Ultrasensitive Mercury (II) Detection Platform by Engineering MoS_2-Based Field-Effect Transistors

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Pollution of water with heavy metal ions represents a severe environmental problem associated with societal development [1]. Among the various hazardous compounds, mercury (II) ions (Hg^{2+}) surely belong to the most poisoning ones. Their accumulation in human bodies results in health deterioration, affecting vital organs and eventually leading to chronic illnesses, and, in the worst-case scenario, premature death. Because of this reason, 5-10 nM represents the maximum permitted level of Hg^{2+} in drinkable water [2].
The most common ways of detection of Hg^{2+} in water are based on chromatographic or electrochemical methods [3]. Nevertheless, chemical sensors comprising highly sensitive and selective materials represent more powerful approaches to detect tiny amounts of specific analytes. In particular, low-dimensional materials combine high sensitivity with low limit-of-detection [4]. Among 2D materials, transition metal dichalcogenides (TMDCs) have attracted great attention because of their unique physical and chemical properties.
In this work, we have used MoS_2-based field-effect transistors (FETs) as a platform for Hg^{2+} sensing, relying on the affinity between heavy metal ions and point defects in TMDCs. By XPS characterization on CVD MoS_2, we found a significant reduction on the weight of the defect related peaks as the concentration of Hg^{2+} increased. Low temperature photoluminescence (PL) was also studied. By monitoring the defect contribution in the PL between 1.7 and 1.8 eV, we also confirmed the defect healing, in good agreement with the XPS measurements.
We found that Hg^{2+} acts as a dopant of MoS_2, evidenced by monitoring the transfer characteristics of the MoS_2 FETs. Interestingly, we discovered a strict dependence of the doping with the concentration of Hg^{2+}, following a semi-log tendency. Up to now, we are able to detect concentrations up to 1 pM, way below the health regulations. Electrical characterization showed the sensing platform can be washed and used several times.

References

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[2] US EPA, O. National Primary Drinking Water Regulations
[3] Malik, L.A., Bashir, A., Qureashi, A., Pandith, A.H., Environmental Chemistry Letters, 17 (4), 2019, 1495–1521
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Figure

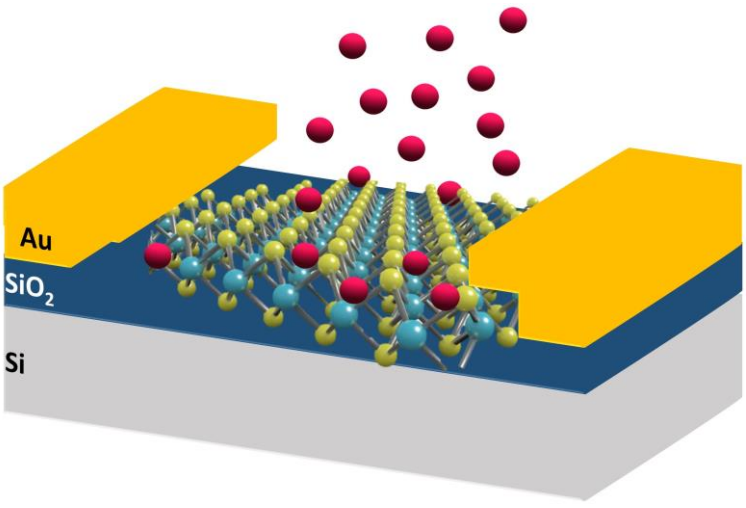

Figure 1: Schematic representation of a MoS_2-based FET interacting with Hg^{2+} ions, represented as red spheres.