A physically-based strain gradient crystal plasticity formulation

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Introduction

Micro-scale tunable capacitors are typical RF–MEMS devices widely used in wireless networks. To develop more reliable devices suitable for dynamic loading conditions requires a full understanding of the time dependent mechanical behavior of thin films (Fig.1).

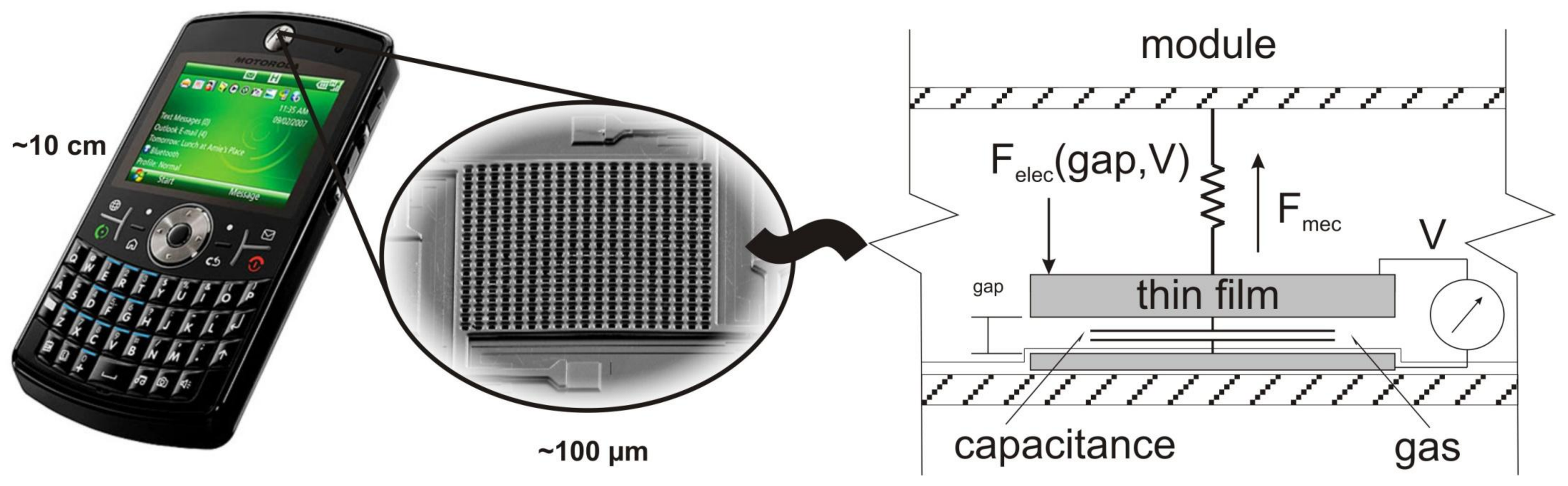


Fig.1: An RF-MEMS and the schematic representation of the accompanying multi-field boundary value problem.

Approach

A physically motivated strain gradient crystal plasticity model (SGCP) proposed by Bayley *et al.* [1] is deeply analyzed in close comparison with the thermodynamically consistent strain gradient crystal plasticity framework (TCCP) of Gurtin [2] to investigate the thermodynamics of the SGCP model by the similarities and differences between them, see Fig.2.

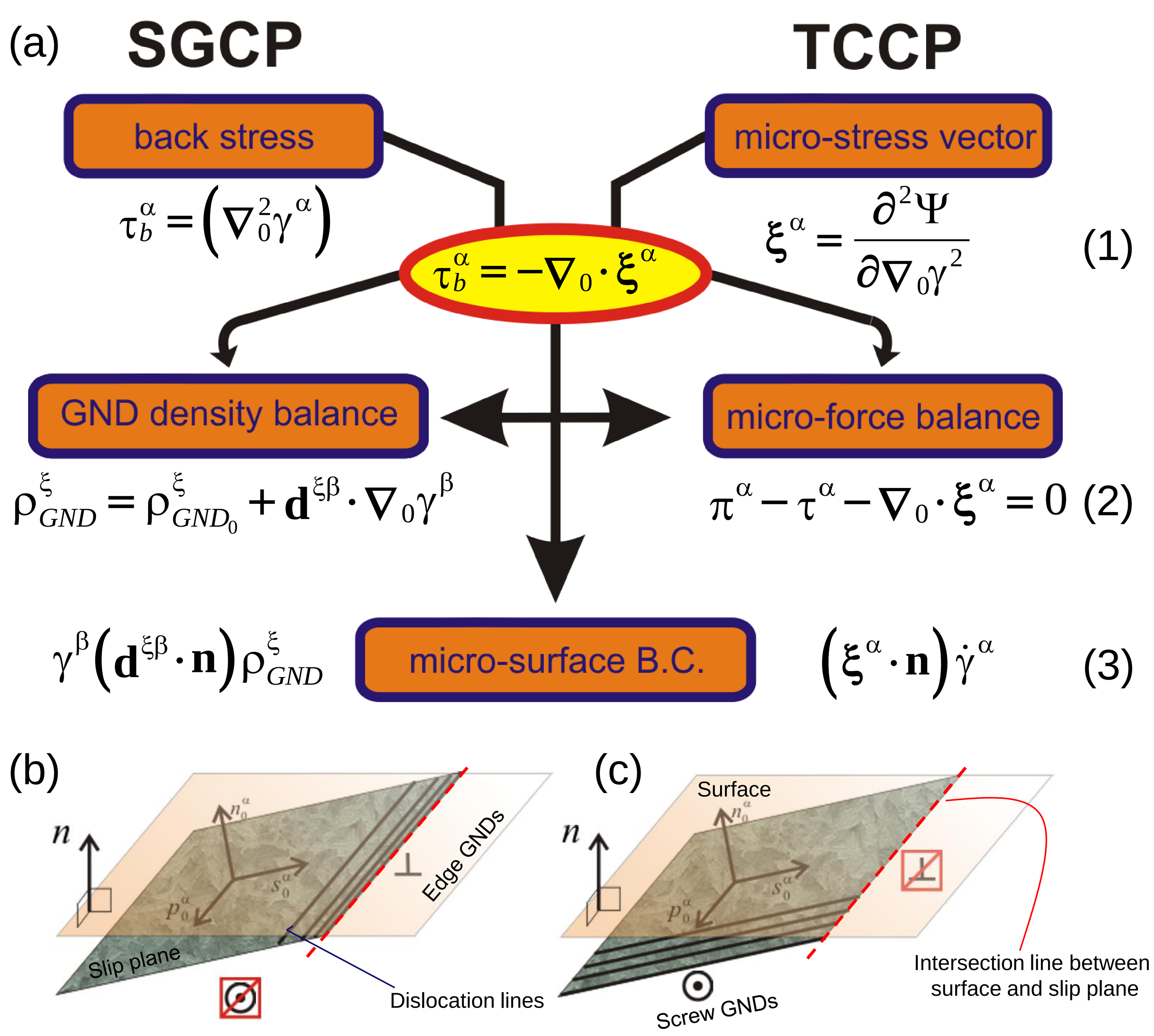


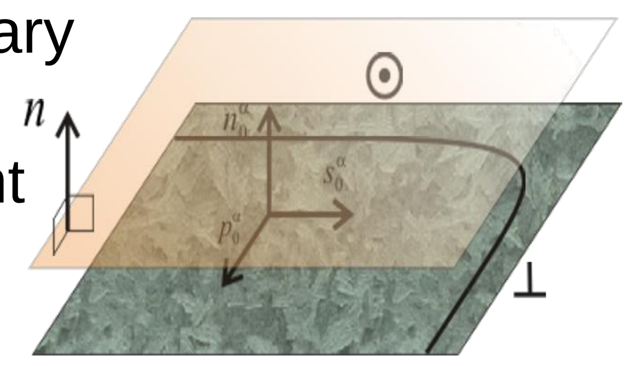
Fig. 2: a) Model comparison. b) Hard interface. c) Free surface.

Linking the physically based back stress of [1] and the phenomenological micro-stress of [2], a micro-stress vector is written for the SGCP framework:

$$\xi^\alpha = \left(-\frac{GBR^2}{8(1-\nu)} \sum_{\xi=1}^{12} \rho_e^\xi \, {}^3\mathbf{A}_0^\xi + \frac{GBR^2}{4} \sum_{\xi=13}^{18} \rho_s^\xi \, {}^3\mathbf{B}_0^\xi \right) : \mathbf{P}_0^\xi \quad (4)$$

and possible defect energy functions leading to micro-stress vector in Eq.(4) are discussed. Based on Eq.(4), it is shown that additional field equations of both models (Fig.2, (2)) yield the same results under specific conditions.

Comparison of micro-surface boundary conditions demonstrates that the model [2] misses a surface constraint (depicted on the right handside), which is captured by the model [1].



Model validation

Beam bending simulations are carried out on single clamped Al and AlCu beams [3] to study the length scale effects on the material response at micro level, see Fig. 3.

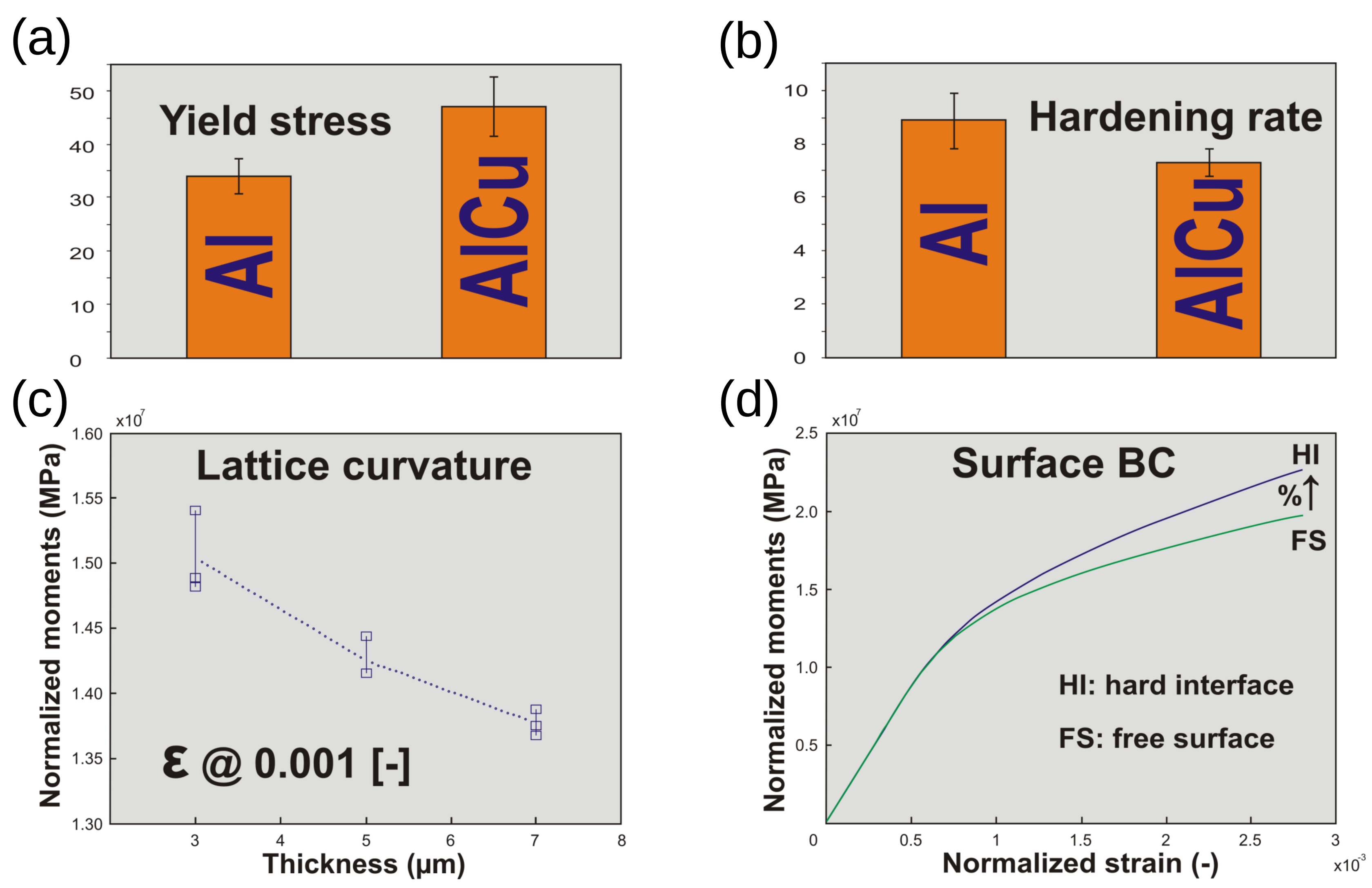


Fig. 3: Effect of precipitates: a) on yield stress, b) on hardening rate. c) Lattice curvature effect. d) Increased hardening rate by a hard interface.

Discussion

This study proves the thermodynamical consistency of the SGCP model [1] by comparison with the TCCP model [2]. It is shown that the energy functions for the derivation of the micro-stress in [2] are away from the real dislocation mechanism. The model succeeds in describing several size effects. Further development will focus on precipitation strengthening, time dependent material behavior, grain boundary properties.

References

[1] Bayley, C.J. et al.: Philos. Mag. 87 (2007) 1361–1378.
[2] Gurtin, M.: Int. J. Plast. 24 (2008) 702–725.
[3] van Schaik, B.G.R.: Mate-WTB-TU/e (2006)