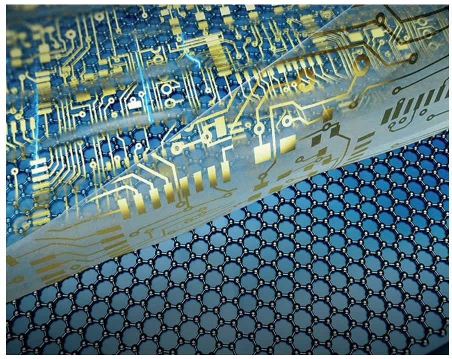
Contacts in 2D

Methods to create van der Waals contacts between two-dimensional semiconductors and three-dimensional metals are helping to unleash the potential of two-dimensional devices.

Junctions between metals and semiconductors are crucial elements in electronic devices. With devices based on two-dimensional materials, the junctions also typically form the bridge between the two-dimensional and three-dimensional domains. To create high-performance field-effect transistors, the electrical contact resistance at these metal–semiconductor interfaces needs to be low. But the potential energy barrier that charge carriers encounter at the interface — known as the Schottky barrier — can lead to a high contact resistance, increasing energy consumption and degrading device performance.

Finding ways to reduce contact resistance remains a key challenge for the future development of integrated circuits based on two-dimensional transistors[1]. A number of promising techniques have recently emerged though. For instance, two-dimensional transistors with contact resistances of only around 123 Ω μm have been reported by contacting the semiconducting monolayer (in this case, molybdenum disulfide) with semimetallic bismuth[2]. An alternative approach is to decouple the metal–semiconductor interaction using a van der Waals gap — and the potential of this technique is highlighted by recent work in *Nature Electronics*.

In last month's issue, Eunha Lee, Mann-Ho Cho and colleagues reported creating van der Waals contacts between two-dimensional semiconductors and three-dimensional metals that are interaction- and defect-free[3]. The approach relies on a metal deposition process in which selenium is used as a buffer layer to reduce physical and chemical interactions. In particular, a 10-nm-thick selenium buffer layer is first deposited on mechanically exfoliated flakes of the two-dimensional material. This is then followed by deposition of 50-nm-thick metal electrodes. Finally, the selenium is removed by annealing to 150 °C.



Schematic illustration of a graphene-assisted metal transfer printing technique for fabricating van der Waals contacts between two-dimensional materials and three-dimensional metals on the wafer scale. Credit: Zengfeng Di, SIMIT CAS.

The researchers — who are based at Yonsei University, Samsung Electronics and Dongguk University — show that the technique can be used with a range of metals (gold, silver, cobalt and platinum) and a range of two-dimensional materials (tungsten diselenide, molybdenum disulfide, molybdenum diselenide and tungsten disulfide). With the gold van der Waals contacts specifically, they construct p-type tungsten diselenide field-effect transistors that offer on/off ratios of 10^6, mobilities of 155 $cm^2 V^{-1} s^{-1}$, contact resistances of 1.25 kΩ μm and Schottky barrier heights of 60 meV.

In a related approach, and reporting in this issue of *Nature Electronics*, Weida Hu, Zengfeng Di and colleagues show that a graphene-assisted metal transfer printing technique can be used to form van der Waals contacts between two-dimensional materials and three-dimensional metals on the wafer scale. (See also the accompanying News & Views article on the work from Soon-Yong Kwon at Ulsan National Institute of Science and Technology.) In this technique, a single graphene layer is first prepared on a germanium substrate, and arrays of metal electrodes are deposited onto it using photolithography and electron-beam evaporation. The surface of the resulting metal/graphene/germanium structure is then coated with the polymer polyvinyl alcohol. Owing to the weak van der Waals forces at the interface between the metal and the graphene, when the polyvinyl alcohol film is peeled off, the metal electrodes are transferred — with a yield of almost 100% — to the polymer. The arrays of metal electrodes can then be printed directly onto other two-dimensional materials.

The researchers — who are based at the Shanghai Institute of Microsystem and Information Technology, the University of Chinese Academy of Sciences, Hunan University, the Shanghai Institute of Technical Physics, City University of Hong Kong, and Fudan University — show that the approach works with metal electrodes with both weak (copper, silver and gold) and strong (platinum, titanium and nickel) adhesion strengths. The metals can also be printed onto different two-dimensional materials (graphene and molybdenum disulfide), as well as three-dimensional ones (silicon dioxide). To illustrate the capabilities of the approach, the team fabricate molybdenum disulfide field-effect transistors with different metal electrodes, which allows the Schottky barrier height to be manipulated and the contact resistance to be modified. They also demonstrate batch production of arrays of molybdenum disulfide transistors with transferred silver electrodes. ❐

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References

1. Das, S. et al. *Nat. Electron.* **4**, 786–799 (2021).
2. Shen, P.-C. et al. *Nature* **593**, 211–217 (2021).
3. Kwon, G. et al. *Nat. Electron.* **5**, 241–247 (2022).