Improved performance of MOCVD-ML-MoS_2 FET by optimized PEALD Al_2O_3 passivation

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We report on an Al_2O_3 passivation process using plasma-enhanced atomic layer deposition (PEALD) on wafer-scale MoS_2 monolayers (ML) prepared by metal-organic chemical vapor deposition (MOCVD). The MoS_2 layers are fully coalesced across the 2-inch sapphire substrate with ~20% parasitic bilayer (BL) coverage and some vertically standing nanosheets (VSN) (**Fig. 1a,b**) [1]. Field-effect transistors (FET) (**Fig. 1c**) are fabricated and then passivated employing various Al_2O_3 PEALD (Al – TMAl, O – O_2 plasma) conditions (**Fig. 2c**). A novel in-situ 2-step process of low- and high-temperature (LT, HT) PEALD compatible with ML MoS_2 is established, improving on-currents up to 100x (**Fig. 2a**). The LT-step is crucial as it promotes uniform growth (**Fig. 1d**) and provides ML MoS_2 sufficient protection against O_2 plasma species (**Fig. 2a** LT+HT(*) and HT vs. Ref). With the 2-step process, we are able to maintain channel control [2], and achieve high on/off ratios of $>10^7$ (**Fig. 2a,b**). The large refractive indices (**Fig. 2c**) of reference LT Al_2O_3 layers hint at the formation of a non-stochiometric AlO_x interfacial layer during the LT+HT process. Nevertheless, the improved FET performance indicates that this layer might be cured during the HT deposition step. We hypothesize that the 2-step Al_2O_3 passivation also acts as an n-type charge transfer doping layer for MoS_2.

References

[1] S. Tang et al., MRS Advances 7 (2022), 751–756
[2] A. Leonhardt et al., ACS Appl. Mater. Interfaces, 11, 45 (2019), 42697–42707

Figures

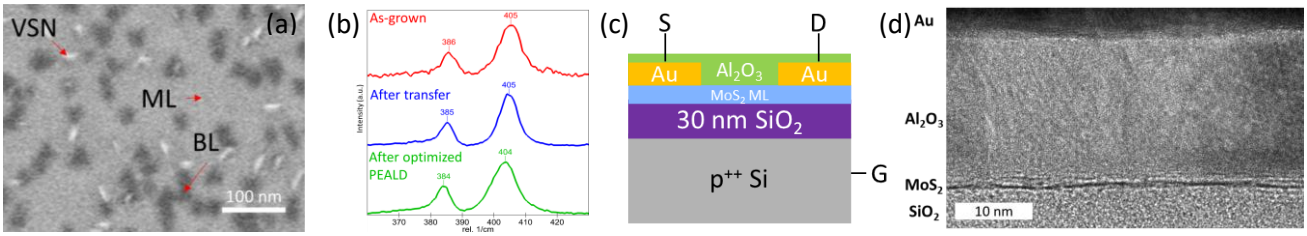
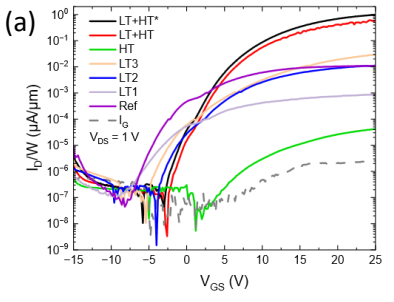
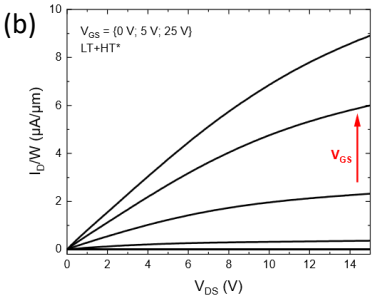


Figure 1: Top-view SEM (a) of as-grown ML MoS_2, showing ~20% BL growth. Raman spectroscopy (b) of as-grown, transferred and passivated ML MoS_2. Schematic of FET (c). Cross-section TEM (d) of the FET channel: ML MoS_2 and ~20 nm Al_2O_3 deposited with LT+HT* passivation process.





(c)

ID	T (°C)	O_2 plasma power (W)	# ALD-cycles	Refractive index (n)
LT+HT*	30+300	25+200	30+200	1.72
LT+HT	30+300	25+200	10+200	1.69
HT	300	200	200	1.68
LT3	75	25	200	2.42
LT2	50	25	200	2.56
LT1	30	25	200	2.79

Figure 2: Transfer (a) and output (b) curves of FET passivated under different PEALD conditions (c). Sizes of all devices are W_{ch} = 100 µm, L_{ch} = 1 µm. Other parameters regarding single PEALD cycles are kept the same, e.g., TMAl soaking and O_2 plasma exposure times, etc.