

Understanding High Contact Resistance in MoS₂ FETs using STEM-EELS

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TMDs, with chemical formula MX₂, where M is a group IV, V, or VI transition metal and X is the chalcogenide, is a sub-group of materials with highly tunable properties within the umbrella of van-der-Waals bonded 2D materials [1]. One promising device application for TMDs, most notably MoS₂, is as channels in ultra-thin field effect transistors (FETs) [2]. However, a major obstacle in realizing MoS₂ channel FETs is the surprisingly high contact resistances measured across the metal contact and MoS₂ channel, which severely limits electron injection from the metal [3]. The origins of this resistance continue to be a topic of scientific debate because our understanding of the MoS₂ atomic and electronic structure at and near the metal contact interface remains muddled.

In this work, we report the interactions of the metal-MoS₂ interface within FETs as observed directly using atomic resolution scanning transmission electron microscopy (STEM) and present their effects on FET performance. Following device fabrication and performance measurements, functioning FETs embedded with MoS₂ are thinned using an FEI Helios G4 with minimum beam damage incurred during TEM sample preparation. Subsequently, analytical TEM is performed using an aberration corrected FEI Titan G2 60-300 S/TEM.

Annular dark field (ADF)-STEM imaging is used in conjunction with electron energy loss spectroscopy (EELS) to show that non-periodic covalent bonding between Ti and S results in a diffuse Ti-MoS₂ interface which alters the atomic and electronic structure of MoS₂ layers as shown in Figure 1. In contrast, similar analysis on FETs with In/Au alloy contacts show an atomically sharp interface between the contact and MoS₂, as shown in Figure 2, and explains the markedly different contact resistance and overall device performances measured between the two FETs. These results show that the properties of the metal used as the contact can greatly affect the performance of the 2D material device and must be tailored to the specific 2D material in order to optimize device performance [4].

References:

- [1] M. Chhowalla *et al*, Nature Chemistry **5** (2013), p. 263.
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- [3] A. Allain, J. Kang, K. Banerjee, A. Kis, Nature Materials **12** (2015), p. 1195.
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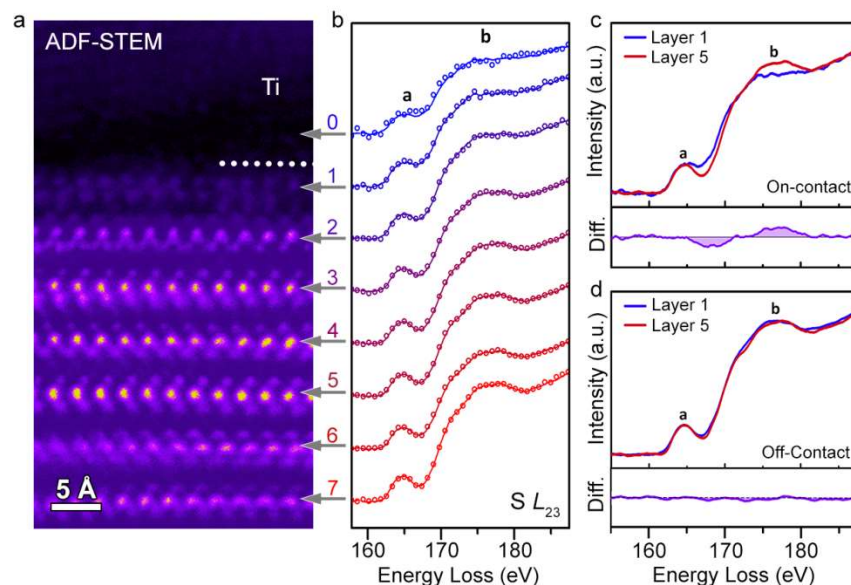


Figure 1. (a) ADF-STEM image of the Ti-MoS₂ interface within a FET in which the topmost layer of MoS₂ appears visibly altered compared to underlying layers. (b) S *L*₂₃ edge measured using EELS at each layer of MoS₂. Changes in the S partial-DOS can be seen in features a and b. (c) comparison of S *L*₂₃ edge at layer 1 and layer 5 of MoS₂ for a region of MoS₂ in contact with Ti. (d) similar comparison for a region of MoS₂ away from contact with Ti. Differences in the spectra are observable above noise in (c) but not in (d)

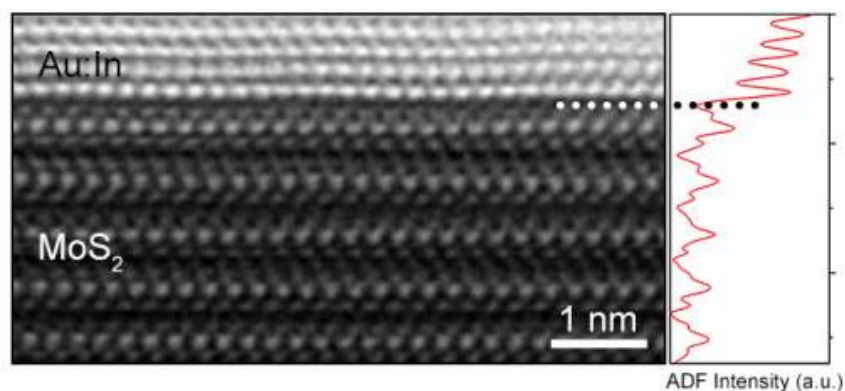


Figure 2. (left) ADF-STEM image of the interface between MoS₂ and an Au:In alloy electrical contact in a FET. (right) Line scan of the ADF intensity across the interface. The position of the interface is denoted by the dotted lines.