Characterizing MoS2-Si p-n Heterojunction Using Laser Terahertz Emission Spectroscopy

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Atomically thin two-dimensional (2D) materials demonstrate markedly different properties from their bulk (3D) counterparts, which could lead to interesting applications for optoelectronic and electronic devices. Advancements in the creation of these 2D semiconductor materials have expedited the fabrication of a variety of 2D-2D and 2D-3D van der Waals heterojunctions with novel properties compared to those of typical covalently bonded semiconductor junctions. However, the characteristics of 2D-3D semiconductor junctions have not yet been extensively studied and are therefore not well understood. In this study, we examined the emission of terahertz radiation from a heterojunction created with n-type monolayer MoS2 and p-type bulk Si using laser terahertz emission spectroscopy. The results of this study will provide new insight into the nature of the MoS2-Si p-n junction energy states (e.g., band alignment and bending) as well as allow us to better understand how the properties of 2D-3D junctions differ from those of conventional 3D-3D junctions.
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Introduction

The “Terahertz Gap”
- Spectral region 0.3 – 3.0 THz (1 mm - 100 µm)
- Final frontier for improving optoelectronic and electronic devices
  - Low energy usage
- Atomically thin two-dimensional (monolayer/2D) materials differ significantly from bulk (3D) counterparts
  - Van der Waals bonds (2D) vs. covalent bonds (3D)
  - MoS$_2$ characteristics
    - Direct band gap of 1.8 eV (2D) vs. indirect band gap of 1.3 eV (3D)
    - Stable charge exciton state at room temperature (2D)
  - Unique applications for optoelectronic and electronic devices

Objectives

Investigate 2D-3D heterojunction MoS$_2$-Si
- n-type (electron majority carrier) monolayer MoS$_2$ and p-type (hole majority carrier) bulk Si

Gain new insight into the nature of the MoS$_2$-Si p-n junction energy states
- Band alignment
- Band bending

Understand how the properties of 2D-3D junctions differ from those of conventional 3D-3D junctions

Methodology

Laser Terahertz Emission Spectroscopy and Imaging
- Sensitive to electric fields in MoS$_2$-Si heterojunction
  - Map out distribution of electric fields (band bending)

Optical Imaging
- Determine resolution of system
- Optimize alignment of system in order to perform terahertz imaging

Methodology

Terahertz Imaging
- Evaluate terahertz emission from MoS$_2$ p-n heterojunction

Raman Microscopy and Spectroscopy
- Monitor the deterioration of MoS$_2$ p-n heterojunction and categorize different materials within the sample

Framework

Results and Discussion

Current alignment and resolution of system
- Photoconductive antenna

Conclusions and Future Work

Finer tuning will be required to achieve higher quality optical and terahertz images
- Currently resolution is ~5 µm
- Resolution up to ~1 µm achievable

Delay the deterioration of p-n heterojunction
- Determine the thickness of resultant bulk MoS$_2$ layers
- Understand why oxidation of silicon results in apparent conglomeration of MoS$_2$

Reference

1 Bo Li et al., in preparation

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