Modelling graphene-polymer heterostructure MEMS membranes with Föppl–von Kármán Finite Element Solver

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Ultra-thin graphene-polymer heterostructure (GPH) membranes have shown significant promise as actuators in large-scale nano-electro-mechanical (NEMS) devices [1]. However, finite element method (FEM) modelling the deflection mechanics of such membranes fits neither of the traditional assumptions of 'purely out-of-plane bending' or 'purely in-plane stretching'. We report highly accurate modelling of GPH membranes using the Föppl–von Kármán (FvK) equations and an object-oriented, multi-physics finite-element library, Oomph-lib.

As can be seen in Figure 1a, we suspended GPH membranes over circular cavities etched into the oxidised layer of a silicon substrate. The micro-blister inflation technique [2] was employed to measure the effective bulk moduli (E_b) of the GPH and the 2D topographical line profiles of the deflected membranes were mapped using Atomic Force Microscopy (AFM). Figure 1b presents the excellent agreement between the deflection shape of a 45 nm thin GPH and the corresponding FEM generated solution. We also present (Figure 1c) the ability of the model to correctly predict the capacitance change of the GPH device at varying external pressures changes. We show that commonly used models such as Hencky's solution and linear bending [3] are unsuitable for GPH membranes. Our goal is to accurately model actuating GPH devices to enable designers to achieve desired sensitivity, operable pressure range and footprint, and to achieve straight-forward capacitance-pressure readout.

References

[1] C. Berger, Nanoscale, vol. 9, no. 44, pp. 17439, 2017.
[2] C. N. Berger, Nanoscale, vol. 8, no. 41, pp. 17928, 2016.
[3] C. Berger, *2D Mater.*, vol. 5, no. 1, 2018.

Figures

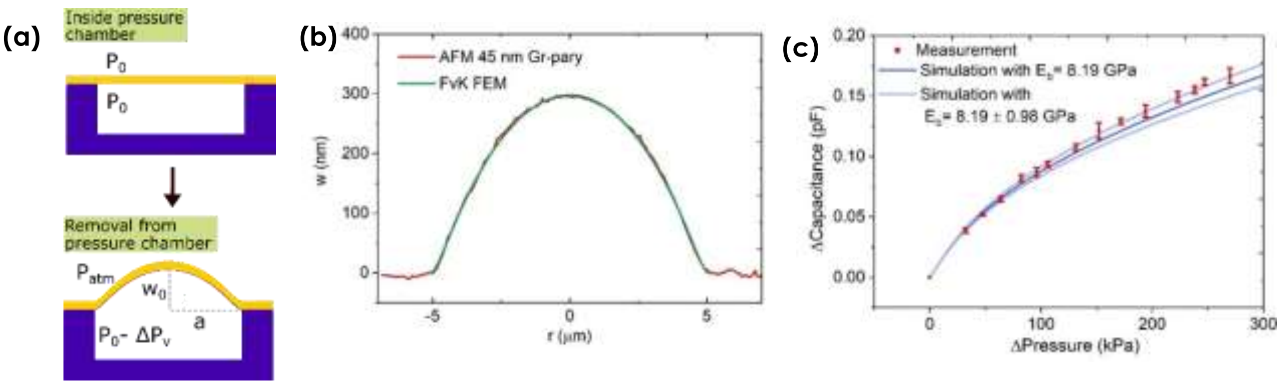

Figure 1: (a) 2-d schematic cross-section depicting the micro-blister inflation testing procedure with a single cavity and actuating membrane with significant parameters labelled. **(b)** 2-d topographical line profile of inflated 45 nm thick GPH micro-blister pressurized to ΔP= 116 kPa, compared to the FEM solution to FvK equations **(c)** Change in device capacitance against change in external pressure compared to that predicted by FEM simulation.