chem2Dmat
August 31 - September 03, 2021 • Bologna, Italy
European Conference on Chemistry of Two-Dimensional Materials

Towards atomic resolution imaging of beam-sensitive 2D polymers and metal-organic frameworks

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Two-dimensional (2D) polymers and metal-organic frameworks (MOFs) hold great promise in the rational materials design tailored for next-generation applications. However, unlike inorganic 2D materials whose atomic structures can be readily revealed via aberration-corrected high-resolution transmission electron microscopy (AC-HRTEM), direct imaging of organic 2D materials has been substantially hindered by their low resilience against electron irradiation. This work will present the key strategies to achieve higher image resolution on 2D polymers and MOFs, even down to atomic scale.

Our recent study demonstrated that, among a wide range of available electron energies (i.e., 80 keV – 300 keV), 120 keV offered the highest amount of structural information per unit damage. When combined with the low-dose imaging technique, 1.9 Å image resolution has been successfully achieved on multiple 2D polymer thin films. The enhanced resolution revealed structural details such as additional molecules and layer shifts, which were not accessible in previous AC-HRTEM studies [1].

Meanwhile, AC-HRTEM investigation on a hydrogen-free 2D BHT-Cu (BHT = benzenehexathiol) MOF (Fig. 1) unraveled that the absence of hydrogen in the framework could significantly increase the sample stability against electron irradiation. Strikingly, we were able to achieve a resolution of 0.95 Å on Cs+Cc-corrected SALVE microscope under 80 kV [2]. It is worth mentioning that the BHT-Cu MOF could withstand an accumulated dose of 1.5×10^5 $e^-/Å^2$ before total structural disintegration, which is comparable to that of inorganic materials, rendering it a superb candidate for subsequent in-situ heating experiments.

References

[1] H. Qi et al., Science Advances 6, (2020) eabb5976
[2] www.salve-project.de

Figure

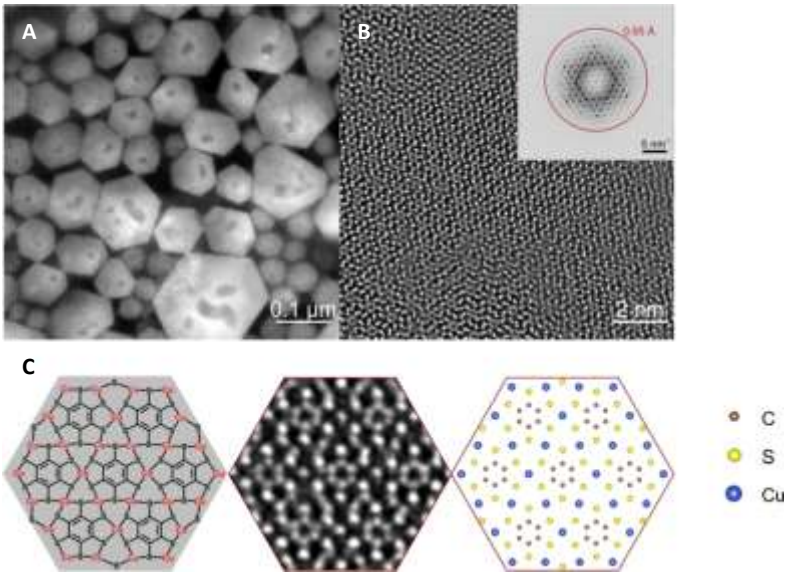

Figure 1: (A) High-angle annular dark-field image showing the morphology of 2D BHT-Cu MOF particles. (B) AC-HRTEM image of 2D BHT-Cu MOF obtained on the SALVE microscope under 80 kV. Inset: fast Fourier transform pattern of the image showing an image resolution of 0.95 Å. (C) Comparison between the atomic structure and experimental AC-HRTEM image.