1 nm Thick Chemically Functionalized Carbon Nanomembranes (CNMs): Two-dimensional Materials for Nanoengineering

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1 nm thick and mechanically stable carbon nanomembranes (CNMs) are made by electron induced cross-linking of self-assembled monolayers of organic molecules, cf. Fig. 1. By further thermal processing, their conductivity and stiffness can be tailored [1] and they can be transformed into graphene and graphenoids [2].

Here we report on the fabrication and characterization of chemically functionalized CNMs, and their incorporation into hybrid materials and devices. For example, placing CNMs over openings and pores produces free-standing membranes (cf. Fig. 2). CNMs with different chemical functionalities on both sides are made by coupling different molecules to the CNM's top and bottom surfaces. We demonstrate the coupling of fluorescent molecules to the top and bottom side, thus creating a bifacial *Janus*[1] membrane [3], cf. Fig. 3. Functionalized Janus CNMs can be fabricated supported or free-standing over openings. Applications of Janus nanomembranes as filters or general platforms for two-dimensional directional chemistry are discussed [4].

In summary, we will show that the building of hybrides from different CNMs opens a path for designing functional materials, whose electrical, mechanical and chemical properties can be tailored for lab-on-a-chip, electronic, filtration, and MEMS/NEMS devices.

[1] A. Turchanin, A. Beyer, C. T. Nottbohm, X. Zhang, R. Stosch, A. Sologubenko, J. Mayer, P. Hinze, T. Weimann, A. Gölzhäuser: *1 nm thin carbon nanosheets with tunable conductivity and stiffness*, Adv. Mater. 21, 1233 (2009).
[2] A. Turchanin, D. Weber, M. Büenfeld, C. Kisielowski, M. V. Fistul, K. B. Efetov, T. Weimann, R. Stosch, J. Mayer and A. Gölzhäuser: *Conversion of Self-Assembled Monolayers into Nanocrystalline Graphene: Structure and Electric Transport*, ACS Nano, 5, 3896 (2011).
[3] Z. Zheng, C. T. Nottbohm, A. Turchanin, H. Muzik, A. Beyer, M. Heilemann, M. Sauer, A. Gölzhäuser: *Janus nanomembranes: A generic platform for chemistry in two dimensions*, Angew. Chemie Int. Ed. 49, 8493 (2010).
[4] I. Amin, M. Steenackers, N. Zhang, A. Beyer, X. Zhang, A. Gölzhäuser: *Patterned Polymer Carpets*, Small 7, 683 (2011).

[1] *Janus is the name of a bifacial Roman god.*

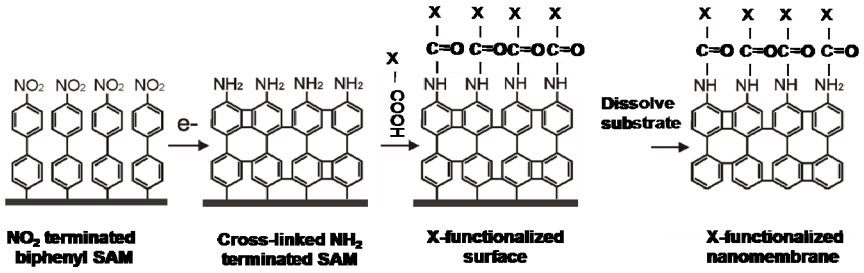

Fig.1: Fabrication of functionalized carbon nanomembrane (CNM) from self-assembled monolayers (SAMs): Upon electron irradiation nitrobiphenyl SAMs are cross-linked. The hydrogen released reduces the nitro groups to amino groups to which other molecules (X) can couple. When the substrate is dissolved, a free-standing X-functionalized CNM is formed.

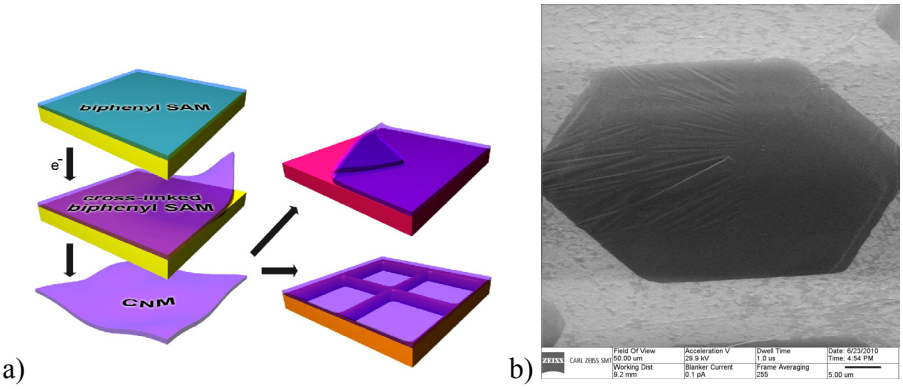

Fig.2: a) CNMs can be transferred onto solid as well as porous surfaces. b) Helium Ion Microscope image of a 1 nm thick CNM transferred onto a ~40 µm diam. opening in a copper TEM grid.

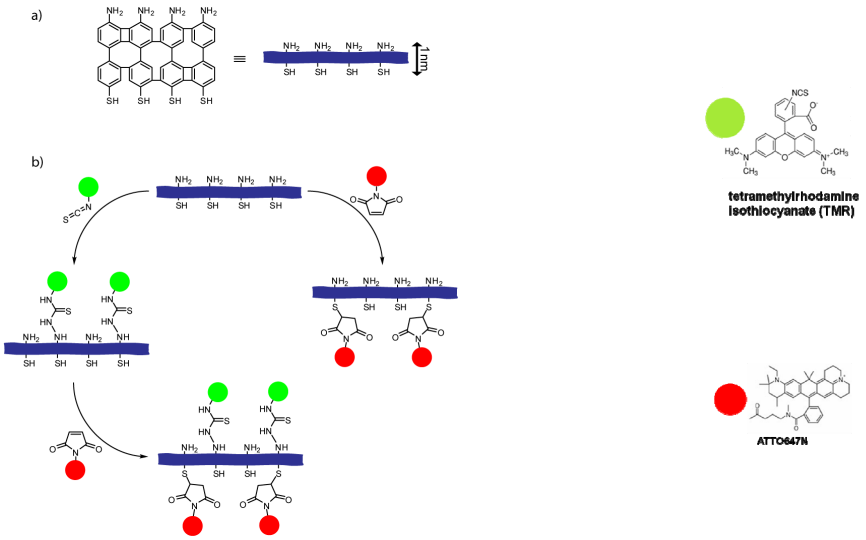

Fig.3: a) Schematic representation of a CNM with amino and thiol groups on its top and bottom sides, respectively. b) Scheme of the coupling of two distinct fluorescent dyes to the top and bottom sides of the CNM. The amino side is functionalized with TMR (green dot) the thiol side with ATTO647N (red dot) forming a *Janus* nanomembrane [3].