Deterministic assembly of arrays of lithographically defined WS$_2$ and MoS$_2$ monolayer features directly from multilayer sources into van der Waals heterostructures

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One of the major challenges of van der Waals (vdW) integration of 2D materials, the process of assembling dissimilar 2D materials together using the universal vdW force, is achieving high-yield and high-throughput assembly of pre-defined sequences of monolayers into heterostructure arrays. Mechanical exfoliation has recently been studied as a promising technique to transfer monolayers from a multilayer source synthesized by other techniques [1], allowing the deposition of a wide variety of 2D materials without the constraints imposed by the harsh synthesis conditions. Although a variety of techniques have been developed to exfoliate the 2D materials mechanically from the source and place them deterministically onto a target substrate, they typically can transfer only either a wafer-scale blanket [2, 3] or one small flake at a time with uncontrolled size and shape [4]. Here we present a method to exfoliate arrays of lithographically defined monolayer WS$_2$ and MoS$_2$ features from multilayer sources and directly transfer them in a deterministic manner onto target substrates. This exfoliate–align–release process, without the need of an intermediate carrier substrate, was enabled by a new transfer medium fabricated by spin-coating a partially-crosslinked and transparent adhesive onto a transparent, electrostatically active backing material with low surface energy. WS$_2$/MoS$_2$ vdW heterostructure arrays produced by this method were characterized, showing the expected coupled exciton between the monolayers. Light-emitting devices using WS$_2$ monolayers were also demonstrated, proving the functionality of the fabricated materials. Our work demonstrates a significant step towards developing mechanical exfoliation as a scalable transfer technique for the manufacturing of functional, atomically thin materials.
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Figure 1: Fabrication of monolayer and heterostructure arrays by the Covalent-Bond Exfoliate-Align-Release (CoBEARs) process. (a) Optical microscopy images of the array of WS2 micro-features after critical steps. The target substrate is 50 nm SiO2/Si. The monolayer array is obtained after one single exfoliation. Scale bars are 200 µm. (b) WS2/MoS2 heterostructure array obtained by repeating the steps in (a), with the first cycle depositing MoS2 and the second cycle depositing WS2. From left to right, scale bars are 200 µm, 200 µm and 100 µm. (c) Raman spectra of the samples in (b). The MoS2-only spectrum was obtained before WS2 deposition. The WS2-only and WS2/MoS2 spectra correspond to the two red spots numbered 1 and 2 respectively in the high-magnification image of (b).