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High-Resolution 3D Device Fabrication by Aligned Stacking of Nanopatterned 2D Materials

Technology Description

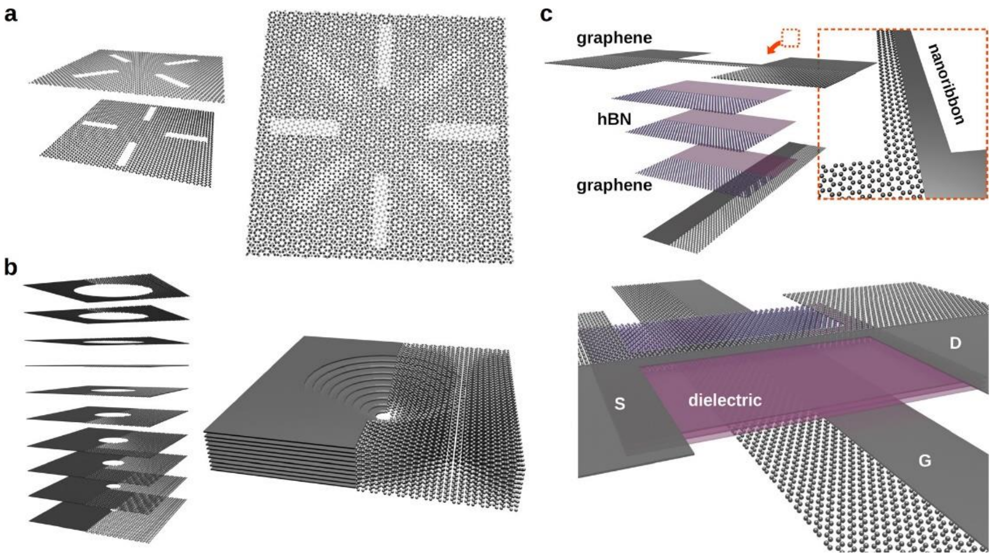

Fig. 1: Formation of arbitrary 3D structures by assembly of pre-patterned 2D layers. (a) two rotated crosses, (b) a nanoscale funnel built from holes of increasing size, (c) transistor structure consisting of graphene leads, a graphene nanoribbon as active element, hBN gate dielectric and a graphene gate electrode.

Structuring matter on the smallest dimensions is a key capability for many areas of technology. Here we present a method to fabricate 3D device structures out of 2D materials, with a resolution in the nanometer-range and almost arbitrary geometries. Our method permits stacking of layers with lateral alignment with an accuracy of currently 10nm via focused electron or ion irradiation under observation in an electron microscope. Each layer can be as thin as a single atom and can be structured with ~1nm resolution. Structured layers can be placed on top of each other with a precise lateral alignment. No medium or binding agent is required, also no need for post-stacking chemical or heat treatment. With our method the existing 2-D fabrication capabilities are extended into a powerful 3D printing technique. Details can be found in our publication (Ref. 1).

Applications

- Nano-electronics, e.g. novel transistor or memory devices
- Nano-fluidics, e.g. specific pore and channel shapes for filtering or for biological and chemical analysis
- Energy applications, e.g. novel separator membranes in fuel cells or batteries

Market Potential / IP Status

Broad potential applications for a very versatile method, enabling improvements in markets like microelectronics, wearables, mobility, health, chemical and medical analysis, IOT.

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EXPERIMENTAL DATA

Examples of Layer-by-Layer-Assembly

Figure 2 shows the precise stacking of two layers. Two crosses are placed accurately on top of each other. In principle, an arbitrary number of layers could be stacked, enabling the definition of arbitrary 3D device geometries from 1-atom thick layers. Also, as each layer can be chosen from the vast selection of 2D materials, functional devices could be prepared directly.

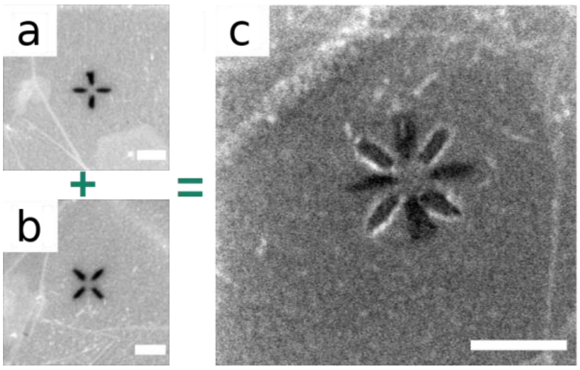

Fig. 2: Assembly of two crosses patterned in graphene. (a,b) individually patterned graphene membranes, and (c) resulting stack (SEM images, all scale bars 500nm)

Figure 3 illustrates stacking of 10 layers, thus creating a funnel-shaped nanopore. With reasonable further improvements in the lateral alignment accuracy, the approach could enable 3D printing with close to atomic resolution. Details can be found in Ref. 1.

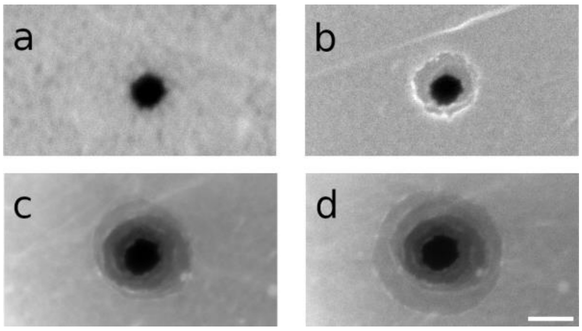

Fig. 3: Stacking of 10 layers for creating a funnel-shaped nanopore. (a) First layer, (b) Stack of 4 layers, (c) 8 layers, and (d) 10 layers. The scale bar is 200nm.

Description of Method

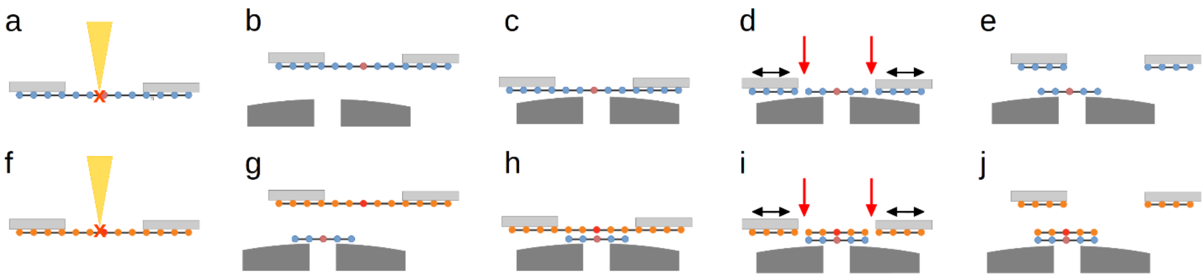

Fig. 4: Fabrication of 3D structures out of individually patterned 2D materials
We start with suspended 2D material, which spans a hole in the support frame (e.g. TEM grid). (a) The 2D material is patterned by focused electron irradiation (modified area indicated as red dot), as described e.g. in Ref. 2. (b+c) The membrane is moved (under SEM observation) onto a second support with a smaller hole. A slight curvature of the second support frame makes it possible to bring the two surfaces into contact at the desired point. (d) Lateral motion of the support frames relative to each other (black arrows) leads to a rupture of the membrane around the edges of the larger hole (red arrows). (e) Upon separation of the support frames, part of the 2D material stays on the target frame. (f-j) The process is repeated with additional layers, resulting in a stack of 2D material layers.

REFERENCES

1 J. Haas et al., Aligned Stacking of Nanopatterned 2D Materials for High-Resolution 3D Device Fabrication, ACS Nano 16, 1836–1846 (2022). https://doi.org/10.1021/acsnano.1c09122

2 X. Zhao et al., Engineering and modifying two-dimensional materials by electron beams, MRS Bulletin 42, 667–676 (2017). https://doi.org/10.1557/mrs.2017.184