Measuring the Bending Rigidity of 2D Silica - New Light on the Yakobson Paradox

B. Holst[1], C. Büchner[2], S. D. Eder[1], T. Nesse[3], D. Kuhness[2], P. Schlexer[4], G. Pacchioni[4], J. R. Manson[5], M. Heyde[2], H.-J.Freund[2]

[1]*Department of Physics and Technology, University of Bergen, Allégaten 55, 5007 Bergen Norway*
[2]*Fritz-Haber-Institut der Max-Planck-gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany*
[3]*Department of Physics, NTNU, NO-7491, Trondheim, Norway*
[4]*Department of Material Science, Università de Milano-Biocca, Via R. Cozzi 55, Milan, Italy*
[5]*Department of Physics and Astronomy, Clemson University, South Carolina 29634, USA*
bodil.holst@uib.no

Chemically stable bilayers of crystalline and vitreous SiO_2 (2D silica) represent a new class of wide band gap 2D material [1]. From a mechanical point of view the flexibility of 2D layers is a big advantage for a range of applications, for example flexible electronics, where both conductive and insulating layers are needed. Furthermore it may be possible to tune properties such as band gap, thermal conductivity and resistivity through strain engineering. One important mechanical property is the so called bending rigidity, known also as flexural bending rigidity, flexural rigidity, bending modulus or bending stiffness.

Up till now graphene is the only 2D material where the bending rigidity has been measured directly experimentally, with big deviations between theory and experiments for the initial measurements [2,3]. In 2015 Al Taleb et al introduced helium atom scattering (HAS) as a new technique for measuring the bending rigidity of 2D materials. They extracted the bending rigidity from the low-energy phonon modes and obtained the first experimental value in agreement with theory [4]. The classical formula for bending rigidity of a plate is dependent on Young's modulus and Poisson's ratio and the thickness of the material. Several experiments exist on the measurements of elastic moduli [5] and it should thus be possible to obtain information about the bending rigidity from the elastic moduli measurements and vice versa. However, this implies knowing the thickness. For graphene the thickness value has proven to be ambiguous with different plausible values giving very different values for Young's modulus for carbon nanotubes. This is known as the Yakobson Paradox. See for example [6,7]

Here we use HAS to obtain the first measurement of the bending rigidity of a non-monoatomic 2D-material - 2D silica [8]. We compare our results with DFT calculations and obtain good agreement. We also compare our results with the classical formula for bending rigidity and discuss the implications for Yakobsons paradox.

References:
[1] C. Büchner and M. Heyde, Prog. Surf. Sci. **92**, 341 (2017)
[2] N. Lindahl et al., Nano Lett. **12**, 3526 (2012)
[3] M. K. Bless et al., Nature **524,** 204 (2015)
[4] A. A. Tlaleb, H. K. Yu, G. Anemone, D. Fariás, A. M. Wodtke, Carbon **95**, 731 (2015)
[5] D. Akinwande et al., Extreme Mech. Lett. **13**, 42 (2017)
[6] L. Wang, Q. Zheng, J. Z. Liu, Q. Jiant, Phys. Rev. Lett. **95**, 105501 (2015)
[7] P. Pine, Y. E. Yaish, J. Adler, Phys. Rev. B. **89**, 115405 (2014)
[8] C. Büchner et al., Phys. Rev. Lett., Submitted