Fabrication and Modification of Carbon Nanomembranes (CNMs) by Helium Ion Lithography

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A helium-ion microscope (HIM) is capable of creating nanoscale patterns and its beam can perform ion milling as commonly done in focused ion beam (FIB) systems. Here we use a helium ion beam as direct writing tool to laterally cross-link self-assembled monolayers (SAMs) of 4'-nitro-1,1'-biphenyl-4-thiol (NBPT) into arbitrary patterns (Scheme I). The cross-linked SAMs were transferred to either silicon substrates with an oxide layer for optical characterization or transmission electron microscopy (TEM) grids for preparing free-standing carbon nanomembranes (CNMs). The required dose for the complete cross-linking with helium ions is quite similar to the dose earlier established with electrons. To determine the feature resolution limit, we prepared dot arrays of CNMs at various doses and 5 nm feature sizes have been achieved. Proximity effect and sample damage on the nanoscale patterns were also investigated. Furthermore, we used the ion beam to mill nanopores with well defined size and shape in CNMs as well as in graphene (Scheme II).

(1) A. Turchanin and A. Gölzhäuser: *Carbon Nanomembranes from Self-Assembled Monolayers: Functional surfaces without bulk (review),* Prog. Surf. Sci. **87**, 108 (2012).

(2) A. Turchanin, D. Käfer, M. El-Desawy, Ch. Wöll, G. Witte, A. Gölzhäuser: *Molecular mechanisms of electron-induced cross-linking in aromatic SAMs,* Langmuir **25**, 7342 (2009).

(3) 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).

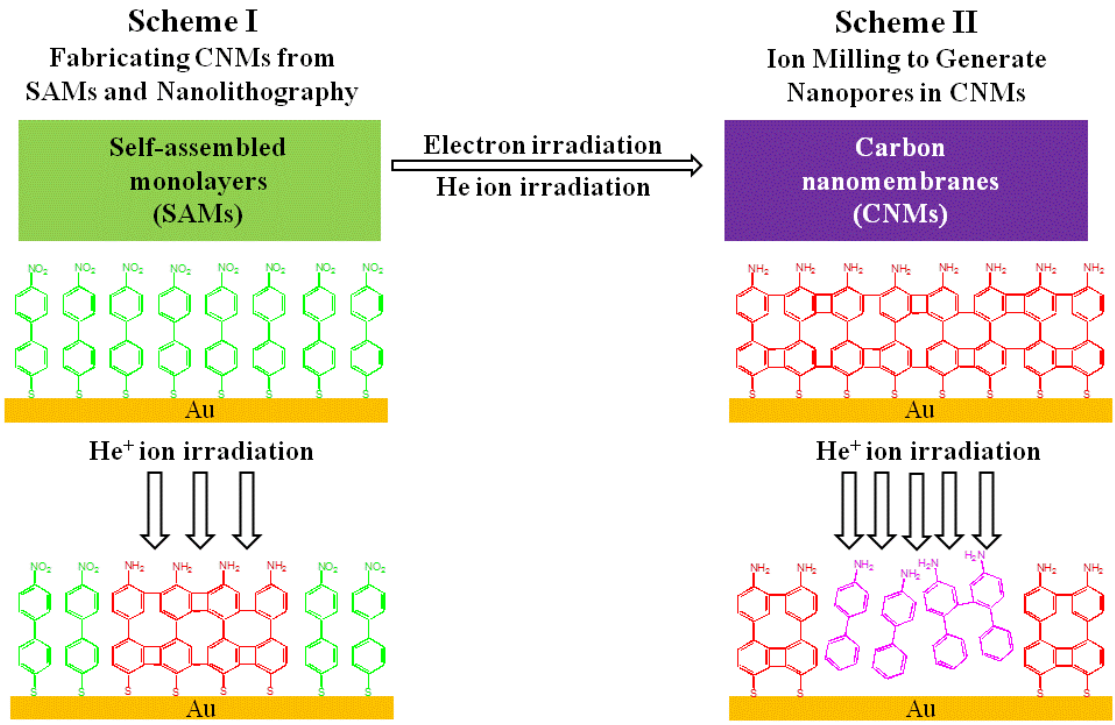

Fig. 1: Schemes of He^+ induced modification of self-assembled monolayers (SAMs). In Scheme I a biphenyl SAM is cross-linked into a Carbon Nanomembrane (CNM). In Scheme II a CNM is milled by helium ions.

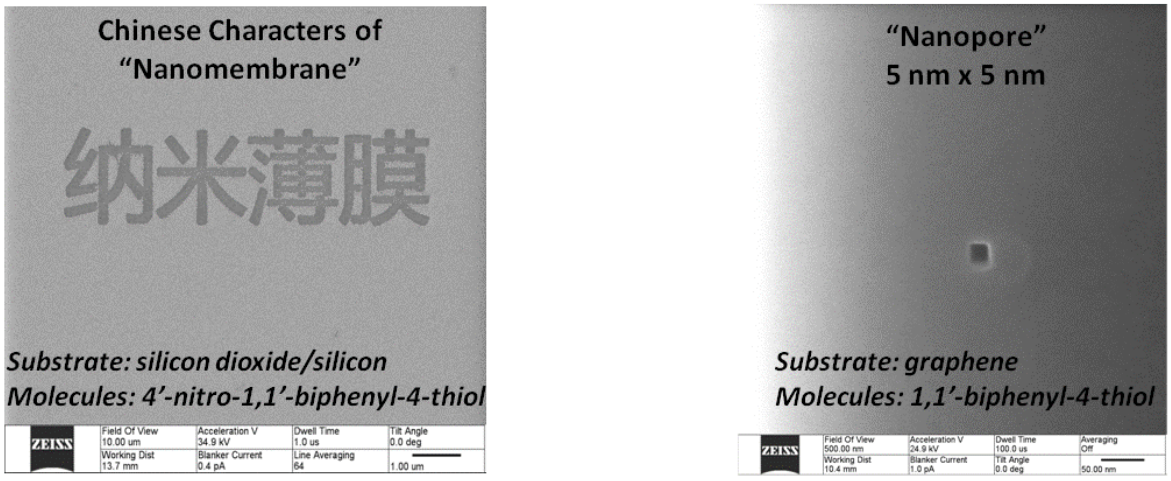

Fig. 2: The left Helium Ion Micrograph shows characters written by the lateral cross-linking of biphenyl SAMs into CNMs. The right Helium Ion Micrograph shows a squared (5 x 5 nm^2) nanopore in graphene made by milling with helium ions.