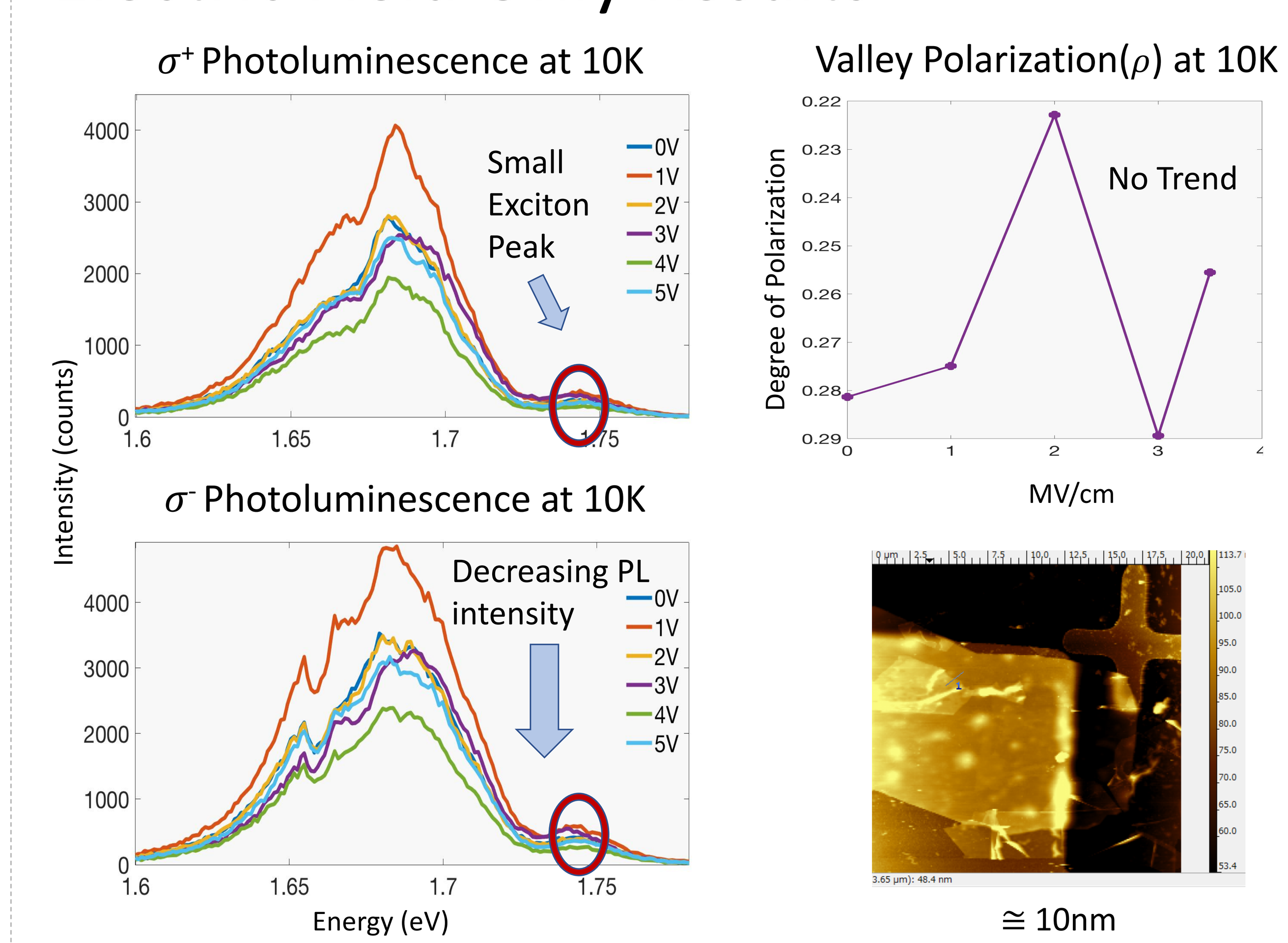
Electric Field Sample



Carrier Density & Electric Field Results



Electric Field Only Results



Conclusions

Successfully created two final devices that meant to test both the electric field and carrier density effects in 2D

- Demonstrated decreasing PL intensity with increasing voltage
- Possible means of controlling valley polarization using a combination of electric field and carrier density change as predicted by our previous work where E_F is carrier density:[4]

$$\rho_x = \frac{\rho_0}{1 + \langle \tau_x \rangle \Gamma_h / C\hbar\left[1 - \exp\left(-E_F / k_B T\right)\right]^2}$$

- Need to continue testing with better sample quality with more noticeable exciton peak

These results are instrumental in further understanding the mechanisms behind manipulating information using Valleytronics

Future Work

- Isolate carrier density and electric field
- Find sample with better exciton/trion separation
- Utilize a heterostructure under electric field
- Confirm repeatability of experiments

References

[1] J.R. Schaibley *et al.* Nature Rev. Mat. **1**, 16055 (2016).
[2] K.P. Loh Nat. Nanotechnol. **12**, 837–838 (2017).
[3] H. Khan *et al.* Nat. Electron. **1**, 14-21 (2018).
[4] Y. Miyauchi *et al.* Nat. Commun. **9**, 2598 (2018).

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