Surface electromigration of Si *ad*vacancy and *ad*atom islands

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When a direct electric current is applied to a material, it may induce a biased mass transport. This effect, called electromigration [1], can play an important role on the dynamics and the morphology of nanostructures at surfaces. It also determines the stability of a working device, and eventually its lifetime. Indeed, it can be responsible for hillocks or voids that may respectively shorten or disrupt electronic circuits. Moreover, in the context of size reduction of electrical interconnects the role of electron scattering at surfaces becomes even more crucial [2]. Surface science tools can open the study of electromigration to atomic scale characterization. It has been recently shown [3] that electron scattering at step edges or kink sites may be responsible for a local resistivity increase and an enhanced electromigration force. Also the complex behaviour in the evolution of Si vicinal surfaces under electromigration [4,5] led to a deep theoretical effort [6,7]. However, despite the development of kinetic theoretical models and the important role of electromigration in future nanoelectronics, experimental investigation of the migration of surface nanostructures under an applied electric current are still scarce [3] whereas they are probably the corner stones for a quantitative understanding of basic mechanisms of electromigration.

We have recently undertaken the investigation of the electromigration of 2D islands at surfaces. As model system we have studied Si surfaces, which fundamental properties have been explored by an abundant literature. We have developed an experimental setup to measure *in operando* by low energy electron microscopy (LEEM) the drift motion of *ad*atom and *ad*vacancy islands on terraces under an applied direct current. In that purpose extremely large Si (100) and (111) monoatomic terraces (> 10μm) have been prepared on two different orientations,.

- On Si(111), at the (7×7) ↔(1×1) surface reconstruction transition temperature, a (1×1) atomic height *ad*vacancy island can be stabilized under a metastable state surrounded by a (7×7) reconstructed terrace. The large difference of diffusivity of species on (7×7) and (1×1) surfaces confines atom exchanges inside the (1×1) vacancy islands unravelling the mass transport mechanisms. Velocity of islands as function of their size shows that a kinetic length of attachment-detachment at step edges of 550 nm is measured. More importantly the electromigrating islands develop faceted step edges and anisotropic shapes depending on the applied current direction. We show that a highly anisotropic kinetics of attachement-detachment at step edges is responsible for this behaviour.
- On Si(100) surface, we have shown that when the electric current is applied along <011> direction, *i.e.* along or perpendicular to dimer rows, reconstructed (1×2) and (2×1) terraces move in opposite directions. Surprisingly if the electric current is applied at 45° with respect to dimers rows then terraces move perpendicular to the electric current. The shape of these terraces is stationary and size independent. These results suggest that the main mechanism controlling the motion is the biased diffusion of species on terraces combined with a highly anisotropic diffusivity along or perpendicular to dimer rows.

References:
[1] A. Blech, J. Appl. Phys. 47, 1203 (1976)
[2] G. Gardinowski *et al.*, Appl. Phys. Lett. 89, 063120 (2006)
[3] C. Tao, W.G. Cullen, E.D. Williams, Science 328 736 (2010)
[4] A.V. Latyshev, A. L. Asev, A.B. Krasilnikov, S. I. Stenin, Surf. Sci. 213, 157-169 (1989)
[5] F. Leroy, P. Müller, J-J. Metois and O. Pierre-Louis, Phys. Rev. B 76, 045402 (2007)
[6] O.Pierre-Louis and T.L. Einstein, Phys Rev. B. 62, 13697 (2000)
[7] P. Khun, J. Krug, F. Hausser and A. Voigt, Phys Rev Lett. 94, 166105 (2005)