CHAPTER I
INTRODUCTION

1.1 Background and motivation

Semiconducting transition metal dichalcogenides (TMDs) materials with high carrier mobility, high ON/OFF current ratio, and versatility have been attractively studied to replace the silicon-based semiconductors (Bhimanapati et al., 2015; Mattheiss et al., 1973). They exhibit unique physical and optical properties such as the transition from indirect to direct bandgap upon thinning down from bulk to monolayer, which are essential for designing the electronic and optoelectronic devices (Mak et al., 2010). For example, the ultrathin MoS_2 layer exhibits intense photoluminescence and tunable bandgap. These behaviors are applicable in tunable optical platforms including phototransistors (Lee et al., 2012; Yin et al., 2011), photodetectors (Lopez-Sanchez et al., 2013), and gas sensors (Kumar et al., 2020).

Furthermore, Raman spectroscopy may be used as a quantitative diagnostic tool to characterize MoS_2-based transport channels (Splendiani et al., 2010). The replacement of the main metal oxide by 2D materials has also been demonstrated by their efficacy in gas sensing, with detection down to 1 ppb concentration of distinct gases (NO_2, NH_3, CO, and H_2O) and detection to even single gas molecule in ambient condition. For example, Schedin et al. utilized graphene, established the first gas sensor (Schedin et al., 2007). Among the all 2D materials, MoS_2 stands out as one of the most promising layered materials for the development of gas sensors due to its remarkable attributes, such as a high surface-to-volume ratio, substantial adsorption coefficient, and distinctive thickness-dependent electrical and chemical properties. Li et al. studied the gas and MoS_2 interaction by fabricating FET sensors from the monolayer, 2 layers, 3 layers, and 4 layers of the MoS_2 (Li et al., 2012).

Another work, Late et al. studied the FET gas sensor from a monolayer to a multilayer MoS_2 using the mechanical exfoliation technique and found that monolayer of MoS_2 exhibited an unstable current response over time.

The NO and NH_3 sensing responses of 3, 4, and 5 layers MoS_2 at room temperature were compared and they found that the 5 layers MoS_2 showed higher sensitivity to gas than 2 layers MoS_2. They explained the result by analyzing the resistance of n-type MoS_2, which changes after adsorption of NO_2 or NH_3 due to the charge transfer mechanism. NO_2 in nature, which contains an unpaired electron on the N atom, removes electrons from MoS_2, which then shifts the Fermi level closer to the valence band. MoS_2 is more sensitive to NO_2 than NH_3 because the adsorption energy of NO_2 is greater than that of NH_3 (Late et al., 2013).

Further studies of the charge transfer mechanism, conducted by Cho et al. via in-situ photoluminescence (PL) experiments, show that the electronic interaction between NO_2 and MoS_2 converts the neutral (A and B) excitons into a quasi-particle trion by creating a hole through the extraction of another electron. Conversely, NH_3 interaction dissociated the trion into neutral excitons by providing electrons to MoS_2. Consequently, in the PL spectra, the trion peak intensity increased (decreased) upon NO_2 (NH_3) interaction with MoS_2, while the opposite occurred for the neural exciton peak intensity (Cho et al., 2015).

Many researchers have put efforts into studying and have found exciting sensing results from MoS_2 gas sensors, however there is still a need to optimize the surface, atomic structure, and electronic structure for better sensitivity. A comprehensive understanding of the gas sensing mechanism requires a more detailed analysis, including a multitude of variables including surface states, edge locations, defects, crystallinity, strain, electrical, and chemical properties. Therefore, in this work, we would like to study the bandgap engineering of the monolayer MoS_2 surface via photoluminescence methods. We modify the surface by electron irradiation, using low energy SEM, and use confocal microscopy to study the photoluminescence of the resulting surface.

1.2 Research objectives

1.2.1 To study the variation of photoluminescence of monolayer TMDs after electron irradiation via SEM.

1.2.2 To study the variation of photoluminescence of monolayer TMDs that was electron irradiated after high power laser exposure.

1.2.3 To understand the mechanism that the photoluminescence intensity of MoS_2 decreases after high-power laser exposure and can recover when stored to ambient air.

1.3 Outline of thesis

This thesis is divided into five main chapters. Chapter I is the introduction that includes the background, motivation, and research objectives. In chapter II, we describe the fundamental structure, the electronic band structure, the photoluminescence of TMDs, defect in TMDs, and the effect of electron irradiation on the TMD surfaces. In chapter III, we describe the preparation of samples irradiated with electron via low energy SEM. Moreover, we explain the basics of confocal microscopy and Raman spectroscopy. Chapter IV presents the experimental results consisting of basic, monolayer characterizations, the behavior after electron irradiation and photoluminescence after high power laser exposure onto the sample. Moreover, we discuss the recovery of photoluminescence intensity after high power laser exposure and storage in the ambient condition. Finally, the conclusions of this thesis are given in Chapter V.