Epitaxial growth of single-crystal hexagonal boron nitride monolayer on copper

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Group meeting

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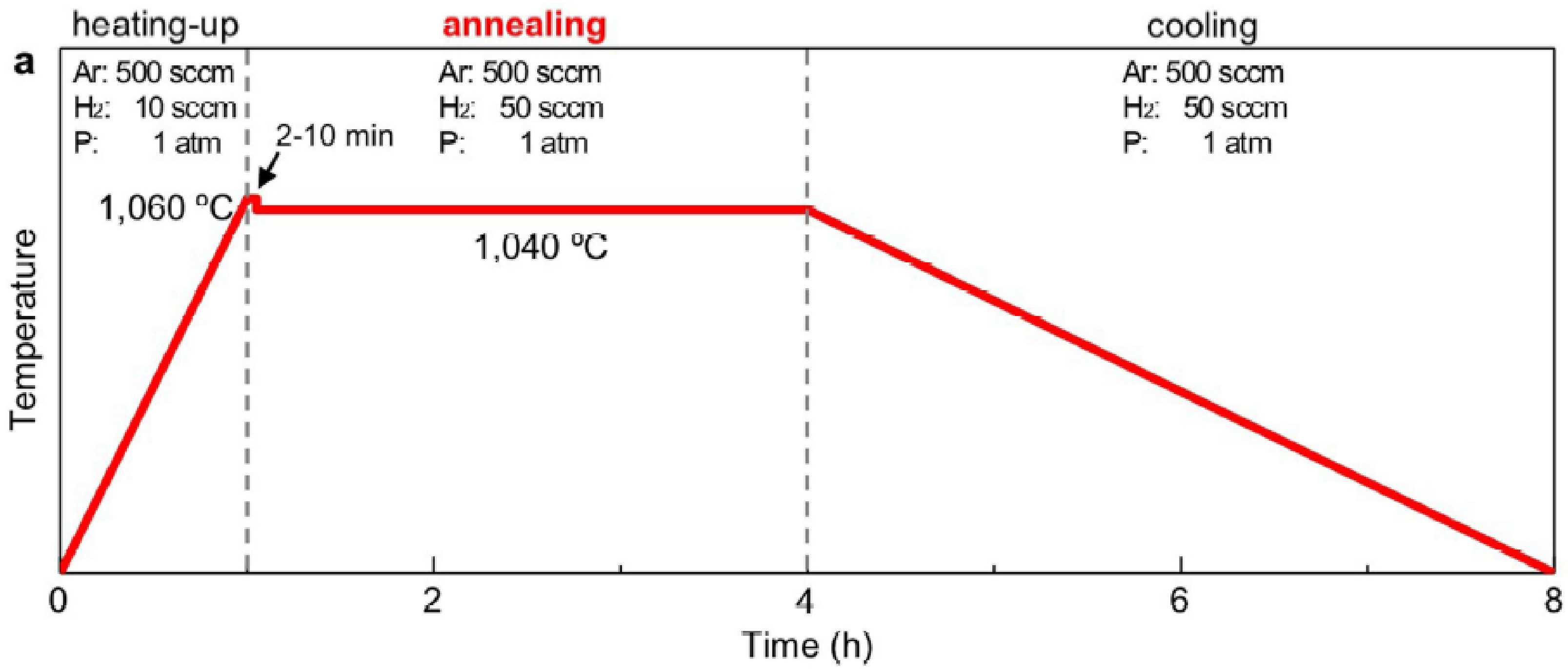
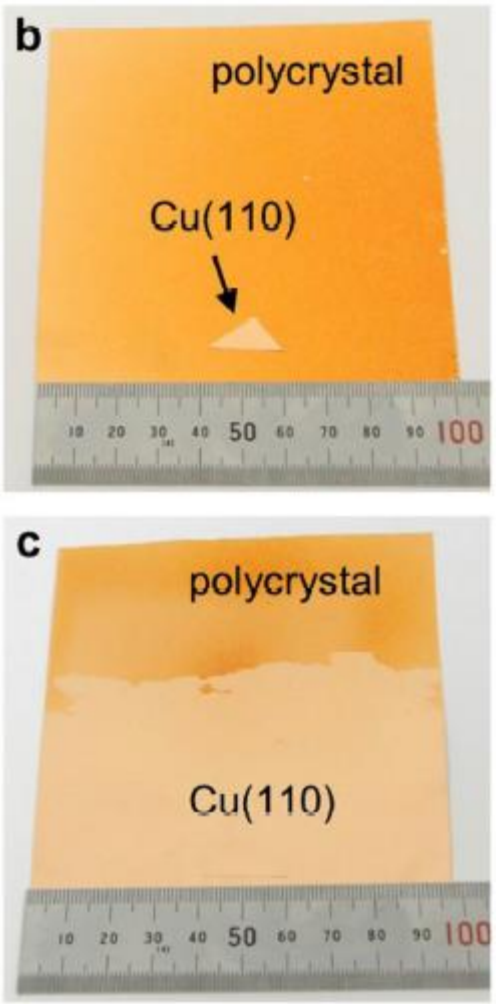
Wang, L., Xu, X., Zhang, L. *et al.* Epitaxial growth of a 100-square-centimetre single-crystal hexagonal boron nitride monolayer on copper. *Nature* **570,** 91–95 (2019).
https://doi.org/10.1038/s41586-019-1226-z

Annealing of a 10 × 10 cm^2 single-crystal Cu (110) foil

1. Anneal polycrystalline Cu foil at 1060 °C for 2–10 min under a mixed-gas flow (Ar, H_2) to melt surface
2. Put a single-crystal Cu (110) foil on the surface as an artificial seed,
3. Anneal Cu foils at 1040 °C for 3 h.

Melting point of Cu: 1085°C



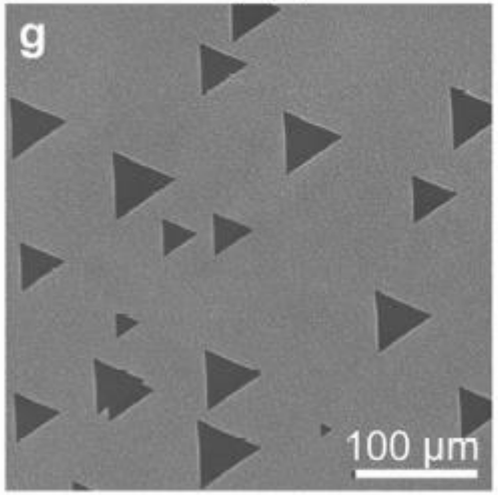


Growth of 10 × 10 cm2 single-crystal 2D hBN films

Precursor: Ammonia borane (BH_6N)
CVD
Substrate temperature 1,035 °C
Source temperature: 65 °C
Pressure: 200 Pa with Ar (5 sccm) and H_2 (45 sccm)

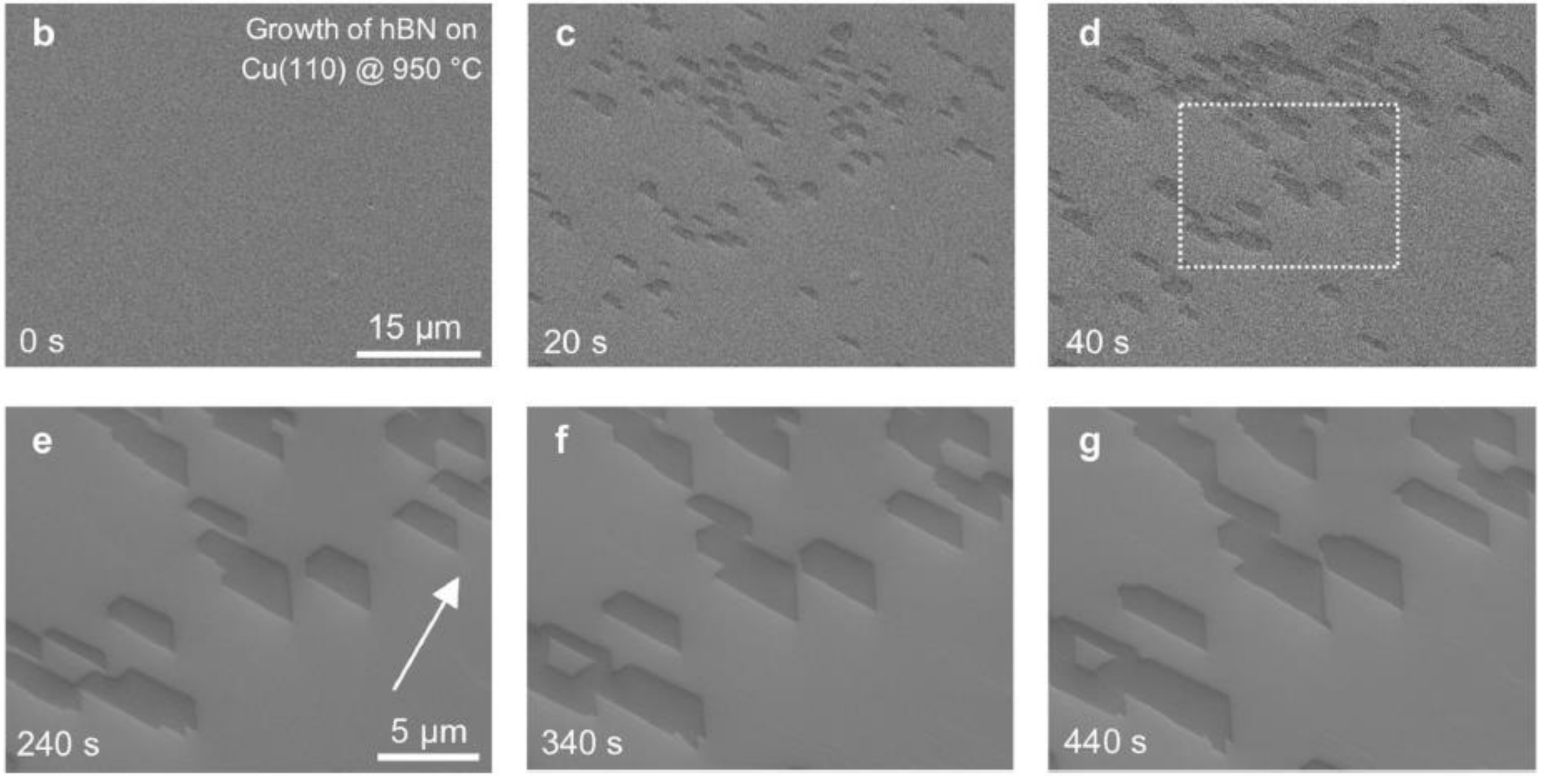
Growth time: 1 h for individual hBN domains; 3 h for a continuous hBN film

SEM image



Epitaxial hBN on Cu (110)

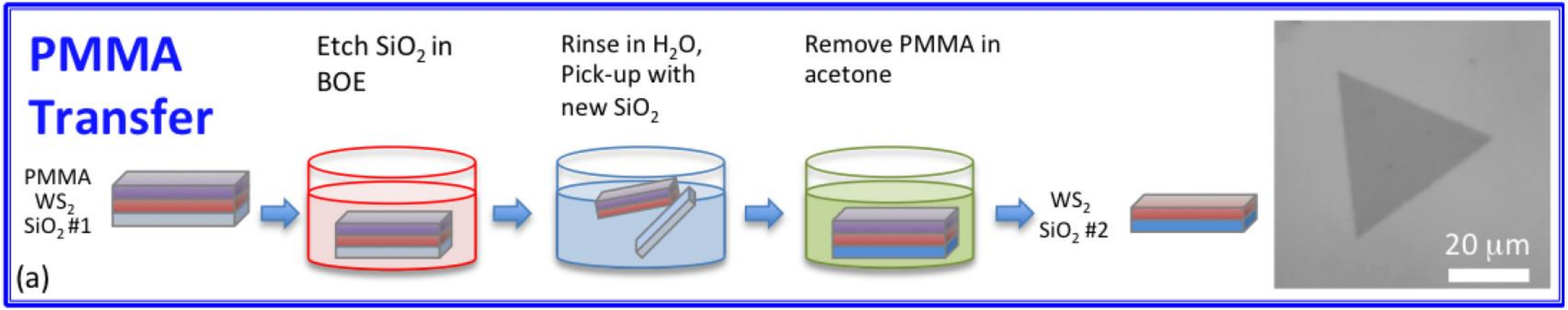
Unidirectional aligned domains



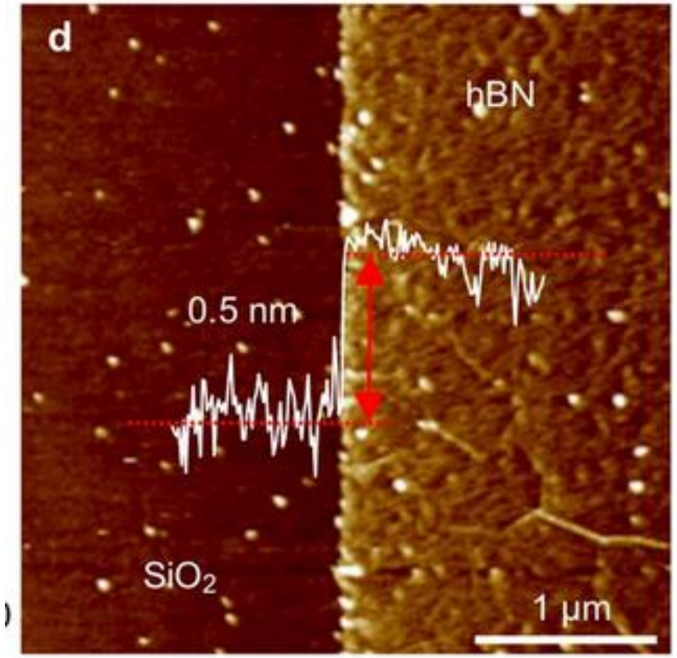
In situ observationof growth

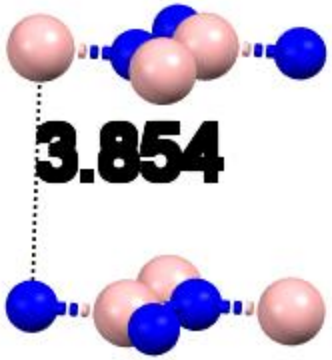
Transfer of hBN films

the polymethyl-methacrylate-based transfer technique.



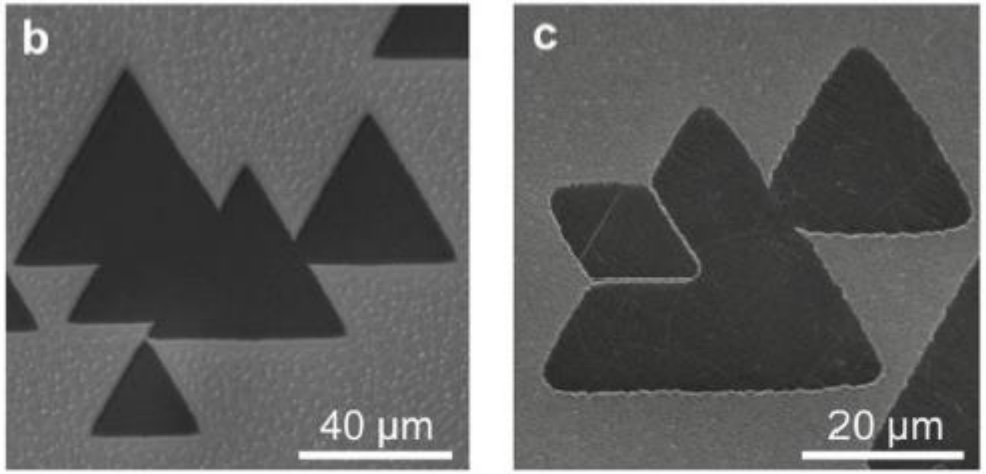
BOE: buffered oxide etchant





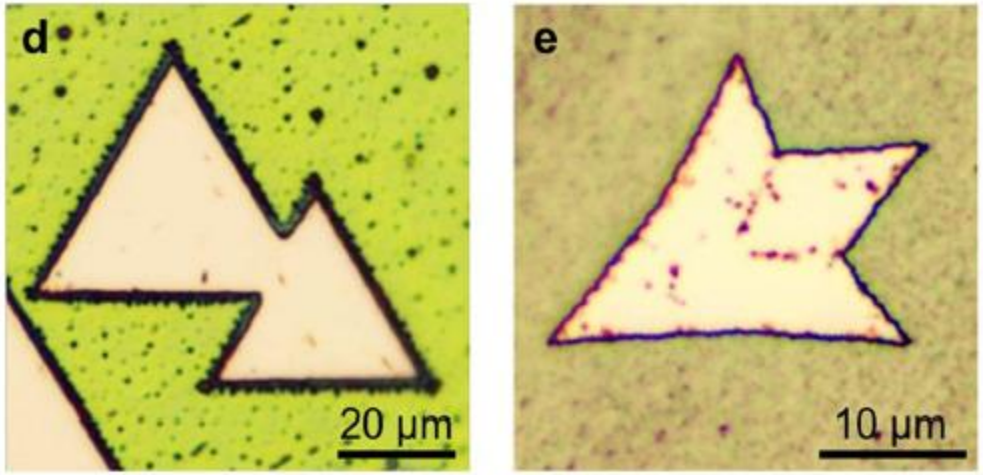
Monolayer thickness

SEM after H_2 etching



Cu (110) / hBN   Cu (111) / hBN

OM after UV oxidation



Cu (110) / hBN

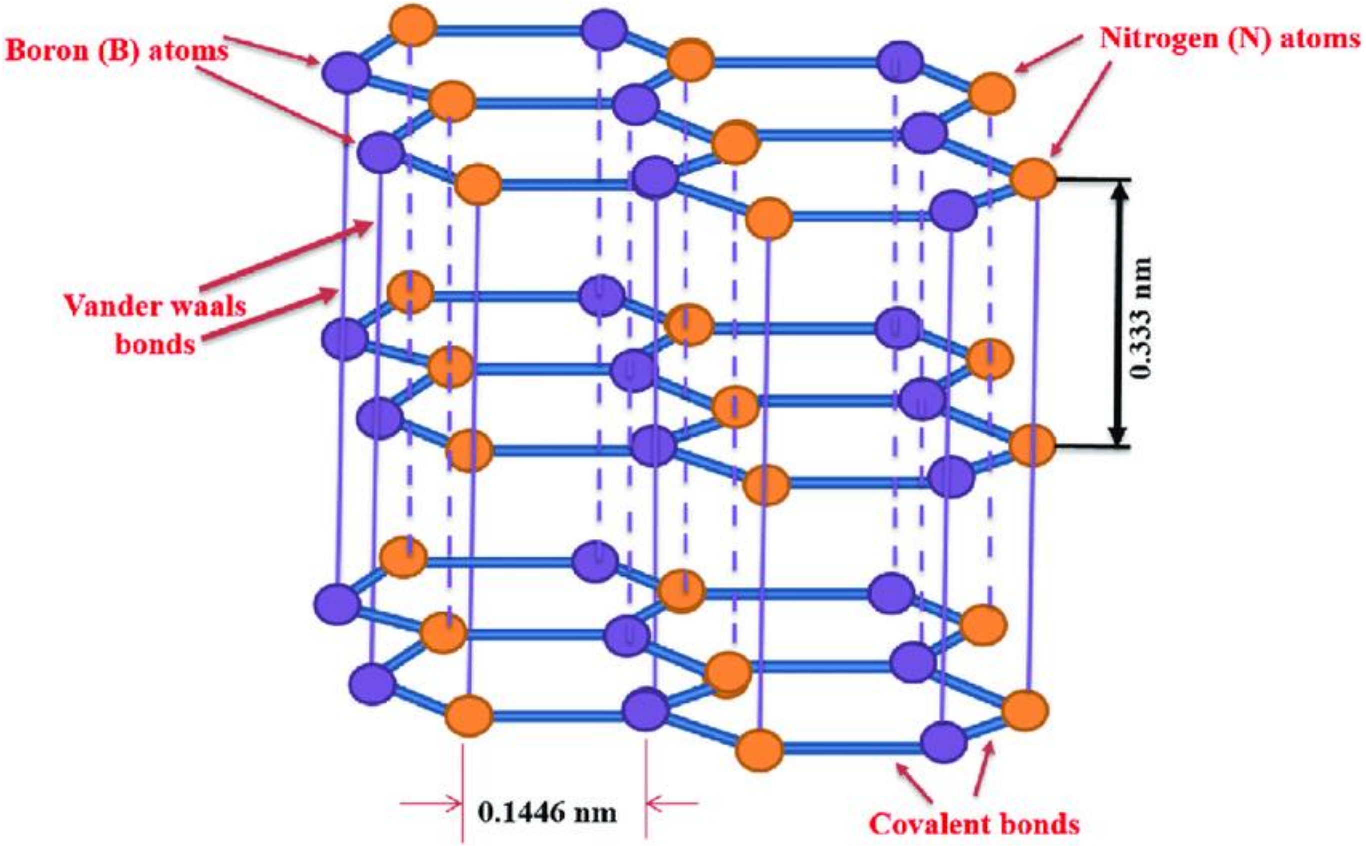
No boundary line

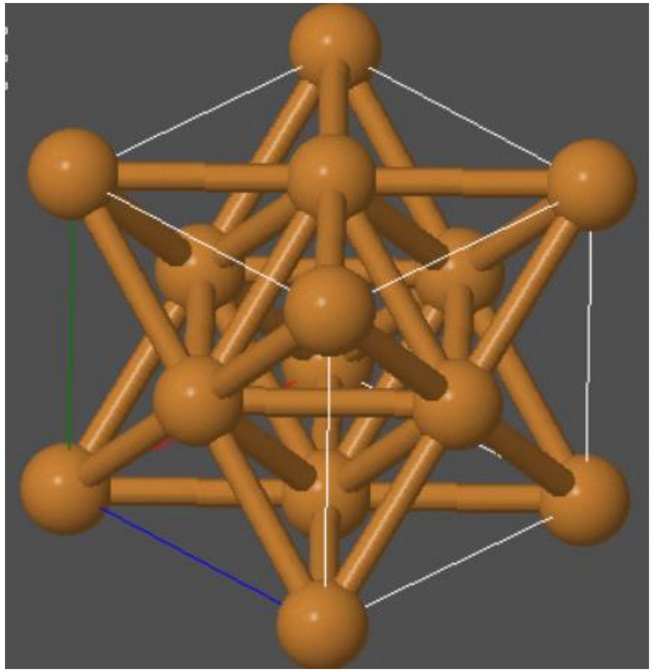
Cu (111) / hBN

a 60° twist angle

Why can hBN be epitaxial on Cu(110), not on Cu (11)?

hBN structure (C_{3v} symmetry) is not compatible with the C_{6v} symmetry of the top-layer atoms of the Cu (111) surface



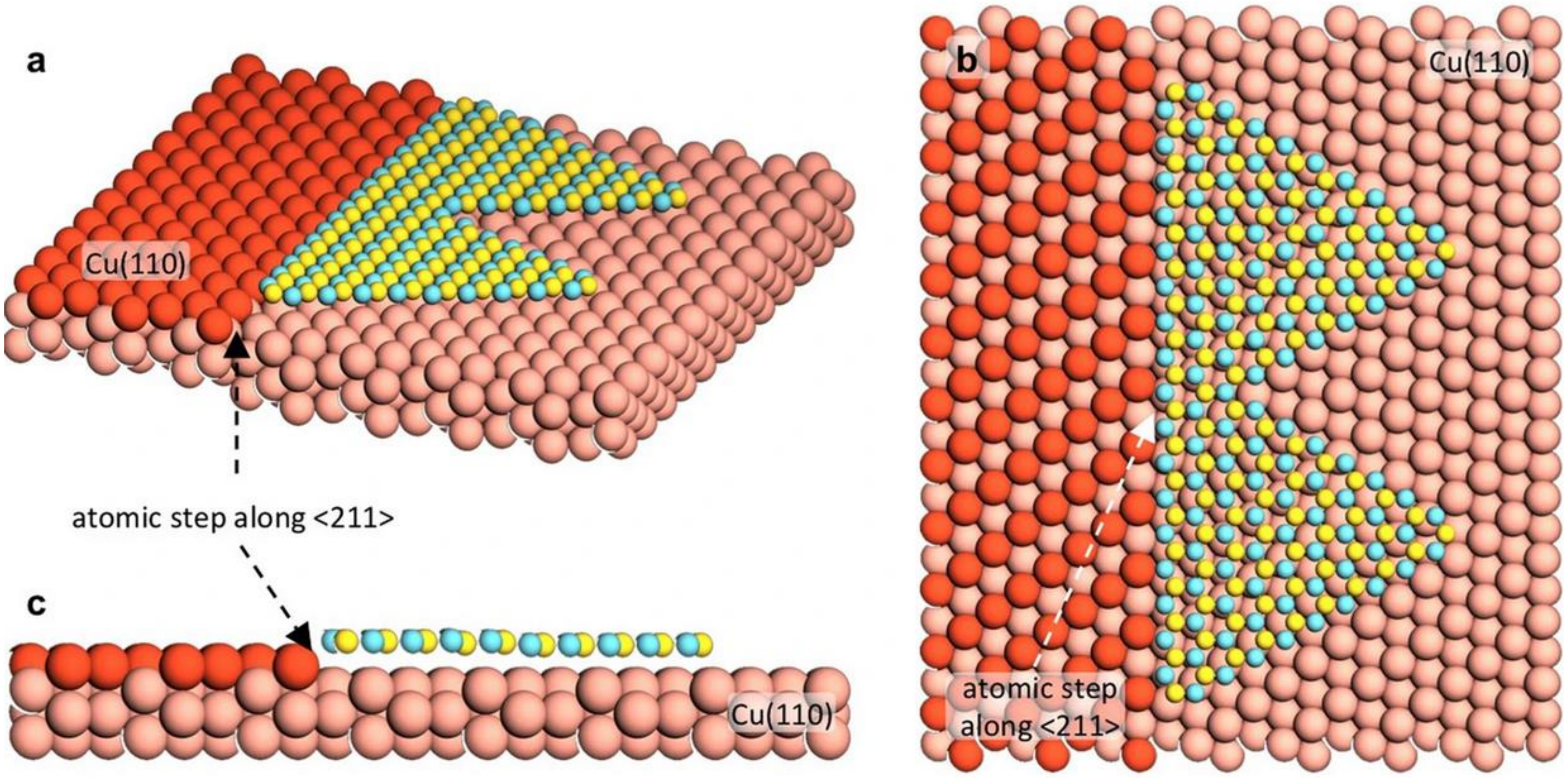


Cu, FCC

hBN structure (C_{3v} symmetry) is compatible with C_{3v}, C_3, σ_v or C_1 symmetry.

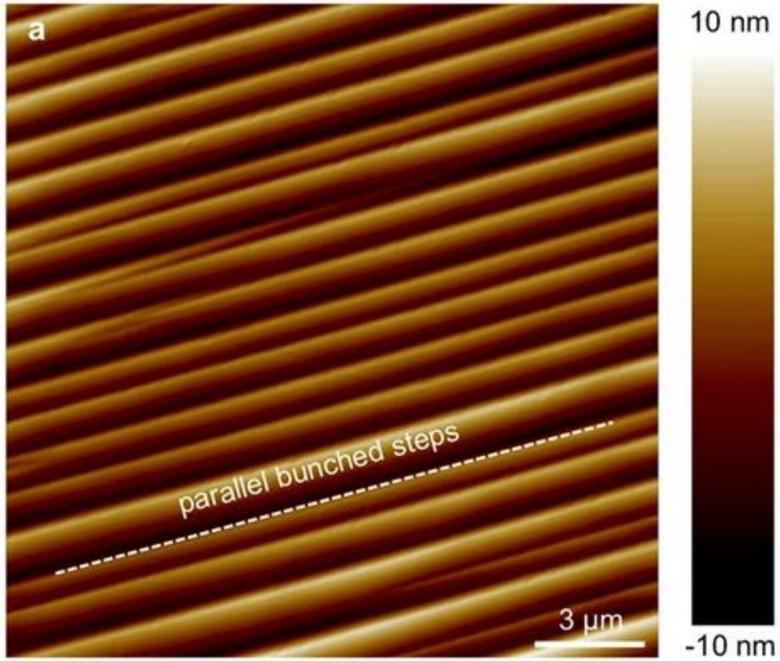
The edge-coupling-guided growth mechanism

Cu (110) vicinal surface, on which the presence of metal steps along the <211> direction led to a C_1 symmetry.

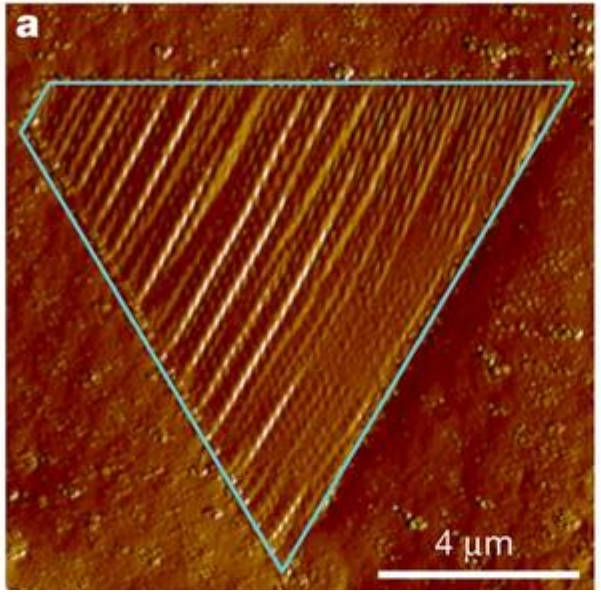


hBN zigzag edges

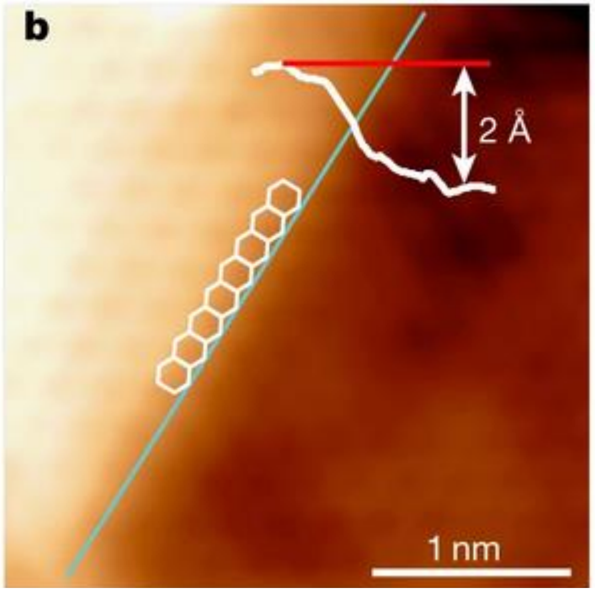
AFM images of parallel bunched steps on a bare as-annealed Cu surface

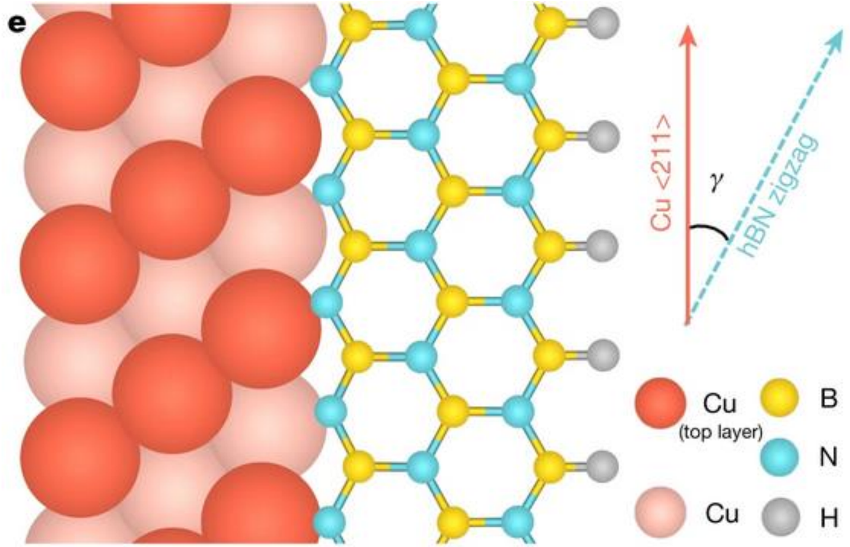


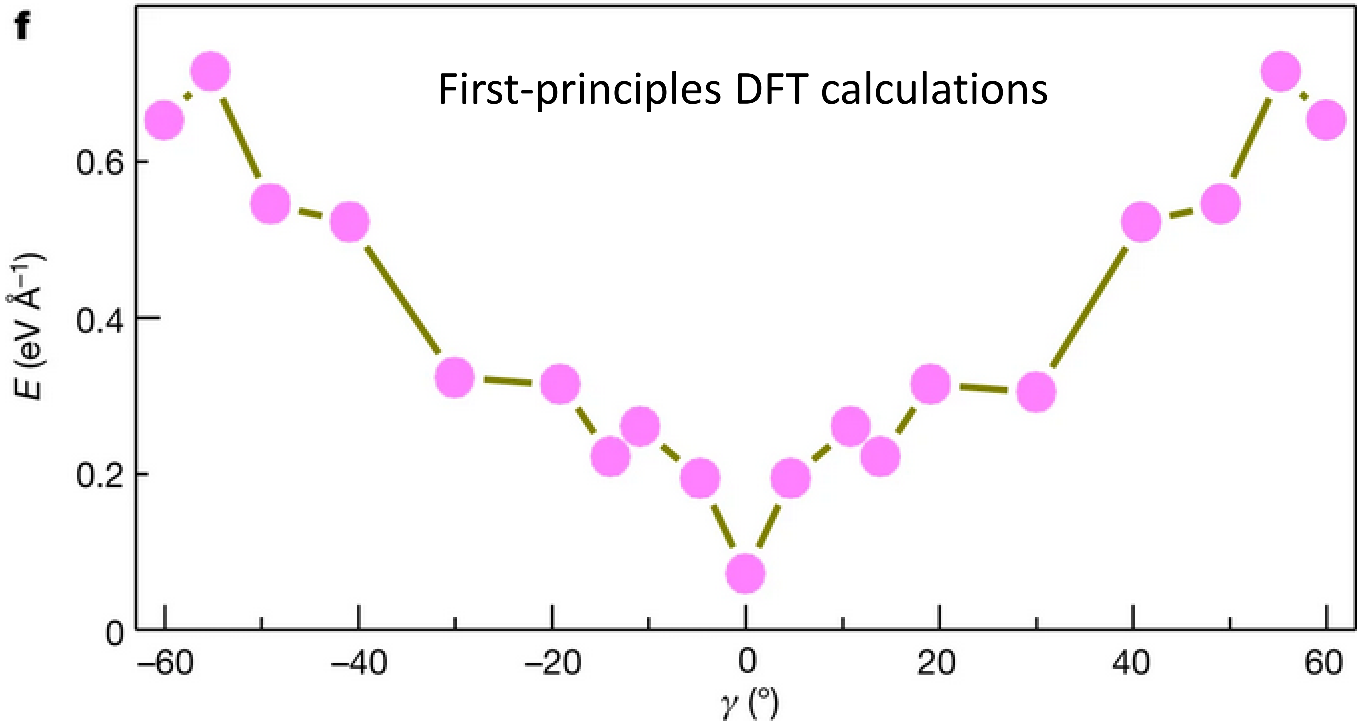
AFM phase image

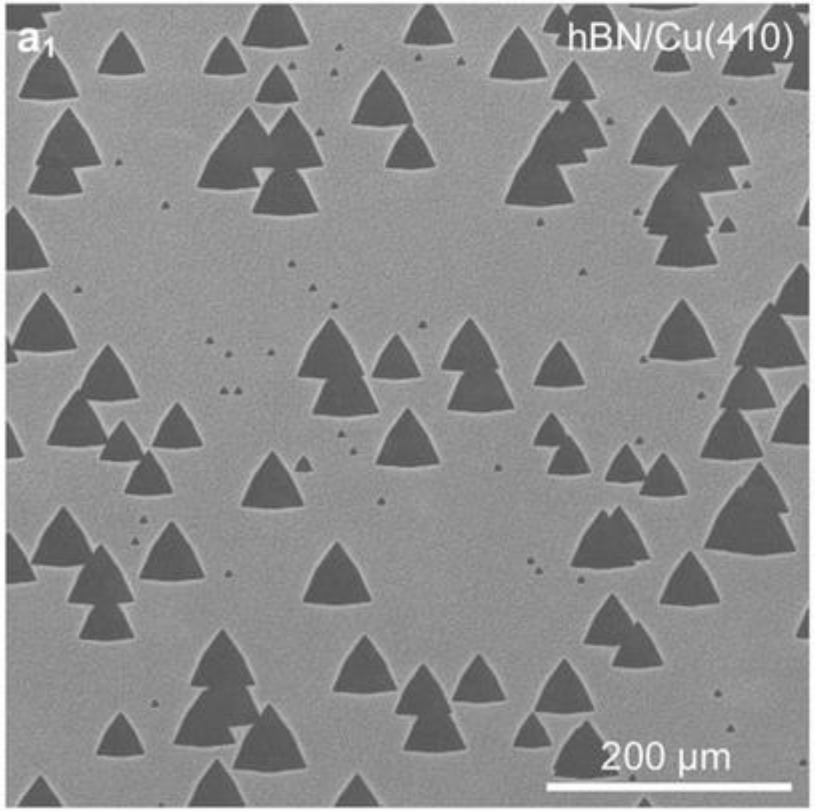


STM image

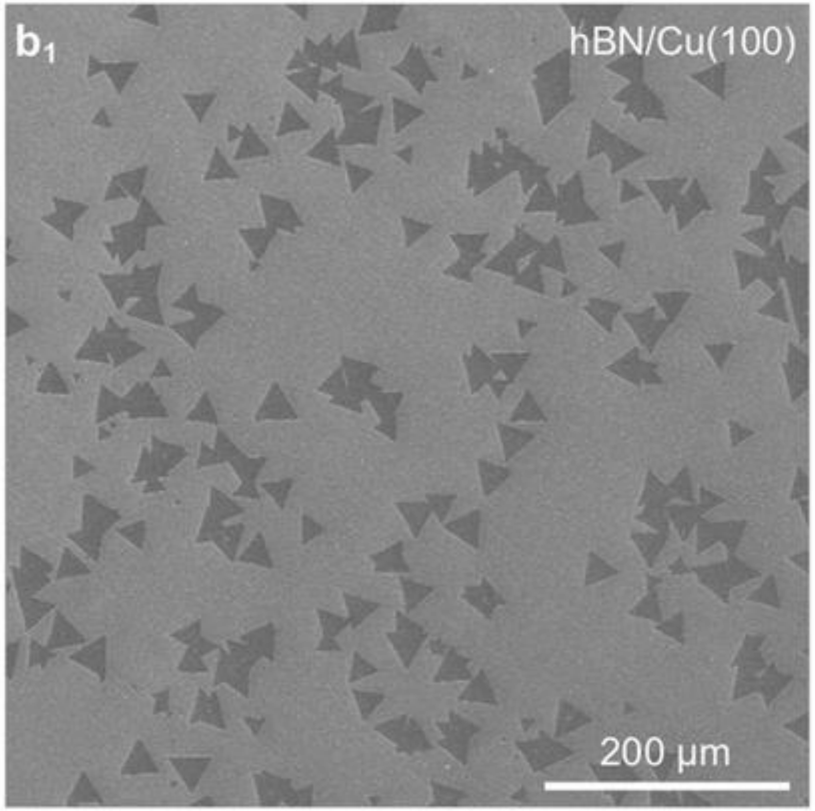




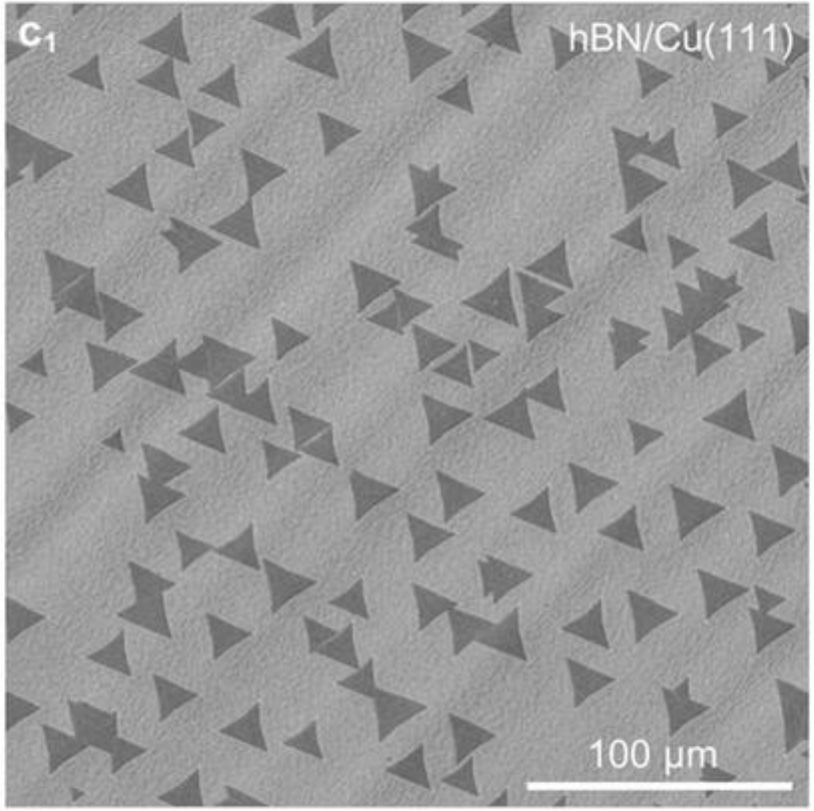




unidirectionally aligned growth



randomly aligned hBN domains



anti-parallel domains

Ferroelectricity of HCl family

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Ferroelectricity in HCl was discovered by Hoshino et al. in 1967.

Melting point: 158.91 K (DCl: 158.44 K) Deuterium

Curie temperature: 98.36 [c]) [D: 105.03 [d])] K

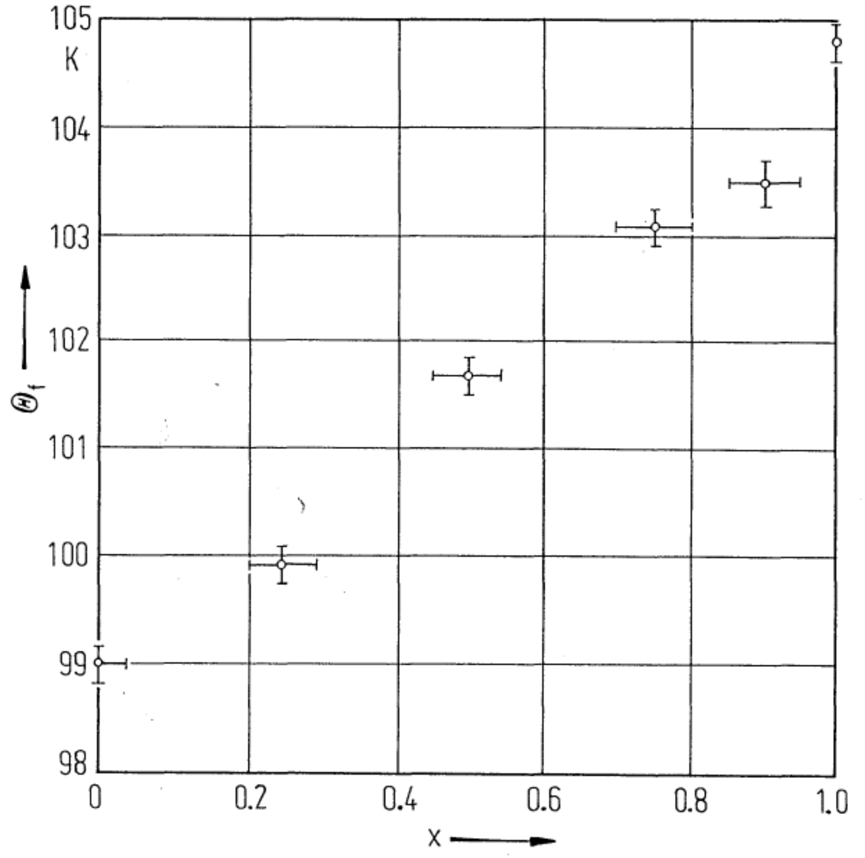
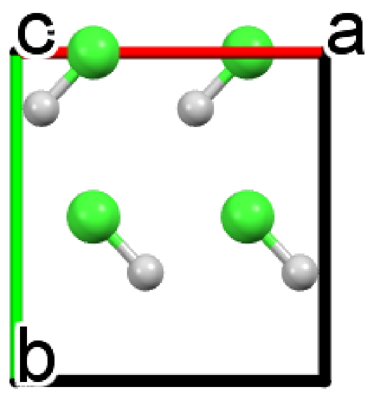


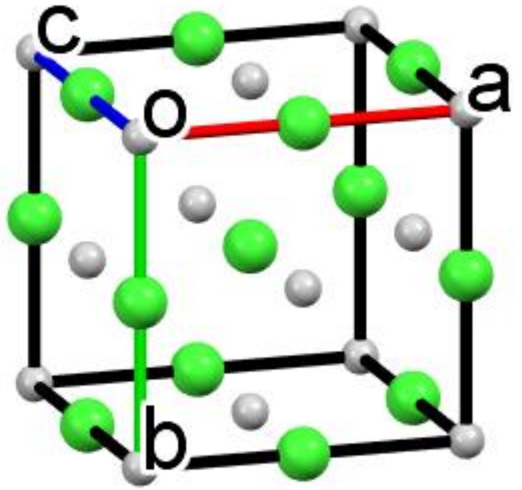
Fig. 27A-1-001. $H_{1-x}D_xCl$. Θ_f vs. x [83Cro].

Ferroelectric orthorhombic phase, $Bb2_1m$



Order-disorder ferroelectric

Paraelectric cubic phase, Fm3m



HCl crystals

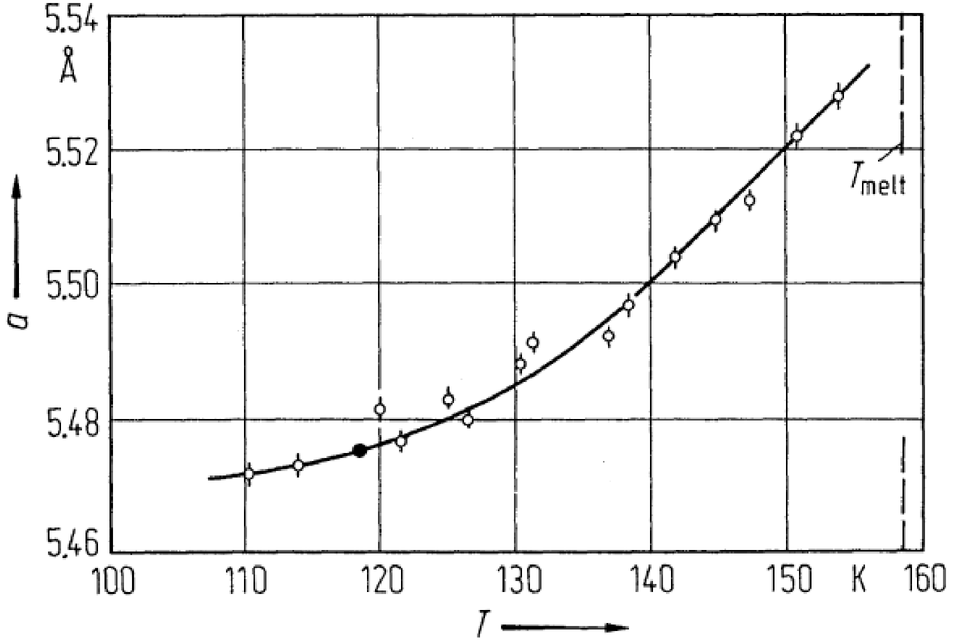


Fig. 27A-1-004. DCl. *a* vs. *T* [73Nii]. Data are normaliz

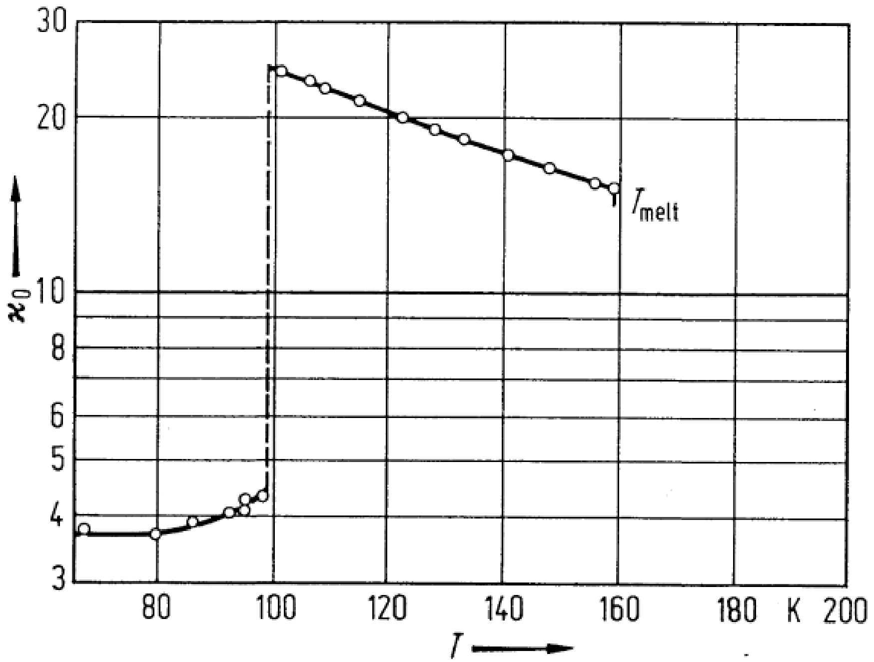


Fig. 27A-1-005. HCl (polycrystal). κ_0 vs. T [54Swe]. κ_0: static dielectric constant.

HCl crystals

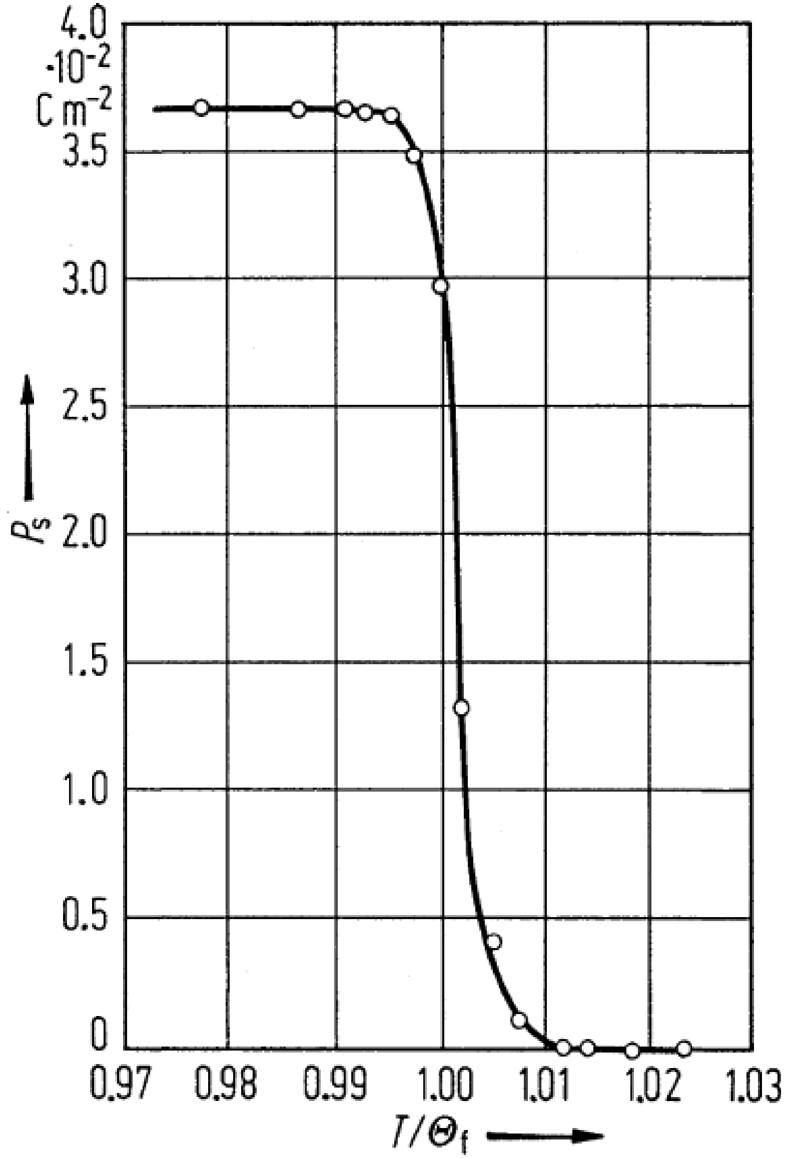
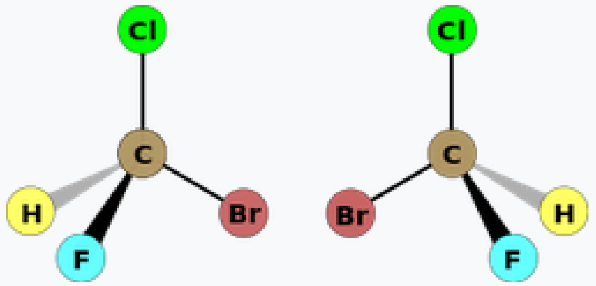
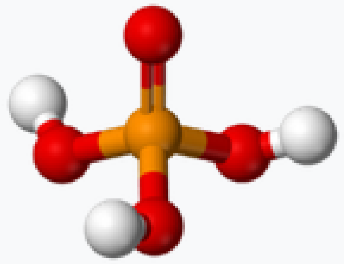
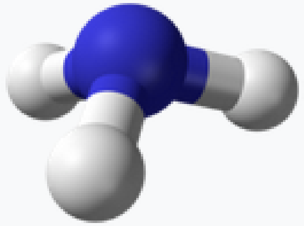


Fig. 27A-1-007. HCl. P_s vs. T/Θ_f [69Ko

Point group	Symmetry operations[15]	Simple description of typical geometry	Example 1
C_1	E	no symmetry, chiral	 bromochlorofluoromethane (both enantiomers shown)
C_3	E C_3	propeller, chiral	 phosphoric acid
C_{3v}	E $2C_3$ $3\sigma_v$	trigonal pyramidal	 non-inverting ammonia