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Bismuth contacts on ultrapure monolayer transition metal dichalcogenides (TMDs)

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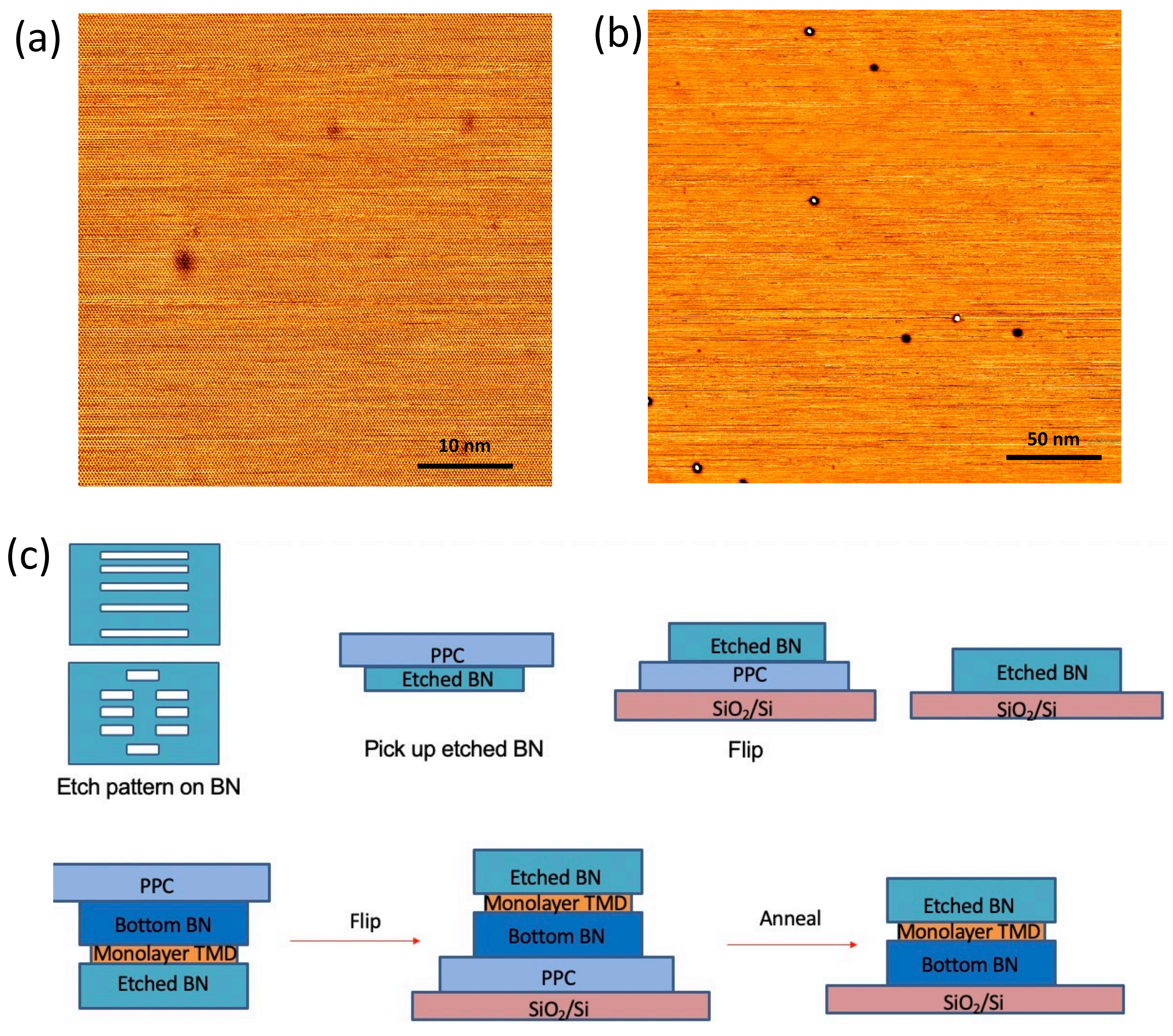
Abstract

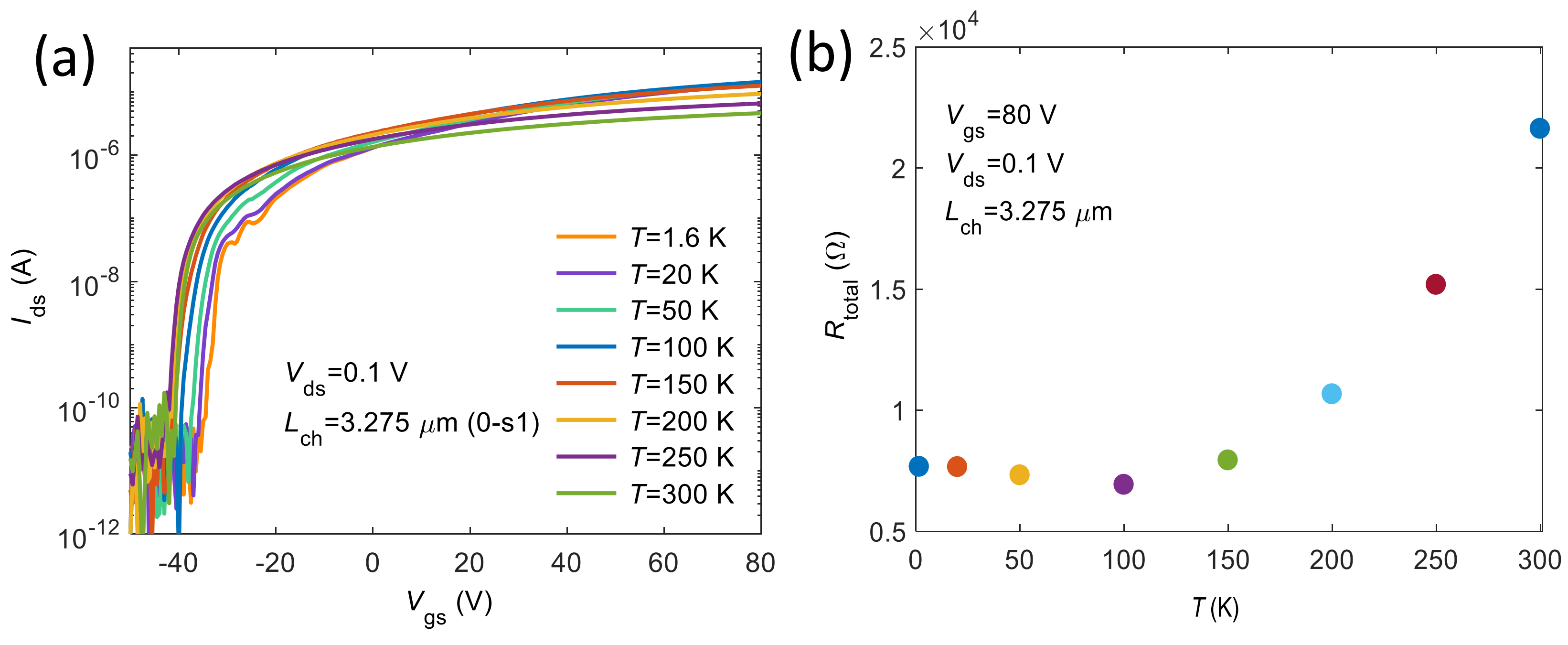
Two-dimensional (2D) monolayer semiconductors such as transition metal dichalcogenides (TMDs) have attracted intense attention in electronics and optoelectronics due to their exotic properties[1]. For fundamental research and most applications, it's necessary to combine high-quality contacts on ultrapure semiconductors to build efficient connections with external circuits, especially for low-temperature scenarios[2]. However, achieving this remains elusive to date. Here, we report a high-quality device construction by combing high-quality material growth, van der Waals assembling and recently reported semimetallic Bismuth contacts[3], which could efficiently operate from 300 K to 1.6 K. We also developed a general analysis model to unveil a panorama understanding of a set of microscopic device parameters.

Material and device assembly



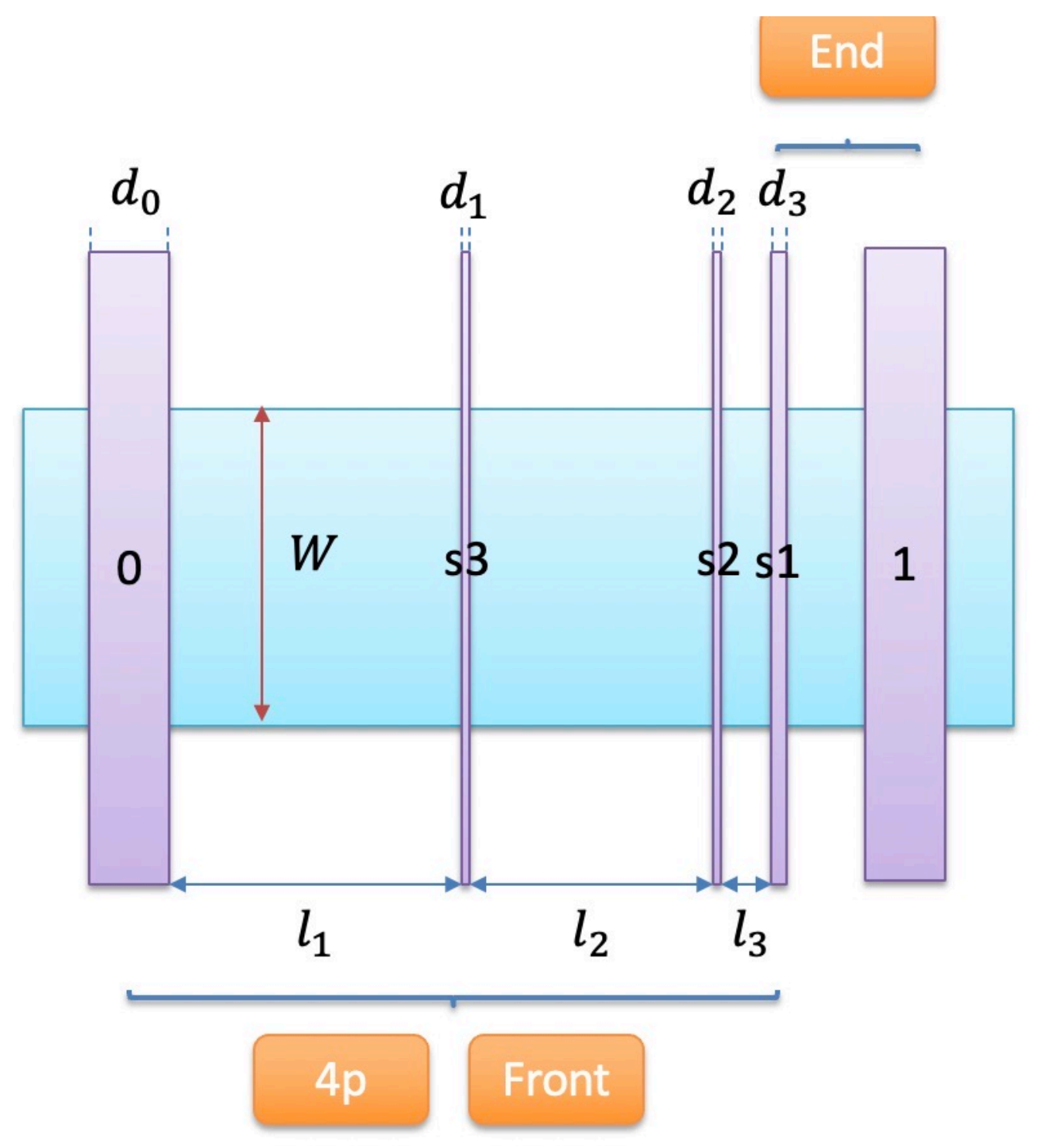
(a-b) STM result of ultrapure $MoSe_2$ grown by flux method. Average small defect density: 3.24 x 10^{11}/cm^2 and average large defect density: 1.37 x 10^{10}/cm^2. (c) Device fabrication process.

Characterization



(a) Transfer curve of monolayer MoSe2 with Bismuth contact FET in the temperature range from 1.6 K to 300 K. (b) Two-probe resistance at different temperature.

Analysis - VD model



Knowns: R_{2p}, R_{4p}, R_{end}
Unknowns: R_{sk}, L_t, R_{sh}

$$R_{cf} = \frac{\rho_c}{L_t W} \coth(L/L_t)$$

$$R_{ce} = \frac{\rho_c}{L_t W} \frac{1}{\sinh(L/L_t)}$$

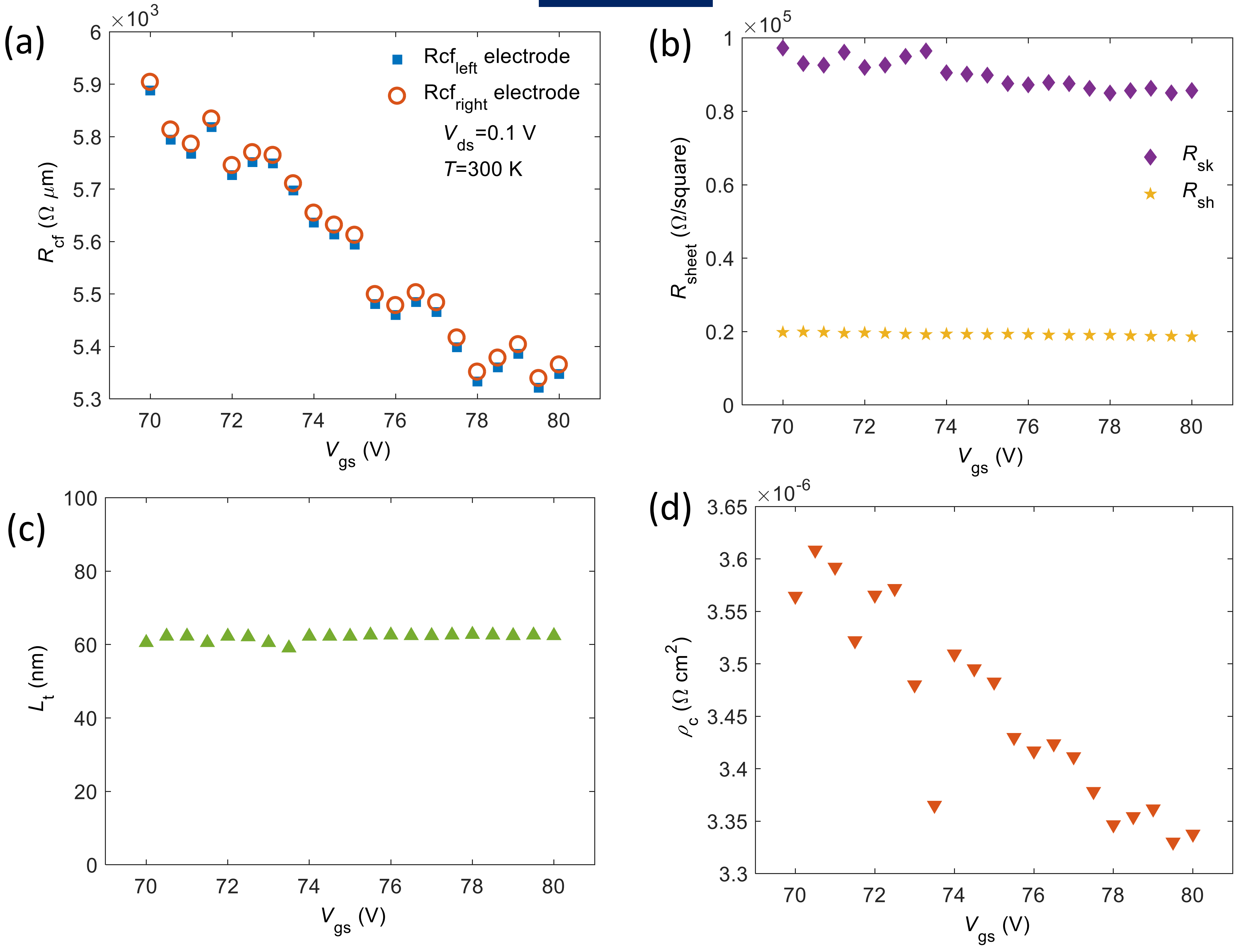
$$L_t = \sqrt{\frac{\rho_c}{R_{sk}}}$$

① $$\left(2 \times R_{sk} \times \frac{L_t}{W}\right) \times \tanh\left(\frac{d_1}{2L_t}\right) + R_{sh} \times l_2 - R_{4p} = 0$$

② $$\left(R_{sk} \times \frac{L_t}{W}\right) / \sinh\left(\frac{d_3}{L_t}\right) - R_{ce} = 0$$

③ $$\left(4 \times R_{sk} \times \frac{L_t}{W}\right) \times \tanh\left(\frac{d_1}{2L_t}\right) + R_{sh} \times (l_1 + l_2 + l_3) + \left(R_{sk} \times \frac{L_t}{W}\right) \times \coth\left(\frac{d_0}{L_t}\right)) + \left(R_{sk} \times \frac{L_t}{W}\right) \times \coth\left(\frac{d_3}{L_t}\right) - R_{2p} = 0$$

Results



Properties extracted from VD model at T = 300K : (a) contact resistance (R_{cf}), (b) sheet resistance beneath contacts (R_{sk}) and sheet resistance in the channel (R_{sh}), (c) current transfer length (L_t) and (d) contact resistivity (ρ_c).

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References

[1] Chhowalla M et al. Nature Reviews Materials 1.11 (2016): 1-15.
[2] Schulman et al. Chemical Society Reviews 47.9 (2018): 3037-3058.
[3] Shen et al. Nature 593.7858 (2021): 211-217.

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