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2D MATERIALS

The thick and the thin

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Transition metal dichalcogenides — a class of 2D materials — have a bandgap that can be tuned by changing the number of layers in the crystal. Typically, it is only the magnitude of the bandgap that is affected by this change. Now, writing in *Nature Communications*, Andras Kis and colleagues report that $PtSe_2$ undergoes a fundamental change from a metal to a semiconductor as the thickness of the crystal is reduced.

Kis's team investigated the electronic transport properties of $PtSe_2$ samples of different thicknesses in field-effect transistors. These samples ranged in thickness from 2 nm to 13 nm and were obtained by mechanically exfoliating bulk crystals onto a SiO_2/Si substrate. Measuring the conductance of the crystals as a function of the back-gate voltage (V_g) reveals key differences in the properties of the different $PtSe_2$ samples. For the thickest samples (~13 nm), the conductance is essentially independent of V_g — behaviour consistent with a metal. The thinnest samples (~2 nm), however, exhibit a clear non-linear increase in conductance with an increase in V_g — behaviour indicative of a semiconductor. "The gate terminal is used to change the charge-carrier density in a device," explains Kis. "For semiconductors, this produces a large change in the current because they normally do not have a high intrinsic charge-carrier density. By contrast, when we try the same with metals, which already have a high charge-carrier density, the change induced by the gate is relatively weak."

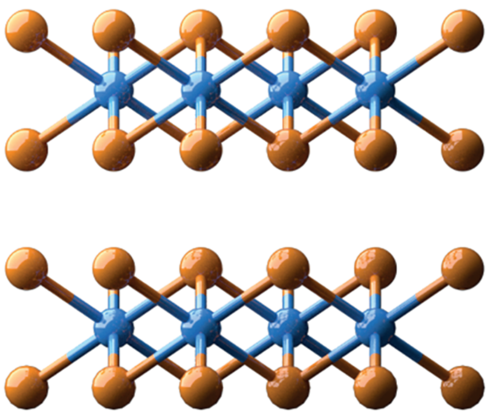

Image: adapted from Ciarrocchi, A. et al. (2018), Macmillan Publishers Limited.

The bandgaps of thin, semiconducting $PtSe_2$ samples were determined by forming electric-double-layer transistors. These were fabricated by spin coating an ion-gel electrolyte (an ionic liquid confined in a polymer matrix) onto $PtSe_2$-based transistors. Kis and co-workers demonstrated that thin samples (<2.5 nm) of $PtSe_2$ exhibit ambipolar behaviour, which, together with the high gate capacitance of the electric-double-layer transistors, enabled the bandgap (<2.2 ± 0.1 eV) to be estimated, showing that even very thin samples of $PtSe_2$ have an appreciable bandgap.

This metal-to-semiconductor transition, achieved by simply changing the sample thickness, is new for transition metal dichalcogenides. "Normally, the change in bandgap is mostly quantitative — semiconductors still stay semiconductors. Here, we see a qualitative change — thick $PtSe_2$ is a metal but thin $PtSe_2$ is a semiconductor," says Kis. Despite difficulties in controlling the thickness of 2D materials, the possibility of tuning their electrical transport characteristics could open doors for the fabrication of electronic devices in which a single material has a dual role. "Electrical circuits are usually made of semiconducting regions connected together with good conductors. $PtSe_2$ could act as both, depending on the thickness," suggests Kis.

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ORIGINAL ARTICLE Ciarrocchi, A. et al. Thickness-modulated metal-to-semiconductor transformation in a transition metal dichalcogenide. *Nat. Commun.* **9**, 919 (2018)