Self-organized nanostructuring of supported polycrystalline metal films

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Outline

- Nanostructuring processes on macroscopic scale

- Synthesis of periodic patterns induced by ion beam irradiation
  IBS (ion beam sputtering)

- Direct patterning of supported polycrystalline metal films

  - Technologically relevant systems (functional coatings, IC interconnects,
catalytic and chemical sensing active elements, magnetic and
  optical devices...)
  - Very broadly studied from the applied point of view

M. Navez et al., C. R. Acad. Sci. 254 (1962)
Nanostructuring surfaces by ion beam sputtering

Erosive instability

- Erosion rate is curvature dependent

The spatial distribution of the energy transferred from the impinging ions to the substrate causes the faster erosion of the bottom of a trough vs. the crest

Surface diffusion

Interplay of erosive instability & diffusive relaxation: development of periodically modulated structures

Single Crystal Metals

Diffusive regime

the Cu(110) case

Ar$^+$ ions, $\theta = 0^\circ$
$T = 360$ K
$E_i = 1$ KeV
$\Phi = (9 \cdot 10^{-2}$ ML$_{Ar}$/s)

Ar$^+$ ions, $\theta = 45^\circ$
$T = 180$ K
$E_i = 1$ KeV
$\Phi = (9 \cdot 10^{-2}$ ML$_{Ar}$/s)


Erosive regime

180 nm

the Ag(110) case

Ne$^+$ ions, $\theta = 76^\circ$, $T = 180$ K, $E_i = 1$ KeV, $\Phi = 5$ µA/cm$^2$ (2.6 $\cdot$ 10$^{-2}$ ML$_{Ne}$/s)
What about supported polycrystalline films?

- Recently few experiments demonstrated the possibility to induce patterns by ion irradiation

The role of the starting topography

- Grains with lateral and vertical size comparable to the typical periodicity of the nanostructures

Direct IBS nanostructuring of supported polycrystalline film

1) Deposition of metal Au (Ag) films with different starting morphology on flat substrates
2) Direct IBS nanostructuring of polycrystalline films at grazing incidence
Polycrystalline Au films

Erosive versus shadowing instabilities in the self-organized ion patterning of polycrystalline metal films
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Grazing Ar ion beam irradiation

\[ Q = 5 \times 10^{17} \text{ions/cm}^2 \]

Sputter deposited Au/glass, thermal evaporated Au/glass, Flame annealed Au/mica

\[ \Lambda \approx 70\text{nm} \]
\[ \Lambda \approx 50\text{nm} \]
\[ \Lambda \approx 120\text{nm} \]

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Pattern evolution

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Sputter deposited Au/glass

![Images of AFM scans and graphs showing pattern evolution over time.]

**Comments**

1. Monotonic trend like in a SC case
2. Starting wavelength closely related to the dominant grain size
3. Starting decreasing trend
4. Acceleration of ripples formation

Graphs showing h (nm) vs. time (7 min, 35 min, 65 min) and L (nm) vs. fluence ($10^{17}$ ions cm$^{-2}$).
The polycrystalline Ag case

Patterning polycrystalline thin films by defocused ion beam: the influence of initial morphology on the evolution of self-organized nanostructures

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AFM representative morphologies of Ag sputtered film of 150 nm thickness. The AFM sampling size is 2 · 2 µm² (scale bar = 500 nm). The Ar⁺ ion irradiation was performed at $T=230 \, \text{K}$, $\Theta=82°$, with ion dose $\Theta$ as a parameter: (b) $\Theta = 6.2 \times 10^{17} \, \text{ions/cm}^2$, (c) $\Theta = 1.0 \times 10^{18} \, \text{ions/cm}^2$, (d) $\Theta = 1.2 \times 10^{18} \, \text{ions/cm}^2$, (e) $\Theta = 1.4 \times 10^{18} \, \text{ions/cm}^2$, (f) $\Theta = 1.6 \times 10^{18} \, \text{ions/cm}^2$. Panel (a) shows the initial surface morphology of the Ag film.
Shadowing instability

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- Lateral distribution of the ion impact sites modulated by the local surface corrugation
- Self levelling mechanism of the ripples along the beam projection
- Initial wavelength driven by a shadowing instability
Ripple propagation across grain boundaries

- At Grain boundaries ripple propagates keeping phase relation from grain to grain
- Even in absence of diffusion at GBs (infinite barrier for diffusion) under extreme grazing incidence conditions a shadowing mechanism can propagate the ripple corrugation
Summary

• We induced ripple modulation on polycrystalline metal films with a low energy Ar ion beam

• A non-singular initial morphology can play a critical role in guiding self-organization

• The primitive roughness of the polycrystalline film can efficiently promote and accelerate the formation of ripple modulations