Chemical Treatment Effects on the Optical Properties of Single to Few-Layer Molybdenum Disulfide

Domenic DiGiovanni1,2, Roel L. Flores3, Angelica Coleman4, Rui Wang5, and Yaqiong Xu3,5,6


Hilldale College, 33 E College Street, Hilldale, WI 53535
Vanderbilt University, 2201 West End Avenue, Nashville, TN 37235

Abstract

This study focuses on the optical properties of single and few-layer molybdenum disulfide to chemically treated with ozone plasma. In particular, we investigated the effects of prolonged exposure to ozone plasma on the photoluminescence and Raman spectra of the treated MoS2 samples. The cumulative length of exposure to ozone plasma, the number of layers of MoS2 in each sample, and whether a given sample was annealed prior to treatment were all considered.

Materials and Methods

Mechanical Exfoliation: MoS2 flakes were taken from bulk MoS2 using Scotch tape. The tape was used to peel back layers from the bulk MoS2, then the tape was folded in order to spread and separate flakes. The flakes were then transferred from the tape to a silicon dioxide-coated wafer. The flakes were characterized by optical microscopy and Raman spectroscopy.

Vapor-Solid Synthesis: MoS2 powder was used as a source and a SiO2-coated wafer as a substrate. The source was placed in a quartz tube and heated to 900°C in a furnace. A carrier gas, argon, flowed through the tube to bring the MoS2 vapor to a colder portion of the furnace. The substrate was placed at the cold region. The collected MoS2 would then form monolayer films on the substrate. This process was attempted but unsuccessful, as no monolayer films and only extremely small crystals were observed.

Background

Molybdenum disulfide, in its monolayer form:
- Acts as a direct bandgap material with a bandgap of about 1.8 eV, unlike bulk MoS2, which is an indirect bandgap material.
- Has a photoluminescence demonstrated to be much higher than thicker MoS2.
- Is often compared to graphene, another two-dimensional material known for its applicability in electronics; graphene has been found to exhibit a higher photoluminescence after oxygen plasma treatments1, though ozone plasma and x-ray treatments can introduce defects into the material and hinder its electronic performance.2 This comparison suggests that it is important to attempt similar treatments on MoS2 in order to expand our understanding of the material.

Results and Conclusions

Comparing the photoluminescence response across annealed and non-annealed samples of varying thicknesses over the course of several intervals of plasma treatment, we found that single-layer molybdenum disulfide samples that had been annealed exhibited a significantly greater response to the ozone plasma treatment. We hypothesize that these responses are a result of the absorption of oxygen by the MoS2 during treatment, as oxygen adsorption has been shown to enhance photoluminescence in MoS2. The Raman spectra show slight separation variations and left-shifting, but the data does not support a definitive conclusion.

Future Research

Future research stemming from this project will involve:
- Continuing study of the etching and photoluminescence enhancement effects.
- Repetition of the experiment using other treatments such as oxygen plasma or x-rays in order to better establish the mechanism of photoluminescence enhancement.
- Study the effects of chemical treatments on the electronic properties of MoS2.
- Re-evaluation and improvement of vapor-solid synthesis methods.

References


The authors are grateful to Dr. Anthony Hmelko, Dr. Bo Choi, Dr. Dimitry Kuklysh, Dr. Jed Ziegler and other VNSE staff members for training and permission to use the facility. This work was supported by the National Science Foundation (TN-SCORE DMR 0907610, ECCS-1055852, and CBT-1264982).