Diffusion of Silver and Nickel into Few-Layer MoS_2 and Its Effect on Contact Resistance

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MoS_2 is attractive for a variety of nanoelectronic devices due to its ability to maintain desirable semiconducting properties at the single layer limit [1]. Understanding the behavior of metal/MoS_2 interfaces is important for developing low-resistance contacts for scaled transistors and other emerging applications of MoS_2. Our recently published work on Ag/MoS_2 contacts shows that after annealing in Ar at 250 and 300 °C, the contact resistance R_C is reduced from 0.8–3.5 kΩ·μm to 0.2–0.7 kΩ·μm, likely due to the incorporation of Ag donors between layers of MoS_2 [2]. This result is very good relative to the state-of-the-art. More recently, we have verified using transmission electron microscopy and electron energy loss spectroscopy that Ag diffuses into MoS_2 at low levels.

Now we have discovered that Ni also diffuses into MoS_2 — without altering its structure — after annealing in Ar at a temperature as low as 200 °C. Therefore, we fabricated Ni-based contacts to MoS_2 and characterized them before and after annealing. However, annealing caused an increase in R_C in every Ni-contacted device. As deposited, R_C varied from 2.5–8.0 kΩ·μm, but it increased by 50% after annealing at 200 °C, and increased by 650% after annealing at 300 °C. While Ag acts as a donor when intercalated in MoS_2 [3], Ni might not. Our further efforts towards understanding the effects of diffusion of Ag, Ni, and possibly other transition metals into MoS_2 may ultimately guide us in achieving even lower contact resistances.

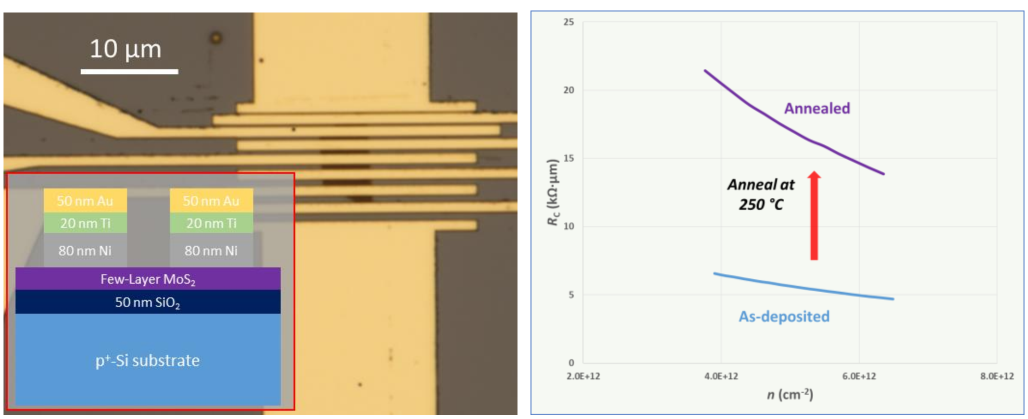

Figure 1. (a) Optical image of a TLM test structure; (inset) schematic of a back-gated MOSFET with Ni contacts. (b) Contact resistance for as-deposited and annealed Ni contacts versus sheet carrier density (n).

[1] K. F. Mak *et al*., Phys. Rev. Lett. **105**, 136805(2010).
[2] M. Abraham and S. E. Mohney, J. Appl. Phys. **122**, 115306 (2017).
[3] D. M. Guzman *et al*., J. Appl. Phys. **121**, 055703(2017).

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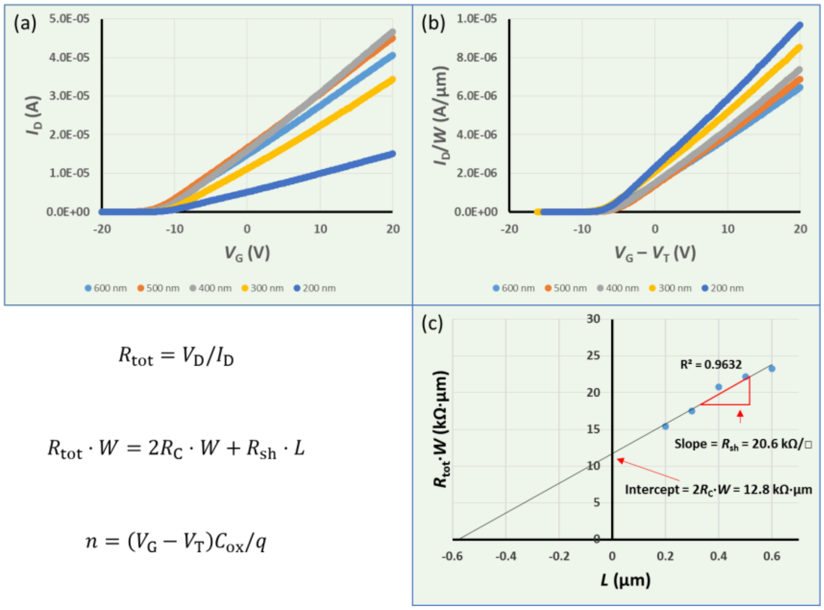
Supplementary Information:

Details of R_C extraction from MOSFETs:



$$R_{\mathrm{tot}} = V_{\mathrm{D}}/I_{\mathrm{D}}$$

$$R_{\mathrm{tot}} \cdot W = 2R_{\mathrm{C}} \cdot W + R_{\mathrm{sh}} \cdot L$$

$$n = (V_{\mathrm{G}} - V_{\mathrm{T}})C_{\mathrm{ox}}/q$$

Figure 2: (a) Raw I_D-V_G characteristic curves of MOSFETs of differing channel length. (b) I_D-V_G curves normalized for channel width (W) and threshold voltage (V_T) variations. (c) Transfer length method (TLM) plot of channel length (L) vs. total resistance (R_{tot}) for n = 5.0×10^{12} cm^{-2} to extrapolate to L = 0, where $R_{tot} = 2R_C$. Also shown are equations relating raw data to R_C, R_{sh}, and n.