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Ironing the 2D black phosphorus using electron beam irradiation

Layered nanomaterials are prone to formation of surface corrugations (wrinkles and ripples) and 2D nanomaterials like Black Phosphorous (BP) are extraordinarily affected by formation of such corrugations due to their high surface reactivity. The surface corrugations give rise to interface disorders such as interface coulomb contaminations, charge traps and local fluctuations in strain, polarised carrier puddles, dielectric screening and suppression of electron transport. While techniques like plasma treatment and thermal annealing have been reported in literature for removal of surface corrugations, the issue is far from resolved [1,2]. Here, we introduce an approach that utilizes electron beam of transmission electron microscope (TEM) for ironing out the wrinkles and ripples of BP flake (Figure 1a-b). Experimental results show the evolution of lattice ridden with line defects and declinations into the uniformly spaced parallel lattice planes which indicates the improvement in crystallinity of the flake under e-beam irradiation (figure 1 c-g). Prolonged exposure to e-beam causes buckling of flake and thus control over electron fluence rates or the exposure time is crucial for optimization of ironing process. The hitherto unattempted electron beam based ironing of 2D flakes with nanoscale precision is likely to open up new prospects for development of 2D nanomaterials with reproducible electron transport properties.

References

[1] L. M. Terman, Solid State Electron., 5 (1962) 285−299.

[2] L. Wang, P. Makk, S. Zihlmann, A. Baumgartner, D. I. Indolese, K. Watanabe, T. Taniguchi, C. Schönenberger, Phys. Rev. Lett. 124 (2020) 157701.

Figures

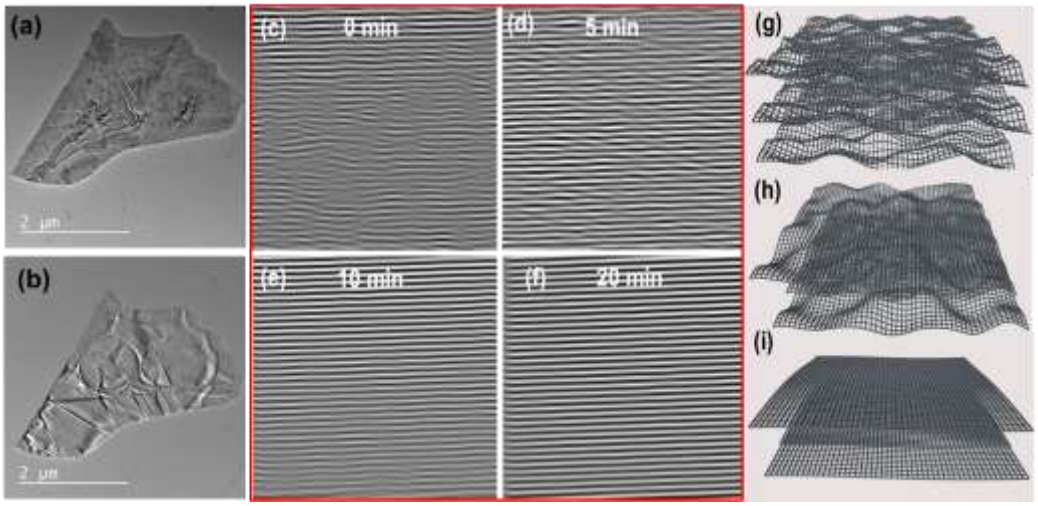

Figure 1: Low magnification TEM micrographs of BP flake (a) before and (b) after ironing. (c-f) Evolution of lattice fringes of BP with time under continuous exposure to electron beam in FEG-TEM set-up. (g-i) Schematic depicting the effect of electron beam irradiation on BP layers.