# Morphological transitions in the patterning of the crystalline Ge(001) surface induced by ion irradiation

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We investigate the nanoscale self-organized pattern formation of the Ge(001) surface induced by ion beam bombardment at sample temperatures above the recrystallization temperature. Two previously-observed kinds of topographies are seen, i.e., anisotropic patterns consisting of upright and inverted rectangular pyramids, as well as isotropic patterns composed of shallow, isotropic basins [1]. In addition, we observe the formation of an unexpected third type of pattern. In this transitional morphology, isolated peaks with rectangular cross sections stand above a landscape of shallow, rounded basins. Which morphology is observed depends on the ion energy and flux and on the surface temperature. An anisotropic pattern is replaced by a transitional pattern and then by an isotropic pattern as the sample temperature is increased. The same sequence of transitions is observed as the ion energy or flux is reduced. Thus, anisotropic patterns are found in the regime in which the effects of ion bombardment are predominant, while isotropic patterns are observed in the regime in which thermal effects are most important. Naturally, transitional patterns occur between these two extremes.

To model the observed pattern morphologies, we extend past theoretical work on the equation of motion to include a second order correction term resulting from the curvature dependence of the sputter yield [2]. This term produces the isolated peaks in the transitional patterns and would result in the formation of spike singularities if this were not averted by the Ehrlich-Schwoebel effect. For a range of parameter values, the resulting continuum model of the surface dynamics produces patterns that are remarkably similar to the morphologies we observe in our experiments [3].

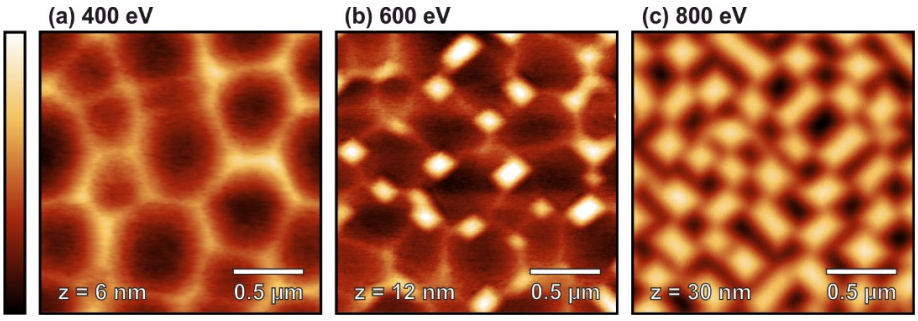


Fig. 1. AFM topographical images of Ge(001) surfaces after irradiation at a sample temperature of 380 °C with Ar+ ions at energies increasing from left to right: (a) isotropic, (b) transitional, (c) anisotropic pattern. The false color ruler indicating the surface height ranges from 0 to z as labeled.

[1] X. Ou et al., Phys. Rev. Lett., **111**, 016101 (2013)
[2] R.M. Bradley and G. Hobler, J. Appl. Phys., **129**, 194301 (2021)
[3] Manuscript in review. Preprint: http://arxiv.org/abs/2304.06302