MoS_2 Field-Effect Transistors for Ion Sensing: Ultrasensitive Hg^{2+} Detection

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Contamination of water with heavy metal ions represents a severe environmental problem resulting from the societal development. Among the various hazardous compounds, mercury (II) ions (Hg^{2+}) surely belong to the class of the most poisoning ones. Their accumulation in human bodies results in health deterioration, affecting all vital organs and eventually leading to chronic illnesses, overall lifespan shortening, and, in the worst-case scenario, premature death [1]. Because of this reason, the United States Environmental Protection Agency (EPA), the World Health Organization (WHO), and the European Union (EU) have established strict regulations on the quality of drinkable water. In particular, the maximum permitted concentration of Hg^{2+} has been set to 5-10 nM.

High performance can be achieved in chemical sensing by using suitable active materials capable to interact at the supramolecular level with the chosen species. Among those materials, 2D transition metal dichalcogenides (TMDCs) have attracted great attention as potential candidates because of their unique physical and chemical properties [2], which are highly susceptible to environmental changes. In this work, we have fabricated Hg^{2+} MoS_2-based sensors, relying on the affinity of heavy metal ions and point defects in TMDCs [3]. X-ray photoelectron spectroscopy characterization showed a significant reduction of the defectiveness of MoS_2 when exposed to Hg^{2+} solutions with increasing concentration. Low-temperature (77K) photoluminescence confirmed the defect healing, when observing a decrease of the defect-related bands after Hg^{2+} exposure. Transfer characteristics in the MoS_2 FETs provided unambiguous confirmation that Hg^{2+} acts as a p-dopant for MoS_2. Interestingly, we observed a strict correlation of this doping with the concentration of Hg^{2+}. Concentrations as low as 1 pM can be detected, being way below the restrictions imposed by health regulations. Moreover, the fabricated sensing devices displayed a high selectivity for Hg^{2+} against other metal ions. Electrical characterization also revealed that our sensing platform is reversible, since it can be washed and used multiple times without losing selectivity or sensitivity.

References:

[1] Holmes, P., James, K.A.F., Levy, L.S., Science of the Total Enviroment, 2009, 408 (2), 171-182
[2] Anichini, C.; Czepa, W.; Pakulski, D.; Aliprandi, A.; Ciesielski, A.; Samorì, P., Chemical sensing with 2D materials. Chemical Society Reviews 2018, 47 (13), 4860-4908
[3] Yi, H.; Zhang, X.; Jia, F.; Wei, Z.; Zhao, Y.; Song, S., Competition of Hg^{2+} adsorption and surface oxidation on MoS_2 surface as affected by sulfur vacancy defects. Applied Surface Science 2019, 483, 521-528

Figures:

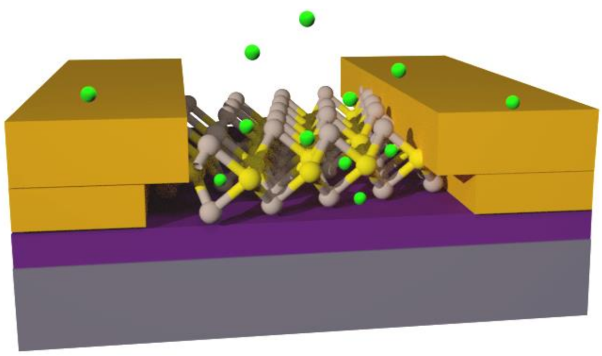

Figure 1: Schematic representation of Hg^{2+} ions (represented as green spheres) interacting with the MoS_2 flake, integrated in a back-gated FET geometry.