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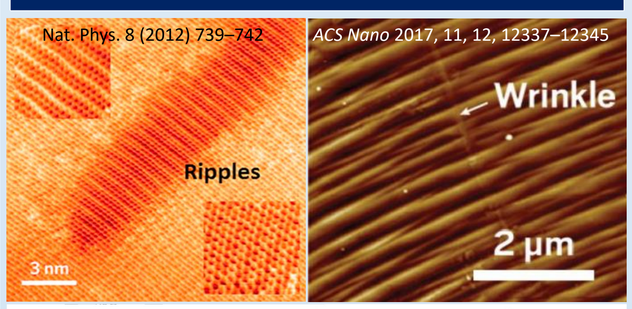
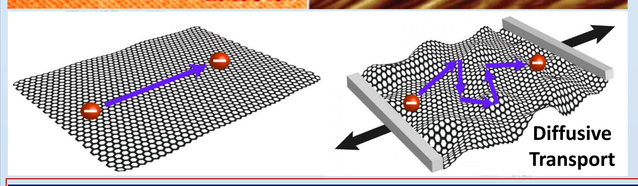
Ironing the 2D Black Phosphorus using Electron Beam Irradiation

Manpreet Kaur[Presenter], Himanshu Tyagi, Anirban Kundu, Kiran Shankar Hazra[*]
Institute of Nano Science and Technology, Mohali - 140306 (Punjab, India)

Institute of Nano Science and Technology

Challenge: Surface Corrugations in 2D nanomaterials





Prevalent techniques

- Plasma treatment # # #
- Thermal annealing # # #
- Mechanical treatment (Contact AFM) #
- Current induced treatment # #

Limitations:

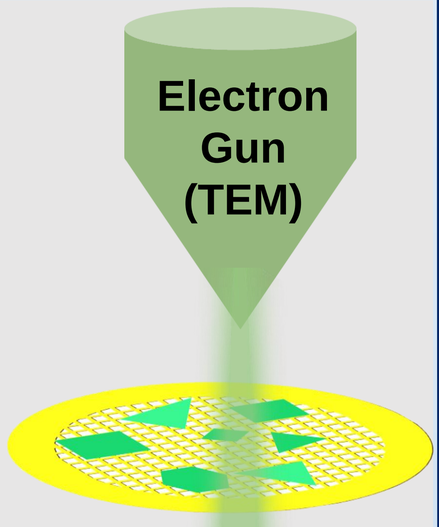
Introduce defects in 2D crystals

Lack nanoscale precision

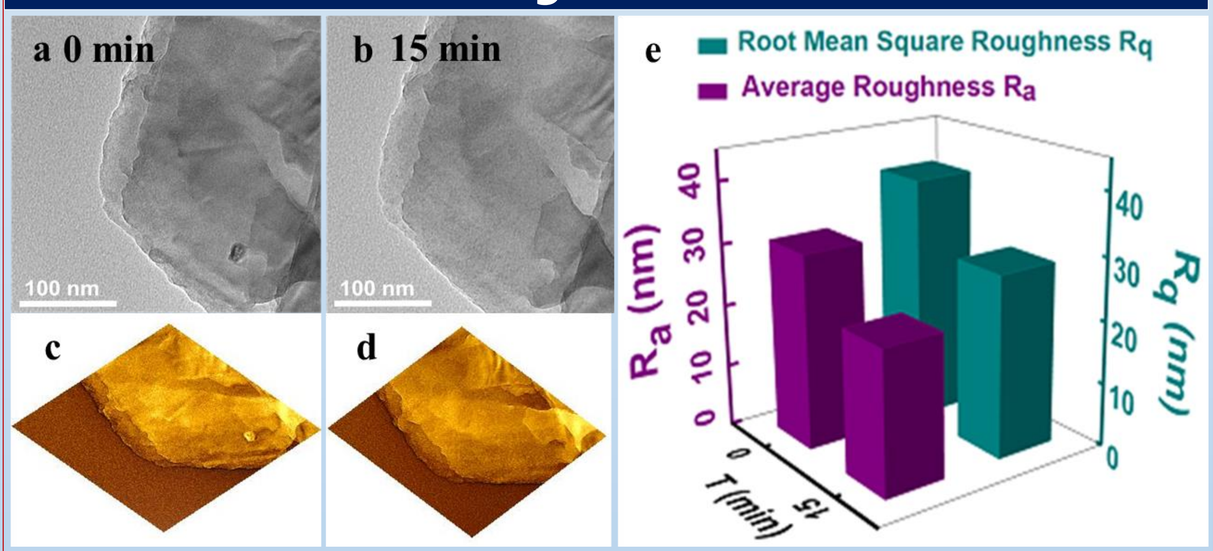
Incompatibility with highly reactive 2D surfaces

Our approach

- Introduce an ironing process which utilizes electron beam irradiation in TEM setup
- Monitoring the temporal evolution of the lattice under e-beam irradiation.
- Controlling the crystallinity by manipulating the electron fluence rate and exposure times.

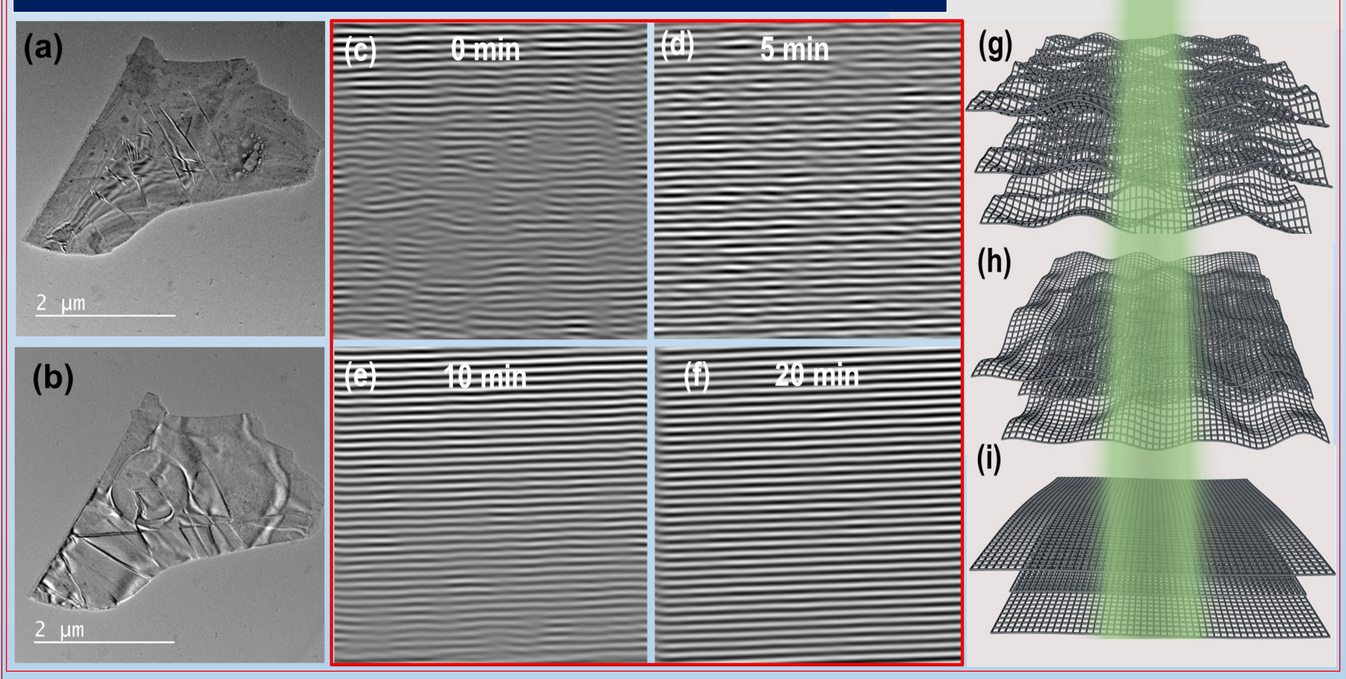


Result 1: De-wrinkling of BP flake under e-beam

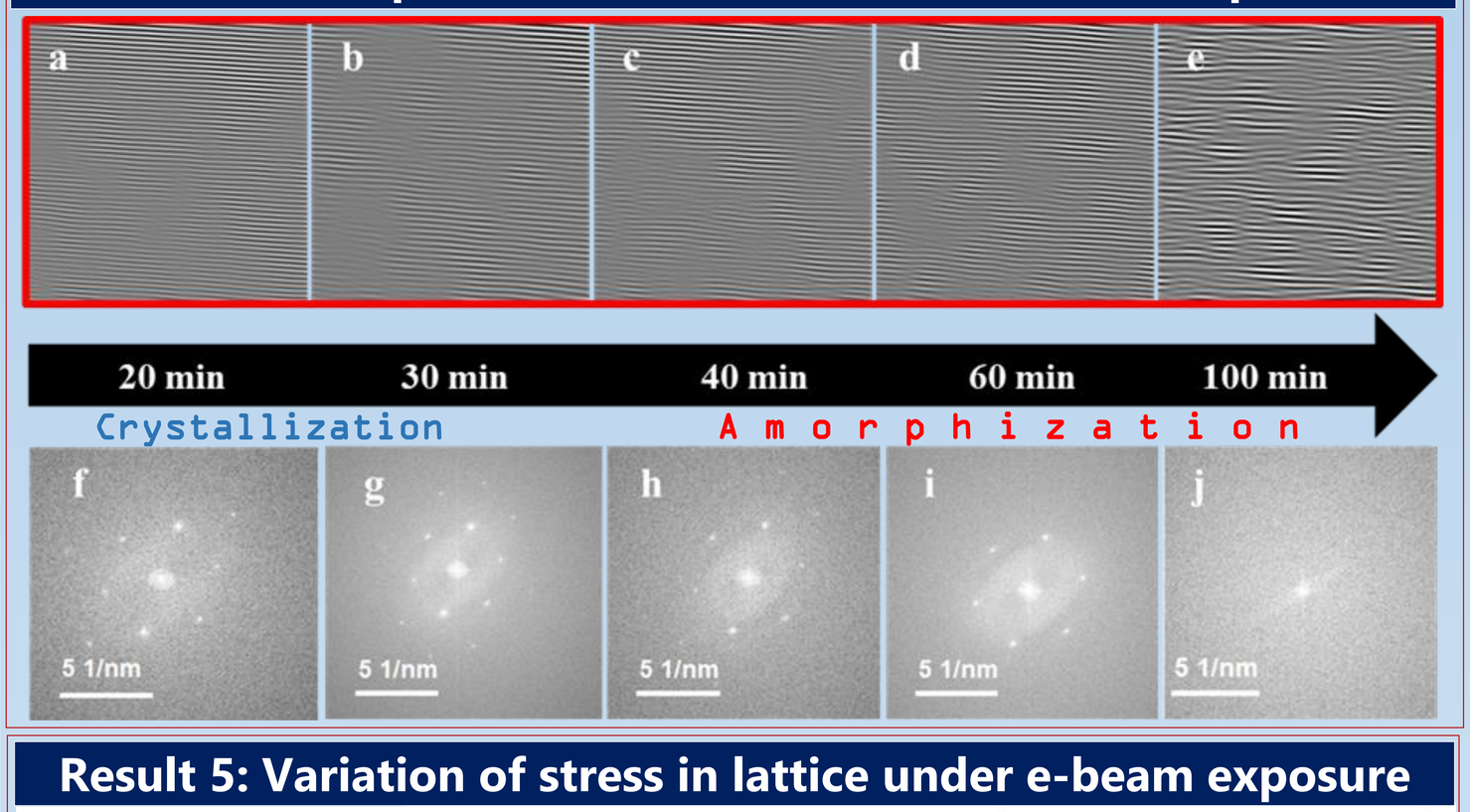


Granular edges smoothen up, ripples on surface of flake appear to be ironed out after 15 minutes exposure and contrast based roughness calculations suggest polished BP flake after exposure to e-beam

Result 2: Removal of line defects

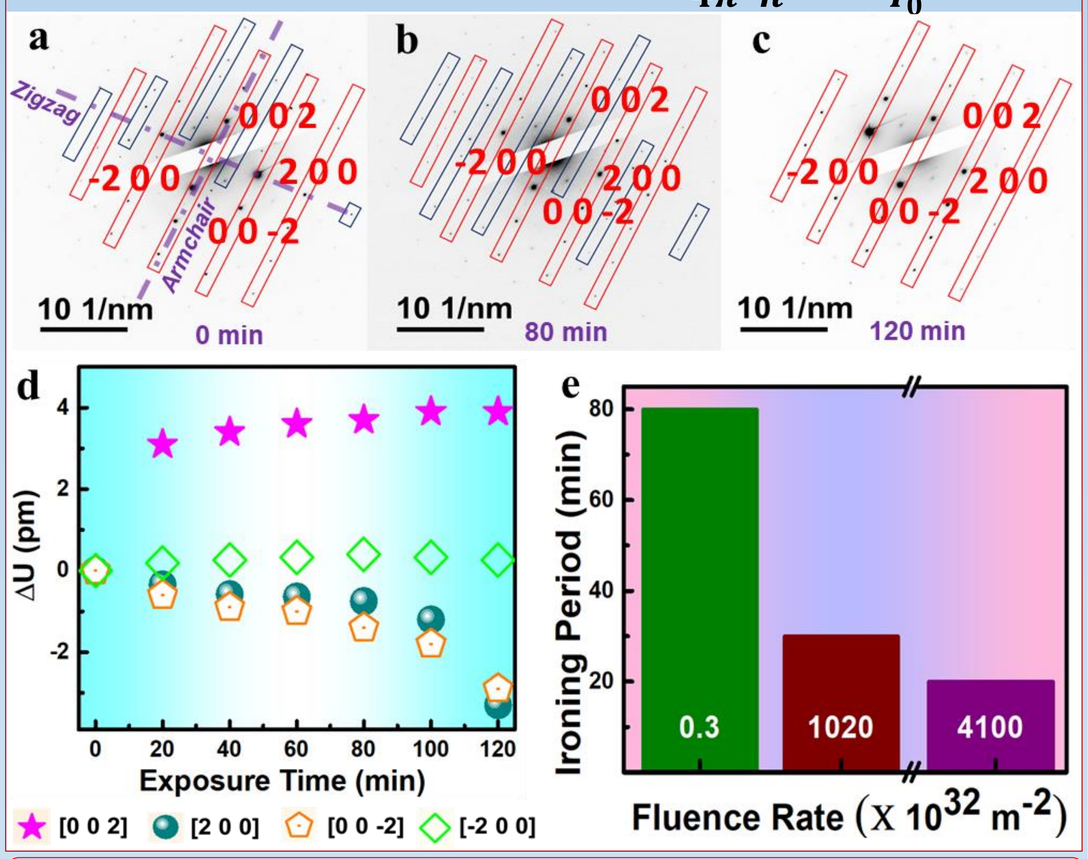


Result 3: Overexposure of BP flake to e-beam & Amorphization



Result 4: Irradiation induced compression along armchair & zigzag direction

Change in MSD, $\Delta U = U_{ii}^0 - U_{ii}(t) = \frac{a^2}{4\pi^2 h^2} ln\{\frac{I(t)}{I_0}\}$



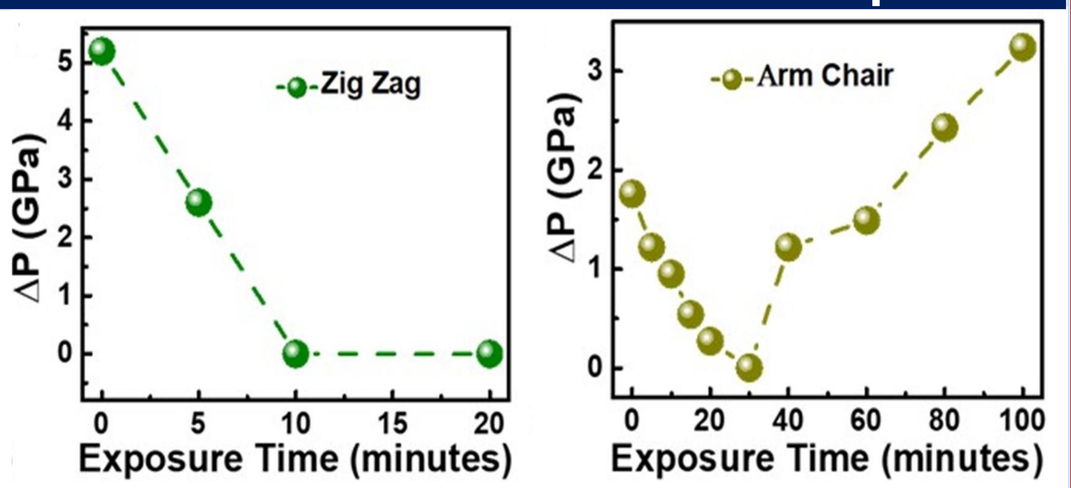
Result 5: Variation of stress in lattice under e-beam exposure

Equation of e-beam induced stress

$$\Delta P = K \frac{\Delta V}{V}$$

K- Bulk compression modulus material

$\frac{\Delta V}{V} (\sim \frac{\Delta d}{d})$- Lattice strain.



Conclusion

- ✓Removal of surface corrugations with nanoscale precision under e-beam exposure.
- ✓Parallelity of lattice planes in crystalline BP achieved by controlling the electron beam flux rate and irradiation time.
- ✓Improvement in crystallinity of flake is attributed to release of stress in lattice .
- ✓Overexposure leads to buckling in flake.

CONTACT PERSON
Manpreet Kaur
manpreet.ph19214@inst.ac.in
Tel: +91-9914676891

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