MEASURING FRACTAL DIMENSION FROM MICROGRAPHS

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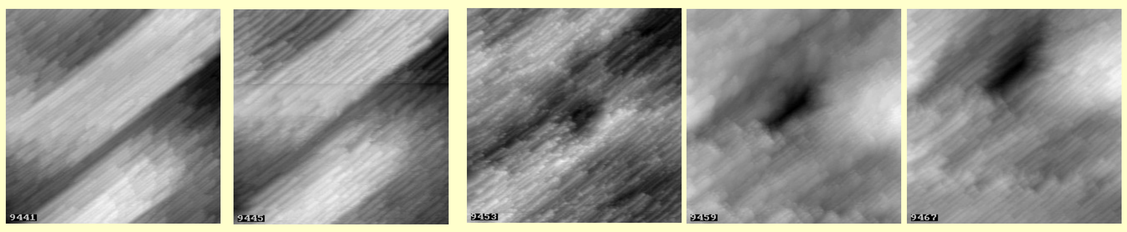
WHY FRACTALS?

- A lot of objects in nature look the same at different observation scales;
1984 - D.Avnir, D.Farin,P.Pfeifer, *Nature*, 308, 1984, 261: "surfaces of most materials are fractals at molecular-size range";
- a lot of studies concerning structural heterogeneity of solids related to fractal geometry.
- Fractal theory provides a powerful method to characterize quantitatively the morphology of a rough surface or of an arbitrary aggregation.

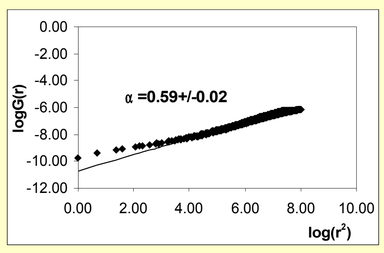


STM image of Cu(110) surface topography at anodic potential (from left to right): -370mV; -200mV;-170mV;cathodic potential:-190mV;-300mV.

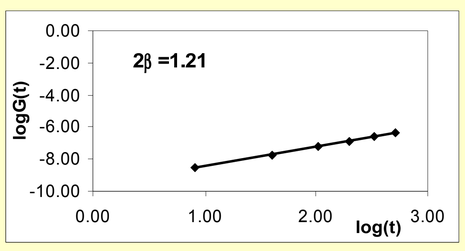
The purpose: to compute the dynamic scaling parameters of surface reconstruction on a larger scale of Cu(110) surface in 10mM HCl electrolyte at different potentials using STM images analysis. In addition, the dynamic of the reconstruction process was simulated. The scaling parameters α and β were computed both from STM analysis and from simulation results.
(the dynamic scaling method: F.Family, T.Vicsek, J.Phys.A18 (1985) L75)

Results:We obtained three classes of universality: first, for the dissolution region, at anodic potentials, α=0.59 and β=0.60; second, for constant potentials, the temporal scaling parameter β> 0.5; this behavior can be assigned to diffusion-bias, meanwhile the value of α, leading to 0.5 is an argument that in the system correlated noise is important; third, at cathodic potentials, α=0.62 and β=0.5, defining a new universality class for surface restructuring, random deposition with correlated noise.

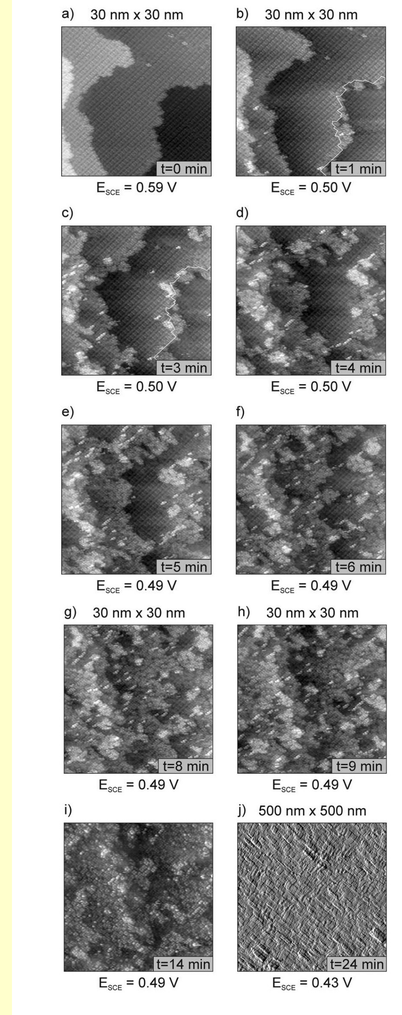
Computer simulations for modified random dissolution and random redeposition on preferential sites were carried on. Results are in good agreement with experimental ones, meaning that: in the case of dissolution, removing randomly a whole row on the direction [200] is a valid assumption in the dissolution regime; in the case of redeposition, the assumption that adding events occurs on sites with probabilities in connection with the number of first neighbors is valid, but simulations can be improved considering probabilities in connection with interaction potentials.



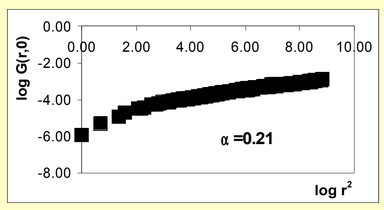
Computation of roughness parameter from STM image analysis for anodic potential E=-250mV



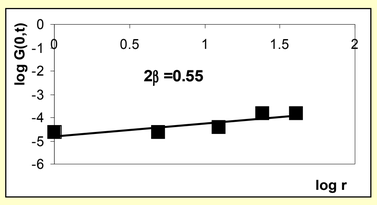
Computation of temporal scaling parameter for dissolution at anodic potentials; the slope is 2β.



Sequence of 10 STM images, (a-i) 30 nm x 30 nm, (j) 500 x 500 nm, showing the initial stages of Pd deposition on Au(110)



Computing spatial correlation parameter α for image in figure e)



Computation of β parameter for sequence indicated in figures c)-i).

The obtained parameters belongs to a well-known universality class described by Kardar-Parisi-Zhang (KPZ) equation. During the first minutes the lateral growth is very important and lead to the formation of the bi-dimensional islands.

$$\frac{\partial h}{\partial t} = \nu \nabla^2 h + B\bar{\mu} + \eta(x,t)$$

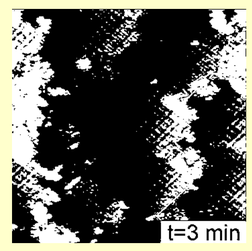
$\bar{\mu}$ = average chemical potential in the solution;

$$\mu(x,t) \sim \nabla^2 h(x,t)$$

= local chemical potential on the surface;

$\eta(x,t)$

= the random fluctuations in the deposition process.

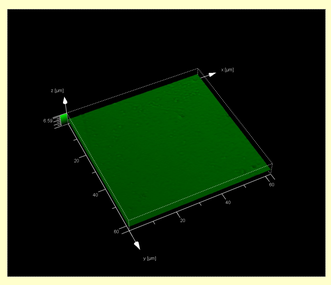


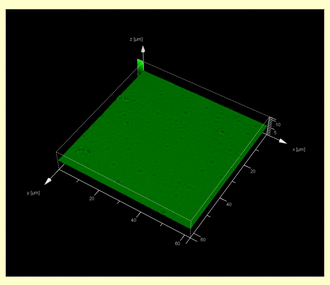
STM digitized image in figure c) by thresholding; intensity filter=128

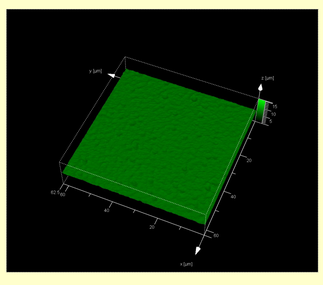
Sample	Fractal dimension
c)	1.69
d)	1.70
e)	1.73
f)	1.64
g)	1.68
h)	1.61
i)	1.51

Fractal dimensions of digitized images of STM micrographs (box-counting method)

The existence of time correlations (β parameter) can be interpreted as a prove of kinetic roughening and of the fact that diffusion bias and Schwoebel barrier did not play an important role in the process.







From left to right: the surface topography of (100) GaAs sample, (100) GaAs sample treated with Na_2S , (100) GaAs sample after $(NH_4)_2S$ treatment; images obtained using confocal laser scanning microscope (CLSM)

The fractal analysis of the CSLM-images has been carried out by dint of conversion of the grey level of each pixel in height. For computing the fractal dimension of GaAs surfaces, we chose two of the routines proposed for characterization of the fractal surfaces: the height correlation function method (Avnir D, Farin D, Pfeifer P. 1983. J. Chem. Phys., 79, 3566-3571;Avnir D, Farin D, Pfeifer P. 1984, Nature, 308, 261-263.) and the variable length scale analysis (Chauvy PF, Madore C, Landolt D. 1998. Surf. And Coatings Technol. 110, 48-56).

Surface	Fractal dimension	Correlation coefficient	Scaling range (nm)
GaAs(100) clean	1.99±0.02	0.100	64-2650
Na_2S / GaAs(100)	1.97±0.03	0.388	130-2658
$(NH_4)_2S$ / GaAs(100)	1.96±0.02	0.319	65-2658

Fractal dimensions of GaAs(100)- clean and -modified surface computed by the height correlation method

Surface	Fractal dimension	Correlation coefficient	Scaling range (nm)
GaAs(100) clean	2.68±0.01	0.998	648-7131
Na_2S / GaAs(100)	2.76±0.01	0.988	1945-7131
$(NH_4)_2S$ / GaAs(100)	2.61±0.02 2.78±0.02	0.998 0.901	648-4538 4538-12318

Fractal dimensions of GaAs(100) clean and modified surface, computed using the variable length scale method

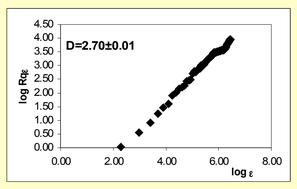
Sample	Explored area (nm x nm)	Fractal dimension	Linear correlation coefficient	Self-similarity limits (nm)
GaAs(100)	500 x 500	2.67±0.02	0.977	15-70
clean	3000 x 3000	-	-	-
surface	5000 x 5000	2.33±0.01	0.999	77-692
GaAs(100)	500 x 500	2.65±0.02	0.966	7-76
treated with	3000 x 3000	2.70±0.01	0.997	1523-2030
Na_2S	5000 x 5000	2.44±0.01	0.995	76-769
GaAs(100)	500 x 500	2.53±0.01	0.996	7-61
treated with	3000 x 3000	2.52±0.07 2.80±0.02	0.939 0.950	415-600 600-877
$(NH_4)_2S$	5000 x 5000	2.44±0.02	0.995	384-769

Fractal dimensions of GaAs(100) surfaces computed from AFM images analysis using the variable scale method

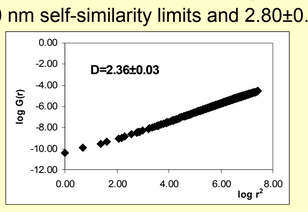
Sample	Explored area (nm x nm)	Fractal dimension	Linear correlation coefficient	Self-similarity limits (nm)
GaAs(100)	500 x 500	2.65±0.08	0.728	0.7-2.77
clean	3000 x 3000	-	-	-
surface	5000 x 5000	2.42±0.01	0.998	7-315
GaAs(100)	500 x 500	2.64±0.01	0.809	0.7-2.77
treated with	3000 x 3000	2.36±0.03	0.993	4-10
Na_2S	5000 x 5000	2.58±0.01	0.714	7-21
GaAs(100)	500 x 500	2.51±0.01	0.971	0.7-5.54
treated with	3000 x 3000	2.41±0.03	0.968	4-24
$(NH_4)_2S$	5000 x 5000	-	-	-

Fractal dimensions of GaAs(100) surfaces computed from AFM images analysis using the height correlation function method

The clean GaAs surface has a self-similar structure characterized by two fractal dimensions: D=2.66±0.02(0.7-70nm) and D=2.38±0.05 (70-692nm), due to its surface defects. After the $Na_2S{\cdot}9H_2O$ treatment, the sample surface becomes rougher with an average fractal dimension of 2.70±0.01(1523-2030nm) showing a high corrugation level while the $(NH_4)_2S$ –modified GaAs(100) surface was found to exhibit a bi-modal fractal behavior: 2.48±0.04 within the 0.7-600 nm self-similarity limits and 2.80±0.02 at 600-877 nm, respectively.

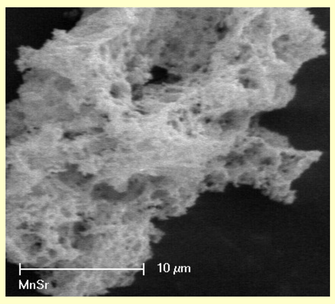


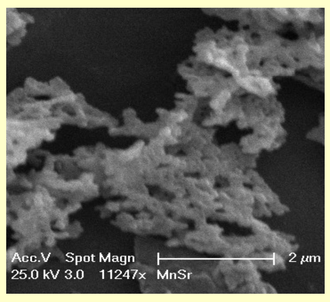
The variable scale method – Na_2S treated surface; explored area 3000nm x 3000nm;

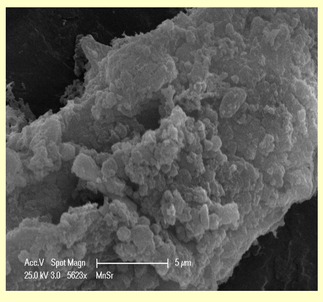


The height correlation function method – Na_2S treated surface; explored area 3000nm x 3000nm;

AFM image of GaAs(100) after the $Na_2S.\ 9H_2O$ treatment





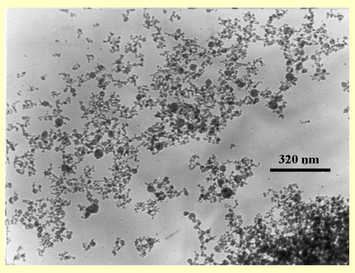


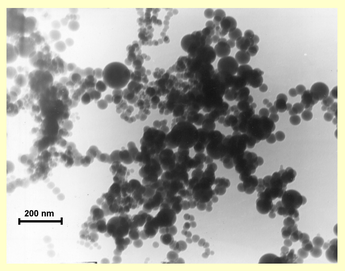
SEM images of $La_{0.9}Sr_{0.1}MnO_3$ perovskites

Image	Method	Fractal Dimension	Correlation coefficient	Scaling range (nm)
left	Correlation function method	2.20±0.01 2.62±0.01	0.994 0.984	20-116 116-820
	Variable scale method	2.58±0.01	0.983	2600-23400
center	Correlation function method	2.28±0.02 2.70±0.01	0.990 0.918	5-28 82-200
	Variable scale method	2.38±0.02 2.72±0.01	0.994 0.894	50-500 500-3150
right	Correlation function method	2.44±0.02 2.76±0.01	0.975 0.909	10-72 72-410
	Variable scale method	2.44±0.02 2.73±0.01	0.992 0.969	100-800 800-7500

The samples exhibit a bi-modal behavior: at lower scale ranges, the fractal dimension is situated in the range 2.20-2.44, meanwhile for higher scale ranges, the fractal dimension has a higher fractal dimension, in the range: 2.58-2.76.

$La_{0.9}Sr_{0.1}MnO_3$ samples were prepared by solution combustion method from metal nitrates and alanine by calcining the isolated complex precursors at 1000°C, 4h.





Two samples of silica powders were analysed using SEM: sample **A** (left), with BET surface area S=400m2/g and sample **B** (right) with BET surface area S=53m2/g. The powders had been produced in the Institute of Electronics, BAS by use of thermal arc plasma method.

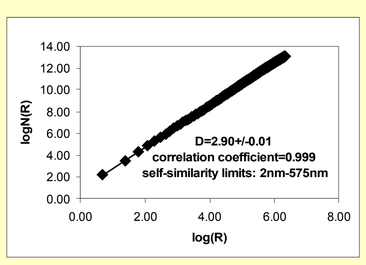
$$\theta(r) = \sum_{x_r, y_t} \rho(x_r, y_r) = Br^{-D_\theta}$$

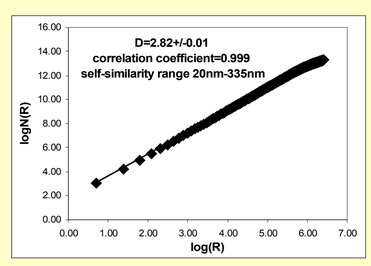
$$D = \frac{3D_\theta}{2}$$

$\rho(x_r,y_r)$ = grey-level of x_r,y_r pixel of TEM micrograph;

D_θ is the TEM micrograph fractal dimension computed from gray-level distribution;

-The fractal behavior of the gray-level is assumed and "mass radius" relation is used to compute Dθ.





Log-log plot of number of occupied sites within R radius sphere for micrographs.