Two-Dimensional Mapping of Energy Transfer in Graphene/MoS$_2$ Photodetectors

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Background

**Single Atom Thick Crystals**

- Used for next-generation electronics
- Stacked into “Heterostructures” to create new electronics
  - Smaller
  - Faster
  - More Efficient
  - Flexible


Graphene and MoS$_2$

Purpose

Problem
Research has yet to uncover how structures of graphene and MoS$_2$ work on an atomic scale

Goal
Use photoluminescence Mapping to understand the energy transfer in heterostructures of graphene and Molybdenum Disulfide
Methods
Sample Fabrication

Crystal Exfoliation

Van der Waals Forces

Images created by the student researcher
Methods
Sample Fabrication

Crystal Exfoliation → Identification

Images created by the student researcher

100x magnification
**Methods**

Sample Fabrication

- **Crystal Exfoliation**
- **Identification**
- **Stamping**

Dual Micromanipulators

Viscoelastic Stamp (Green)

Images created by the student researcher
Results

Three-Layer: MoS$_2$ on top, MoS$_2$ on bottom

Images created by the student researcher
Two-Dimensional Mapping
LabVIEW

Images created by the student researcher
Two-Dimensional Mapping
LabVIEW

Images created by the student researcher
Two-Dimensional Mapping

LabVIEW

(This process takes 30 min. to 2 hours)
Photoluminescence

• Photoluminescence is a measure of light absorption\(^1-3\)
  • The less photoluminescence we see emitted, the more energy is being absorbed
Results

Photoluminescence Maps

Images created by the student researcher
Discussion
Photoluminescence Maps

Graphene decreased MoS$_2$’s PL by a factor of 27 and 35

Electrons are not allowed to recombine

Electrons are moving from MoS$_2$ to graphene

27x Quenching

35x Quenching

Images created by the student researcher
Discussion

Photoluminescence Maps

6x higher photoluminescence where graphene touches MoS$_2$

This sample was studied over a year after fabrication

A new phenomenon is dominating the energy transfer in this structure
Discussion
Photoluminescence Maps

A new phenomenon is dominating the energy transfer in this structure.

Clean Heterostructure

- Graphene
- MoS$_2$
- Graphene

Pure Silicon Crystal
A new phenomenon is dominating the energy transfer in this structure.

Oxidation creates an ion layer on top.

Si becomes SiO$_2$ with oxide ion layer.

**Heterostructure exposed to air**

Images created by the student researcher.
**Discussion**

**Photoluminescence Maps**

A new phenomenon is dominating the energy transfer in this structure.

**Heterostructure exposed to air**

Images created by the student researcher
A new phenomenon is dominating the energy transfer in this structure.

**Discussion**

**Photoluminescence Maps**

*Images created by the student researcher*

**Heterostructure exposed to air**

![Diagram showing a heterostructure with layers labeled as Oxide Layer, Graphene, MoS2, Graphene, and Pure Silicon Crystal.]
**Discussion**

**Photoluminescence Maps**

A new phenomenon is dominating the energy transfer in this structure.

Graphene protects MoS$_2$ from environmental effects.

**Heterostructure exposed to air**

- Pure Silicon Crystal
- Oxide Layer
- Graphene
- MoS$_2$
- Graphene
- Oxide Layer

Images created by the student researcher
Our research is the first to create a working model of how graphene and MoS$_2$ interact.

Establishing the groundwork principles of crystal interactions will enable the application of these crystals in new electronics.

Graphene can encapsulate MoS$_2$ and preserve its electronic properties.

Preservation techniques will help bring these electronics out of the lab and into everyday life.
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The data and figures presented in this research were created entirely by the student researcher unless otherwise noted. All procedures were carried out by the student researcher.
Review of Literature

Zhang et. al (2014)

- Proof-of-concept for CVD-grown graphene/MoS$_2$ devices
- Used preliminary Raman Spectra to extrapolate charge carrier movement

Buscema et. al (2014)

- Investigated the effect of substrate on the photoluminescence (PL) of MoS$_2$
- SiO$_2$ ions reduced PL of MoS$_2$
- Zhang et. al (2014) did not investigate effect of substrate