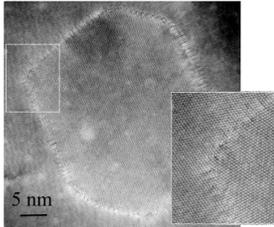


Atomic-Level Mechanisms of Grain Boundary Migration

K. L. Merkle, L. J. Thompson, and F. Phillipp (MPI, Stuttgart)

Grain boundary (GB) migration is vitally important to processing and properties of crystalline materials, but the underlying atomic-scale processes are largely unknown. Utilizing high-resolution transmission electron microscopy the first direct real-space observation of GB motion at the atomic level and at elevated temperature have been accomplished. We present examples of surface energy as well curvature driven GB migration. Typical to high-angle GBs is the "jerky" motion, i. e. periods of rapid advance followed by periods of rest. For the first time, direct evidence for the existence of collective effects in GB migration is obtained by studying the spatial GB fluctuations at high temperature. This proves the existence of rapid atomic shuffles that accomplish the necessary lattice rotations. The periods of rest are thought to be necessary to relieve the back-stress on the GB by point defect migration.

Epitaxially grown Nanograin of Au



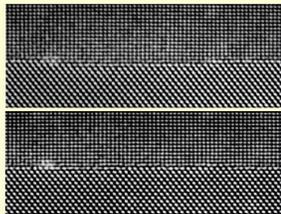
In-situ video recording of HREM images of bicrystals at elevated temperature $> 0.5 T_m$.

Grain boundaries:

[001] and [110] tilt as well as general GBs in Au.

(113) symmetric tilt GB in Al.

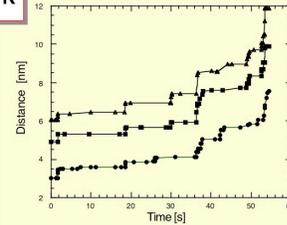
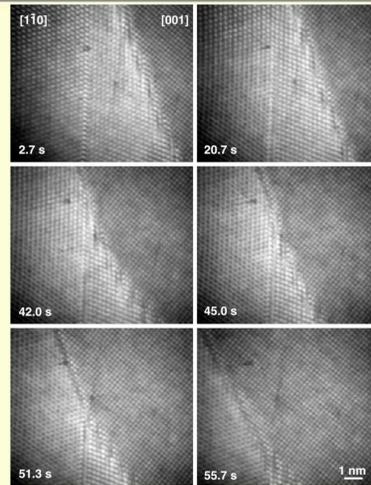
Surface energy as a driving force for GB migration



[010] 45° twist GB

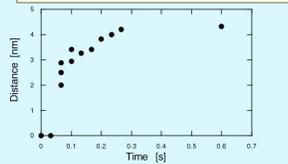
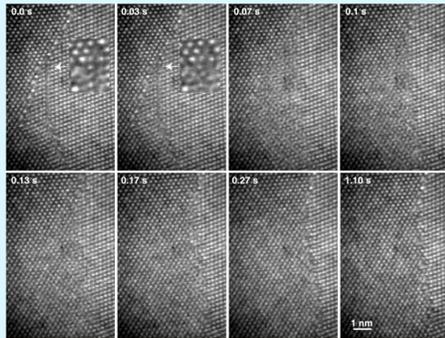
Surface energy driving force is independent of GB curvature
Difference in surface energy between (110) and (100) grains: $\Delta\gamma = \gamma_{(110)} - \gamma_{(100)}$
Driving force: $P = 2\Delta\gamma/t$ (t = film thickness)

Surface energy driven GB migration, Au, 723 K

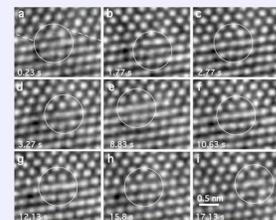
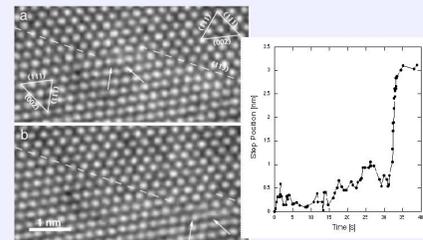


Curvature driven GB migration

HREM Video Sequence of ~9 Au grain during migration at 823 K (0.62 T_m)

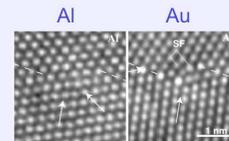


[110], (113) STGB ledge motion in Al, 523 K (0.56 T_m)



Positional fluctuations of step dislocation

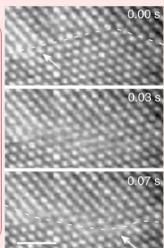
Phil. Mag. Lett. 82, 589 (2002)



Comparison of Step structure in Al and Au

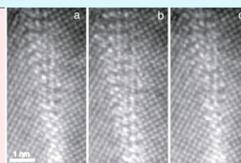
Collective effects in GB migration

Positional fluctuations of GBs at high temperature indicates **collective atomic shuffles**, involving hundreds of atoms



Au, [110]
 $q = 50^\circ$
 710°C
 $0.74 T_m$

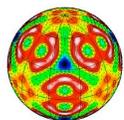
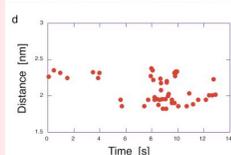
Phys. Rev. Lett. 88, 225501 (2002)



Fluctuations of general GB in Au.

390 °C

Position of left boundary edge changes by about 0.5 nm as a function of time.



BES - DOE

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MSD - ANL

