Supplementary Information

Ultralow-Voltage All-Carbon Low-Dimensional-Material Flexible Transistors Integrated by Room-Temperature Photolithography Incorporated Filtration

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1. Atom Force Microscope (AFM) characterization of the PET filter membrane.

The pores of the purchased PET filter membrane are obtained by heavy particle bombardment and chemical erosion to enlarge the apertures (according to technical documentation). Therefore, the smooth surface can be well preserved. We characterized the surface roughness of the bare PET filter membrane with AFM, and the result indicates that the average roughness of the nonporous area is within 5 nm. Since the pore does not cause prominent concave or convex to its adjacent area, as shown in the following images, the surface of the PET filter membrane, therefore, is safely deemed to be flat.

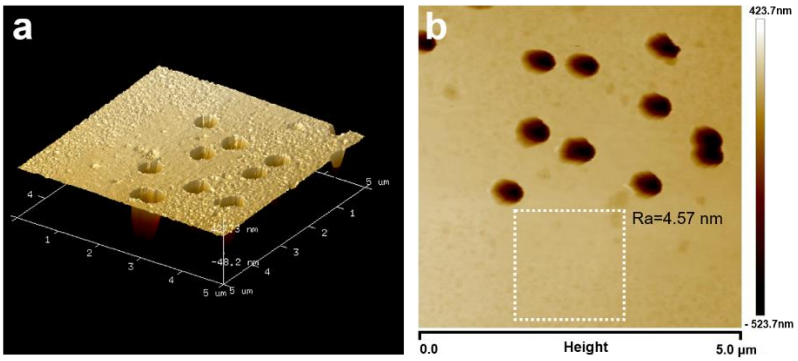

Figure S1. AFM characterization of the bare PET filter membrane. **a**, 3D image of the surface morphology. **b**, 2D surface image of the PET filter membrane. The average roughness of the enclosed rectangular area is 4.57 nm.

2. Effect of the vacuum pressure on the deposited graphene oxide (GO) film.

The vacuum pressure should be carefully designed and tuned before filtrating GO dielectric. Relatively speaking, the vacuum pressure for depositing CNTs has more margin. The following images show the results of one deposited films under a vacuum pressure of <10 kPa and the other one of about 50 kPa (relative to normal atmosphere), respectively. As we can see, the structure of GO is well preserved under a milder vacuum pressure, while it is broken under a relatively higher vacuum pressure.

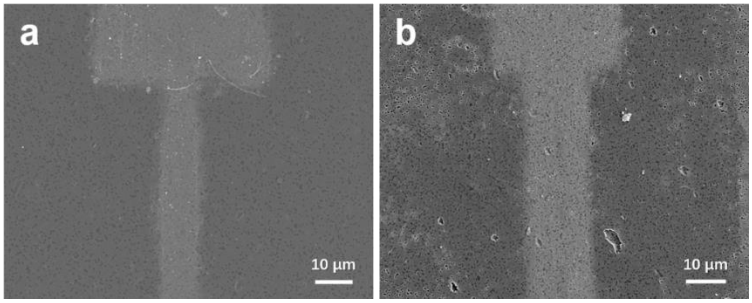

Figure S2. SEM images of the filtrated GO and CNT films under different vacuum pressures. **a**, The filtrated films under a vacuum pressure below 10 kPa. **b**, The

filtrated films under a vacuum pressure about 50 kPa.

3. Distribution of the vacuum pressure affected by the previous deposited materials.

During the deposition of multiple layers, the previous deposited film affects the deposition of following layer. In this experiment, GO shows a strong resistance for water penetration during filtration. In contrast, the CNT film shows a negligible effect. The different resistance against solvent during filtration is due to the structure of the deposited film and the interaction force between the film and the solvent. Therefore, it is necessary to properly design the stacking order, alignments and patterns to avoid or reduce non-uniformity during the filtration. The Figure S3a below is a preferred design, while Figure S3b is an inferior one due to the non-uniform pressure distribution caused by GO.

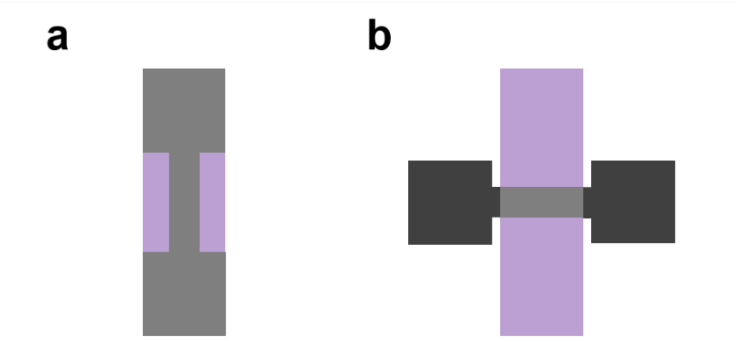

Figure S3. Schematic diagrams for examples of different pressure distributions induced by different patterns. **a,** Stacking in parallel alignment. **b**, Stacking in crossed alignment. The purple color is a representation of GO film, and grey or black color is a representation of CNT film with different thickness, which is the darker, the thicker.

4. Characterization of the filtrated graphene oxide film.

The surface roughness of a deposited 30 nm thick GO film is also measured to evaluate the film quality. The average roughness of the enclosed rectangular area is 3.4 nm, which indicates the surface of the deposited GO is ultra-flat. The flatness is very important for low dimensional electronics, especially for the dielectrics in field-effect transistors.

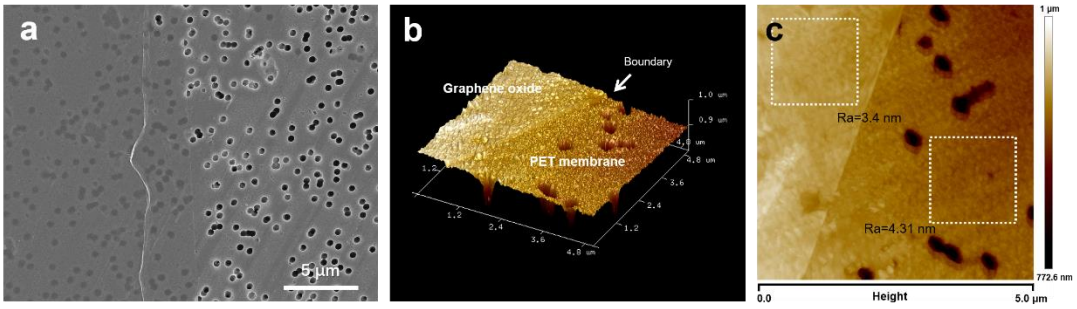

Figure S4. Characterization of surface roughness on deposited GO film. **a,** SEM of the deposited GO films. **b,** 3D image of the boundary between GO and the bare PET substrate. **c**, The corresponding 2D image of Figure b. The average surface roughness of GO is about 3.4 nm.

5. SEM characterization on the MWCNT source/drain morphology with different channel length

A series of source/drain (S/D) patterns with different channel length was fabricated, and then the conductivity between the two pads was measured. The result shows a 5 μm spacing is reliable enough to separate the S/D electrodes.

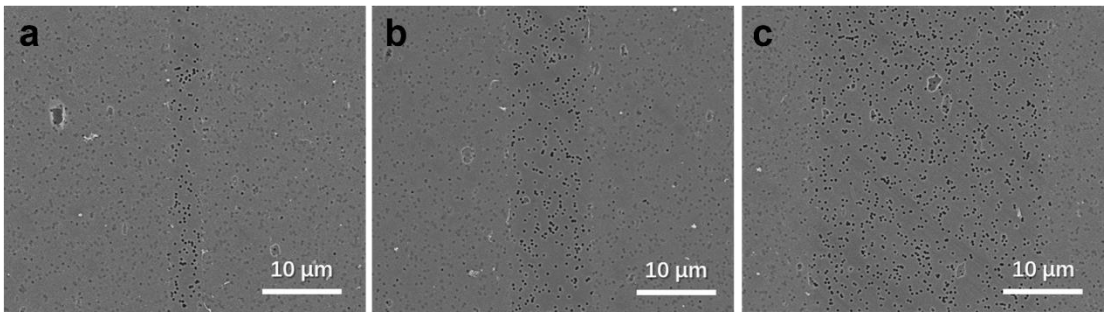

Figure S5. SEM images of the MWCNT source/drain patterns with 5, 10 and 30 µm spacing, respectively.