Electrical and mechanical investigations of the membranes based on transition metal dichalcogenides

Another of such material invented in recent years, giving new and unprecedented properties, become two-dimensional crystals. One of such material that has come into great attention is graphene. Although graphene band structure is the source of many interesting properties, but due to absence of a difference in the density of states and consequently the energy gap makes graphene difficult to use in conventional electronic switching systems. The discovery of this material has been recognized to the extent, that for study of its properties Andrei Gejm and Konstantin Nowosiolow in 2010 received the Nobel Prize.

In contrast, transition metal dichalcogenides (TMD) of general formula *MX2*, wherein M is a metal atom: Mo, W, Ti, Ta, Nb, Zr, and *X* is: S, Se or Te, exhibit a wide band-gap (e.g. 1.58 eV for MoS_2) as a result of breaking symmetry of the atoms forming a crystal lattice. TMD materials are particularly interesting for applications in electronics, e.g. for the construction of the Field Effect Transistors (FET). In the context of the presented project we would like to focus on the devices in the form of single layer of TMD material suspended above the micro cavity which forms a membrane. In the initial stage of the project, we will develop a membranes made from MoS_2, a material that is easily accessible. Subsequently, we plan to perform a basic research on other TMD materials, to predict the most interesting material in terms of application in proposed device. Basic research done on the TMD devices and structures is of great importance from research point of view e.g. its ultralow mass and exceptional optical properties, making them intriguing materials for opto-mechanical applications. The research done in the project will involve:

1. Development a process for manufacturing TMD materials suspended over microcavities.

In this task we want to develop a methodology that allows us to fabricate up to a single atomic layer TMD structure using mechanical exfoliation. Our aim is to develop a reliable process of TMD transfer from bulk crystal onto special fabricated Si/SiO_2 substrate containing microcavities, enabling also electrical biasing and contacting to the fabricated device. To control the quality of the exfoliation process, the following microscopic method: AFM, STM, SEM and Raman spectroscopy will be used.

2. Examining of electrical and mechanical properties of the TMD based devices.

The preliminary studies enabling to gather the knowledge about the properties of the TMD membranes are of the particular interest due to the lack of impact of the substrate material. This will allow to perform a series of investigations and characterization of the basic parameters, such as: Young's modulus, resonant frequency of the membrane, spring constant, work function and thermal conductivity factor. To our knowledge this type of complex research for TMD materials is generally unknown or little explored. The proposed metrology procedure will enable precise and versatile characterization of the fabricated TMD membranes.

In this project, we intend to apply: AFM, STM, SEM microscopic methods and related technologies. The use of these investigation technologies will allow to study electrical, mechanical and thermal properties of the TMD membranes. Raman spectroscopy is used to control the exfoliation process, but also to improve the accuracy of the estimated material parameters appointed by the microscopic methods. Structural studies will be associated with the use of X-ray diffraction and TEM microscopy. Please note that these research methods and techniques are complementary and have been performed by the project research team for many years. Moreover the research team have many years of experience in field of research of membranes fabricated from 2D material and especially graphene.

Investigations of the materials suspended over the microcavity will allow to study the properties of the material devoid from the influence of the substrate. In the case of such research, conducted investigations aimed at the understanding of the material properties are very important from not only scientific point of view but also will get deep insight to their potential use. The obtained results and the development of research methodologies allow for the development of innovative applications of new TMD materials e.g. in sensors and nanomechanical devices. Therefore, we believe that the study of two-dimensional TMD materials, will lead to their wide application possibilities, arising from their properties is very important from the point of view of the science done both in Poland, and across the world. Furthermore, the proposed research will help to train research team of specialists involved in the investigations of TMD materials.