Tapered carbon nanocone tips obtained by dynamic oxidation in air

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Supportive Information

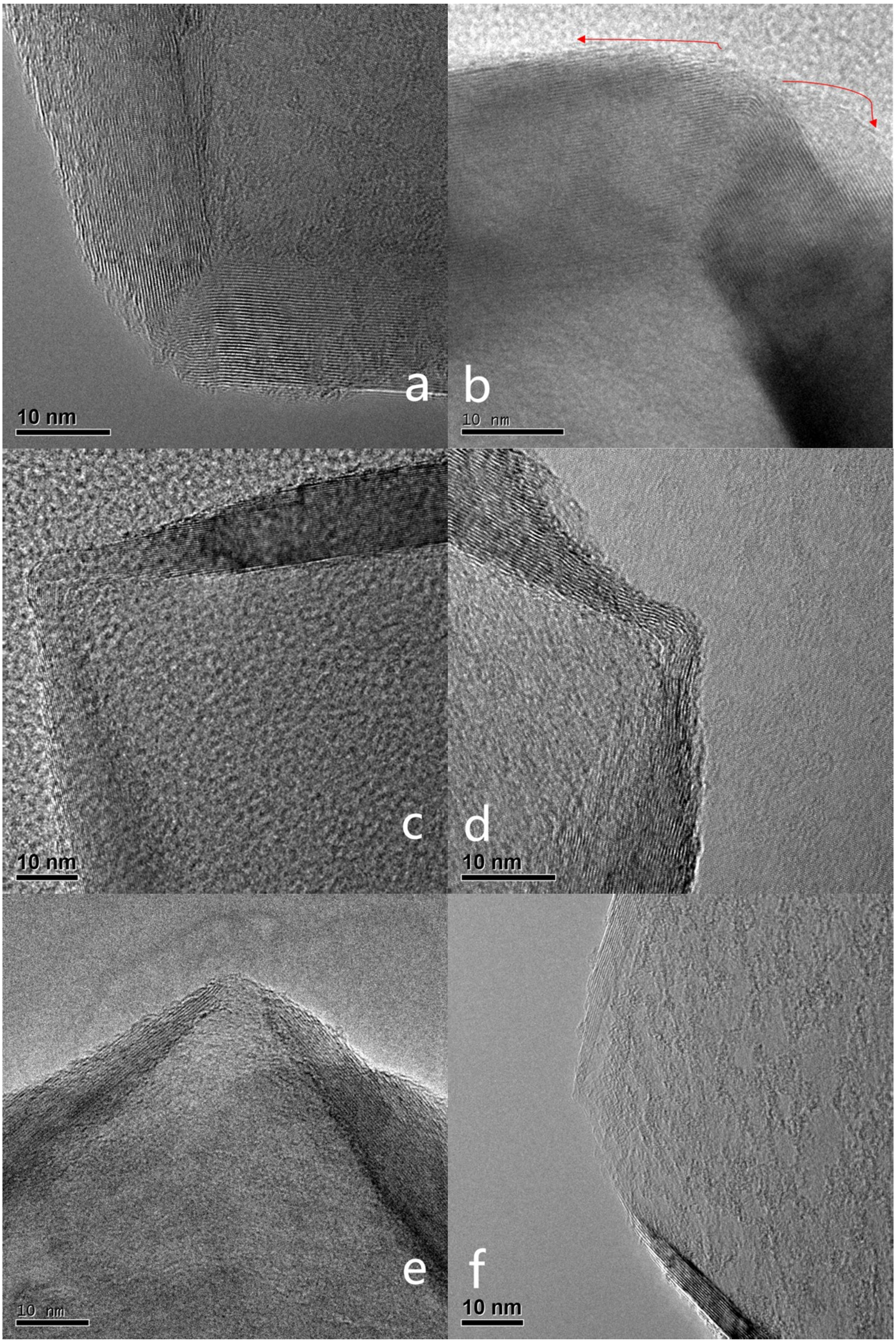
- **Mathematically calibration of carbon nanocones angles in TEM images**

There were inevitable measurement errors owing to the intrinsic disadvantages of transmission images (projective images) for measuring the real angles of the cones, which getting worse when the cones with large angles were being identified. But if we regard the carbon cones as ideal circular cones, we could make the situation better by mathematically calibration. Eq.1 shown below was deduced to de-project the projected cones in TEM images to reduce measurement errors.

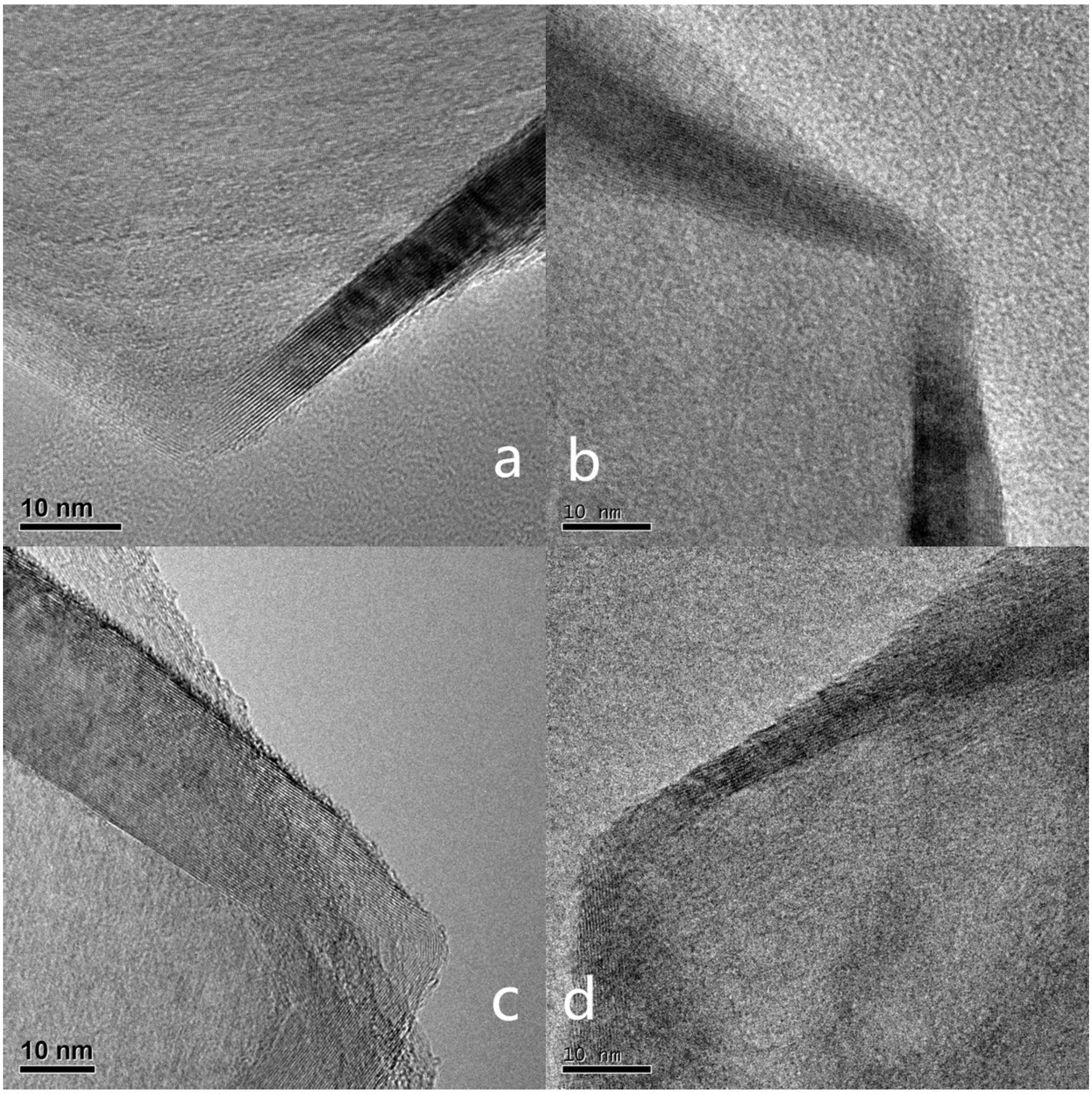
$$\theta = 2\arctan\left(\sqrt{1-n^2}\tan\frac{\beta}{2}\right) \qquad \text{eq.1}$$

In this equation, ϑ represents the real angle value of a measured cone, β the measured angle value. n is the ratio of short diameter to long diameter of the ellipse that is the projection of the cone end. Resulted from many factors, it was hard to keep projection direction unchanged under transmission electron microscope. So different projection directions would make de-projection for cone angles harder. For example, for 84.6° and 112.9° cones lie flat on TEM carbon film, measured cone angles will be 101.8° and 139.7° theoretically with relative error rate up to 20.3% and 23.7% respectively. The corresponding fluctuation rate for 19.2°, 38.9° and 60° cones are 1.4%, 5.6% and 12.3% respectively. Different projection directions in practical TEM characterization would result in different deviations for the same cone making confusions of distinguishing large angle cones between each other. Tough the real carbon cones are not ideal cones, de-projection by eq.1 would be more accurate for large angle cones.

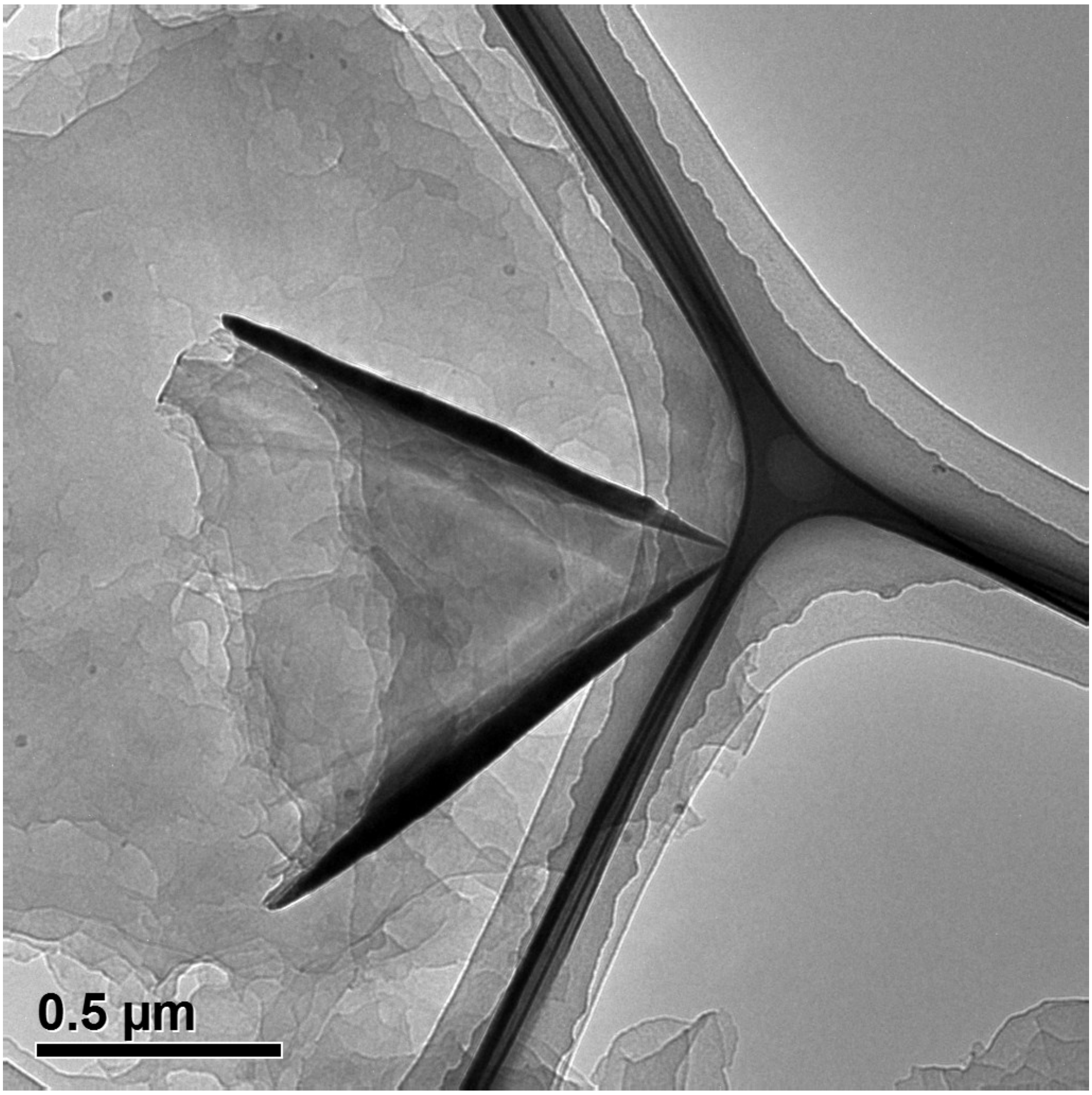
- **Supplementary images of tapered carbon nanocone tips**



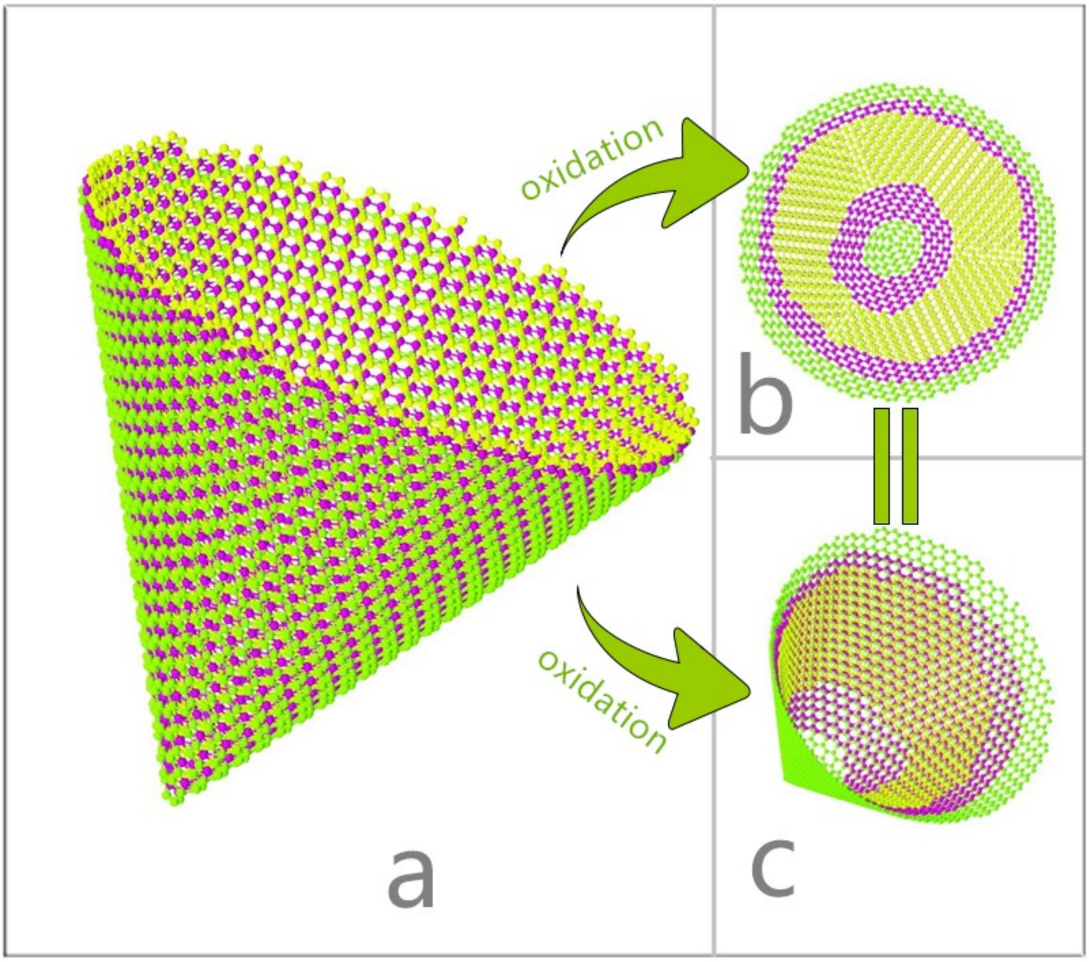
S1-(a)-(f) show HRTEM images of the dynamically oxidized CNC tips with different oxidation extent in the samples CNC-675-1 and CNC-688-1. The characteristic step-shaped structures are apparently presented in these images indicating a step-by-step oxidation mechanism of the dynamically oxidation of the CNCs.



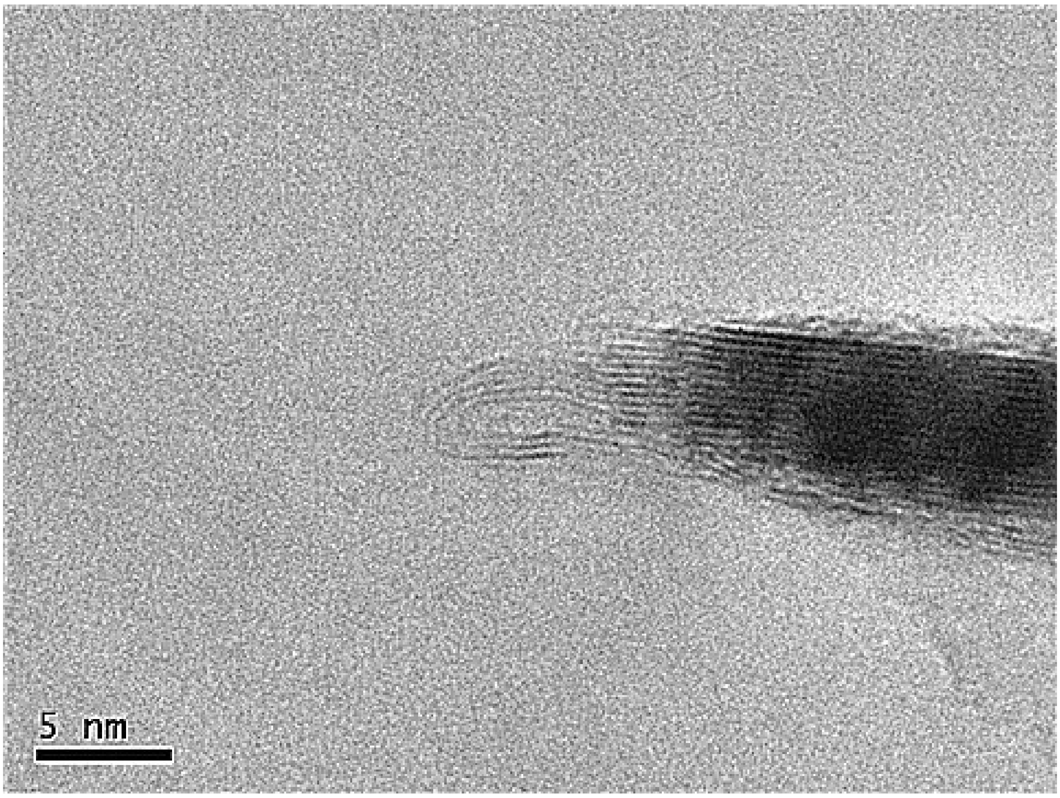
S2-(a)-(d): four typical tapered carbon nanocone tips in the samples CNC-675-1 and CNC-688-1.



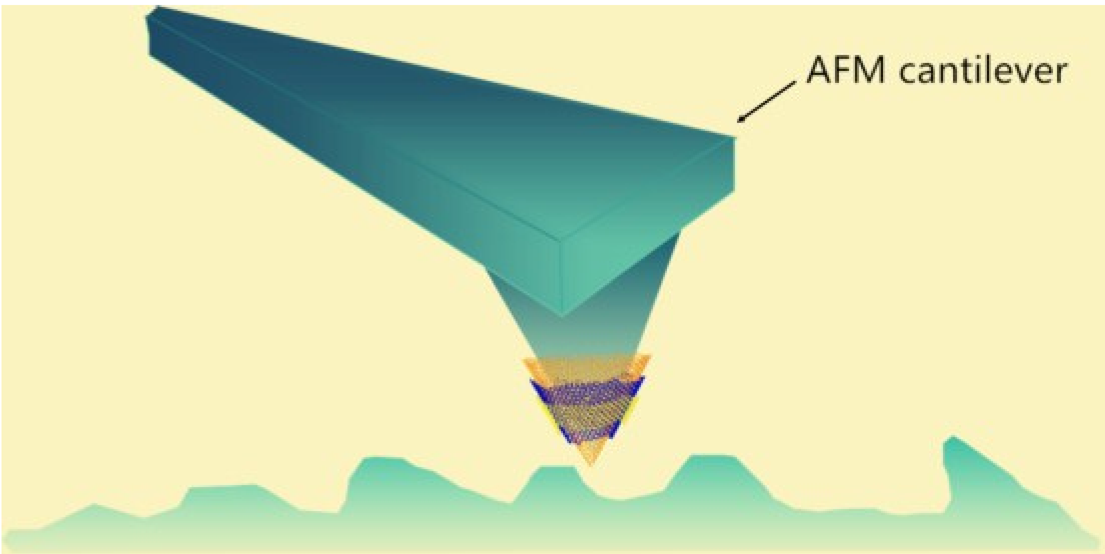
S3-overall view of a typical gradually tapered carbon nanocone. The gradually sharpened structure and the oxidized cone end are clearly presented.



S4-schematic illustration of the oxidation process on the N side (Figure 1b) of the processed carbon nanocone. (a): side view of pristine cone. (b) and (c): bottom view of processed cone. Similar gradually oxidation from the apex and the cone end during the dynamically oxidation processing would also be the mechanism on the N side. The loop ends are omitted here.



S5-the residual inner layers of the loop ends of an oxidized nanocone. The curly structure remained for the inner graphitic layers.



S6-Conceptual diagram of an AFM probe attached with a tapered carbon nanocone tip.