doi:10.1017/S1431927615005784 Paper No. 0499 Microsc. Microanal. 21 (Suppl 3), 2015
© Microscopy Society of America 2015

Atomic Structure of Amorphous 2D Carbon Structures as Revealed by Scanning Transmission Electron Microscopy

Jani Kotakoski, Franz Eder, Giacomo Argentero, Stefan Hummel, David Lindner, and Jannik Meyer

Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Wien, Austria

The atomic structure of disordered materials is one of the remaining challenges in materials science due to the difficulties related to imaging non-repeating arrangements of atomic positions. In fact, since over 80 years, the popular concept of the atomic structure of amorphous materials has been for a large part based on the drawings of a random network by Zachariasen [1].

Only very recently, the first possibility to image the complete atomic structure of a disordered material appeared in the form of two-dimensional materials. So far, two different materials have been described: a truly 2D silica glass [2,3] and graphene amorphized utilizing the imaging electrons in a transmission electron microscopy (TEM) experiment at a voltage of 100kV [4,5].

While the silica structure offers us a glimpse to the atomic arrangements in a naturally forming amorphous structure, introducing the disorder step-by-step during atomic resolution imaging allows the study of all of the intermediate states between a perfect crystal and a completely amorphized material. We show [5] that the change from a crystal to a glass happens suddenly, and at a surprisingly early stage. Right after the transition, the disorder manifests as a vitreous network separating individual crystallites, similar to the modern version of the crystallite theory. However, upon increasing disorder, the vitreous areas grow on the expense of the crystallites and the structure turns into a random network (See Fig. 1 a-c). Thereby, our results show that both of these two models for amorphous structures can be correct, and can even describe the same material at different degrees of disorder.

In addition to the already-reported materials, in this contribution, we show two additional disordered 2D carbon materials: graphene amorphized with ion irradiation (in contrast to electron irradiation) and evaporated thin carbon films with mainly sp2-hybridized bonding (Fig. 1 d). Further, we explore the structural differences in graphene membranes amorphized at different acceleration voltages during a TEM experiment.

While the study of amorphous materials is itself interesting from the fundamental science perspective, the controlled introduction of disorder into graphene is also of technological relevance. For example, patterning of amorphous patches into graphene can, at least in principle, be utilized to create all-graphene devices for nanoelectronics and spintronics, and their use can be explored for applications in thermoelectrics. Additionally, because disorder enhances the chemical reactivity of graphene, selectively amorphized graphene structures may have use in the field of sensor applications [6].

References:

[1] Zachariasen, W., Journ. Am. Chem. Soc **54** (1932), p. 3841.
[2] Lichtenstein, L. *et al*, Angew. Chem. **51** (2012), p. 404.
[3] Huang, P. Y. *et al*, Nano Lett. **12** (2012), p. 1081.
[4] Kotakoski, J. *et al*, Phys. Rev. Lett. **106** (2011), p. 105505.

https://doi.org/10.1017/S1431927615005784 Published online by Cambridge University Press

[5] Eder, F. *et al*, Sci. Rep. **4** (2014), p. 4060.
[6] The authors acknowledge funding from the European Research Council (ERC) Project No. 336453-PICOMAT, Austrian Science Fund (FWF) through Grant No. P25721-N20, M1481-N20, and I1283-N20.

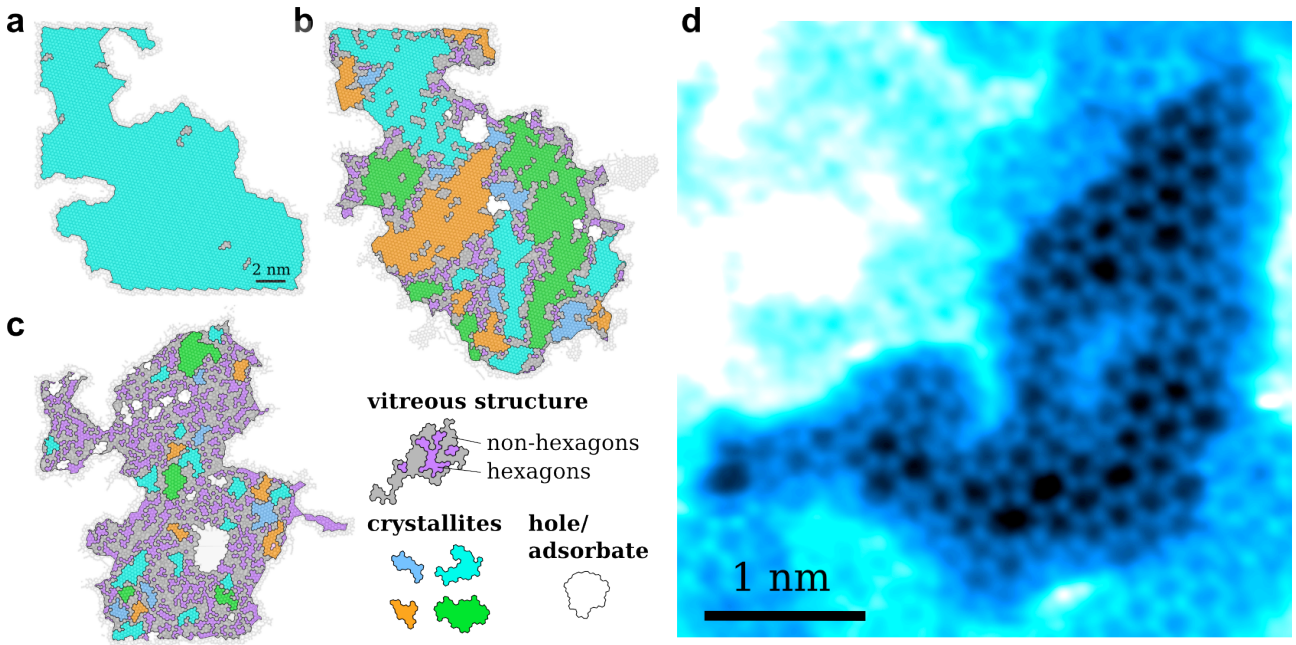

Figure 1: a-c. Transition from a crystalline graphene (a) through a crystallite structure (b) into a random network (c) due to electron irradiation. d. Atomic structure of a sputtered 2D carbon membrane.

https://doi.org/10.1017/S1431927615005784 Published online by Cambridge University Press