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# $MoS_2$ FETs for Ultrasensitive Heavy Metal Ion Sensing

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## Abstract

Pollution of water with heavy metal ions represents one of the most severe environmental problems associated with societal development[1]. Among the assorted hazardous compounds, mercury ions ($Hg^{2+}$) are in 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[2]. Because of this reason, 10 nM represents the maximum permitted level of $Hg^{2+}$ in drinkable water[3].

The most common ways of detection of $Hg^{2+}$ in water are based on chromatographic or electrochemical methods[4]. On the other hand, chemical sensors comprising highly sensitive and selective materials represent powerful approaches to detect tiny amounts of specific analytes. As sensory materials, low-dimensional materials, displaying a highest surface-to-volume ratio, combine high sensitivity with low limit-of-detection[5].

Among 2D materials, 2D 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 (i.e. sulfur vacancies). We found that $Hg^{2+}$ acts as a dopant of $MoS_2$, evidenced by monitoring the transfer characteristics of FETs. Interestingly, we discovered a strict dependence of the doping with the concentration of $Hg^{2+}$, following a semi-log tendency. Preliminary results showed $MoS_2$ FETs can be used as ultrasensitive sensors, with an ultra-low limit of detection, below 100 pM.

## Experimental Results

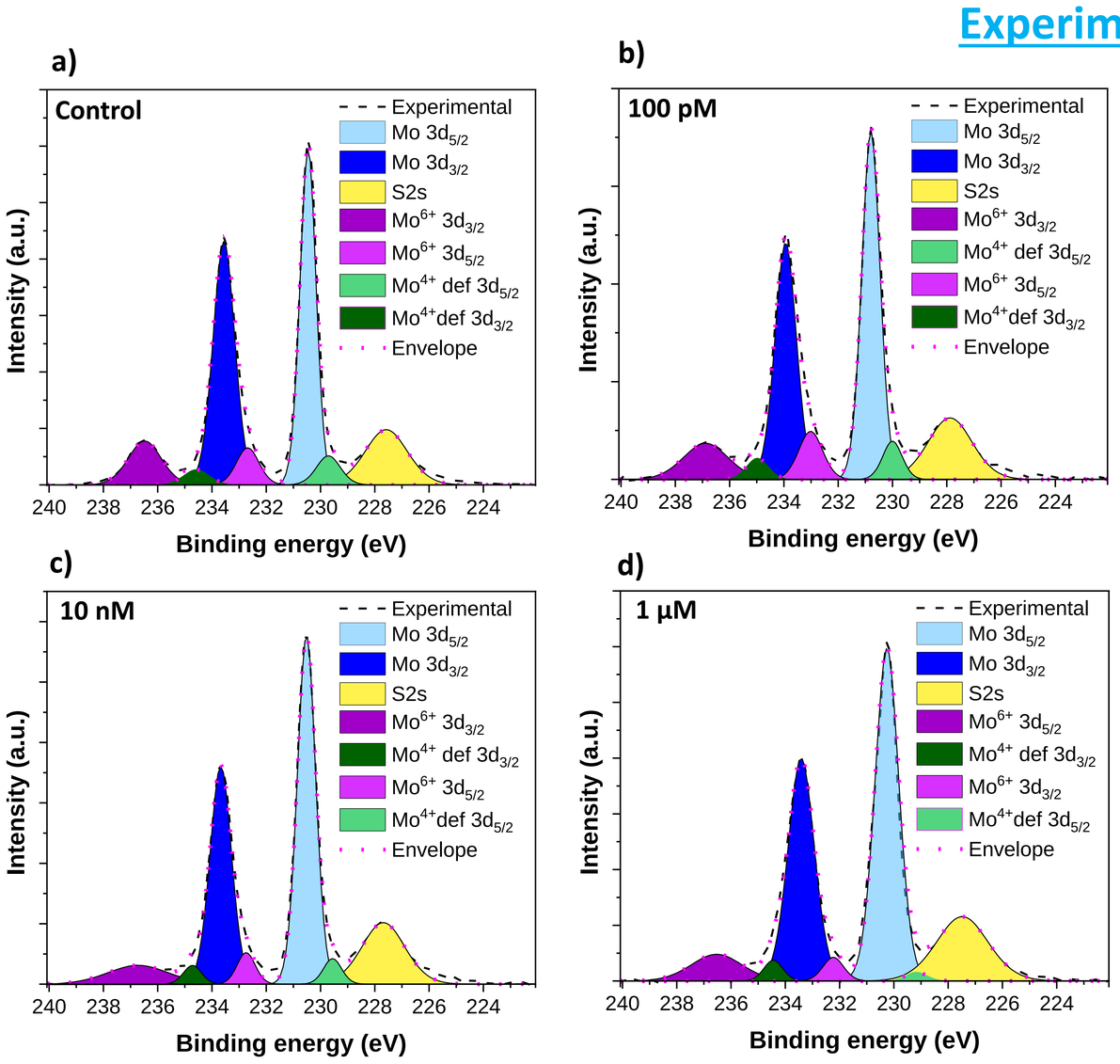


**Figure 1.** XPS characterization on CVD grown $MoS_2$ as a function of different $Hg^{2+}$ concentrations. Mo signal of: **a)** Pristine CVD $MoS_2$. **b)** $Hg^{2+}$ 100 pM. **c)** $Hg^{2+}$ 10 nM. **d)** $Hg^{2+}$ 1µM.

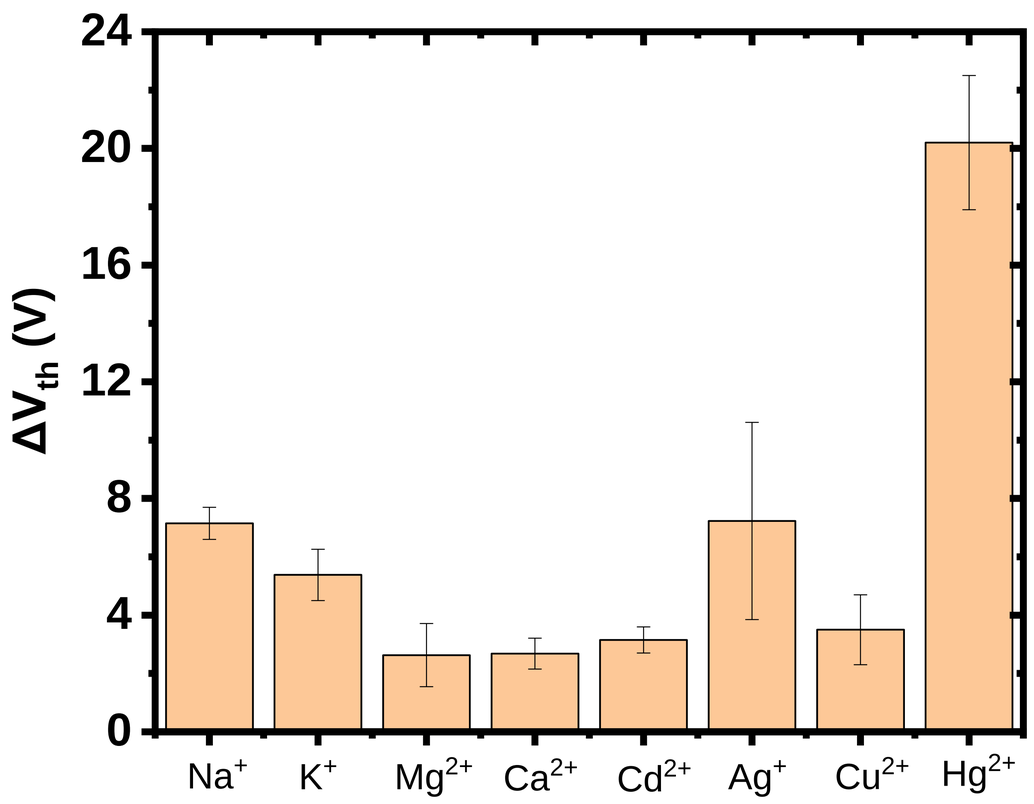


**Figure 2.** Selectivity study on $MoS_2$ FET. Variation in threshold voltage ($\Delta V_{th}$) as a function of different heavy metal ions at a concentration of 10 nM .

## Conclusions

In this work we have demonstrated $MoS_2$ FETs can be used as proof-of-concept devices for heavy metal ion sensing. In particular, we discovered a strict dependence of the doping with the concentration of $Hg^{2+}$, evidenced by monitoring the transfer characteristics of FETs.

XPS characterization displayed that, by increasing the $Hg^{2+}$ concentration, the defect contribution decreases. This is fundamental to understand the interaction between mercury ions and point defects.

Selectivity study shows the $Mos_2$ is highly reactive to $Hg^{2+}$ ions. It can be explained by the affinity between $Mos_2$ point defects and mercury.

More importantly, we observed the devices can be washed after every functionalization recovering the initial state, probing that $MoS_2/Hg^{2+}$ is a reversible sensing platform.

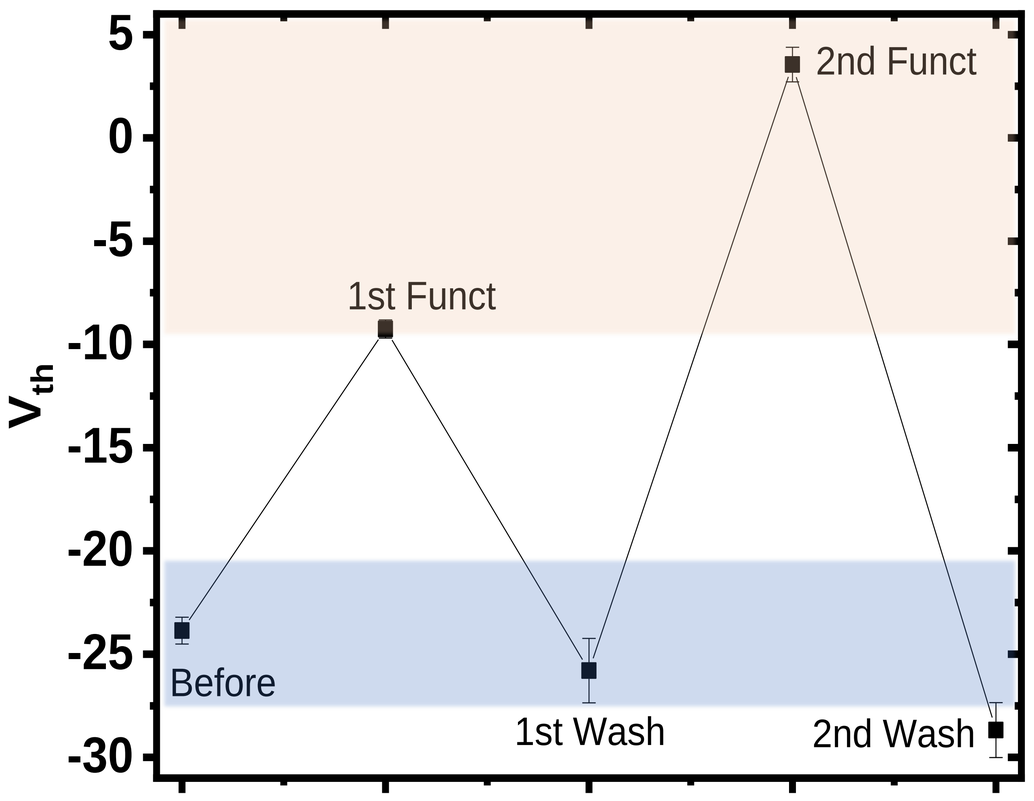


**Figure 3.** Reversibility study of the $MoS_2/Hg^{2+}$ sensing platform at a concentration of 100 pM. The device can be washed after every functionalization recovering its initial state.

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