Supporting Information

Large-area Freestanding Gold Nanomembranes with Nanoholes

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In-plane modulus measurement

The in-plane modulus measurements were performed as per method described by Vucaj et. al.[1] with Bruker Nanoscope V Multimode 8 Atomic Force Microscope (AFM), using Tap 300 Al-G tips from Innovative Solutions Bulgaria Ltd. Before the measurement the cantilever was calibrated for sensitivity on a quartz substrate, with the measured value being of 42.8 nm/V. The spring constant of the tip was calculated using thermal resonance spectra of the cantilever as per Sauder method[2] with the value being 15.6 N/m at the resonant frequency of 293 kHz. Prior to the test the measured area was inspected by optical microscope to avoid measurements on buckled film. Each sample was tested at 5 different spots in the centre of the mesh.

Following the test, the slope of the force curves (F/S) was measured by performing linear fit on the collected curves in the contact zone. The average value of these slopes was then used to calculate the flexural rigidity D of the film: $D=0.0056*L^2*|F/S|$, where, where L is the length of the edge of the TEM grid. This value was finally used to calculate the in-plane modulus $E_{in\text{-}plane}= D*12*(1-v^2)/t^3$, where v is the Poisson ratio of the gold film v =0.44 [4] and t is thickness of the film[5].

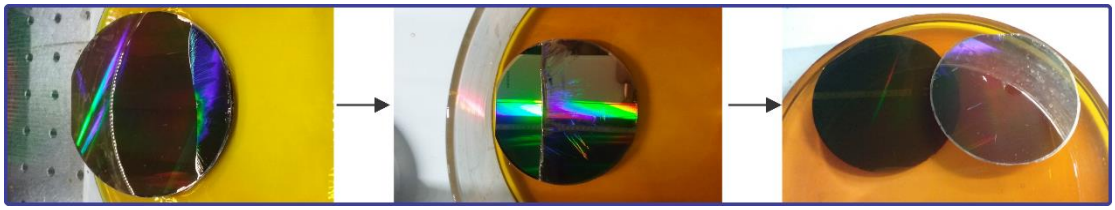

Figure S1 Release process of a freestanding gold nanomembrane (NM, 50-nm-thin). The $FeCl_3$ solution gradually etched the sacrificial copper layer and released the NM from the Si template. Finally, the NM floated on the surface of the solution. Typically, the saturated 30% $FeCl_3$ solution or commercial $FeCl_3$-based copper etchant (Sigma-Aldrich) were used to get high etching efficiency. The Si template was settled in an oblique angle less than 30°. With these conditions, the etching process for wafer scale NMs is usually completed in 2 hours. The released NMs can be transferred to the surface of diluted HCl solution (2%) and then deionized water to remove the $FeCl_3$ residue on them.

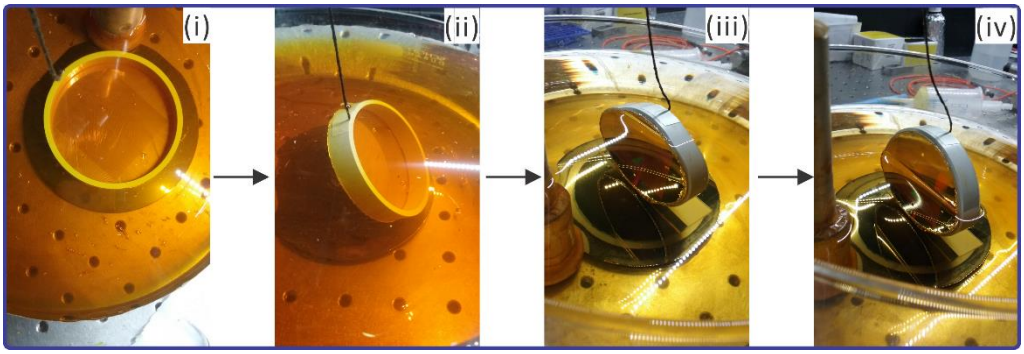

Figure S2 Release and free the 100-nm-thin gold NMs from the solution: (i) place the template with the gold NM (attached on a plastic support ring with a string) at the bottom of a container with $FeCl_3$ etching solution; (ii) after completely etching the copper sacrificial layer, pull the support with the gold NM up with caution; (iii) continue to pull the support to the stand-up position and release the string; (iv) slowly siphon the solution out of container to maintain equal pressures on both sides of the NM and thus avoid any damage.

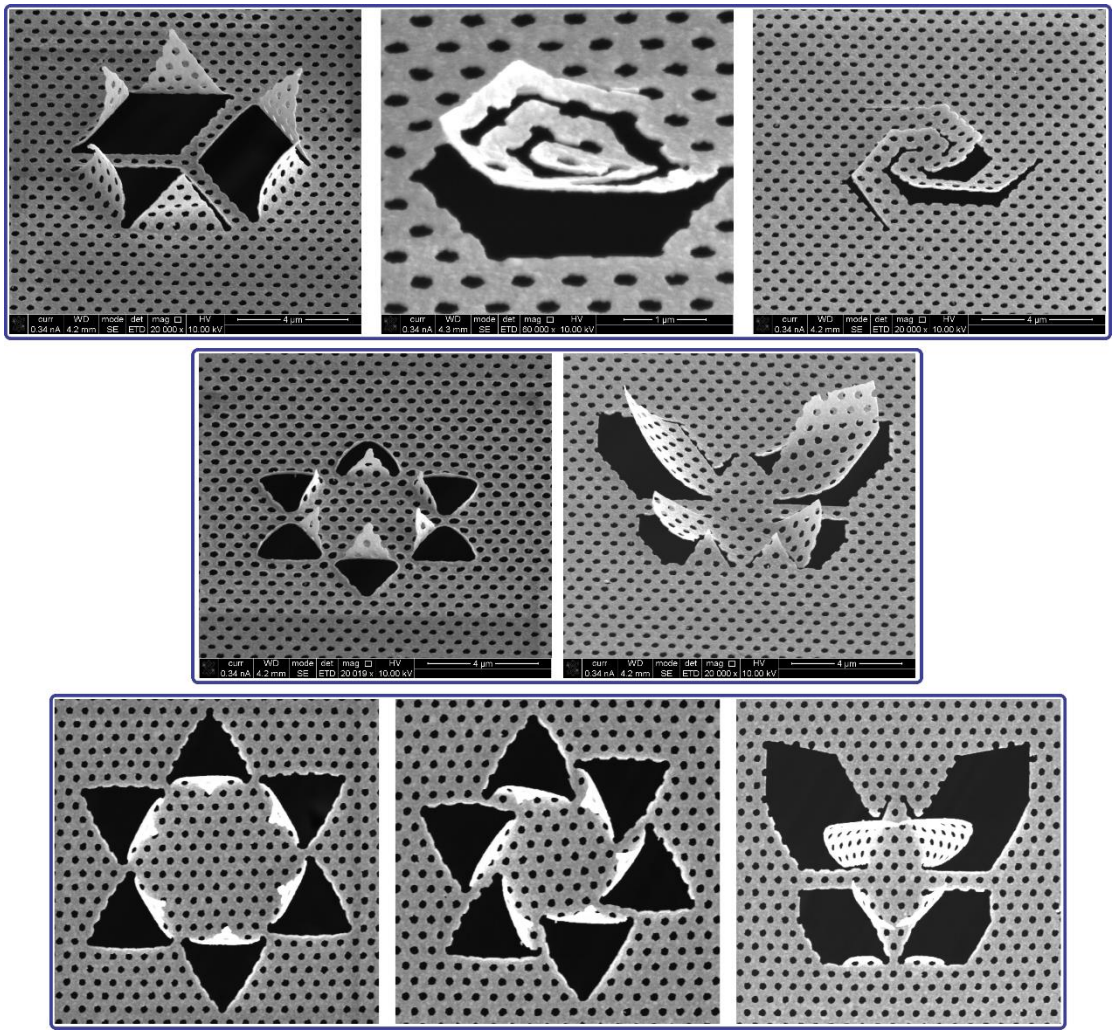

Figure S3 Top: examples of focus-ion-beam (FIB) milled micro-beams and springs; Middle: serious structure damage and unbalance induced by high dose ion cutting; Bottom: top-view of several 3D-transformed structures.

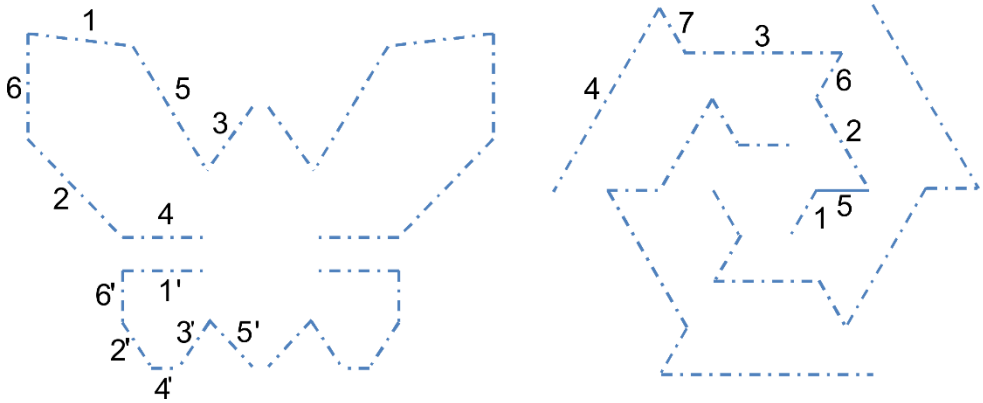

Figure S4 Cutting sequences for the micro-butterfly and spring in Figure 3 to keep these irregular objects in balance after shaping. Generally, continuous cutting along one direction should be avoided as much as possible.

References

1. Vucaj N, Quinn MD, Baechler C, Notley SM, Cottis P, Hojati-Talemi P, Fabretto MV, Wallace GG, Murphy PJ, Evans DR. Vapor phase synthesis of conducting polymer nanocomposites incorporating 2D nanoparticles. *Chemistry of Materials* 2014, 26:4207-4213.
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