Single crystal plasticity modelling of precipitate hardened alloys

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Single Crystal Plasticity Modelling of Precipitation Hardened Alloys

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Micro-Electro-Mechanical Systems

RF-MEMS, a class of MEMS (Fig.1), are tuneable parallel plate capacitors (Fig.2a) that are used as switches in high-tech wireless network systems.

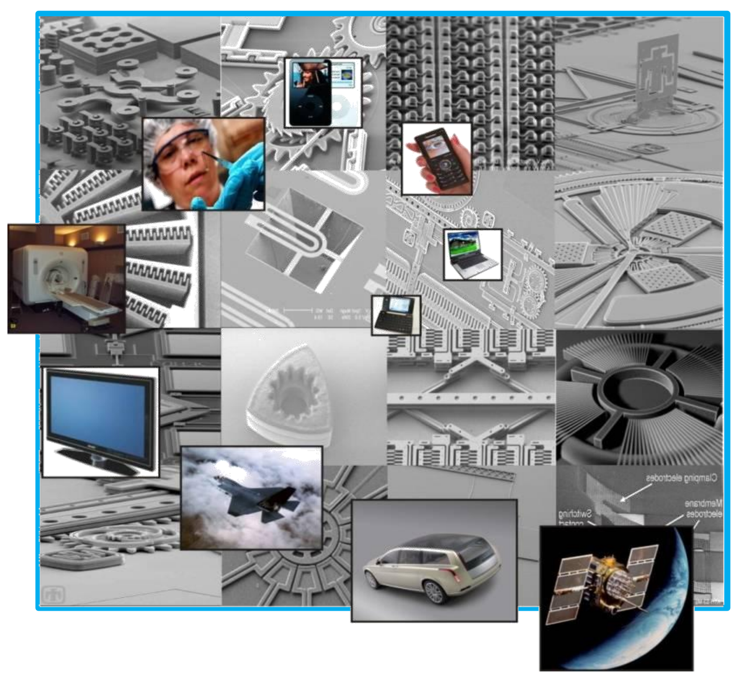


Fig.1: MEMS applications.

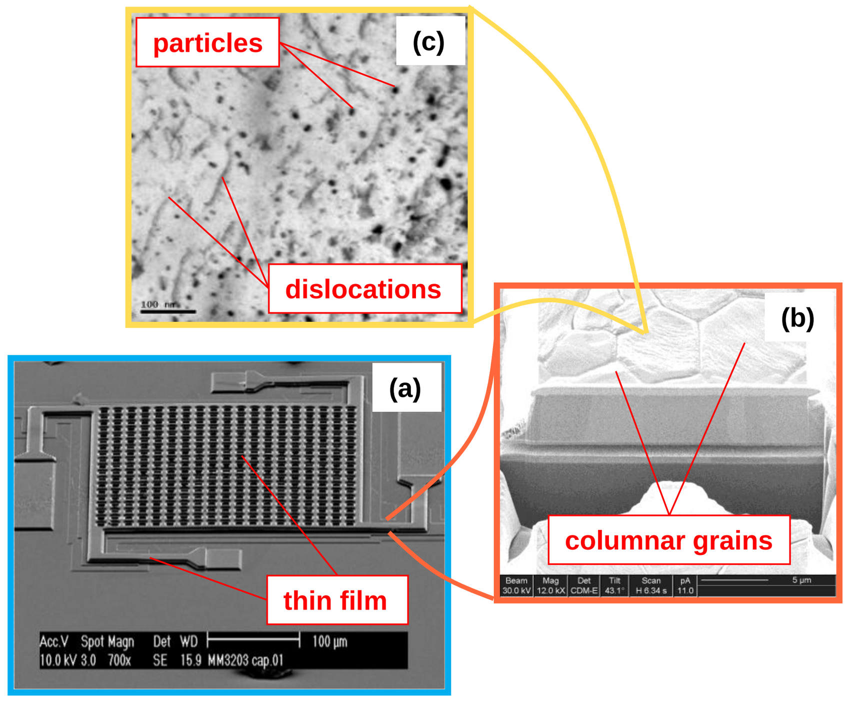


Fig.2: a) An RF-MEMS. b)-c) SEM pictures of metal film's microstructure.

Reliability of an RF-MEMS switch (Fig.3) depends on the **time** and **scale dependent** mechanical behavior of its thin metal film arms, which is heavily influenced by the **microstructure,** Fig.2b-c.

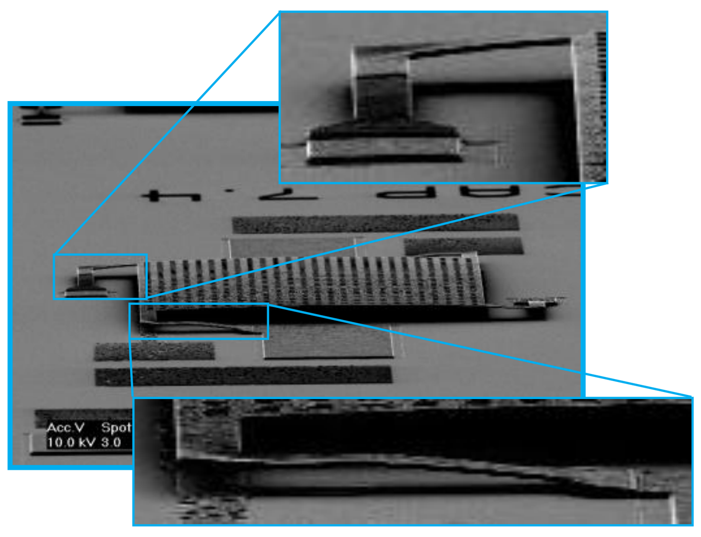


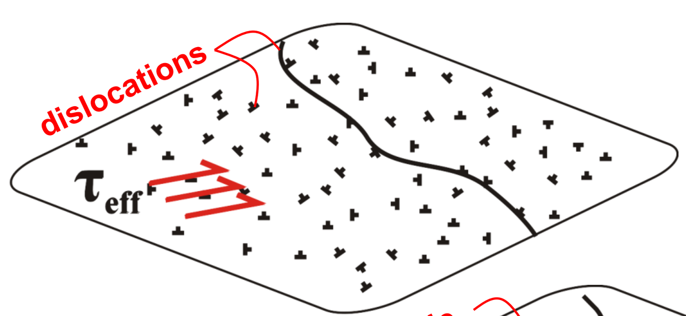
Fig.3: a) An RF-MEMS irreversibly deformed after voltage loading.

Scope

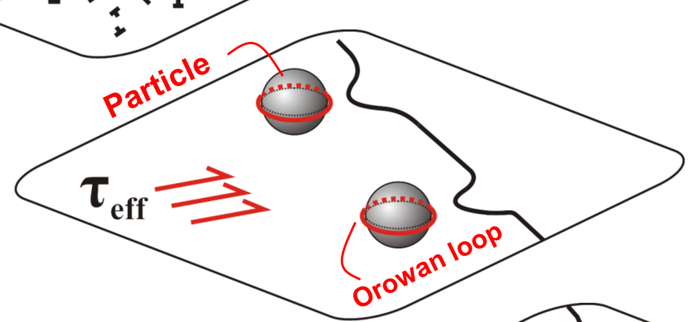
The purpose of this work is the development of a strain gradient crystal plasticity framework for **particle hardened alloys** in order to be used in the design and analyses of RF-MEMS devices.

Model developement

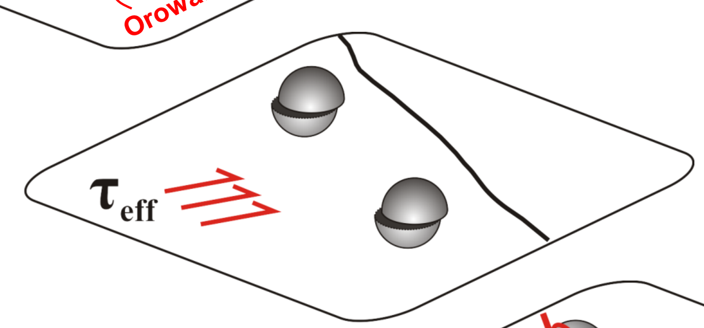
The following types of interactions between the gliding dislocations and various obstacles are considered:



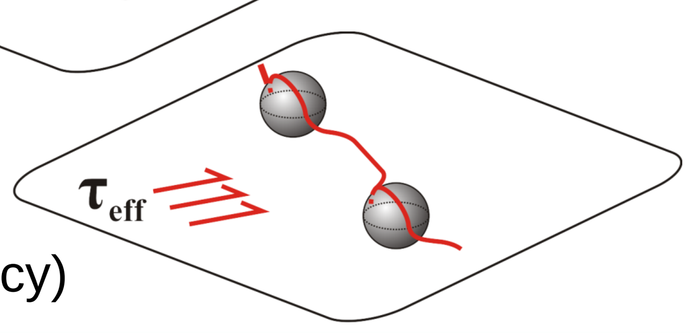
Dislocation-dislocation: unobstructed glide (forest hardening etc.)



Dislocation-particle: Particle by-passing (Orowan process)



Dislocation-particle: Particle cutting (Friedel process)



Dislocation-particle: Climb over particles (main source of time dependency)

A constitutive relationship between slip rate $\dot\gamma$ and shear stress τ_{eff} is constructed by combining individual flow rules (1) of four different interaction mechanisms, Fig.4.

$$\dot\gamma_{i,j}=\rho_m(\tau_{k,j}(\nabla\rho),\hat\tau_{i,j})\cdot b\cdot v(\tau_{k,j}(\nabla\rho),\hat\tau_{i,j},T) \qquad (1)$$

$\dot\gamma_{i,j}$: slip rate
ρ_m: mobile dislocation density
$\tau_{k,j}$: shear stress in branch
$\hat\tau_{i,j}$: treshold stress
b : Burgers vector
v : dislocation velocity
T : temperature
i : u. glide, orowan, friedel, climb
j : edge, screw dislocation
k: branch 1, 2

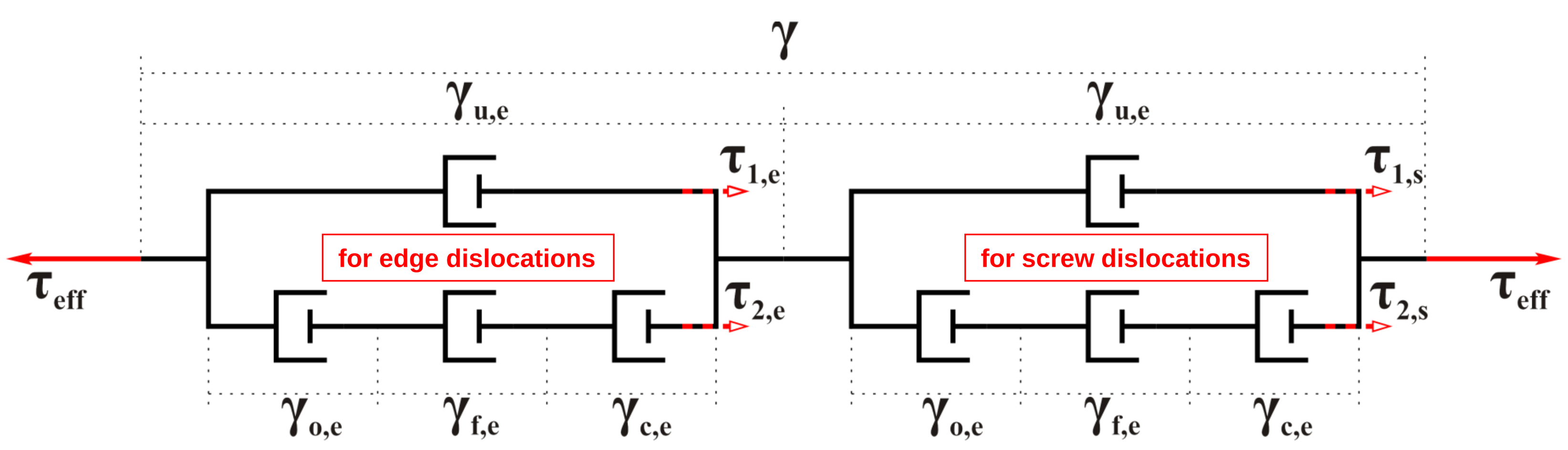


Fig.4: Schematic representation of the new constitutive law.

Results

For an AlCu alloy with an average particle size of 12µm and volume fraction of 1.2%, the model predicts (Fig.5):

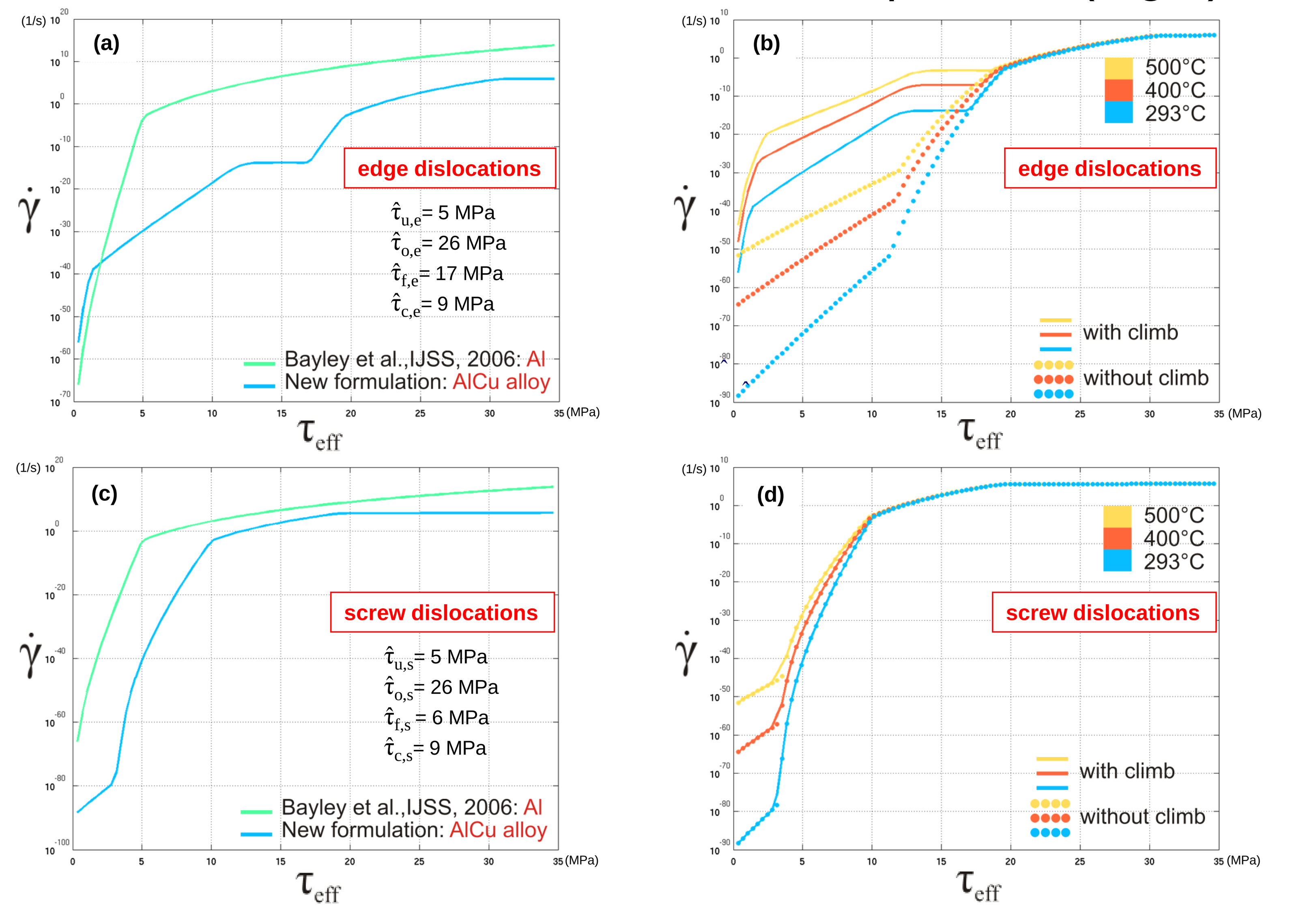


Fig.5: Numerical experiments with the new model. (a)&(c) Comparisons to Bayley et al., 2006. (b)&(d) Effect of climb and temperature sensivity.

- increased strength due to particles
- larger slip rates for screw dislocations than edge type
- larger slip rates at higher temperatures
- increased slip rate of edge dislocations due to influence of climb, which vanishes at larger stresses
- almost no effect of climb on slip rate of screw dislocations

Conclusion

The new strain gradient crystal plasticity model is promising as being complementary to the multiphysical simulations of RF-MEMS by quantitatively describing the time and scale dependent material behavior.