IBM Research

Probing strain in microelectronic materials

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Back-end-of-line (BEOL) characterization

BEOL metallization issues

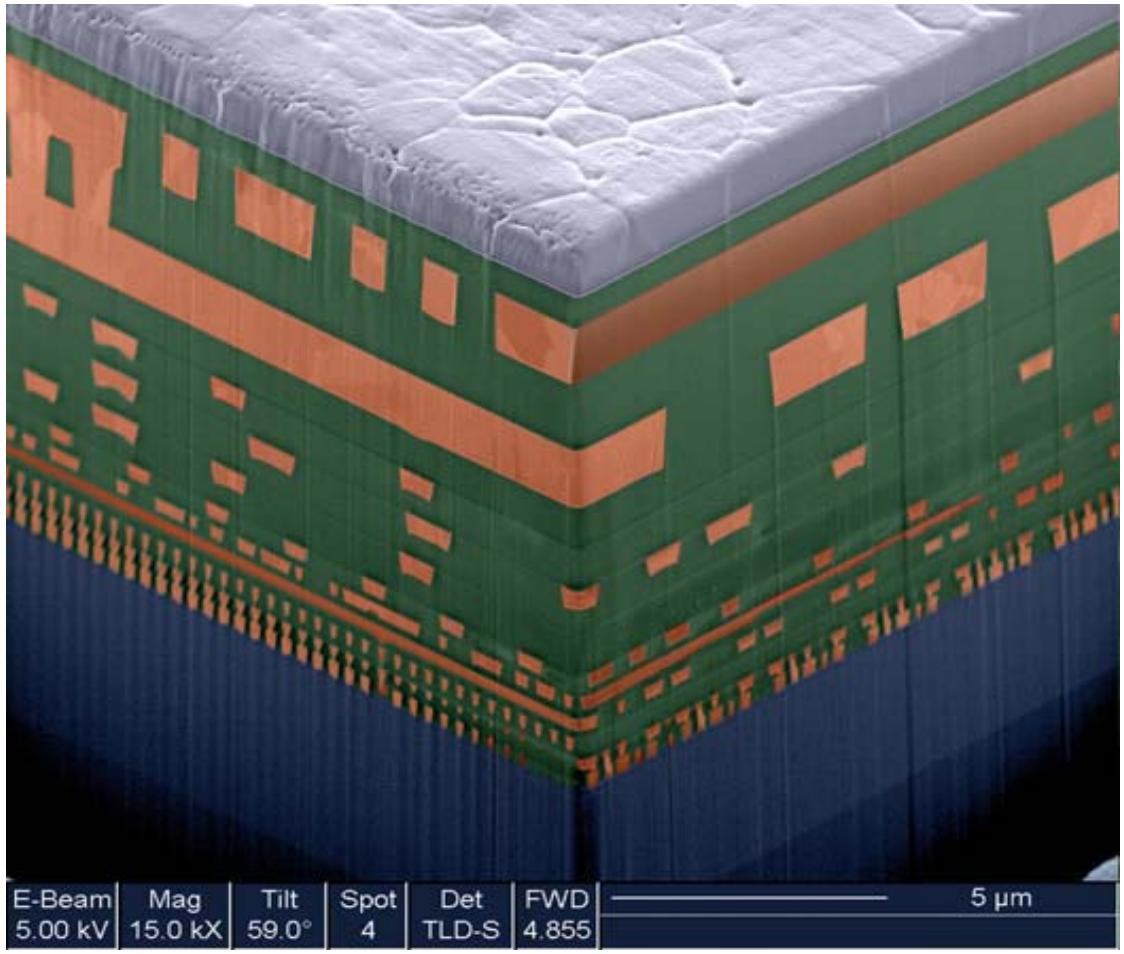
- voiding
- texture, recrystallization
- strain distributions

Mechanical integrity

- cohesive strength decreases with porosity
- ultra low-K, airgap dielectrics

Interfaces

- contamination
- "dielectric" breakdown



Non-destructive measurements are critical

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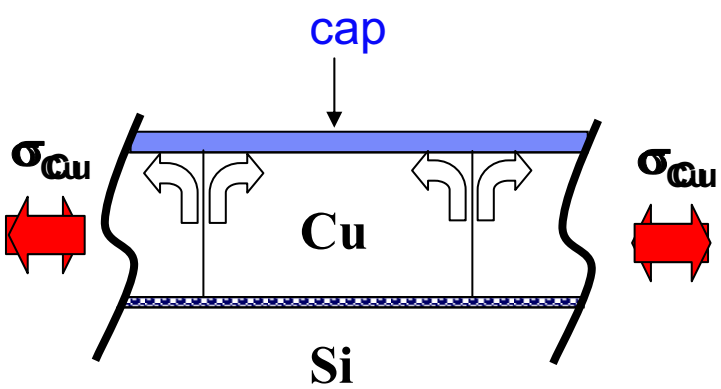
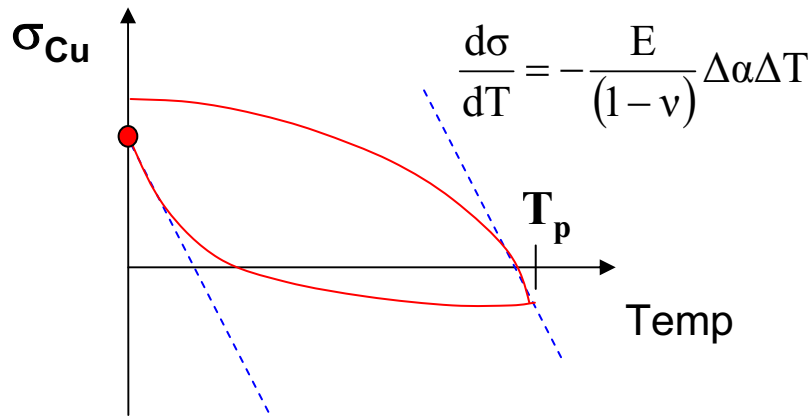
Processing-induced stresses in plated Cu films





$$\frac{d\sigma}{dT} = -\frac{E}{(1-\nu)}\Delta\alpha\Delta T$$

- CTE mismatch induces compressive stress in Cu at elevated temperatures
  - free surface accommodates Cu extrusions to reduce stress
  - as Cu film temperature decreases from process temperature, T_p:
    - deviates from linear stress / strain behavior (2.77 MPa / ^{0}C)
    - without plastic deformation, $\Delta T = 325\ ^0C$ increases stress by ~ 900 MPa
- Presence of a capping layer modifies the relaxation of the Cu film
  - $SiC_xN_yH_z$ and CoWP caps mitigate diffusion at cap / Cu interface
  - potential strain gradient in Cu film due to constraint of the overlying cap
  - higher tensile stress at Cu surface → exacerbate stress-induced voiding

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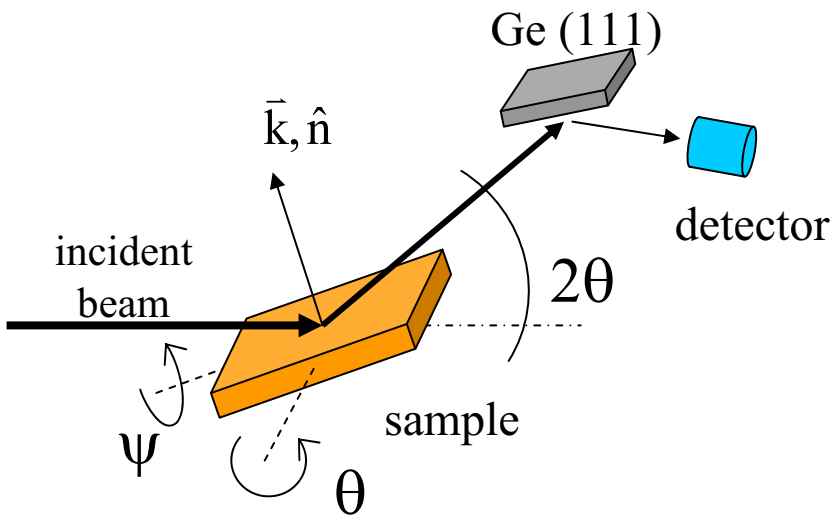
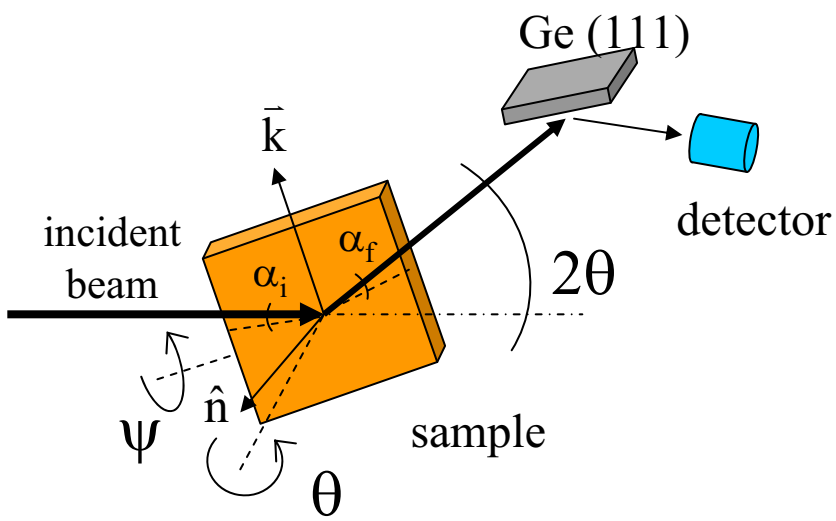
Stress measurements in Cu films using XRD



- Conventional XRD
  - Cu (222) diffraction measured at several ψ-tilts
  - change in peak position corresponds to Cu stress



- Glancing angle XRD:
  - special case of $|\psi| \sim 90^0$
  - symmetric condition ($\alpha_i = \alpha_f$) mitigates refraction effects
  - Cu (220) measured at several α_i
  - convolution of Cu film above penetration depth
  - x-rays penetrate through 0.65 μm Cu films for $\alpha > 1^0$

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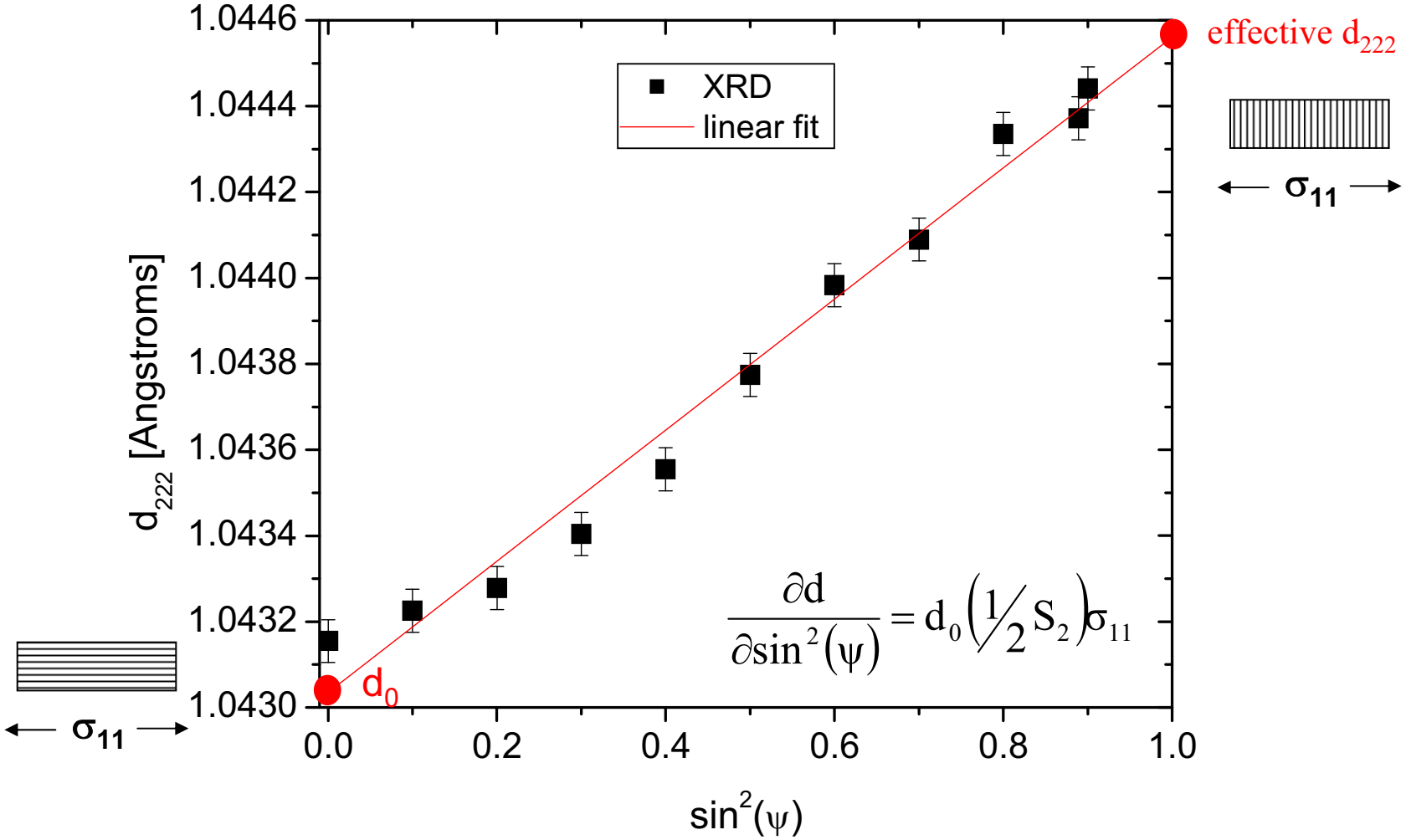
Results: bulk Cu (222) strain measurements



- **larger in-plane lattice spacing ($\psi \sim 90^0$) than out-of-plane lattice spacing ($\psi = 0^0$)**
  - elastic constraint applied by substrate introduces in-plane tensile stress (σ_{11})

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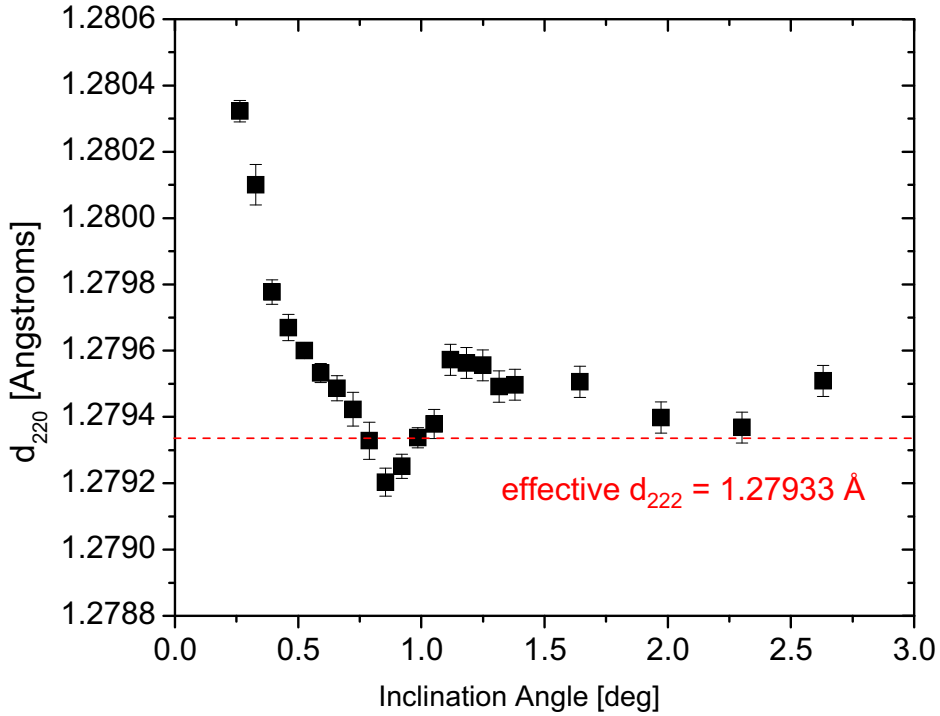
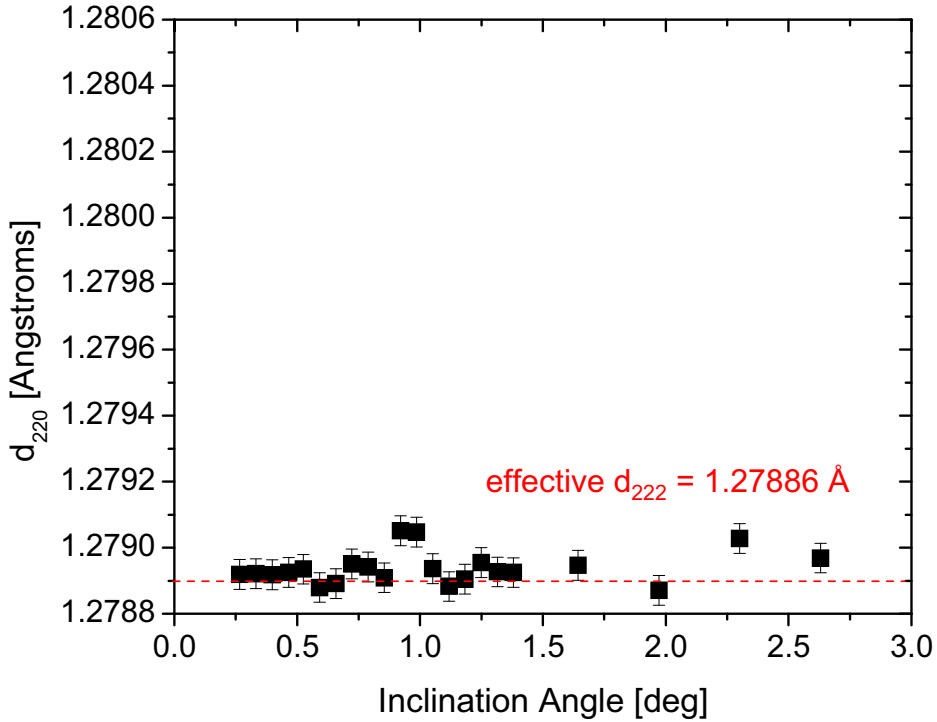
Results: near-surface lattice spacings

35 nm $SiC_xN_yH_z$ -capped Cu



7.5 nm CoWP-capped Cu



- Cu (220) lattice spacing is larger near surface of plated Cu films capped with $SiC_xN_yH_z$
- bulk in-plane lattice spacing corresponds to that measured using Cu (222)
- larger in-plane lattice spacing due to constraint imposed by $SiC_xN_yH_z$
  - no change in in-plane lattice spacing for Cu film capped only with CoWP

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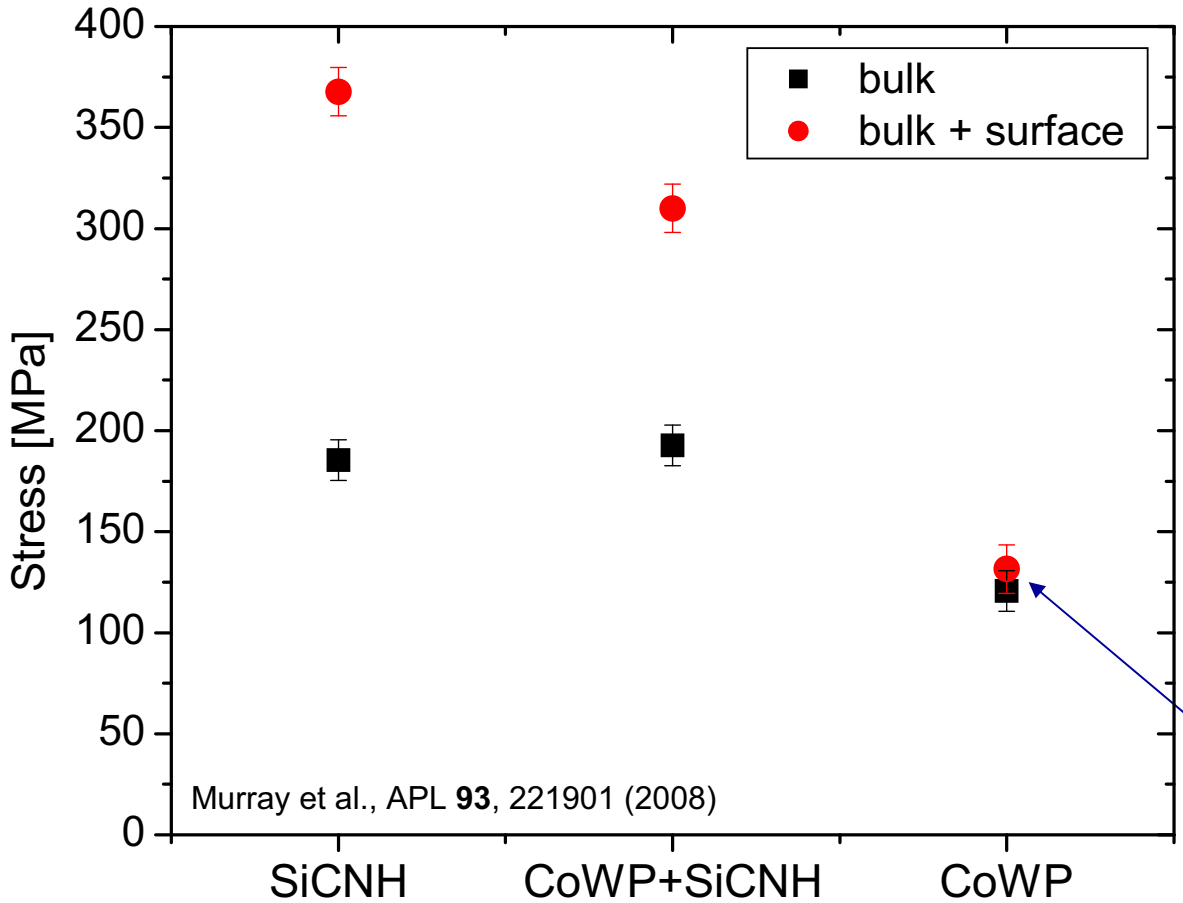
Results: comparison of residual stresses



$$\sigma_{surf} = \sigma_{bulk} + \left(\frac{E}{1-\nu}\right)_{XEC}\left(\frac{d_{surf} - d_{\psi=90^0}}{d_{\psi=90^0}}\right)$$

XEC: X-ray elastic constants under Neerfeld-Hill limit

CoWP-capped Cu

- $SiC_xN_yH_z$ deposition temperature + constraint increases in-plane stress near surface
- CoWP deposition (~90 ^{0}C) only produces elastic deformation in Cu (no increase)

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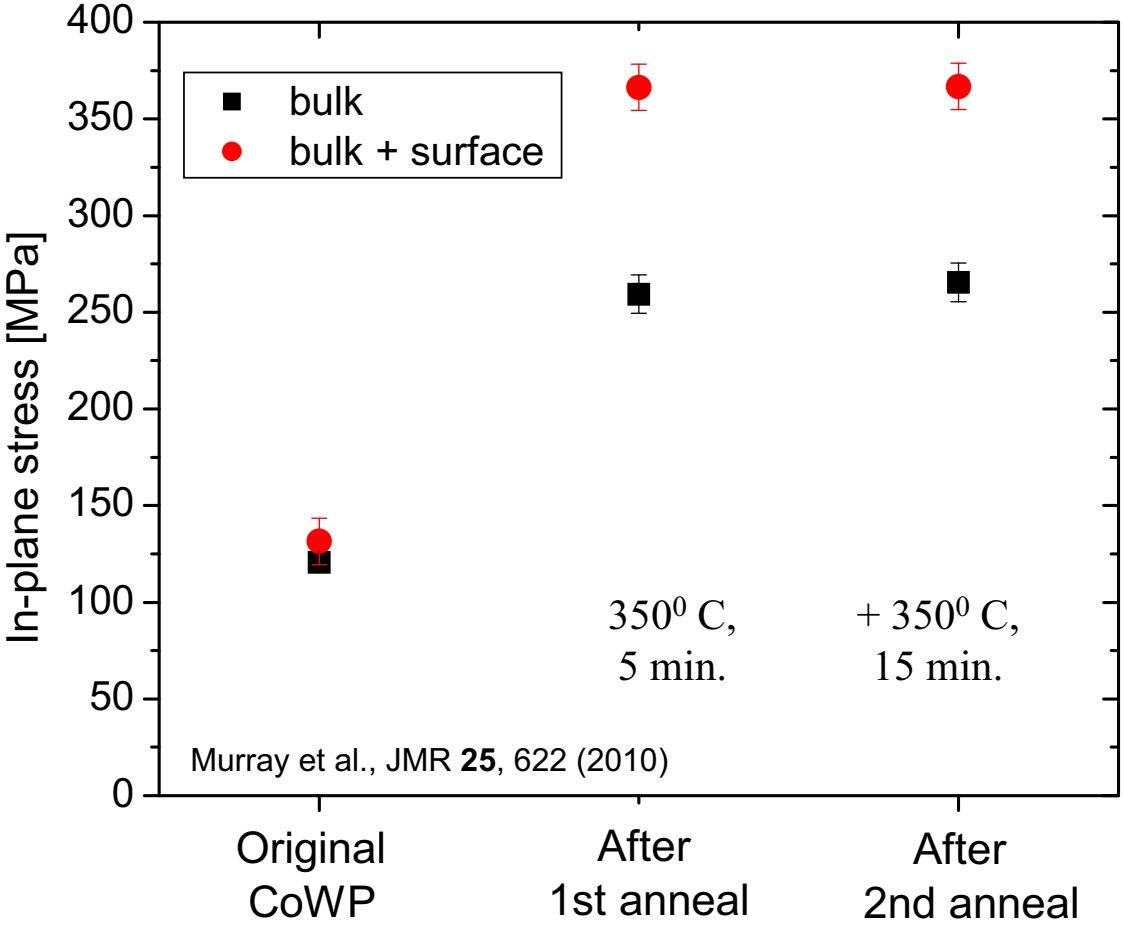
Results: thermal cycling of CoWP-capped Cu films



- thermal excursion increases (bulk) in-plane stress
- stress gradient introduced in Cu films
- ➢ constraint imposed by CoWP during cooling

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