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SMR.1135 - 16

THIRD WORKSHOP ON
THIN FILMS PHYSICS AND TECHNOLOGY
(8 - 24 MARCH 1999)
including
TOPICAL CONFERENCE ON
MICROSTRUCTURE AND SURFACE MORPHOLOGY
EVOLUTION IN THIN FILMS
(24 - 26 MARCH 1999)

"Effects of ion bombardment on the evolution of surface morphology"

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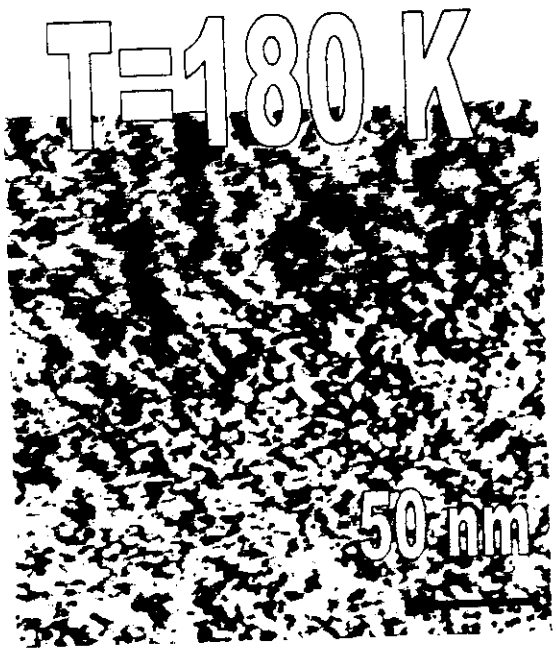
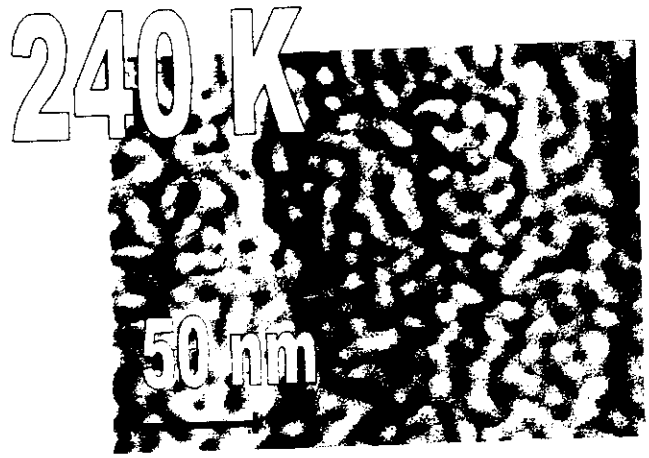
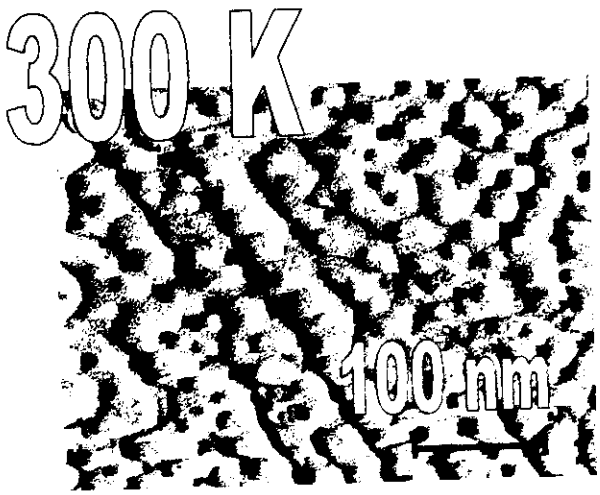
16146 Genova
ITALY

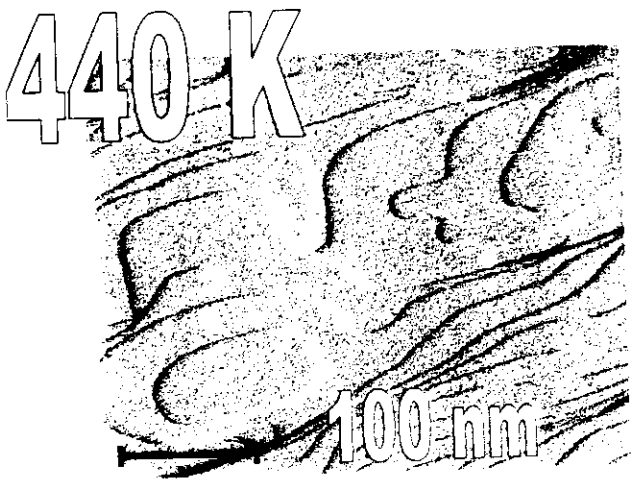
These are preliminary lecture notes, intended only for distribution to participants

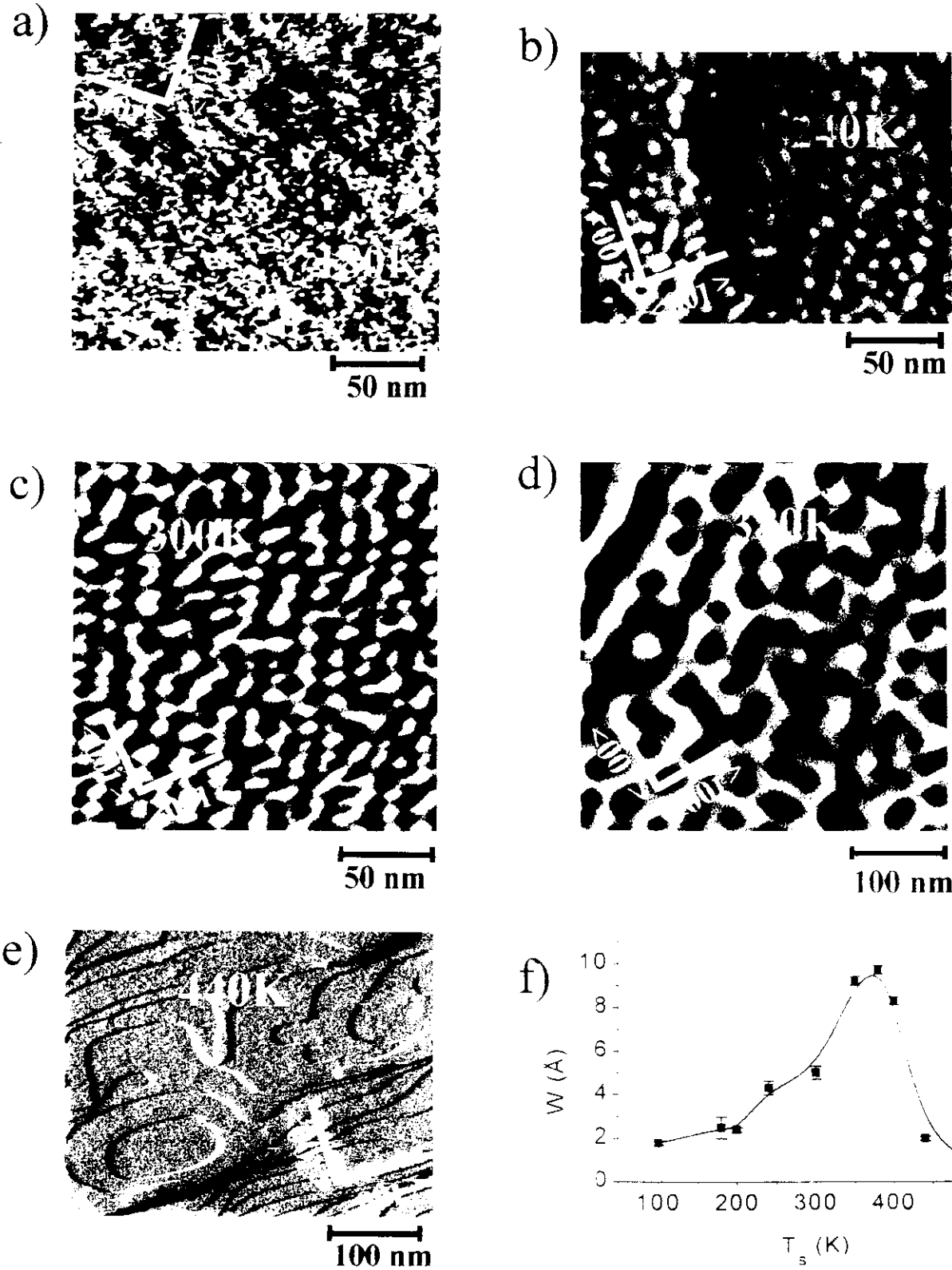
Ag (100)





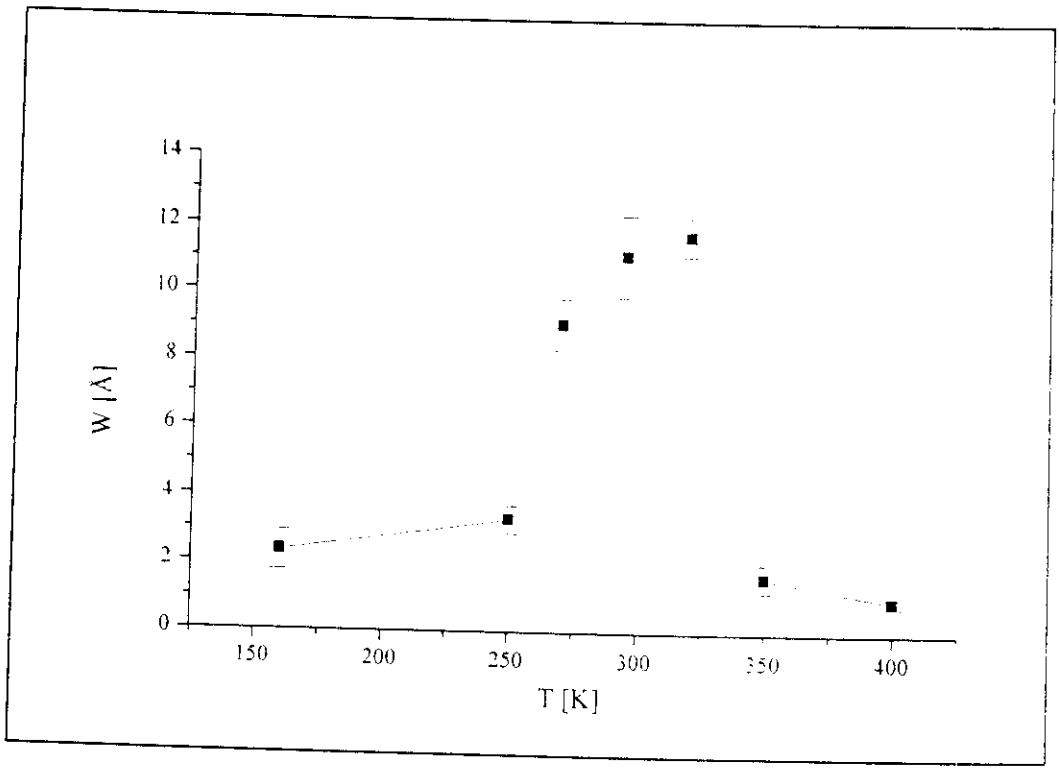




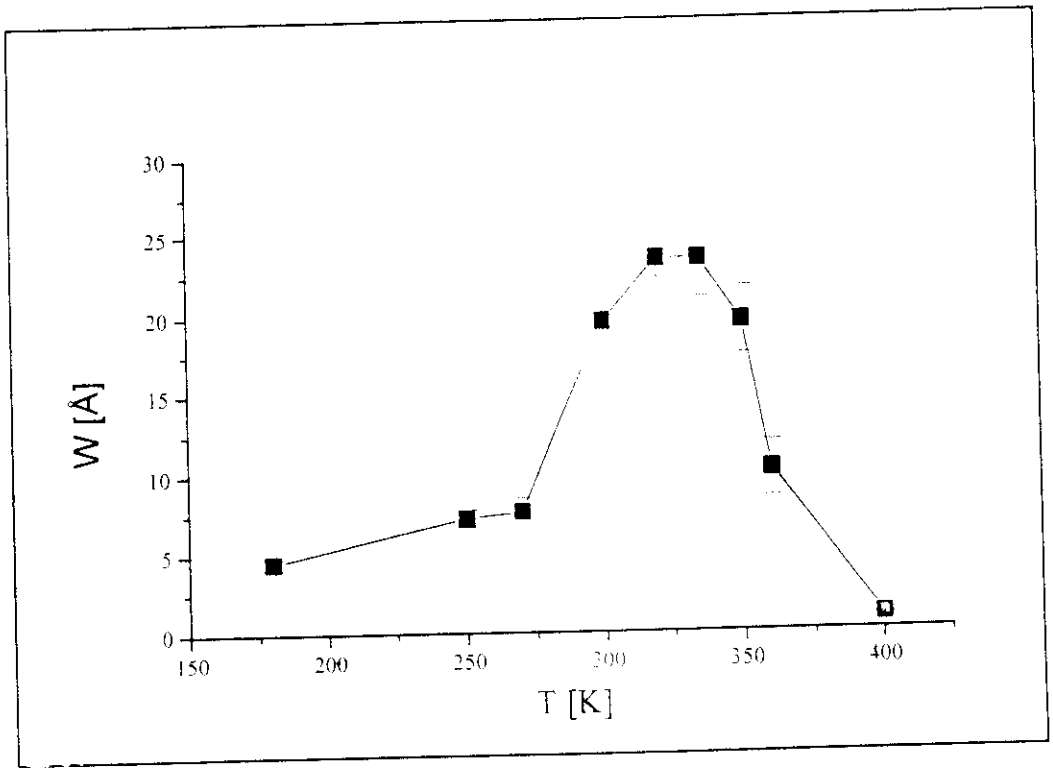

a)
50 nm
b)
240K
50 nm
c)
300K
50 nm
d)
100 nm
e)
440K
100 nm
f)
W (Å)
T_s (K)
0
2
4
6
8
10
100
200
300
400
500

Ag(100)

Temperature evolution of roughness W Ag(110)



Temperature evolution of roughness W Cu(110)



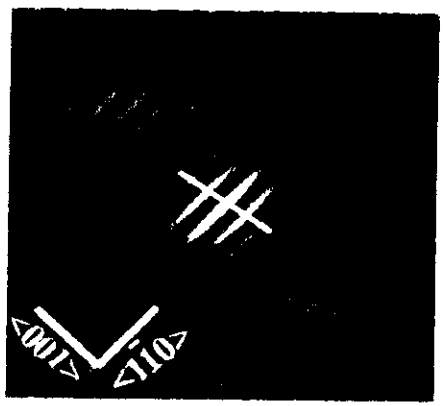
ANALYSIS

Raw data

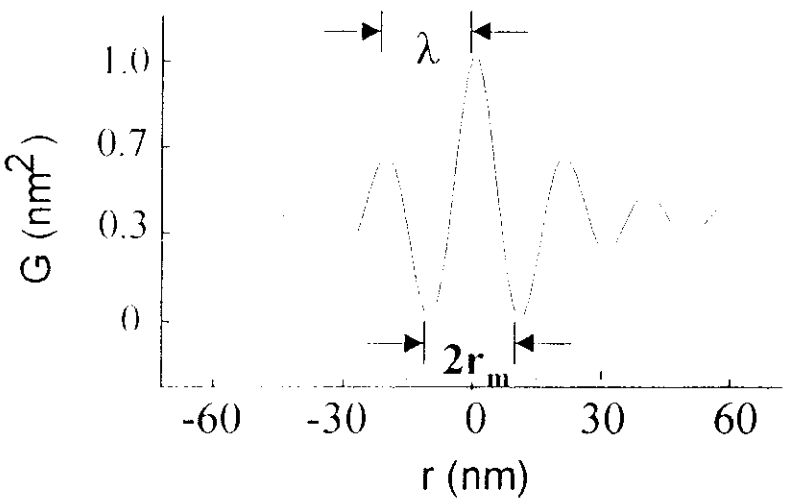
2D-Autocorrelation function

$$G(i,j)=\langle h(i,j)h(0.0)\rangle$$

G(i,j)



Linear section



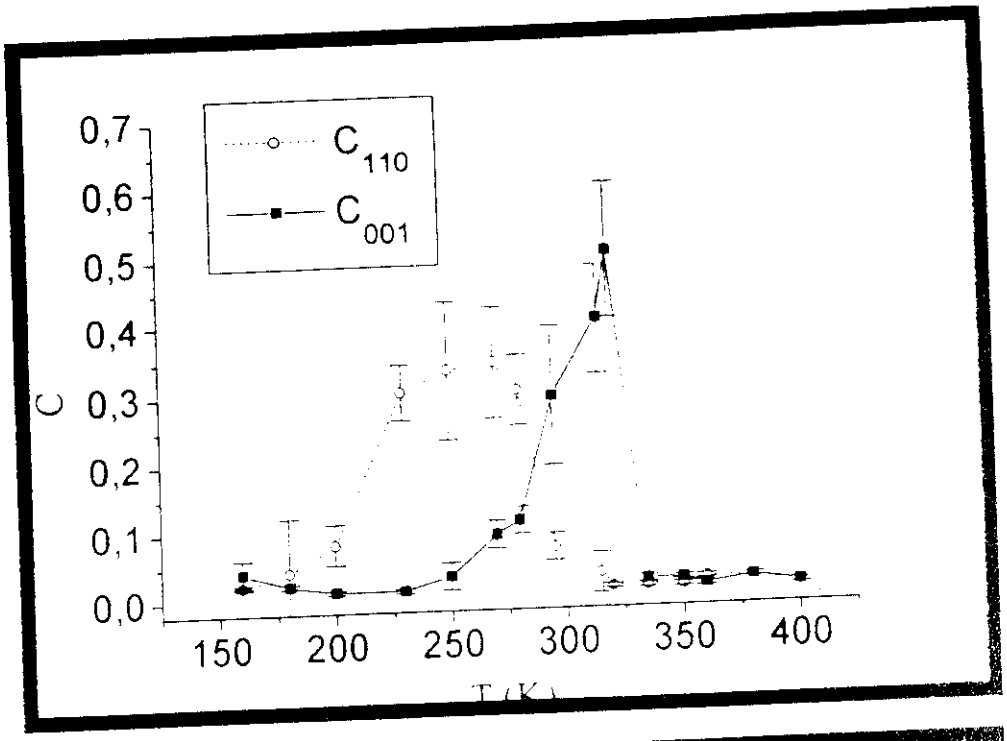
Roughness ➡ $W = 1/2\ \sqrt{G(0,0)}$

Coherence ➡ $C_{001} = G(i_1, j_1)/G(0,0)$

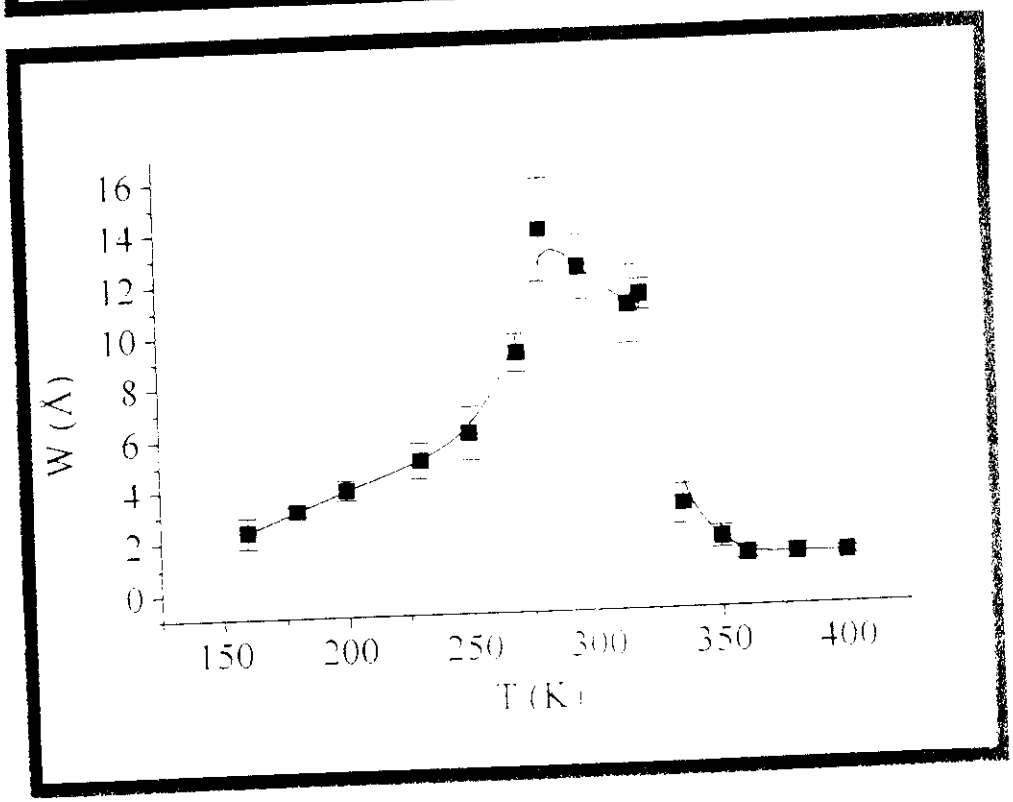
Wavelength ➡ λ

Slope ➡ $S = \dfrac{\sqrt{G(0,0)}}{r_m}$

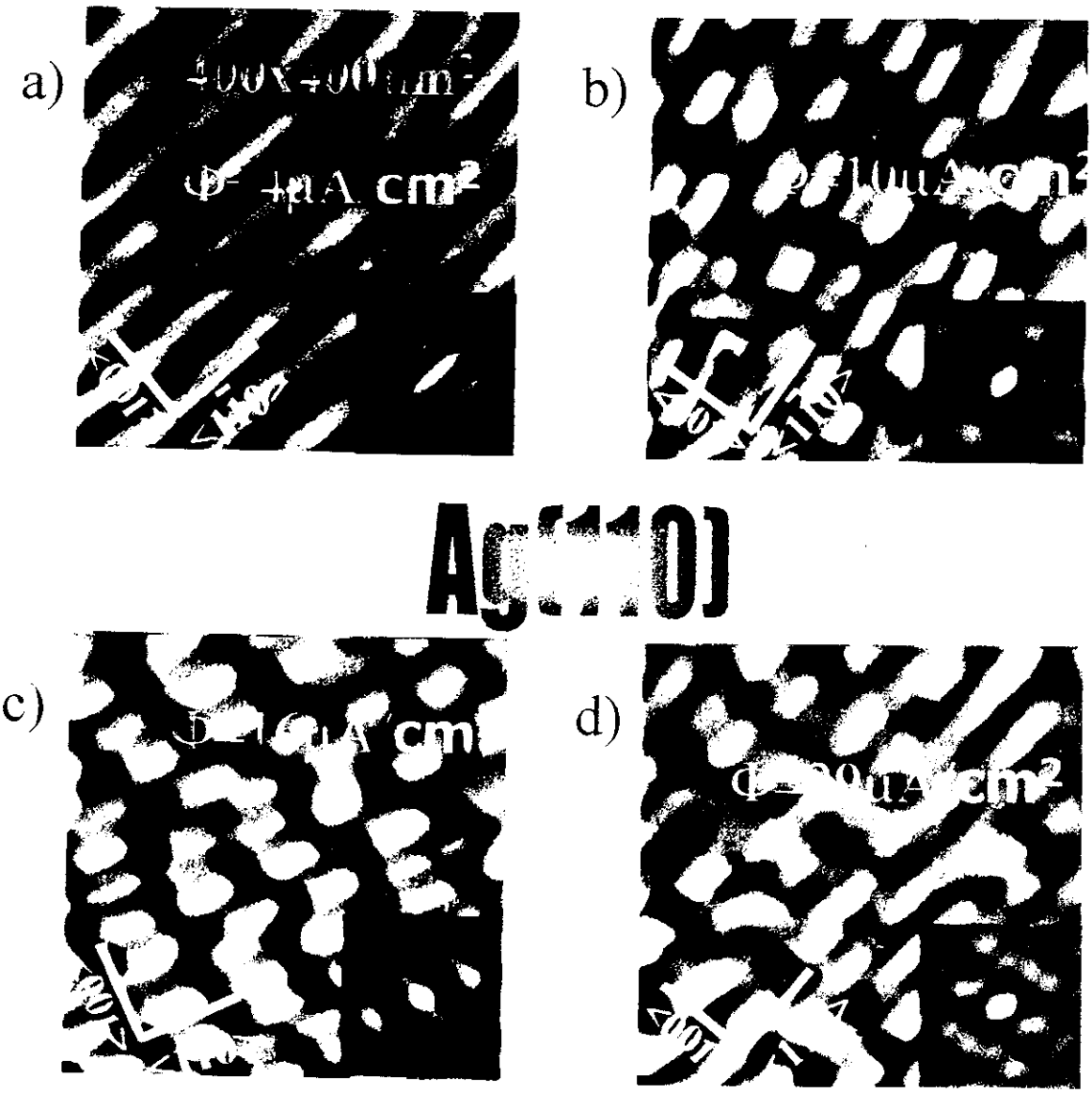
a)


C110
C001
C
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
150
200
250
300
350
400
T (K)

b)

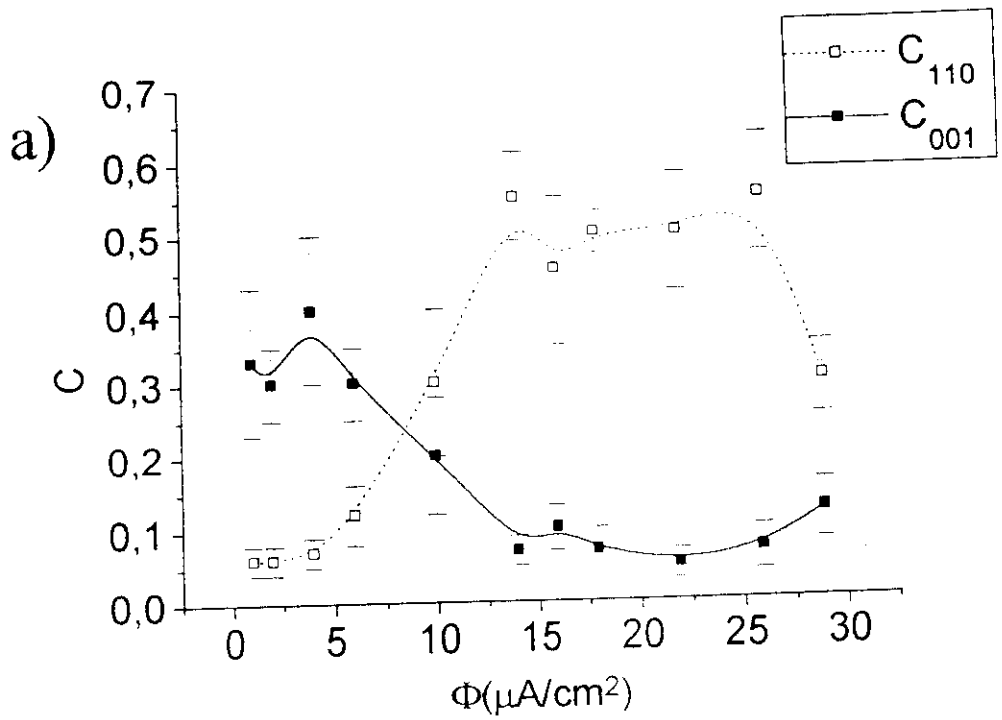

W (Å)
16
14
12
10
8
6
4
2
0
150
200
250
300
350
400
T (K)

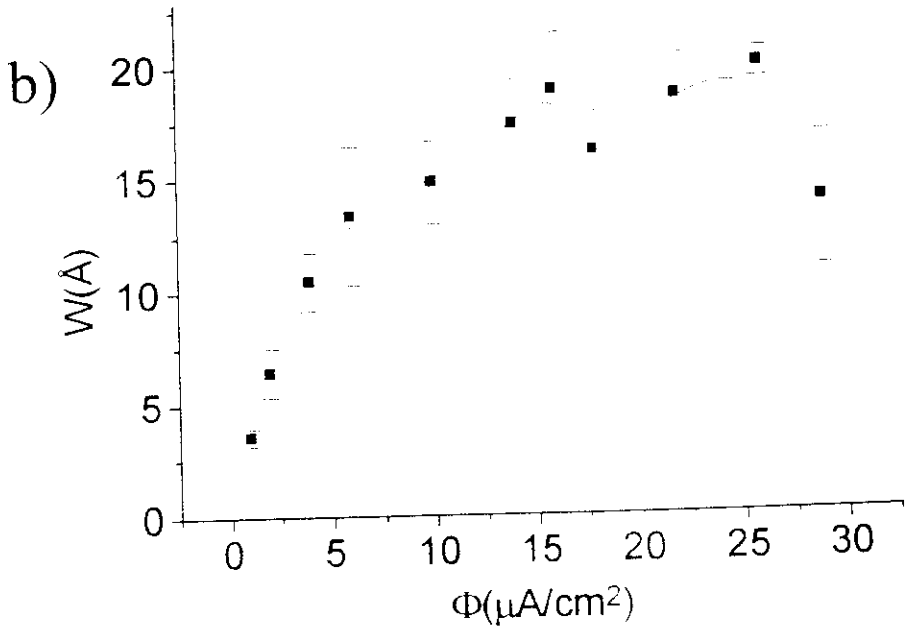
Ag(110)



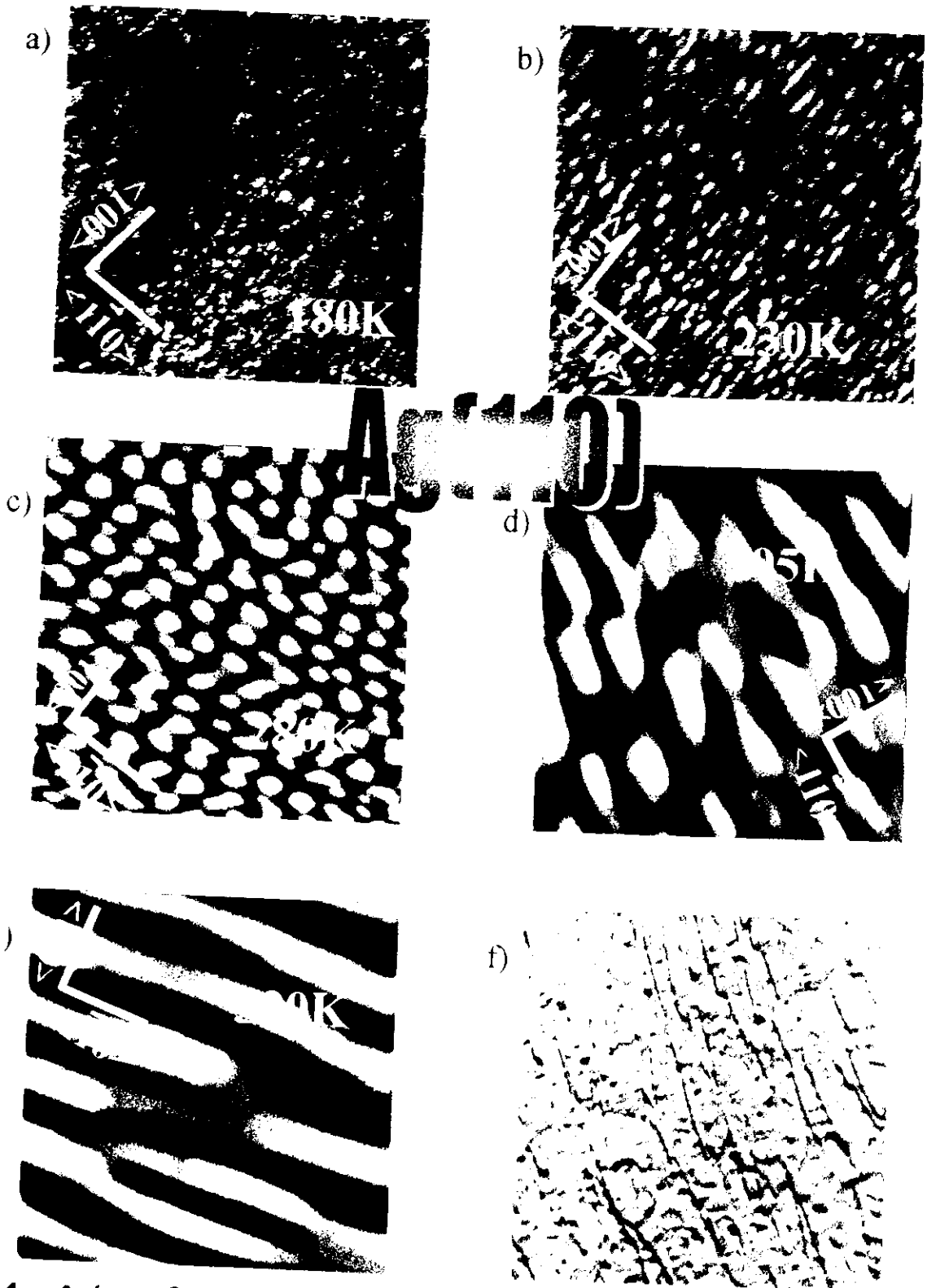
T=295 K t= 20 min

G® 250x250 nm²

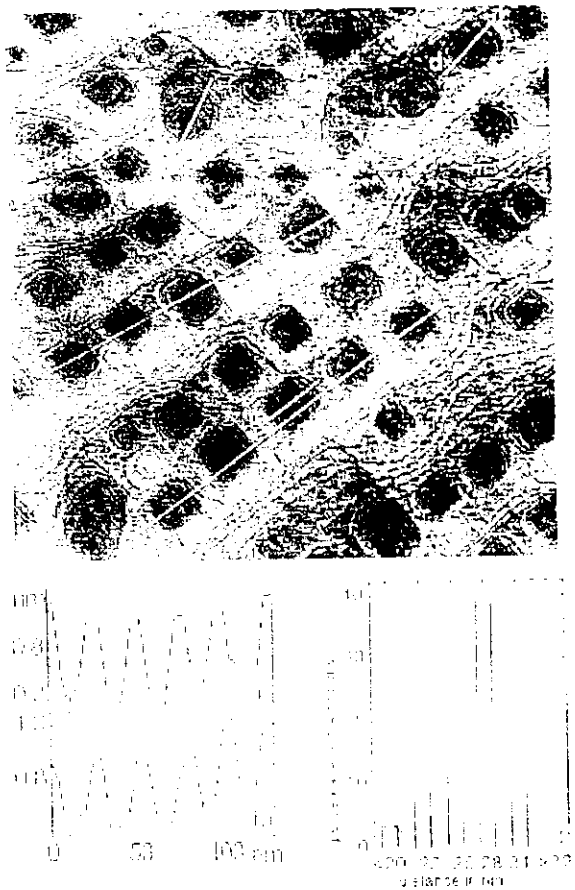




Ag(110) T=295K t=20min.



$\Phi=4\mu A/cm^2$ t=15min $\theta=0°$ 400x400 nm^2



M.Ritter, M.Stindtmann,:M.Farle, K.Baberschke

348 (1996) 243

[redacted] structure has been never observed, but only pits and holes reflecting the surface simmetry

⇒ Pt(111) , Michely & Comsa (1993)
⇒ Cu(111) , Naumann et al. (1997)
⇒ Cu(001) , Ritter et al. (1996)
⇒ Fe films , Krim et al. (1993)

This difference is due to the prevalence of the smoothing terms (i.e. diffusion terms) and then it should be possible to induce a ripple structure by lowering the temperature

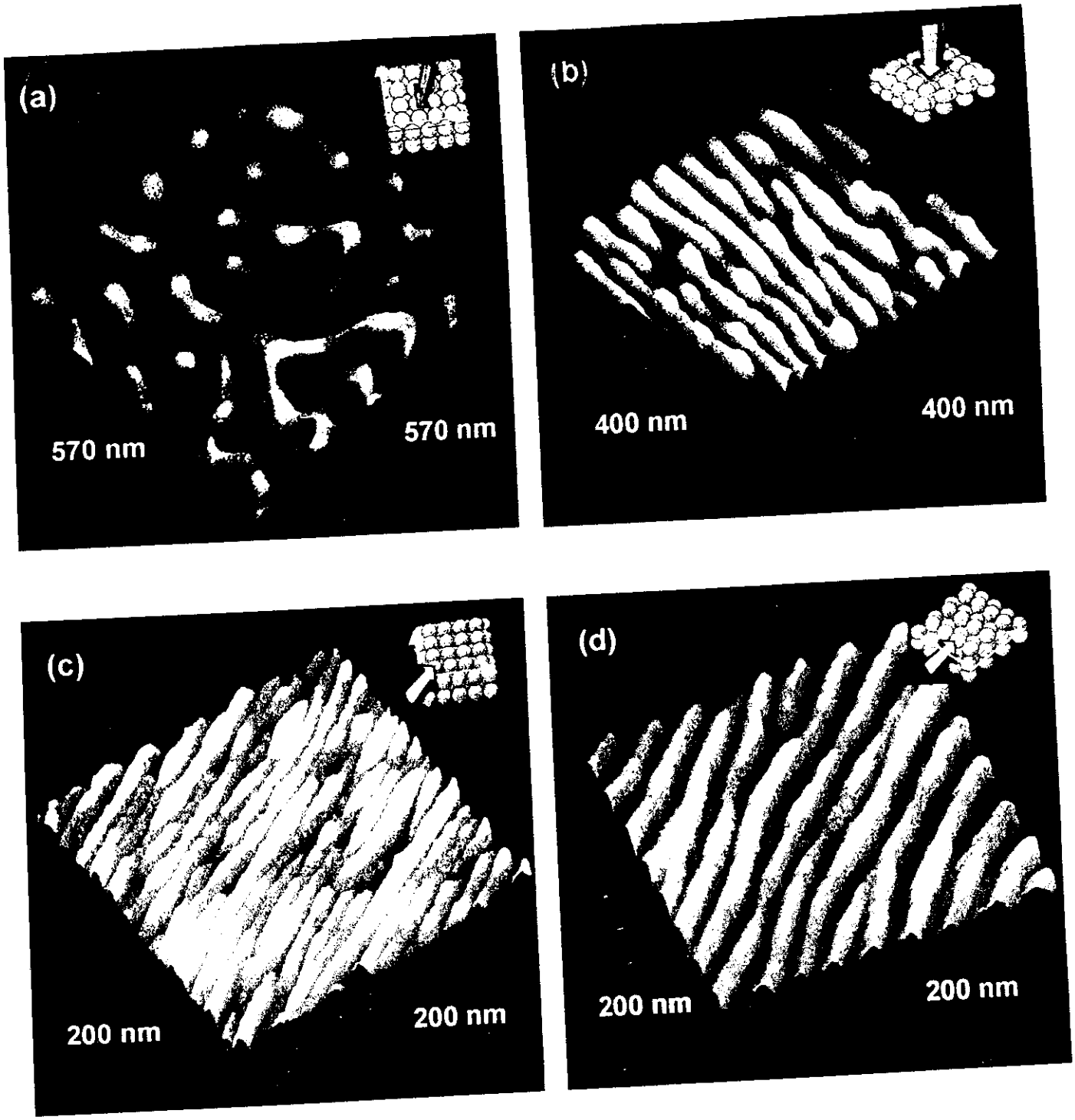
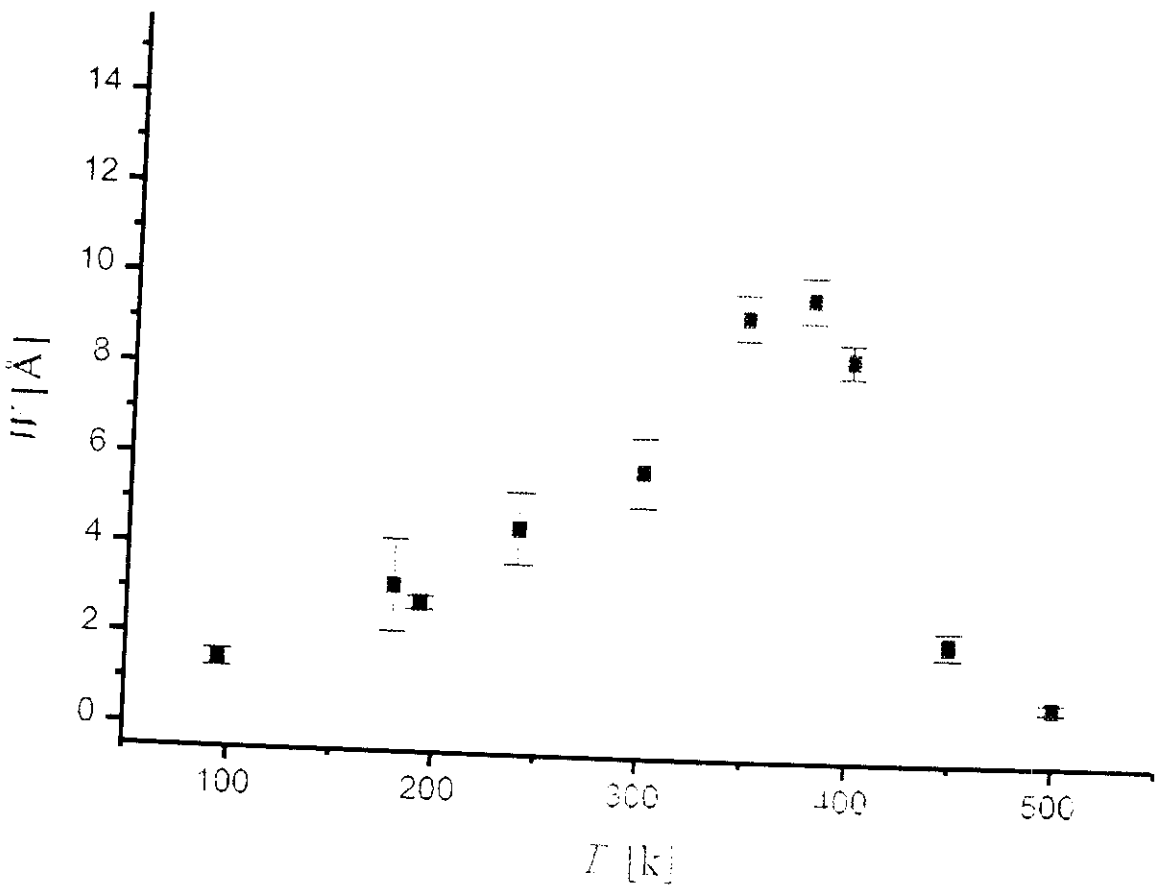


Figure 1

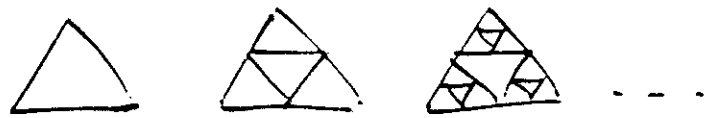
Ag(001)

Temperature evolution of the roughness W



SELF SIMILARITY

One object can be self-similar if it is formed by part that are "similar" to te wohle.



Deterministic fractal

Many objects existing in nature are random. Despite this randomness such objects may be self-similar in a <u>statistical</u> sense.

Statistical fractal

If the scale trasformation is isotropic

<u>Self similar - fractal</u>

Fractal objects that must be rescaled using an anisotropic transformations are

<u>Self-affine fractal</u>

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

Edwards - Wilkinson equation

$$\vec{x} \longrightarrow \vec{x}' \equiv b\vec{x}$$
$$h \longrightarrow h' \equiv b^{\alpha} h$$
$$t \longrightarrow t' \equiv b^{z} t$$

$$\frac{\partial h}{\partial t} = \nu\, b^{z-2} \nabla^2 h + b^{-\frac{d}{2} + \frac{z}{2} - \alpha} \eta$$

$$\alpha = \frac{2-d}{2} \qquad \beta = \frac{2-d}{4} \qquad z = 2$$

Once we obtain a growth equation we must find its predictions determining the scaling exponents and scaling functions.

If the growth process is described by a sufficiently simple equation we can solve it exactly.

However for many equations no exact solutions exist so we must apply serious approximations to uncover the scaling behavior.

RENORMALIZATION GROUP METHOD.

Stochastic Model for Surface Erosion via Ion Sputtering: Dynamical Evolution from Ripple Morphology to Rough Morphology

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[1]*Center for Polymer Studies and Physics Department, Boston University, Boston, Massachusetts 02215*
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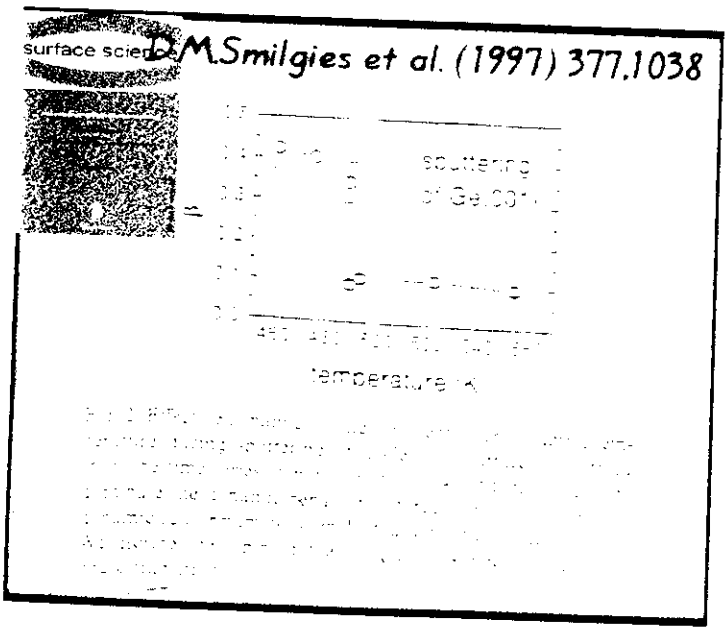
(Received 25 July 1995)

Surfaces eroded by ion sputtering are sometimes observed to develop morphologies which are either ripple (periodic) or rough (nonperiodic). We introduce a discrete stochastic model that allows us to interpret these experimental observations within a unified framework. We find that a periodic ripple morphology characterizes the initial stages of the evolution, whereas the surface displays self-affine scaling in the later time regime. Further, we argue that the stochastic continuum equation describing the surface height is a noisy version of the Kuramoto-Sivashinsky equation.

PACS numbers: 05.40.+j, 05.70.Ln, 64.60.Ht, 79.20.Rf

$$W \approx t^{\beta}$$



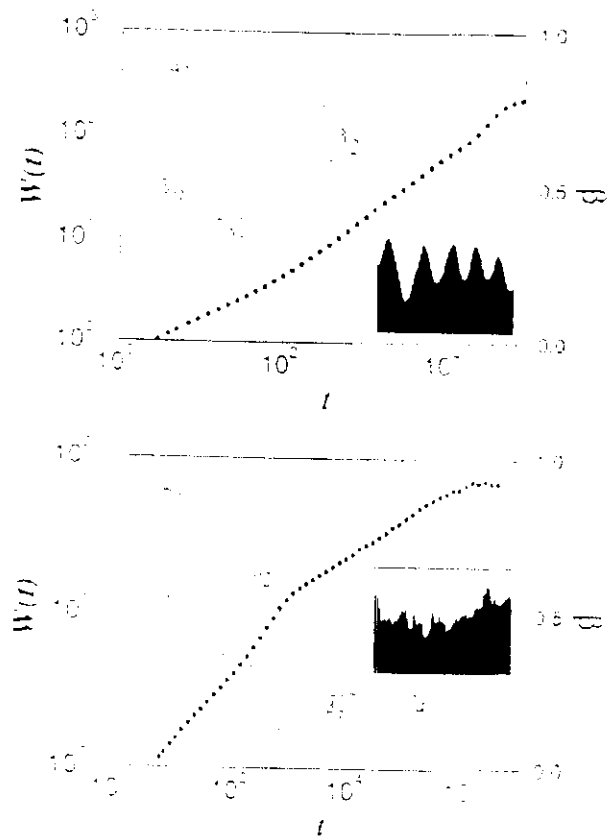
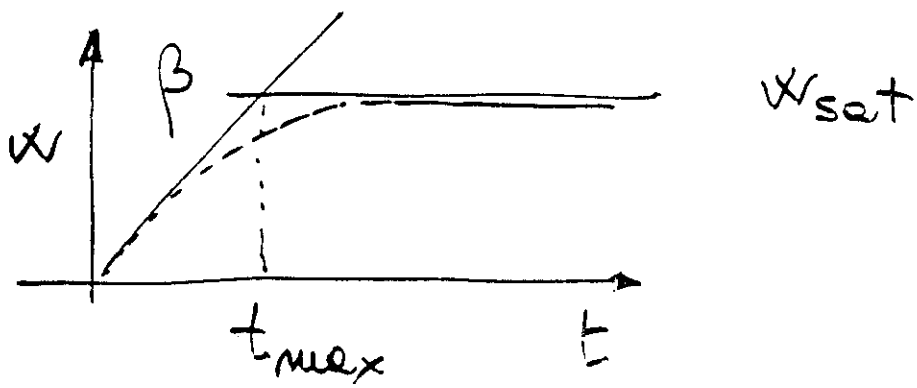


FIG. 2. Time evolution of the surface width $W(t)$ for the cases $p = 1$ and $p = 0.5$. The solid line is the corresponding slope of the width, showing the value of the growth exponent β in each regime. The inset shows the morphology of the interface at $t = 1000$. The saturation observed for $p = 1$ is due to the discreteness of the lattice: the erosion rule creates down steps of the order of the interface roughness (see Fig. 2(a)). This effect can be avoided by using a bigger box in the interface width (see Appendix A). Line for the KS model, showing the asymptotic behavior $\beta = 0.248$. As in the solid line in the main figure, the dashed slope. The inset shows a portion of the rough morphology of the late regime, where the self-affine scaling holds [see Fig. 3]. The arrows indicate the cross at which the interface roughness is analyzed in Fig. 3.

Scaling laws

$W \sim t^{\beta}$ β growth exponent



$W_{sat} \sim L^{\alpha}$ $t >> t_x$

α roughness exponent

t_x depends on the system size

$t_x \sim L^{z}$

α β and γ are not independent

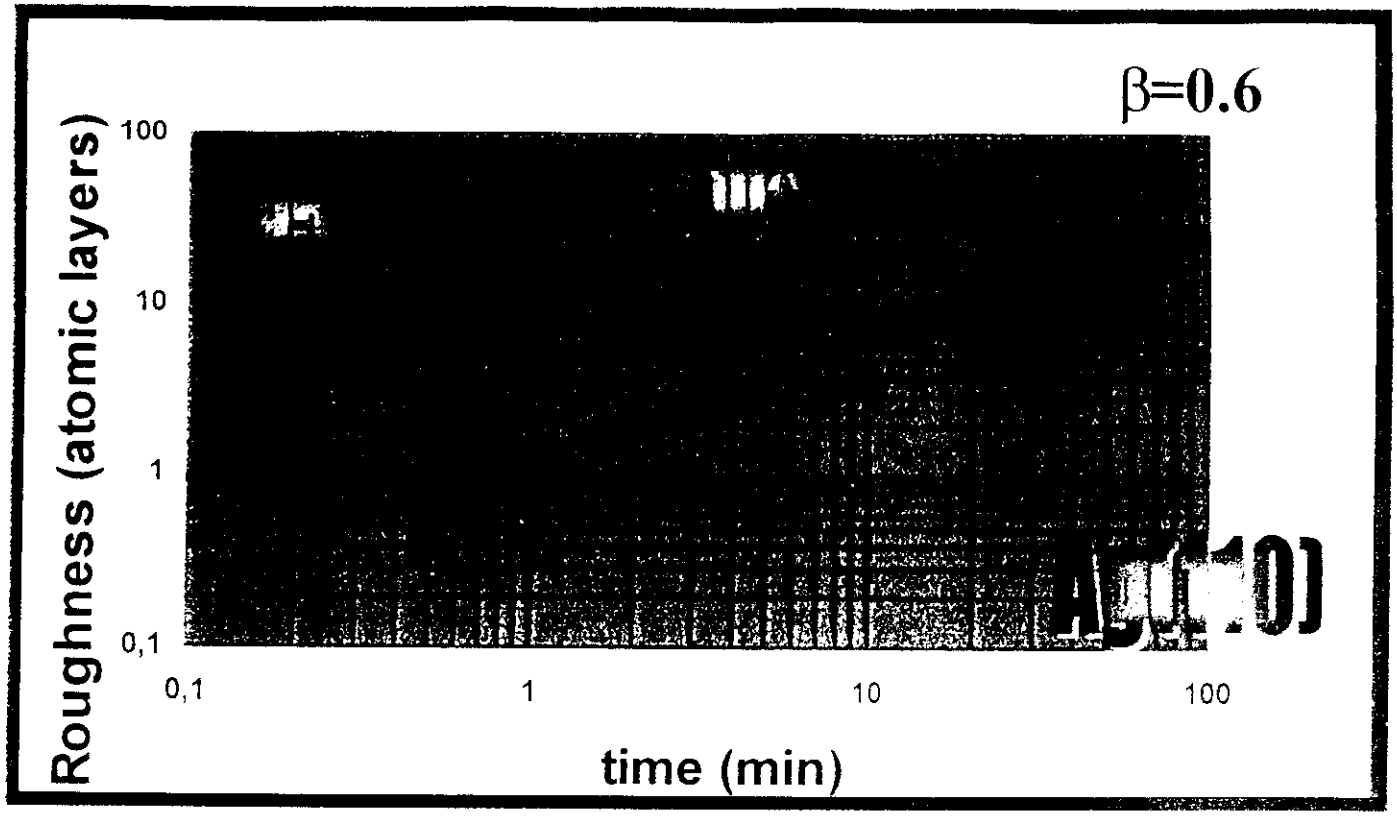
$$\gamma = \frac{\alpha}{\beta}$$

Family - Vicsek scaling relation -

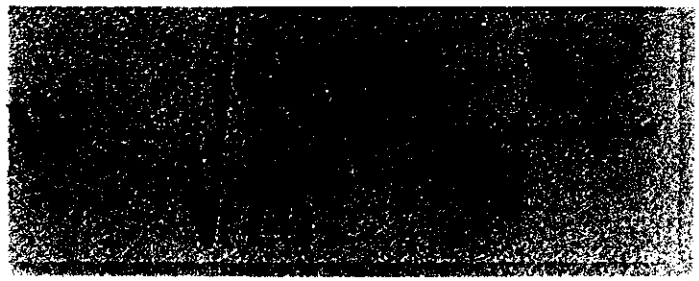
$$W(L,t) \sim L^{\alpha} f\left(\frac{t}{L^{z}}\right)$$

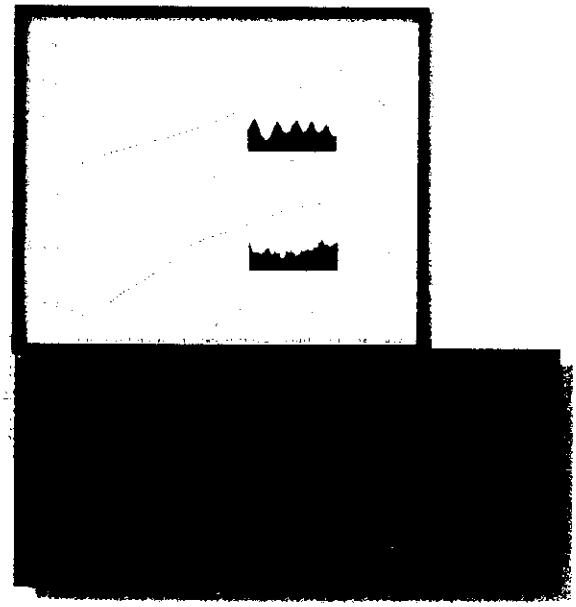
$$\Downarrow$$

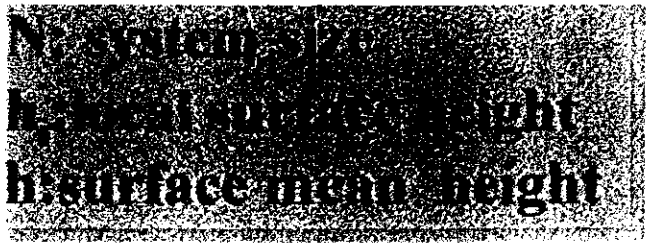
$$\frac{W(L,t)}{W_{sat}(L)} \sim f\left(\frac{t}{t_x}\right)$$



Roughness





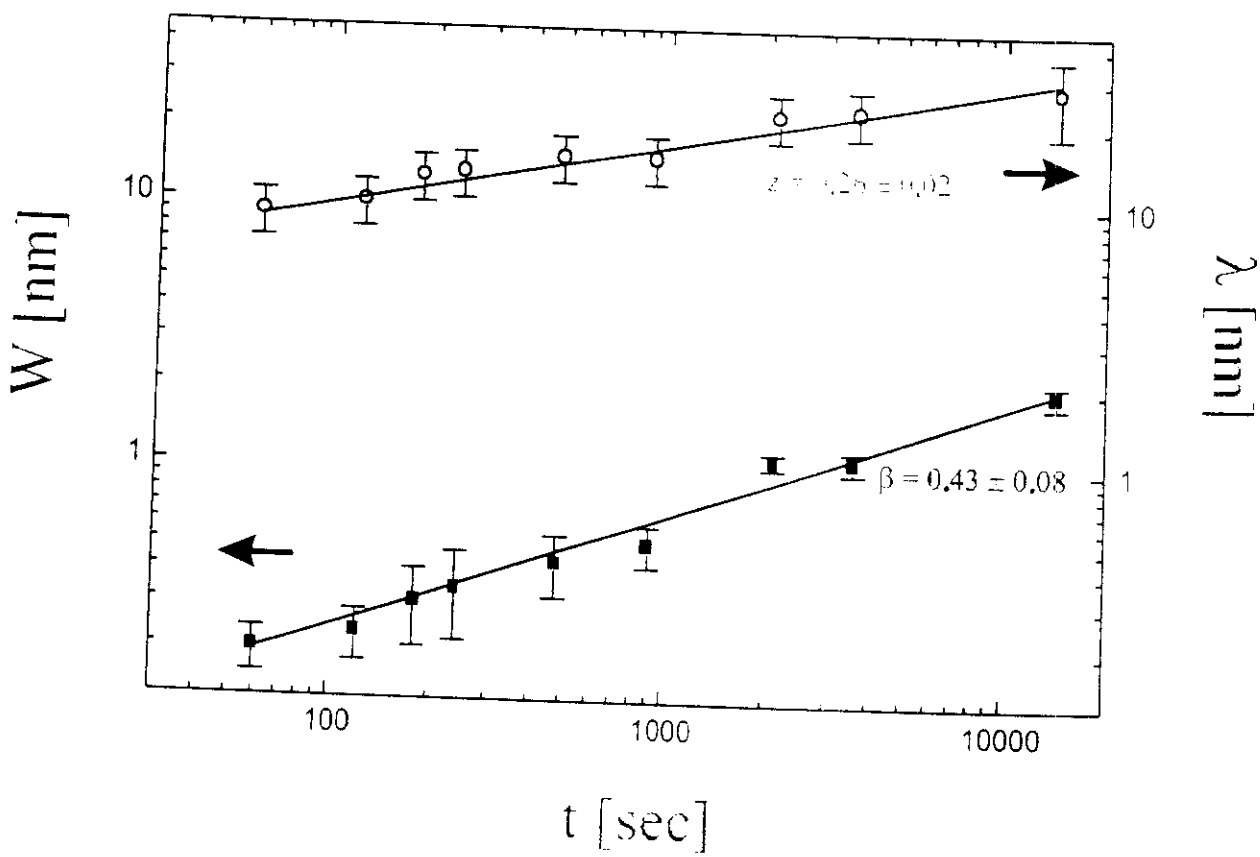


Scaling law

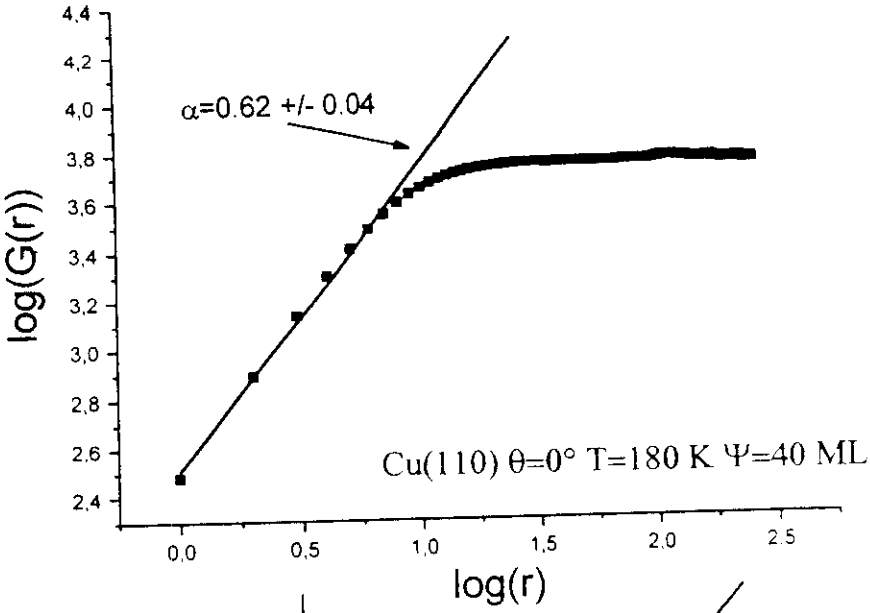
Family, Phys. Rev. A 168 (1990) 561

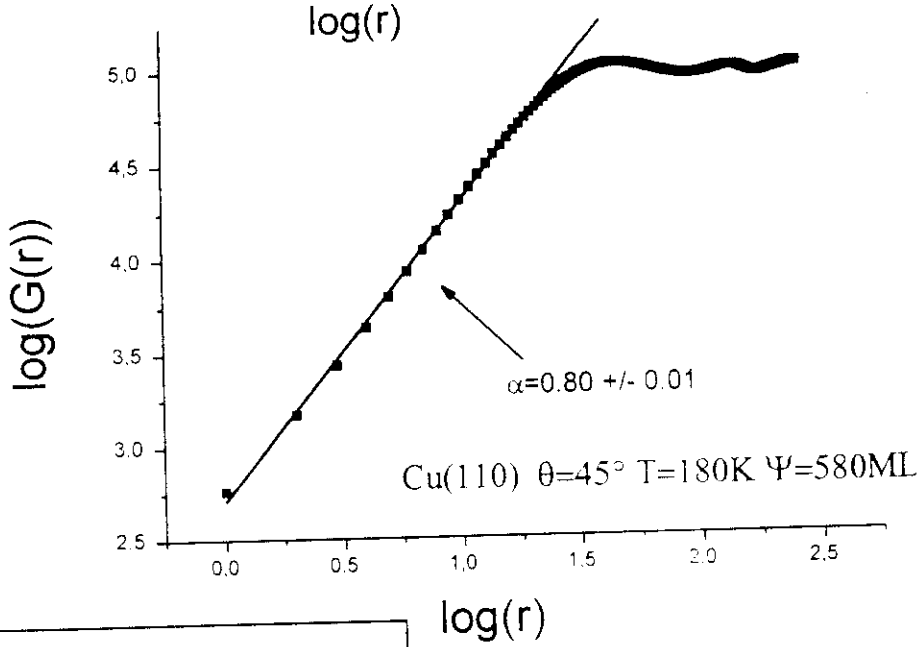
Time evolution of roughness and ripple wavelength

$T = 180$ K, $\theta = 45°$, $\delta = 0°$, $\Phi = 0.09$ ML/sec

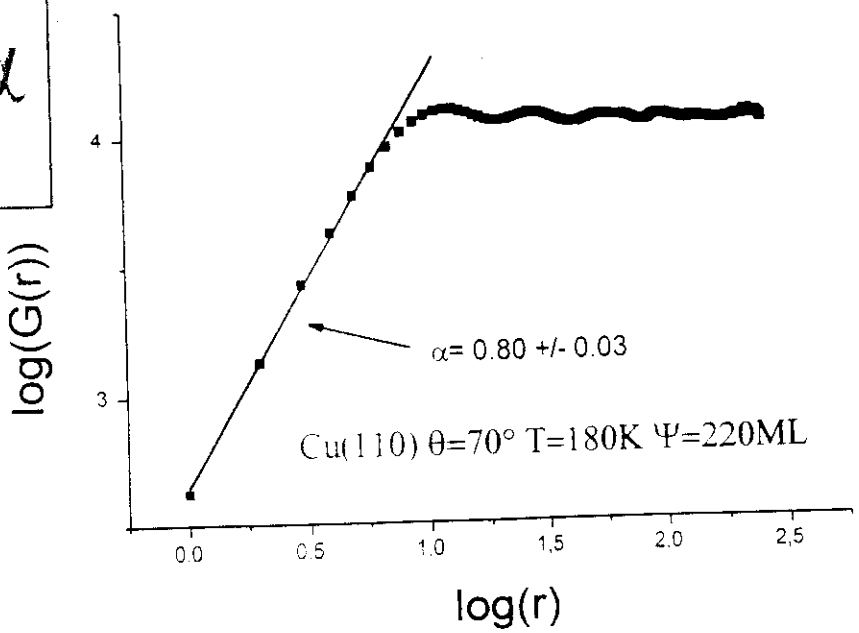


Two scaling laws: $\lambda \propto t^{0.25}$, $W \propto t^{0.43}$





$$W \propto L^{\alpha}$$



The wavelength grows as $\lambda \propto t^{0.25}$, with the same scaling law observed in MBE growth when a Schwoebel barrier is present cfr. Fe/Fe(001) , Cu/Cu(001)

in sputtering process the presence of a Schwoebel barrier is important to determine the final morphology

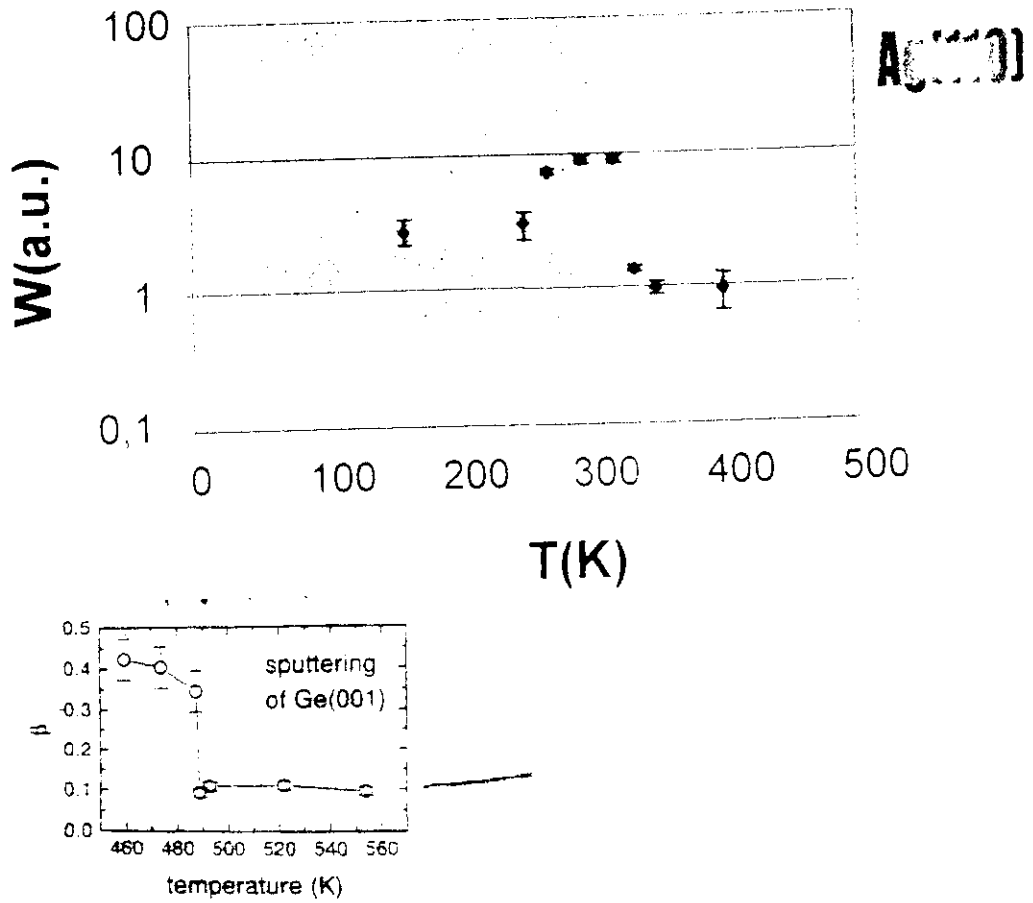
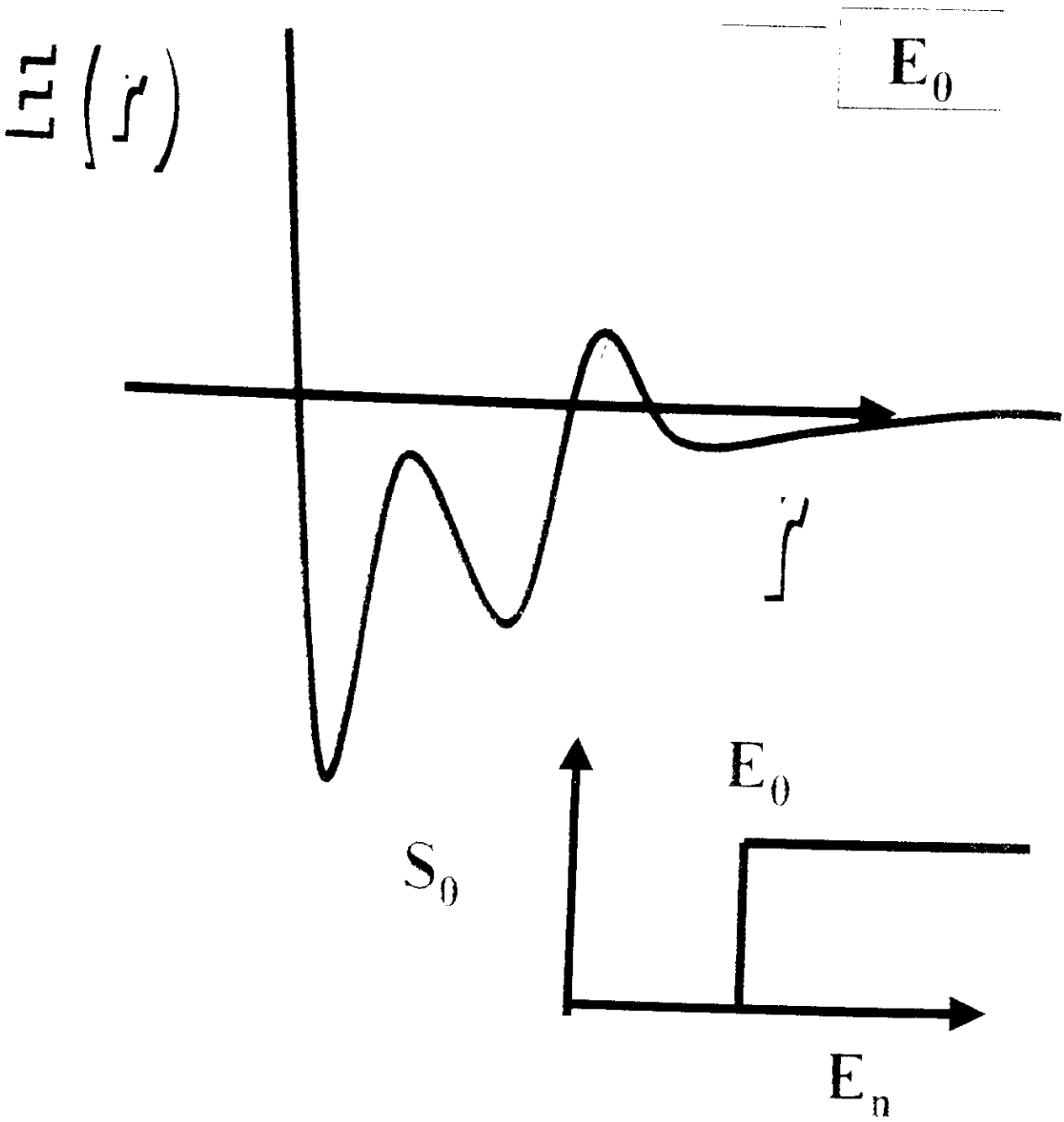
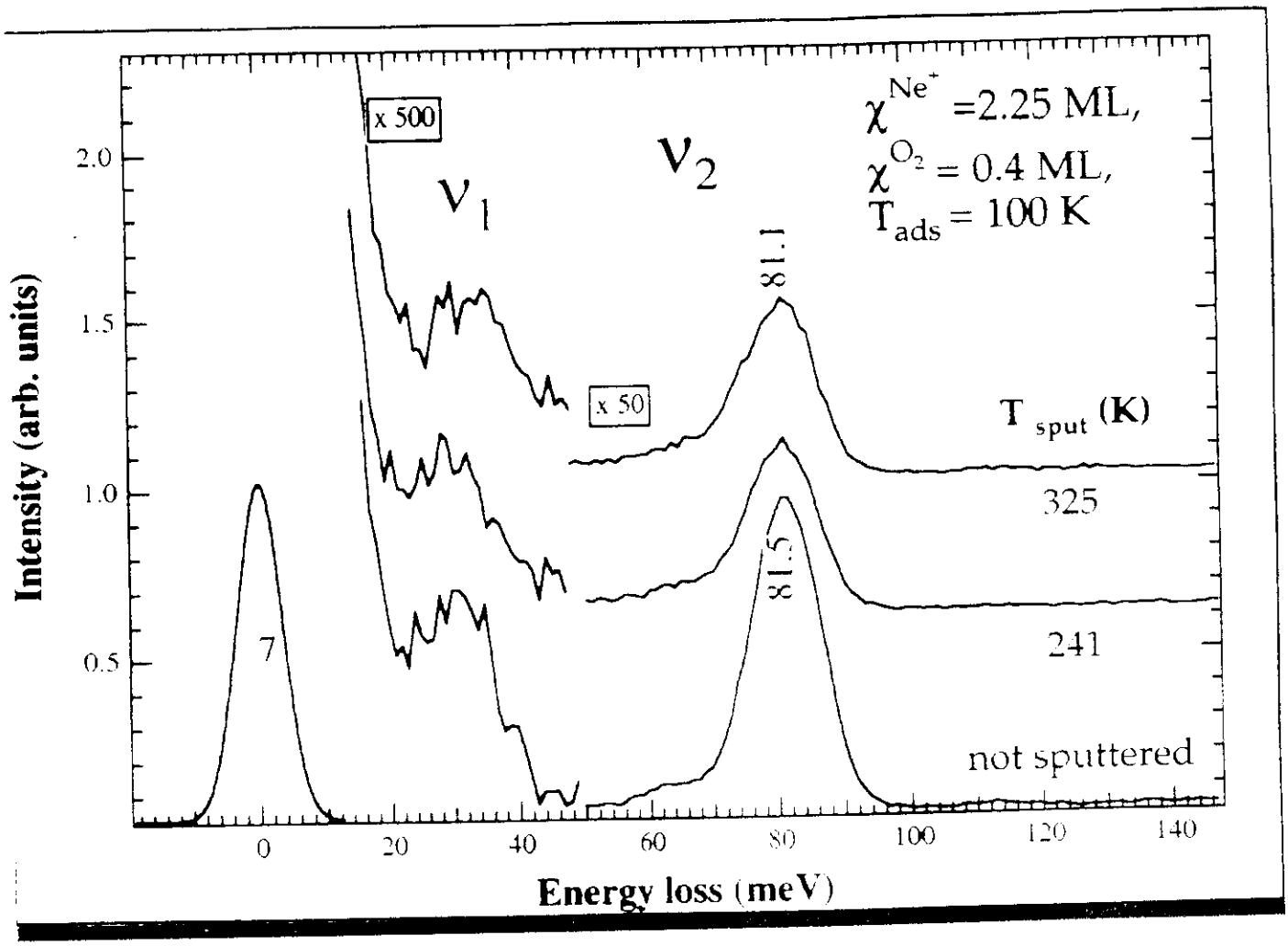
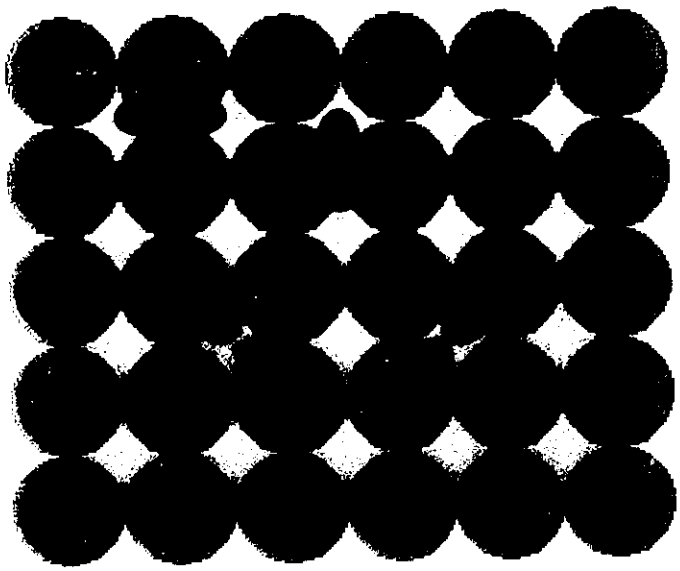


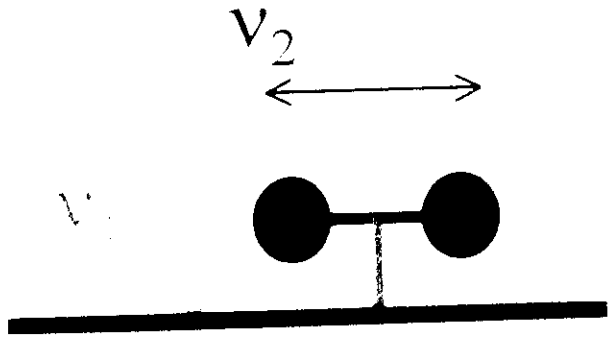
Fig. 2. Effective dynamic scaling exponent β versus sample temperature during sputtering of a Ge(001) surface, as derived from the time series in Fig. 1. For $\beta \approx 0.4$ random fluctuations dominate the dynamic behavior, whereas for $\beta = 0.1$ there is a dynamic equilibrium between fluctuations and surface diffusion. We ascribe the jump of the β value at 488 K to a dynamic phase transition.

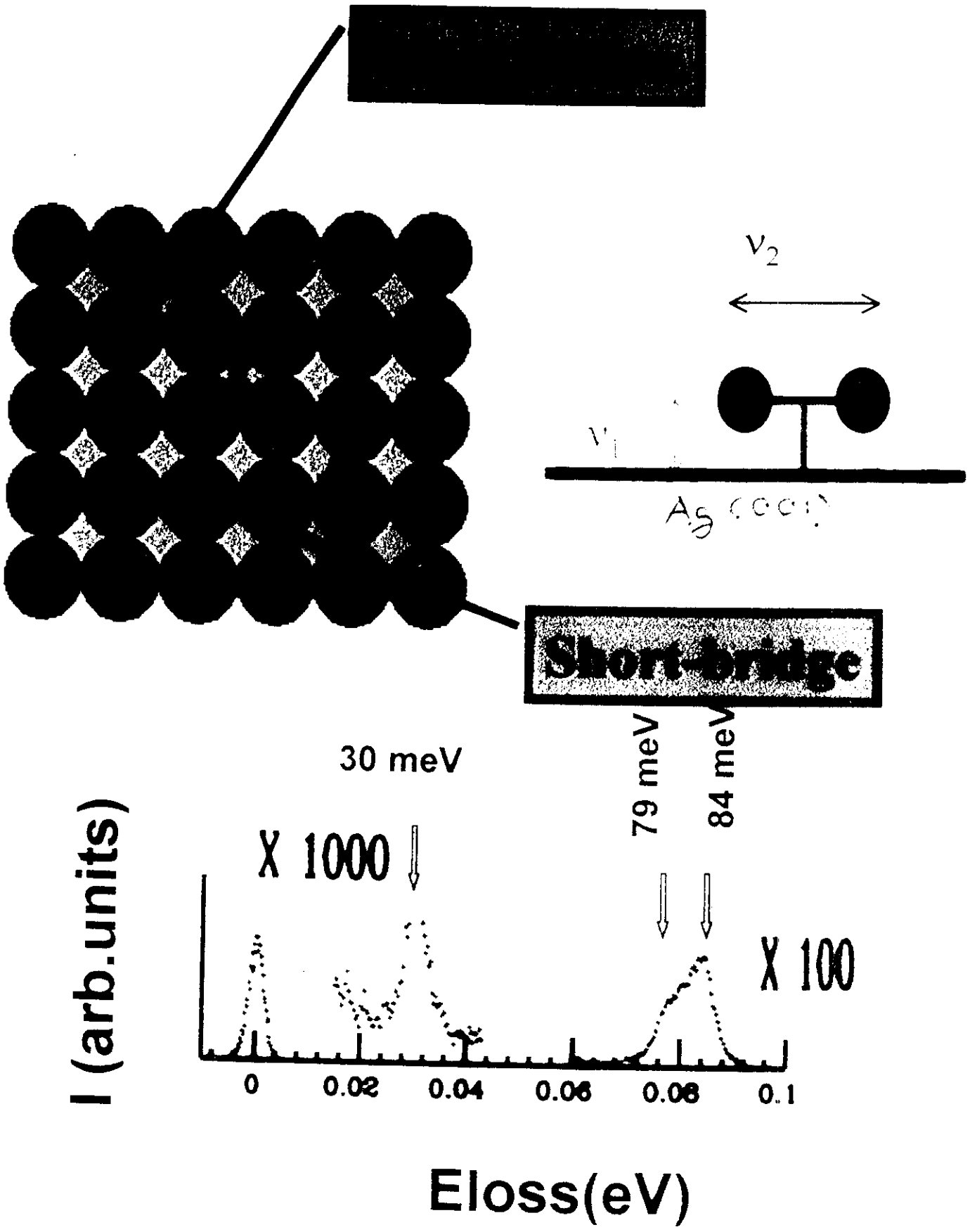

rT(r)
E0
r
E0
S0
En

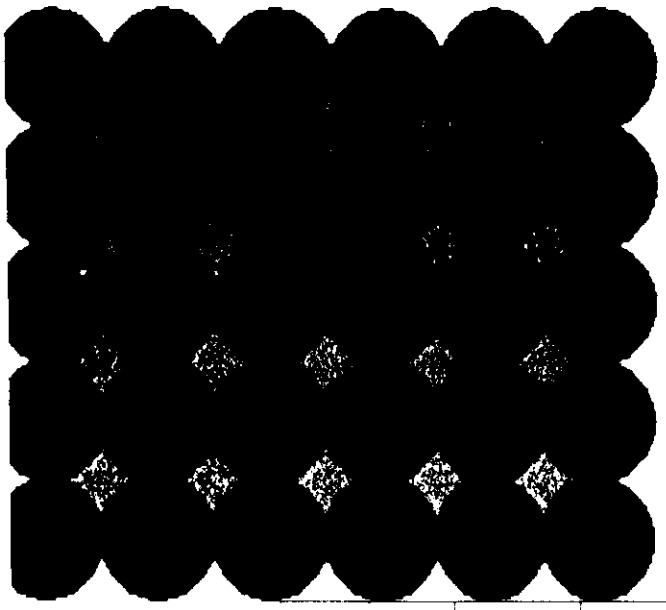

x 500
x 50
ν_1
ν_2
χ^{Ne^+} =2.25 ML,
χ^{O_2} = 0.4 ML,
T_{ads} = 100 K
81.1
81.5
7
T_{sput} (K)
325
241
not sputtered
Intensity (arb. units)
Energy loss (meV)
0
20
40
60
80
100
120
140
0.5
1.0
1.5
2.0

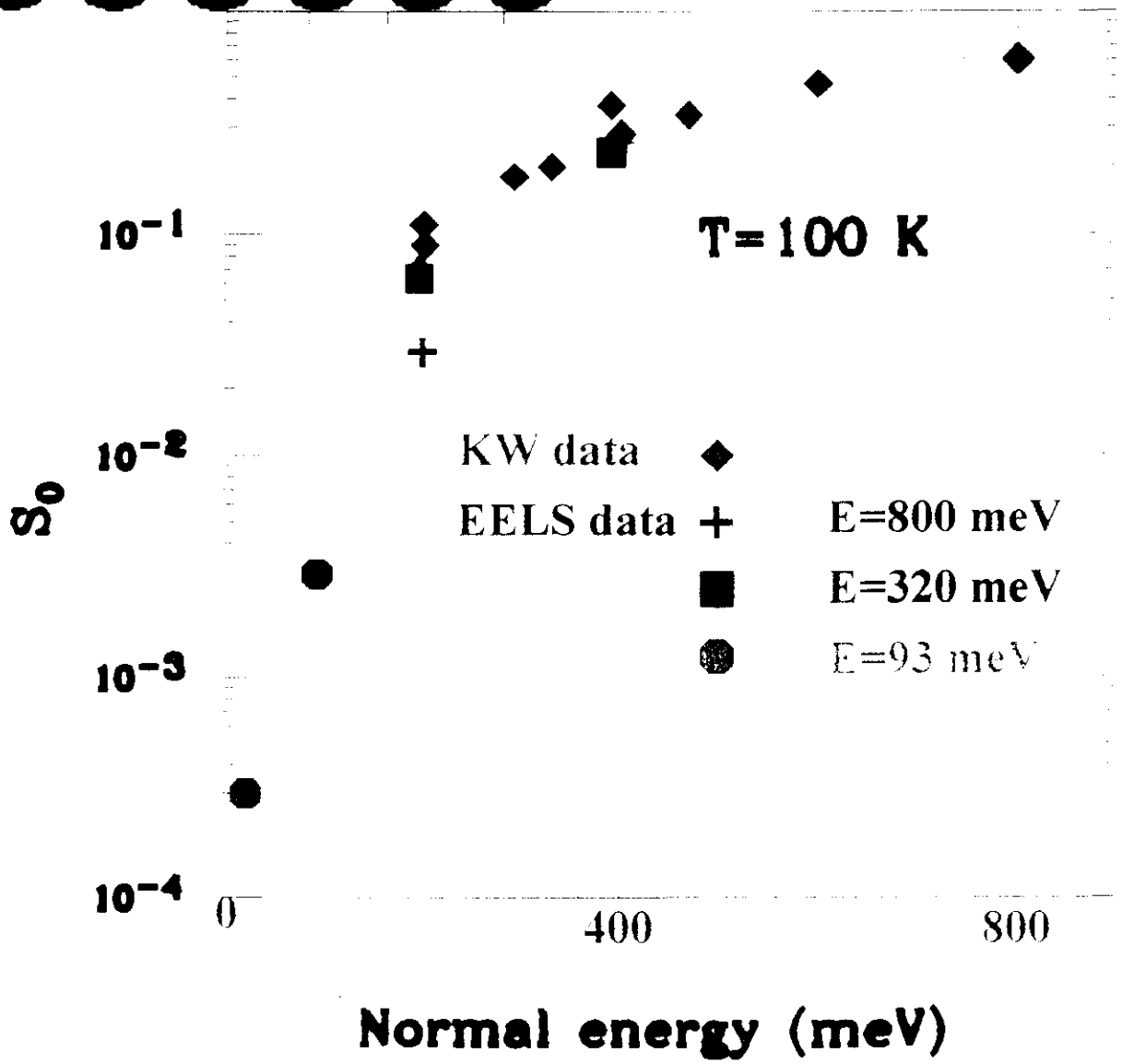
Ag(100)

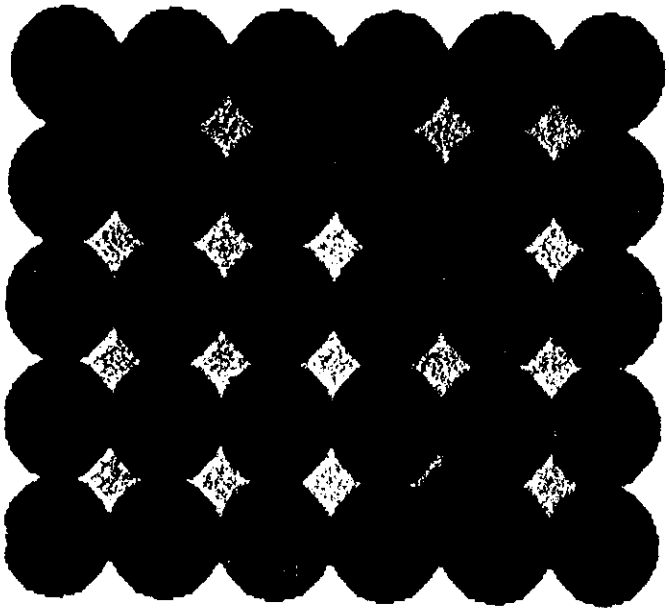


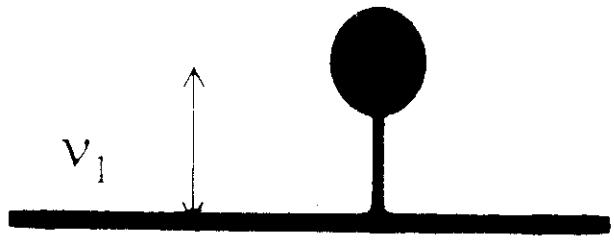

ν_2

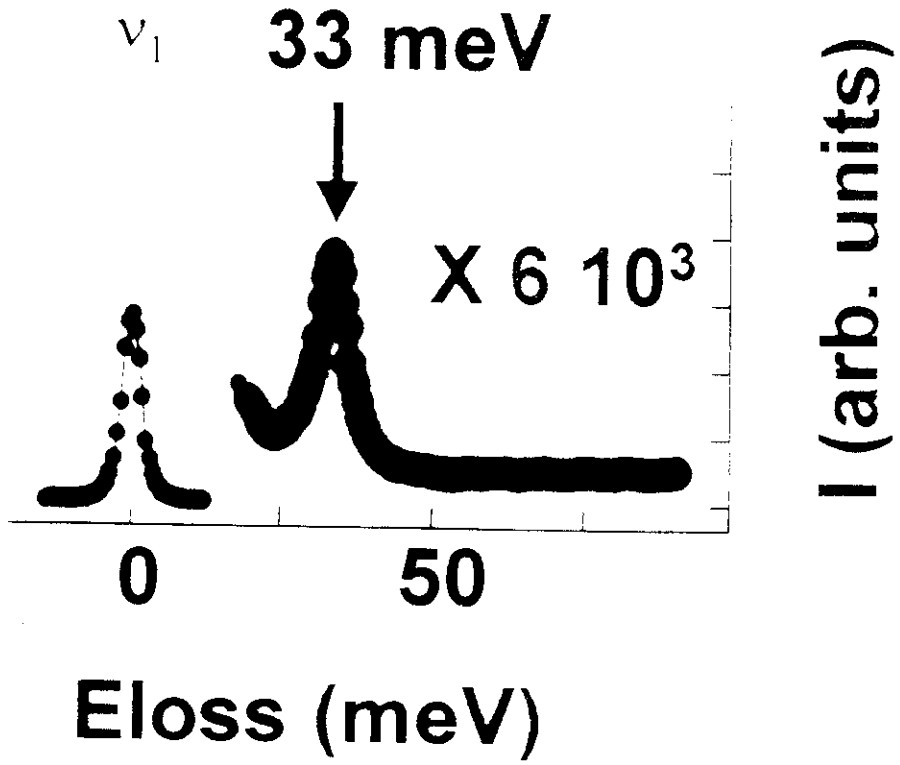

ν_2
ν_1
Ag (001)
Short-bridge
30 meV
79 meV
84 meV
X 1000
X 100
I (arb.units)
0
0.02
0.04
0.06
0.08
0.1
Eloss(eV)

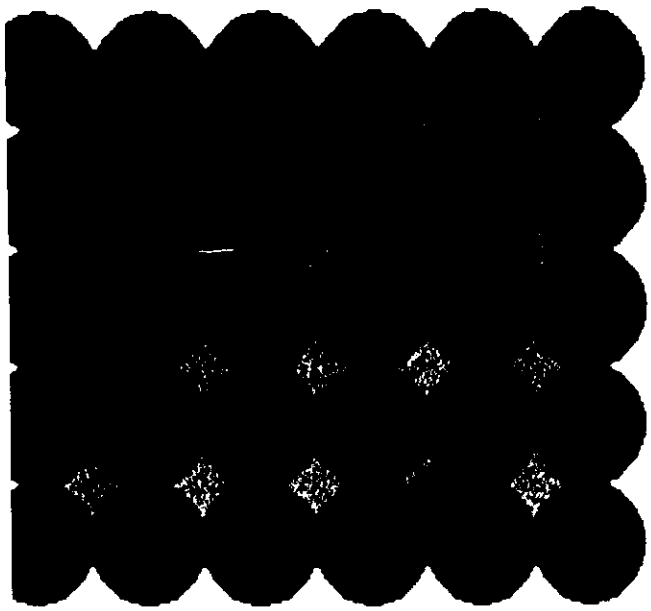


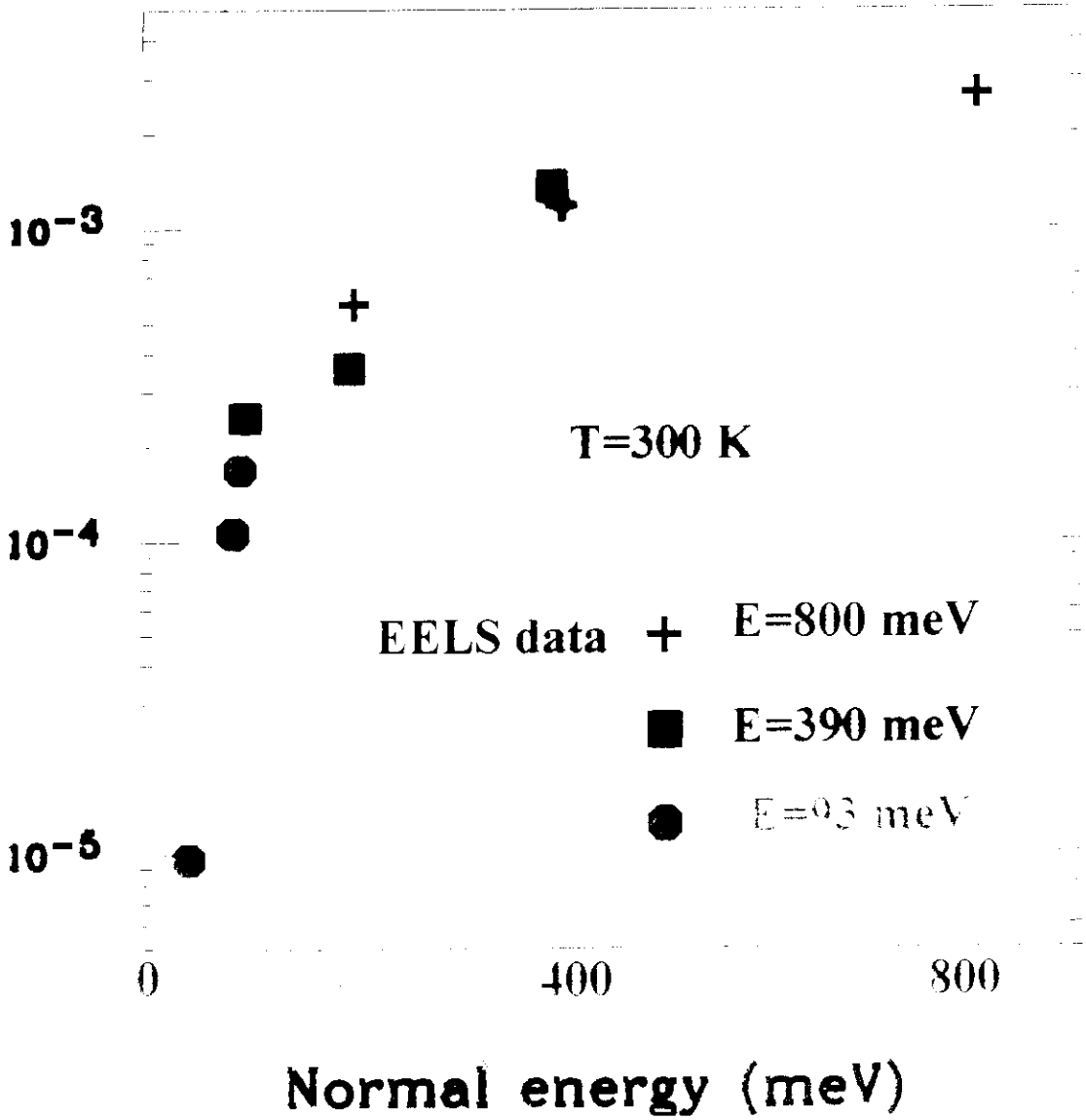

T=100 K
KW data
EELS data
E=800 meV
E=320 meV
E=93 meV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
S^0
0
400
800
Normal energy (meV)



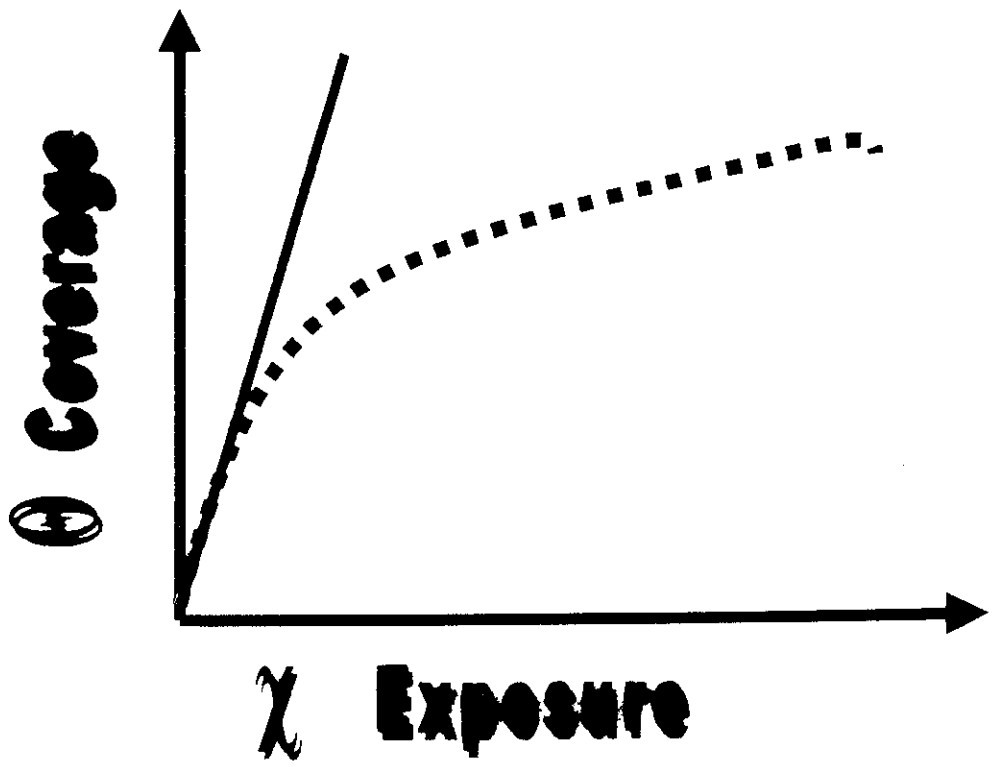

ν_1


ν_1
33 meV
X 6 10^3
I (arb. units)
0
50
Eloss (meV)



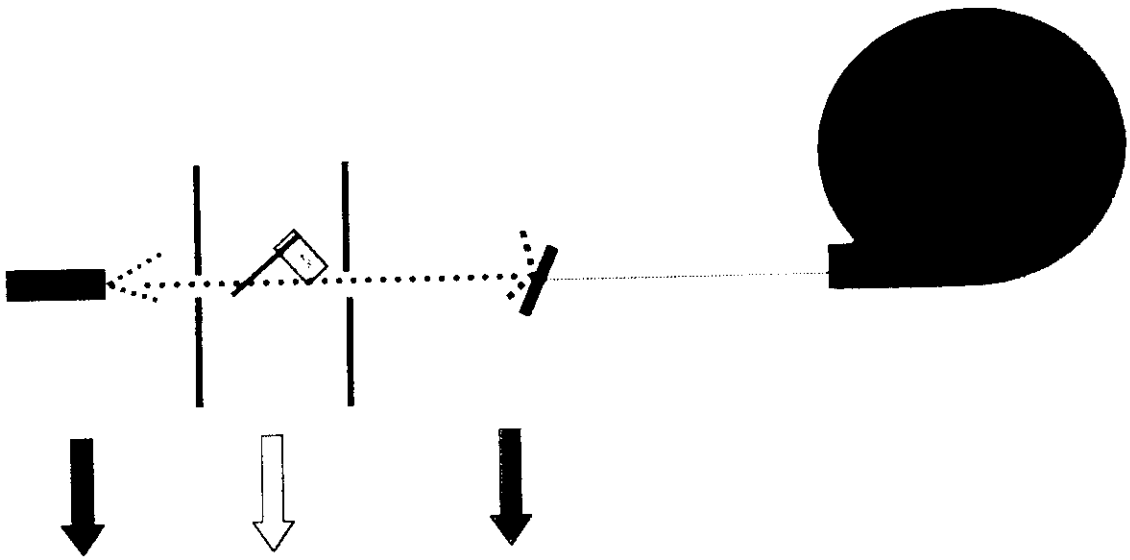

10^-3
10^-4
10^-5
T=300 K
EELS data
E=800 meV
E=390 meV
E=93 meV
0
400
800
Normal energy (meV)

Sticking

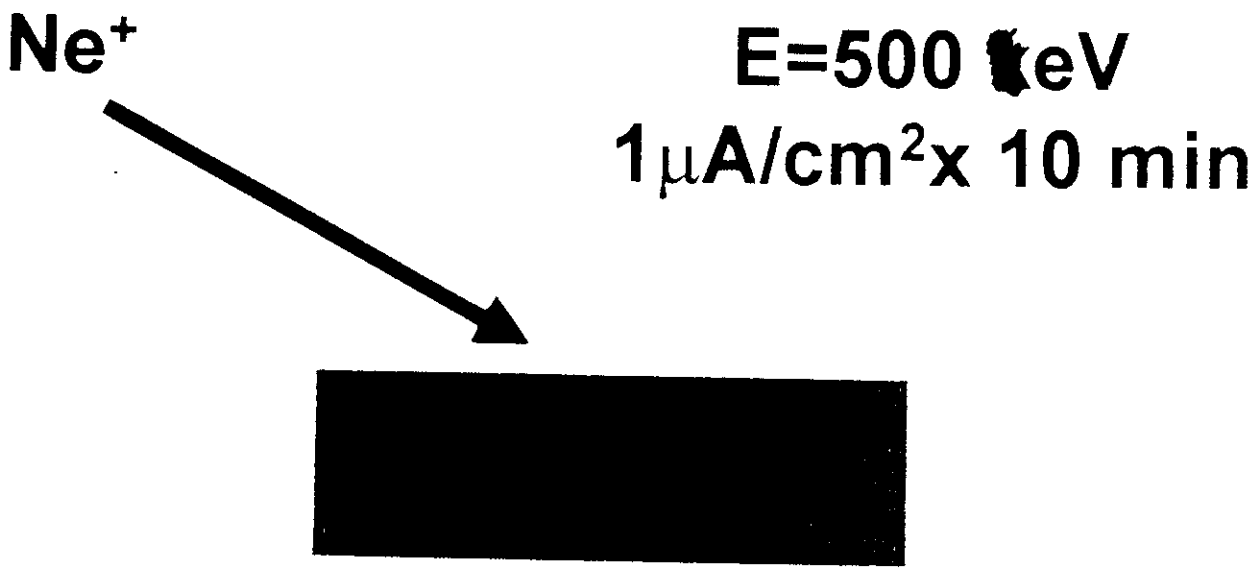


$$S_0 = \left.\frac{d\Theta}{d\chi}\right|_{\Theta=0}$$

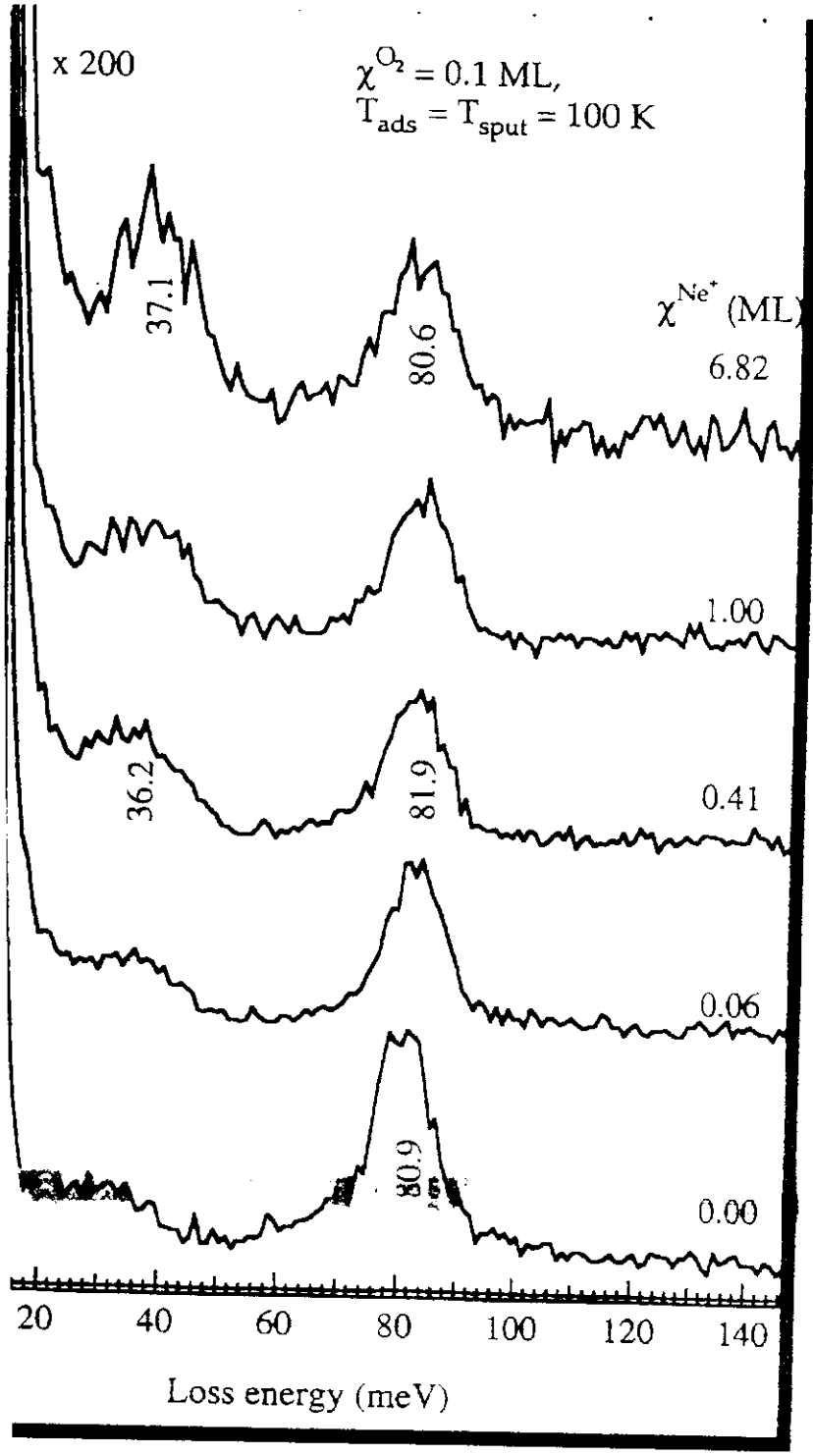
$\chi \longrightarrow$ Molecular beam



$$\chi = \Phi t A$$



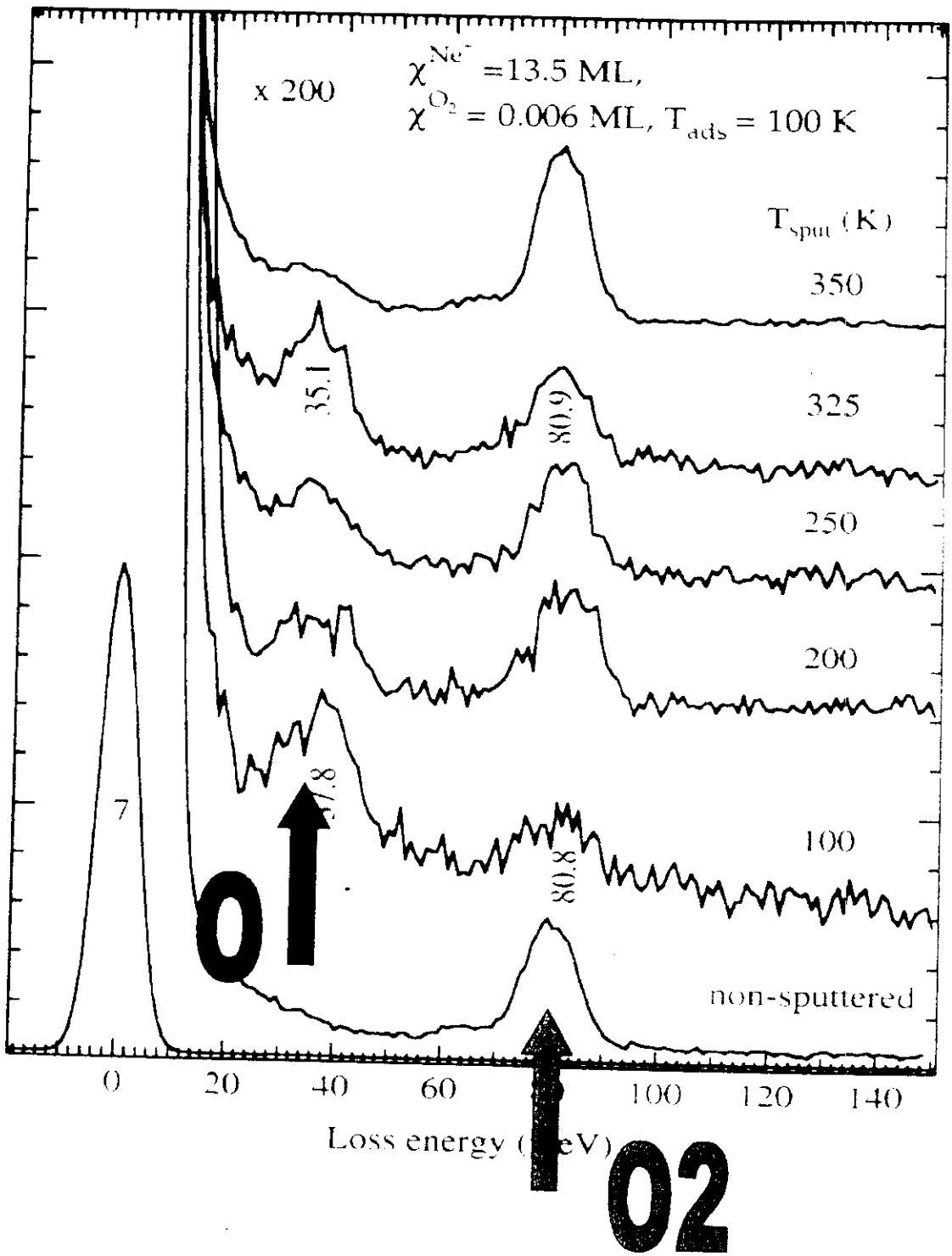
We observe a ten fold increase of dissociation probability compared to the case of the well annealed surface

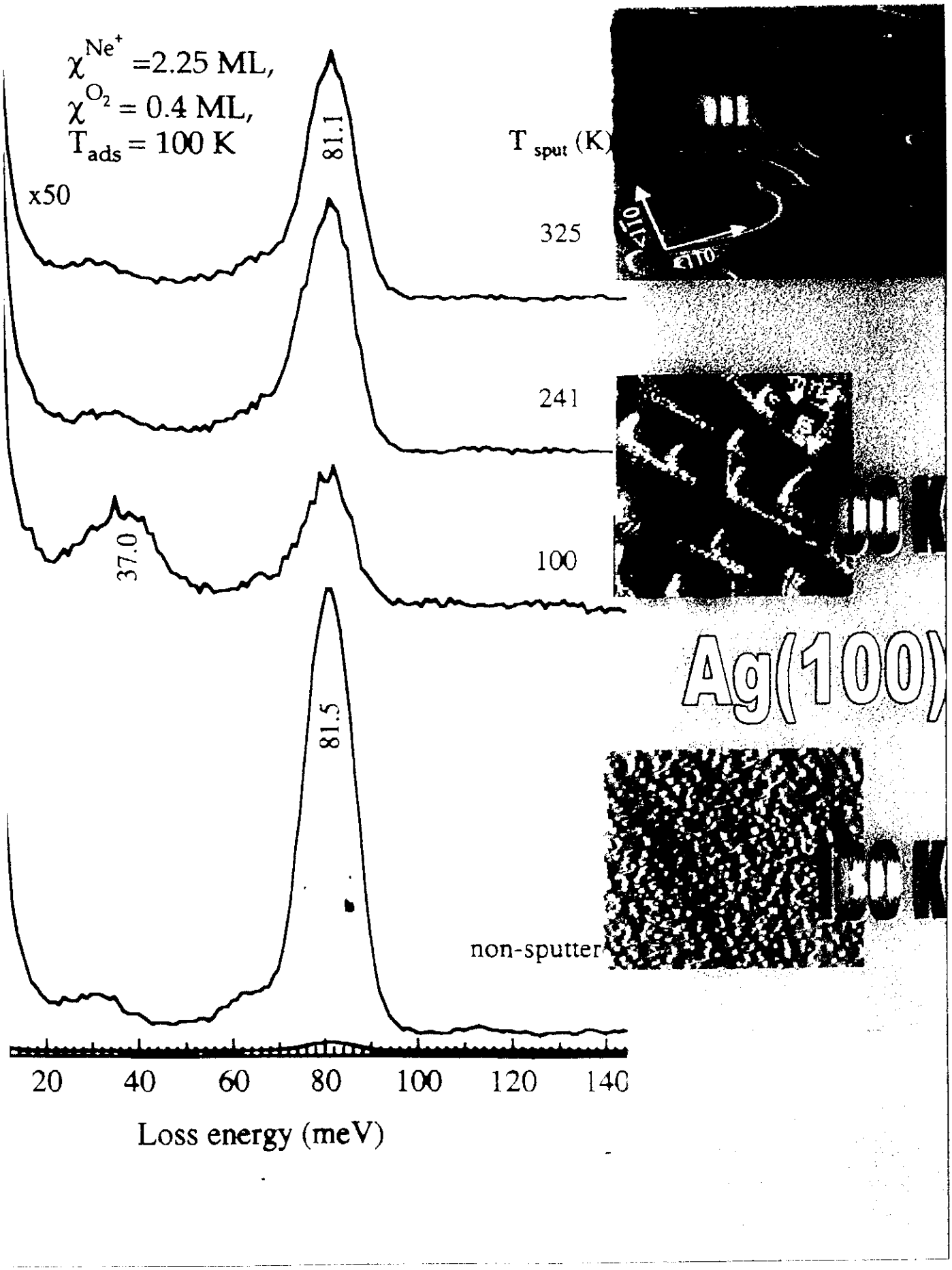


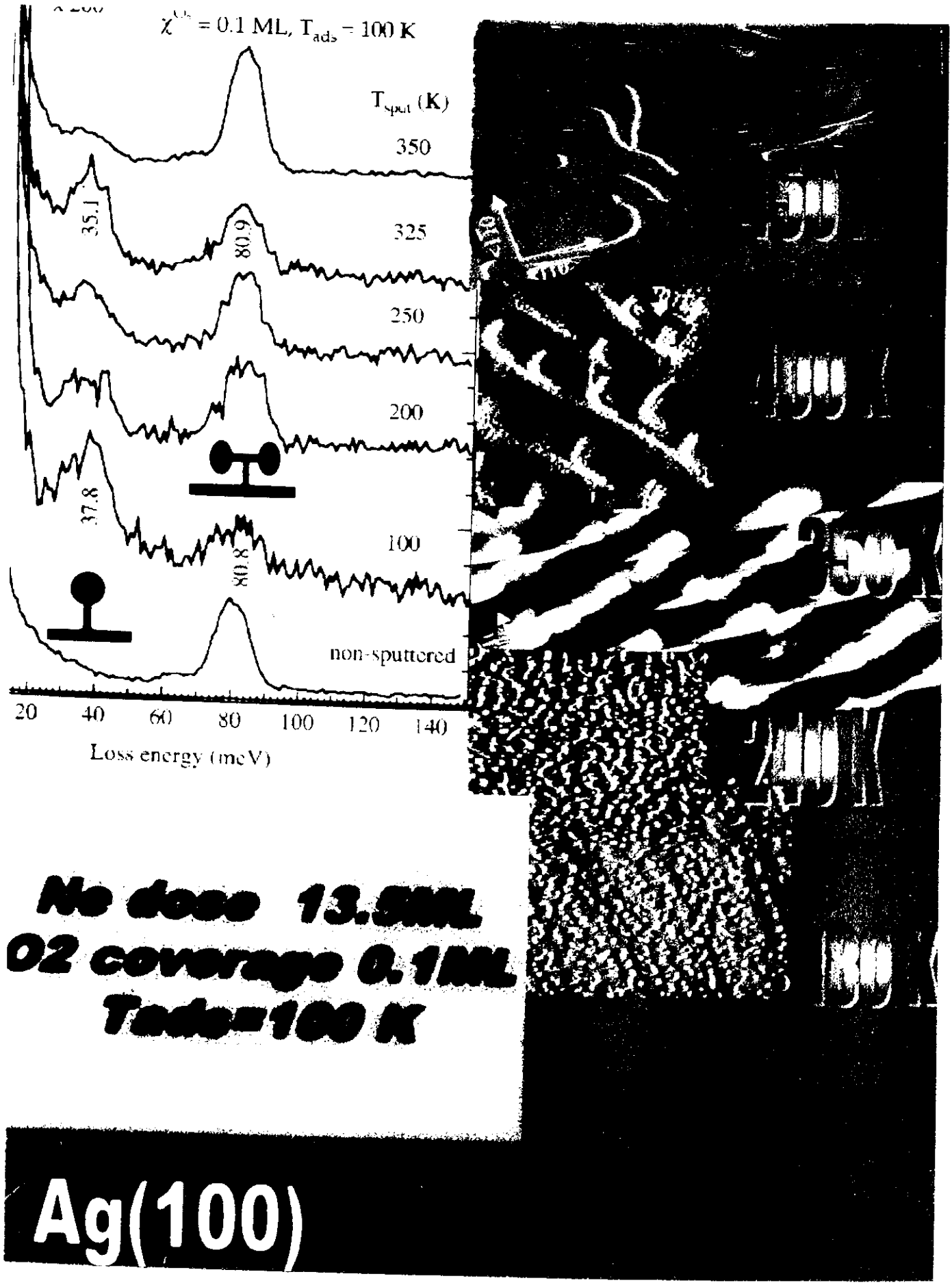
EELS spectra as function of the neon exposure

Ag(100)

Fig. 6B: Defect enhanced dissociation...
by M. Rocca, et al., submitted to ???




χ^{Ne^+} =2.25 ML,
χ^{O_2} = 0.4 ML,
T_{ads} = 100 K
x50
81.1
37.0
81.5
T_{sput} (K)
325
241
100
non-sputter
Ag(100)
<110>
<1$\bar{1}$0>
20
40
60
80
100
120
140
Loss energy (meV)

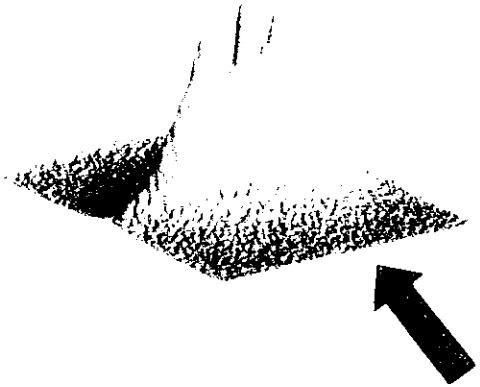

χ^{O_2} = 0.1 ML, T_{ads} = 100 K
T_{spt} (K)
350
325
250
200
100
non-sputtered
35.1
80.9
37.8
80.8
20
40
60
80
100
120
140
Loss energy (meV)
No dose 13.5ML
O2 coverage 0.1ML
Tads=100 K
Ag(100)

LEED

Ag(001)

T=180K

θ=70°

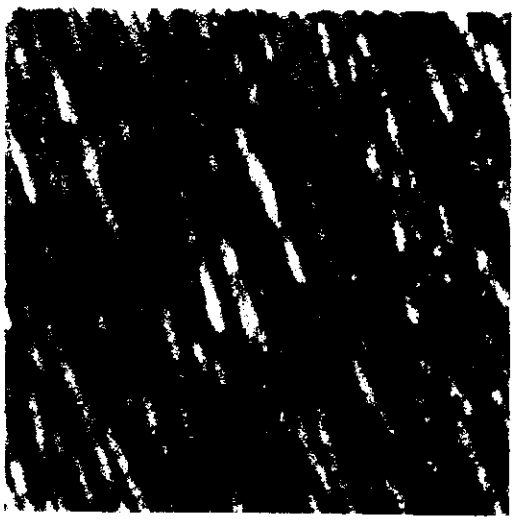


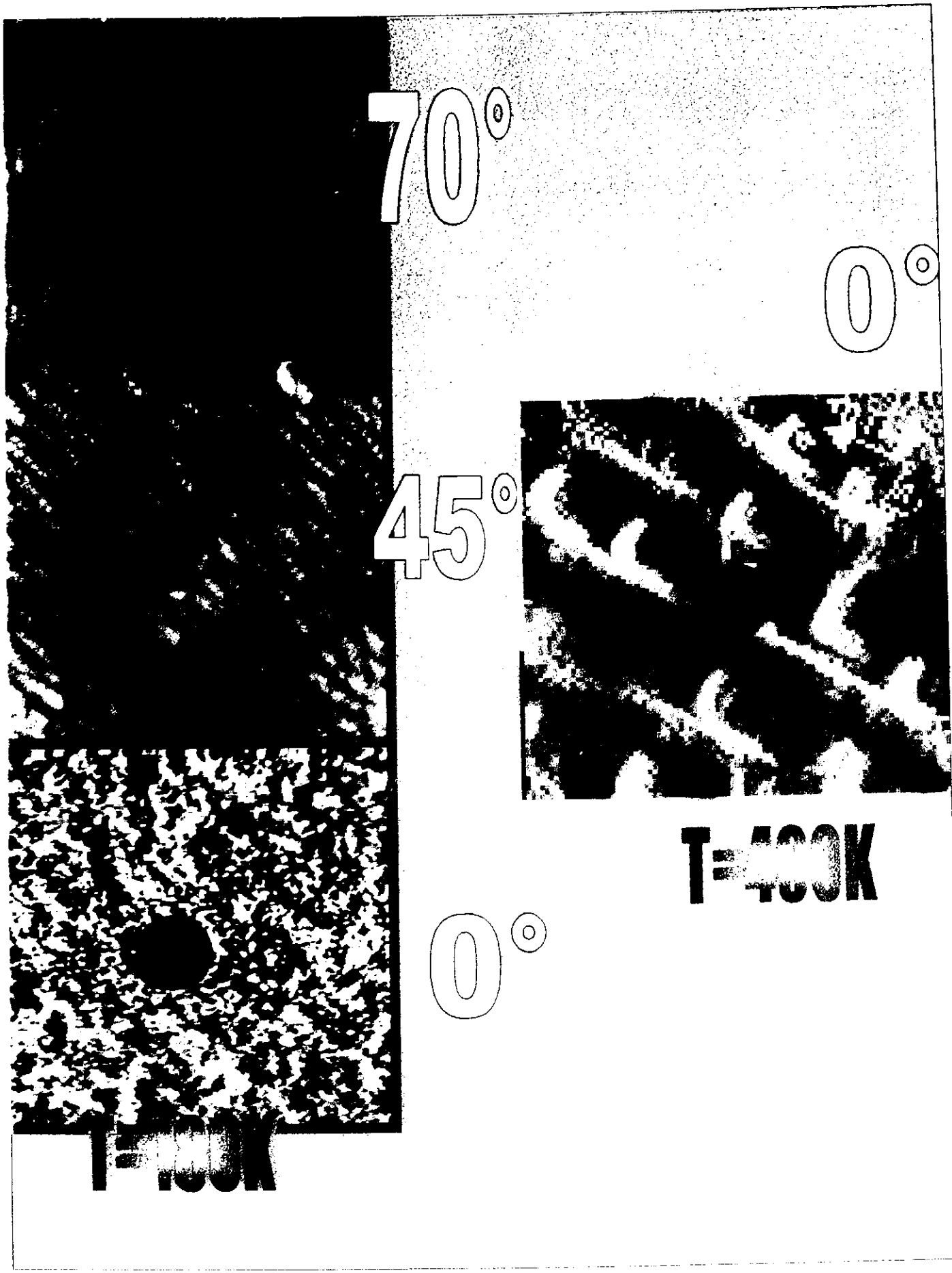
STM

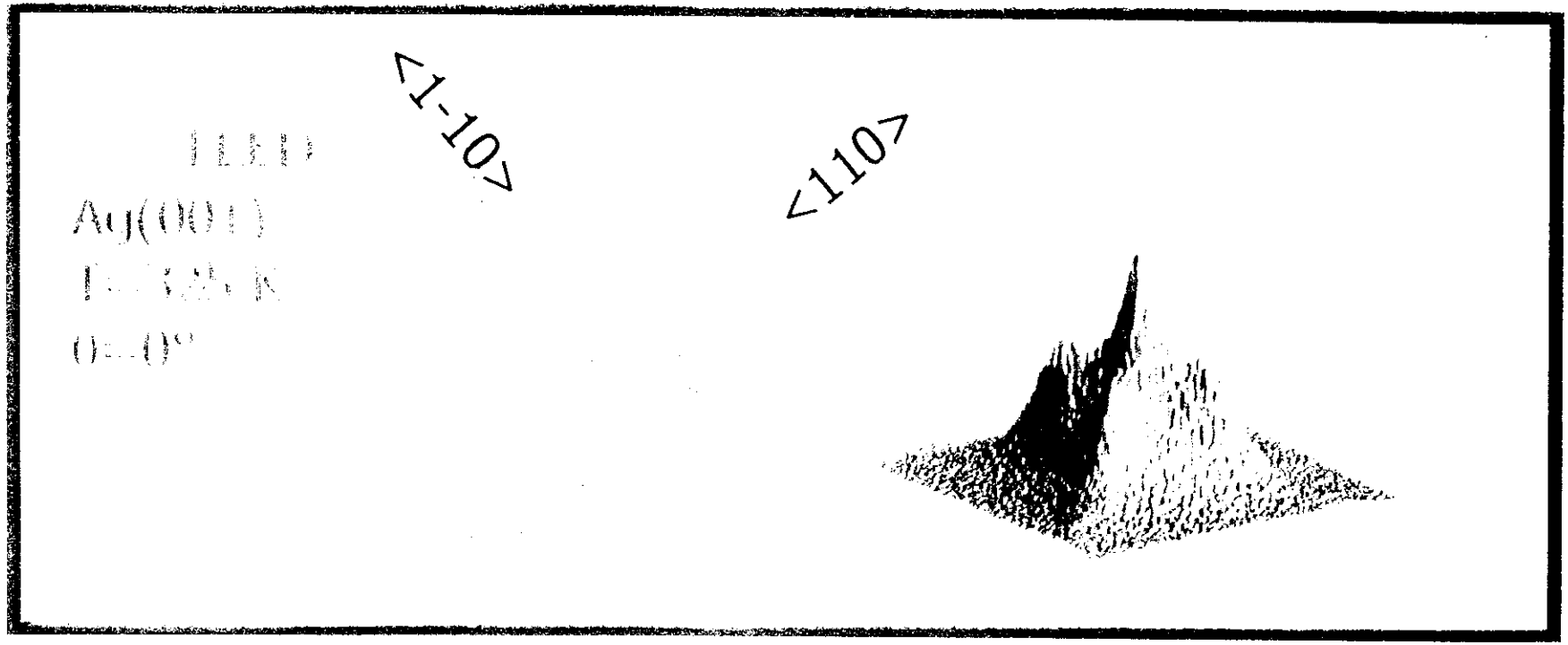
Ag(001)

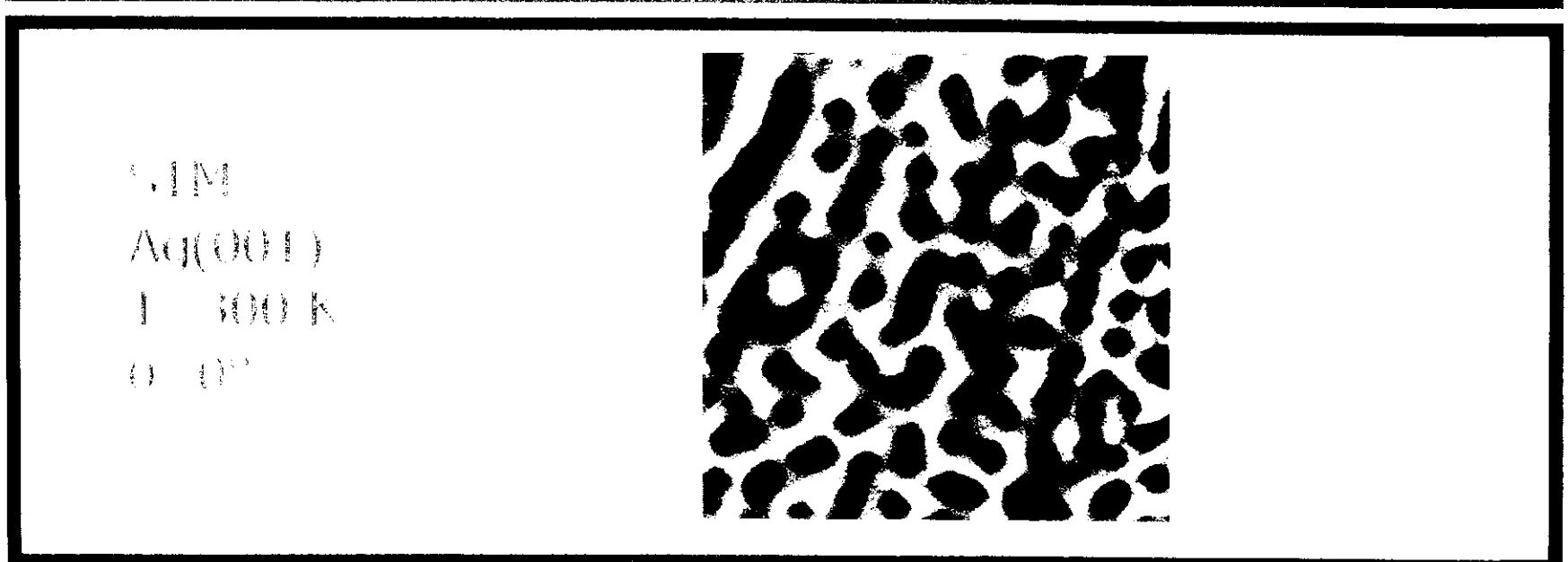
T=180K

θ=70°




70°
0°
45°
T=400K
0°
T=400K


<1-10>
<110>
Ag(001)
T=325 K
θ=0°


STM
Ag(001)
T=300 K
θ=0°