Abstract

Development in the manufacturing of transition metal dichalcogenides monolayers enables obtaining samples of increasing size, better optical quality, and higher sample stability over time. In particular, monolayer encapsulation in hexagonal boron nitride results in a narrowing of the observed emission lines in the photoluminescence spectrum. Therefore, the separation of numerous lines presents in the spectrum of so called dark materials, such as WS_2 or WSe_2, and their accurate study as a function of excitation power or the applied external magnetic field is possible. Such research empowers to analyse excitonic complexes present in the material. The narrowing of emission lines allows also the observation of dark excitonic complexes brightening in the magnetic field applied in plane of the investigated monolayer.

The main goal of the research conducted in this dissertation was to study excitonic complexes in monolayers of transition metal dichalcogenides. Bright excitonic complexes were observed in the optical measurements such as photoluminescence, reflectance contrast or photoluminescence excitation. To determine the energy of dark excitonic complexes in WS_2 monolayer encapsulated in hexagonal boron nitride photoluminescence spectrum in the external magnetic field applied in plane of the sample was examined. In such an experimental condition dark and bright states are mixed resulting in the brightening of the dark excitons. Their optical recombination observation is possible. To identify phonon replicas of the forbidden excitonic complexes g-factors of observed emission lines in an external magnetic field were measured. Additionally, it was investigated how the photoluminescence spectrum of the monolayer is influenced by its dielectric environment. For this purpose WS_2 and WSe_2 monolayers placed in three dielectric environments are studied, in particular, the ML encapsulated in hBN flakes, the ML deposited on an hBN layer, and the ML embedded between the hBN flake and SiO_2/Si substrate.

The doctoral dissertation begins with an introduction which is a literature review and summary of the current state of knowledge about excitonic complexes in transition metal dichalcogenides. The next chapter presents measured samples, used techniques and measurement systems in the conducted research.

Chapters 3 – 8 contain research results along with analysis. The work begins with the characterization of the basic bright exciton complexes (chapter 3) in the photoluminescence and reflection contrast spectrum. Chapter 4 concerns the interaction of excitons with phonons. This interaction causes amplification of Raman modes and observations of a rich phonon spectrum. The next three chapters are devoted to the study of the WS_2 monolayer encapsulated in hBN. First, the dark excitonic complexes observed in this sample are presented (chapter 5). Chapter 6 is about the analysis of the remaining

emission lines present in its spectrum: phonon replicas, charged biexciton and semi-dark trion. Chapter 7 summarizes the obtained results of emission line g-factors in WS_2 encapsulated in hBN and compares them with theoretical calculations. This chapter also presents the method of determining the band g-factors in this material. Finally, in chapter 8 the influence of the dielectric environment on the photoluminescence spectrum, observations of dark excitonic complexes and the presence of phonon replicas in the WS_2 and WSe_2 monolayers are studied.

The last chapter summarizes the main results obtained in the work and presents the scientific author's achievements.