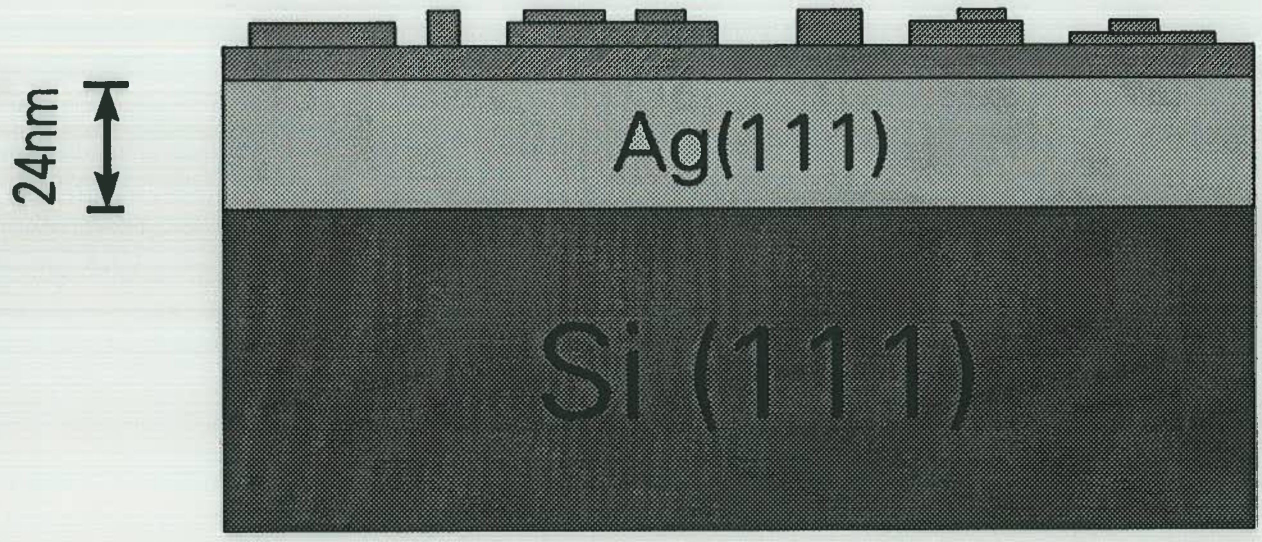
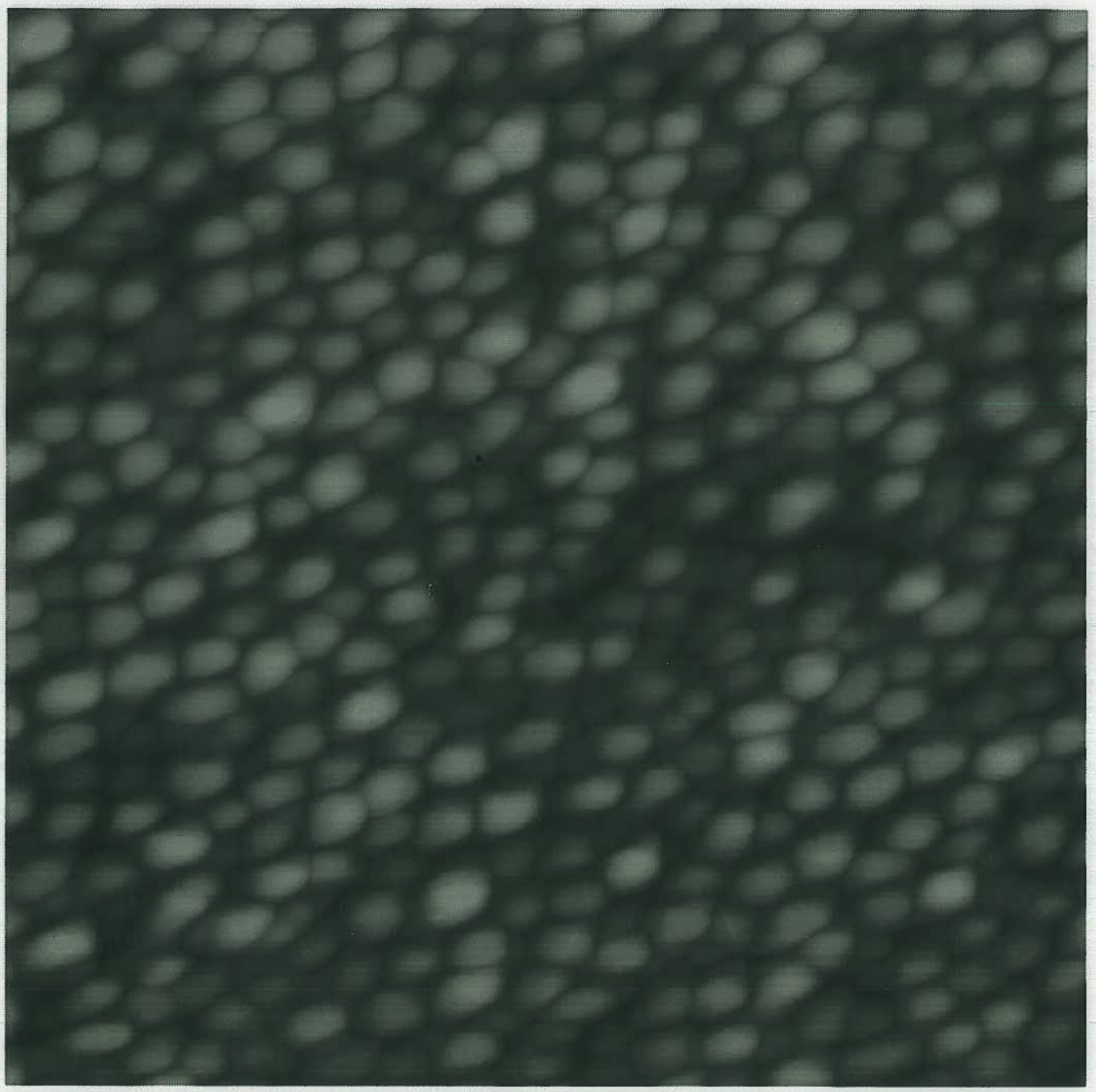
DC-conductivity and SPA-LEED measurements of the growth of Ag/Ag(111)/Si(111)



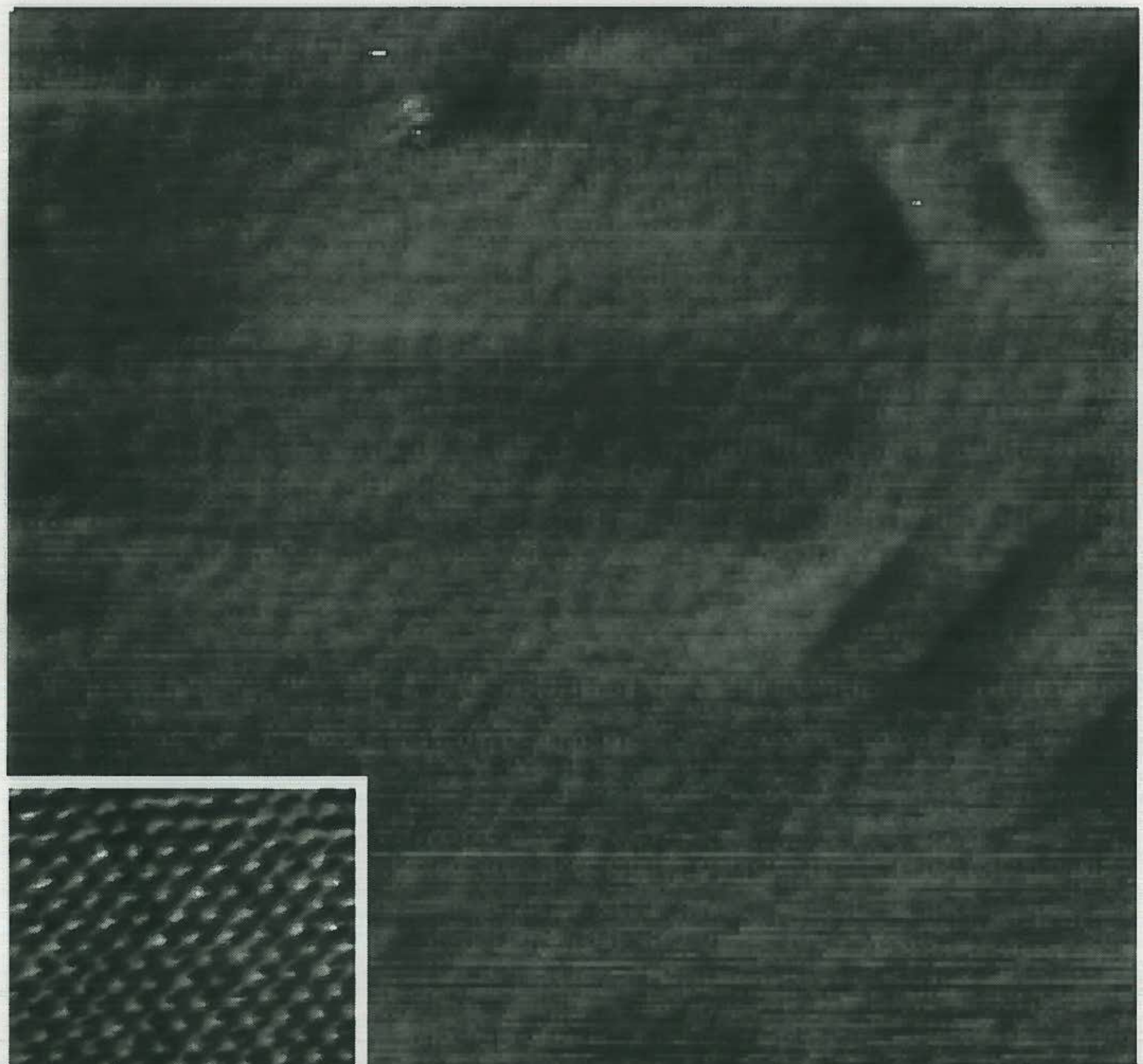
S. Heun, M. Kennedy
E. Luo, M. Henzler

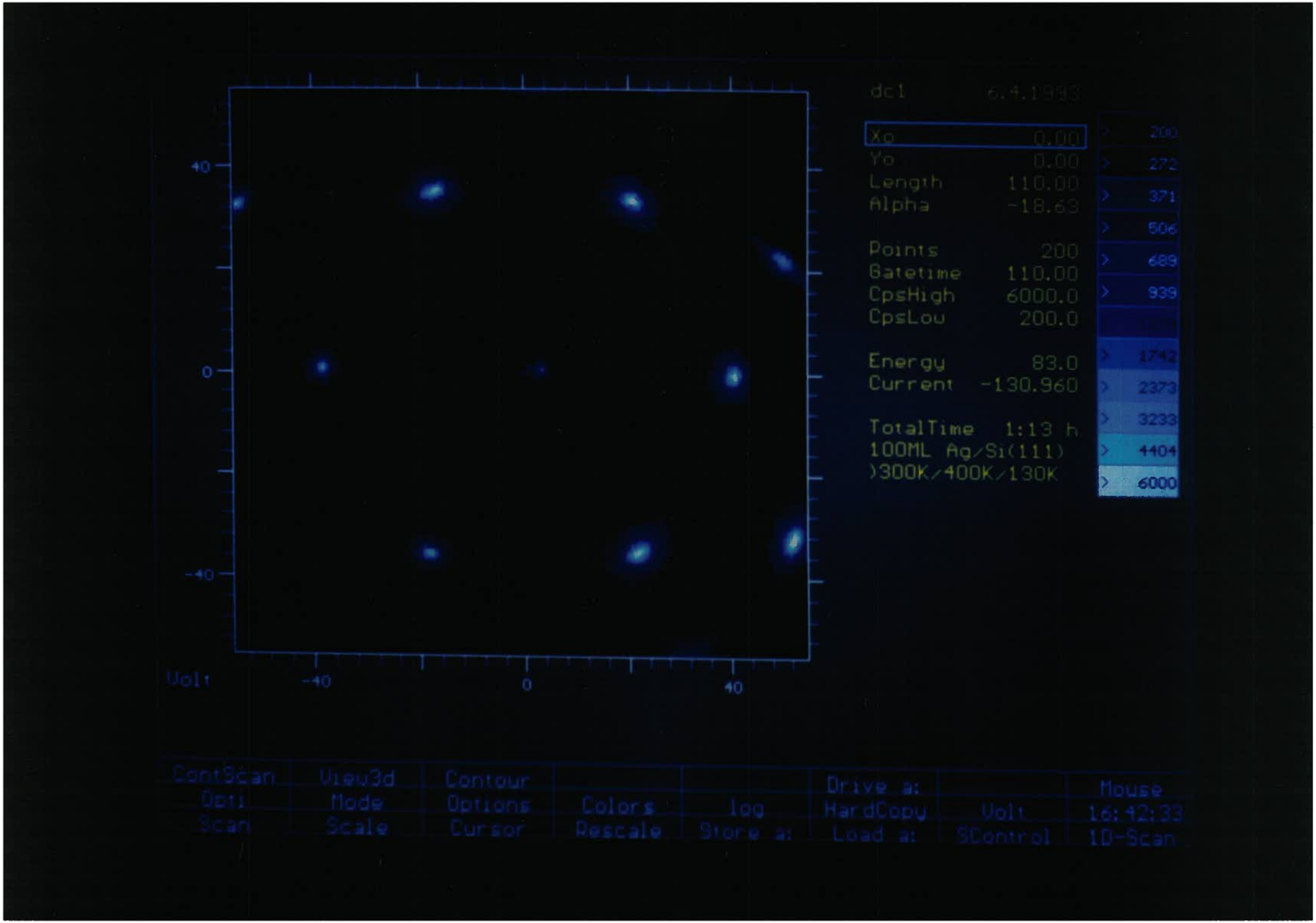
Inst. f. Festkörperphysik
Uni Hannover

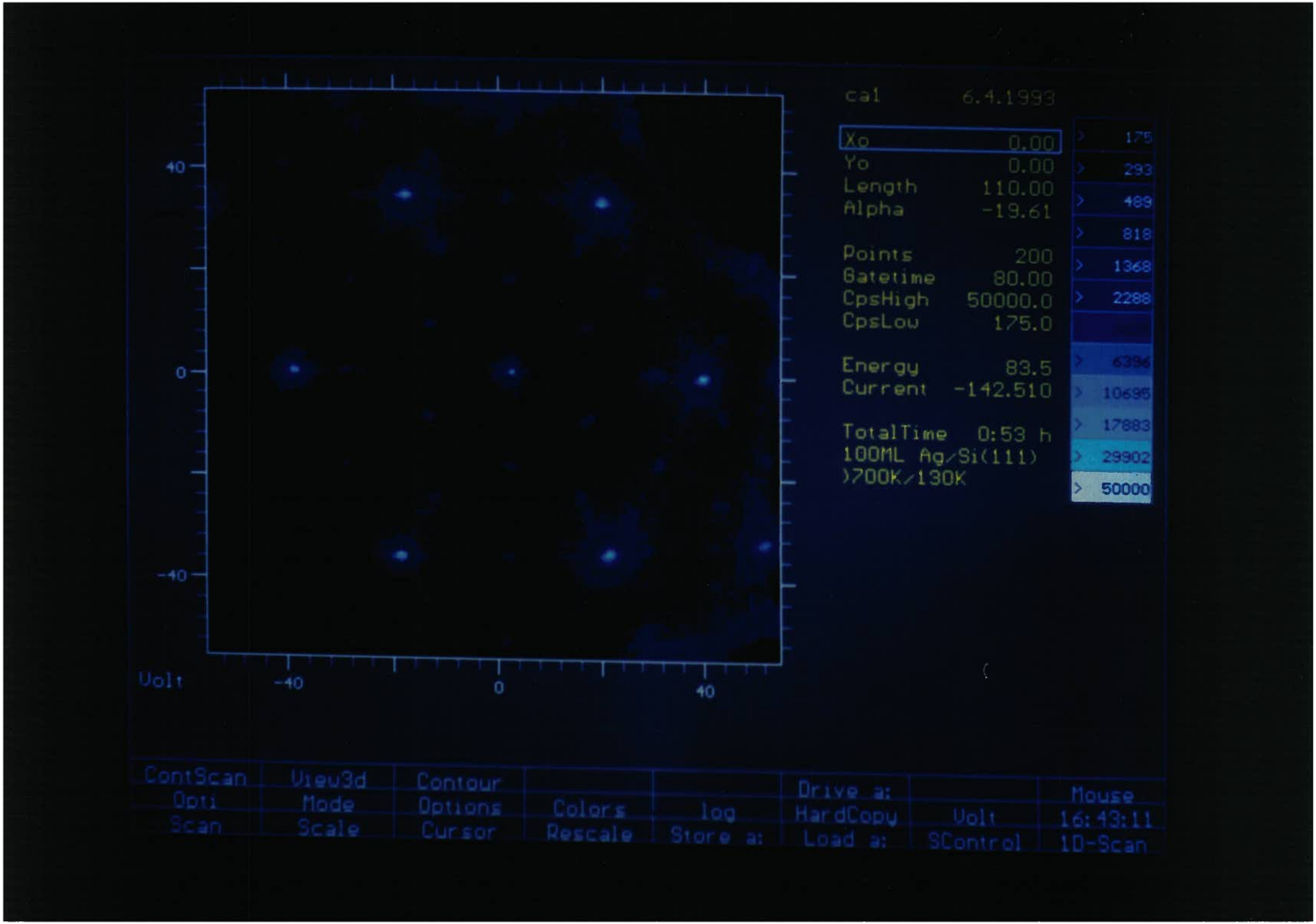
20 ML Ag / Si(111)-7x7 at 80K
920Å x 920Å



20 ML Ag / Si(111)-7x7 at 80K, annealed to 300K 460Å x 460Å



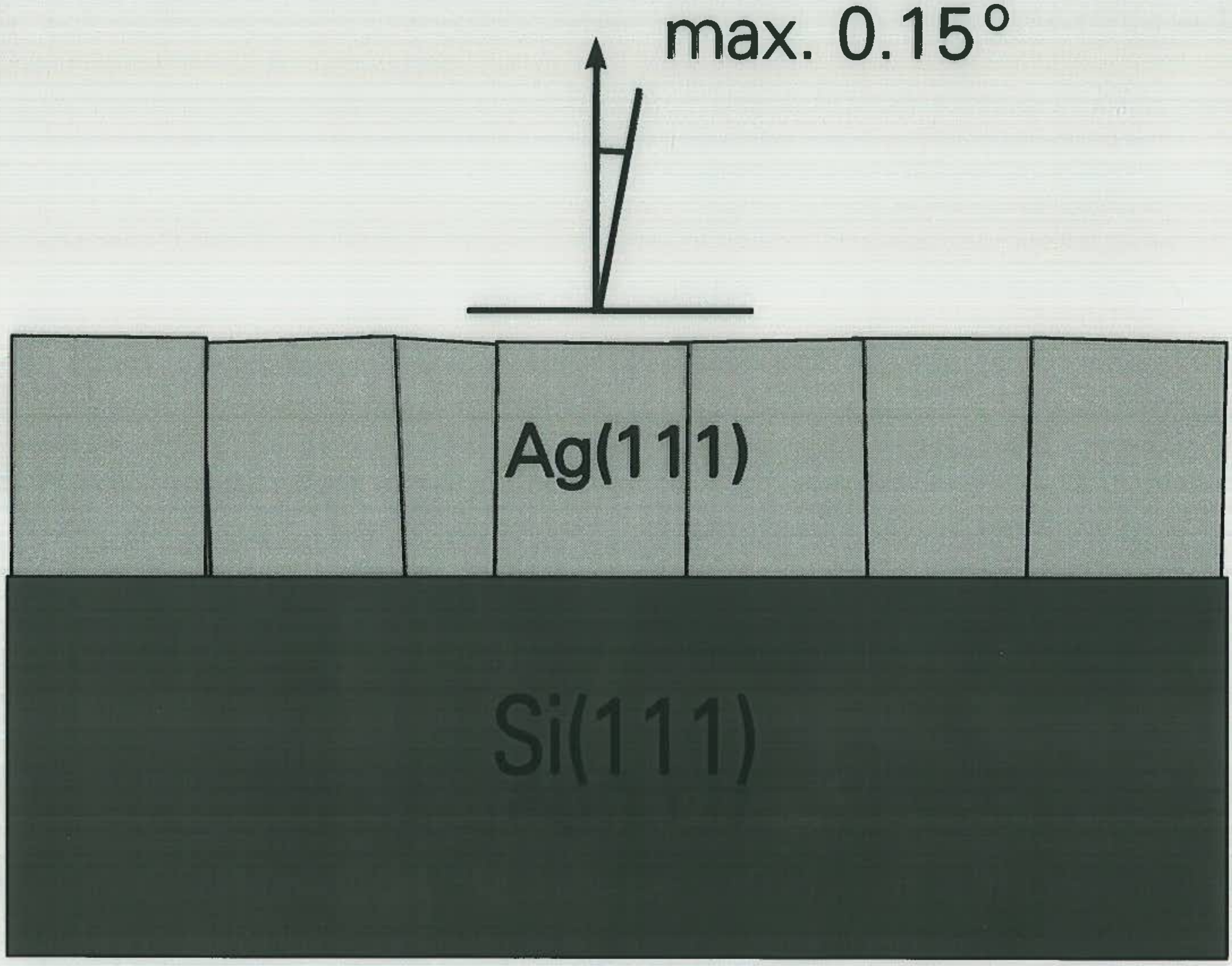

dc1 6.4.1993
Xo 0.00
Yo 0.00
Length 110.00
Alpha -18.63
Points 200
Gatetime 110.00
CpsHigh 6000.0
CpsLow 200.0
Energy 83.0
Current -130.960
TotalTime 1:13 h
100ML Ag/Si(111)
)300K/400K/130K
200
272
371
506
689
939
1742
2373
3233
4404
6000
40
0
-40
Volt
ContScan
View3d
Contour
Drive a:
Mouse
Opti
Mode
Options
Colors
log
HardCopy
Volt
16:42:33
Scan
Scale
Cursor
Rescale
Store a:
Load a:
SControl
1D-Scan


cal 6.4.1993
Xo 0.00
Yo 0.00
Length 110.00
Alpha -19.61
Points 200
Gatetime 80.00
CpsHigh 50000.0
CpsLow 175.0
Energy 83.5
Current -142.510
TotalTime 0:53 h
100ML Ag/Si(111)
)700K/130K
175
293
489
818
1368
2288
6336
10695
17883
29902
50000
40
0
-40
Volt
-40
0
40
ContScan
Opti
Scan
View3d
Mode
Scale
Contour
Options
Cursor
Colors
Rescale
log
Store a:
Drive a:
HardCopy
Load a:
Volt
SControl
Mouse
16:43:11
1D-Scan

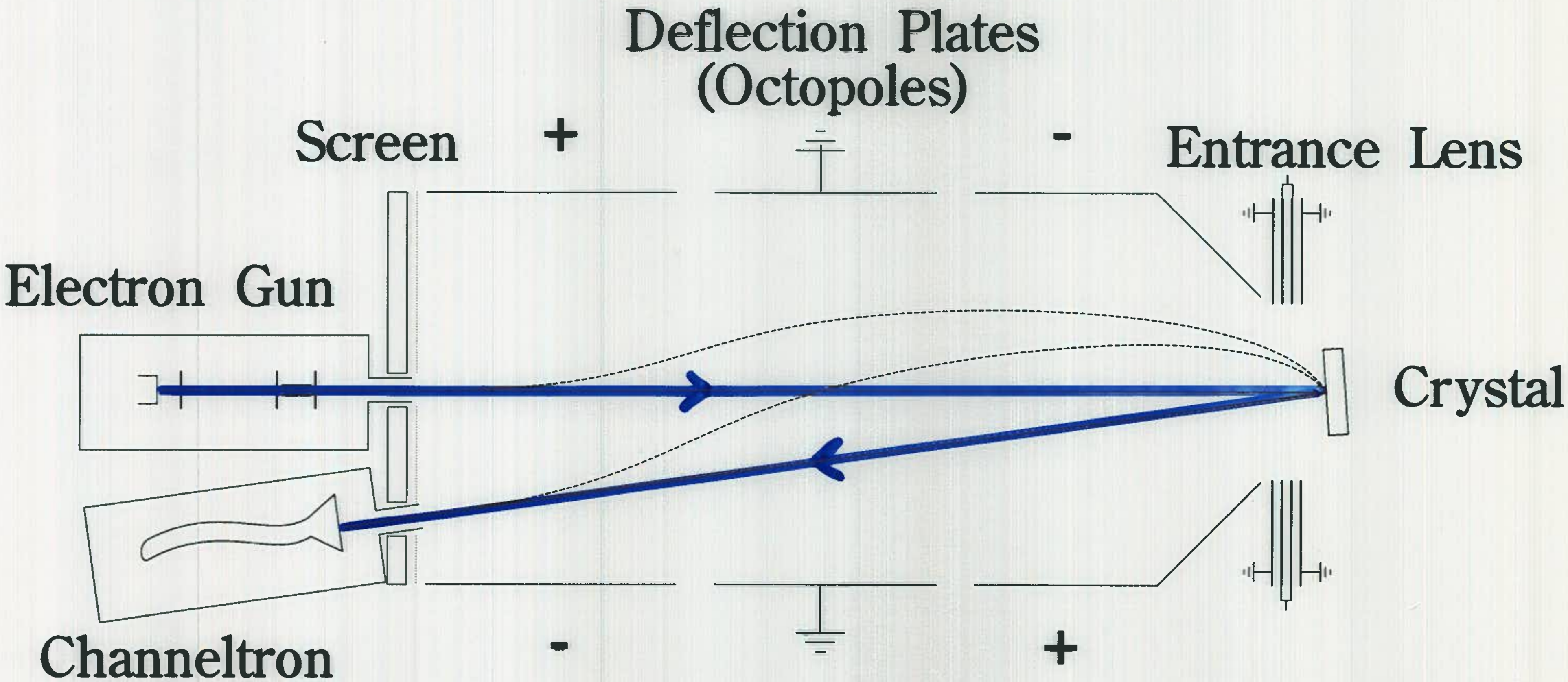
100 ML Ag / Si (111)

90 K / 500 K

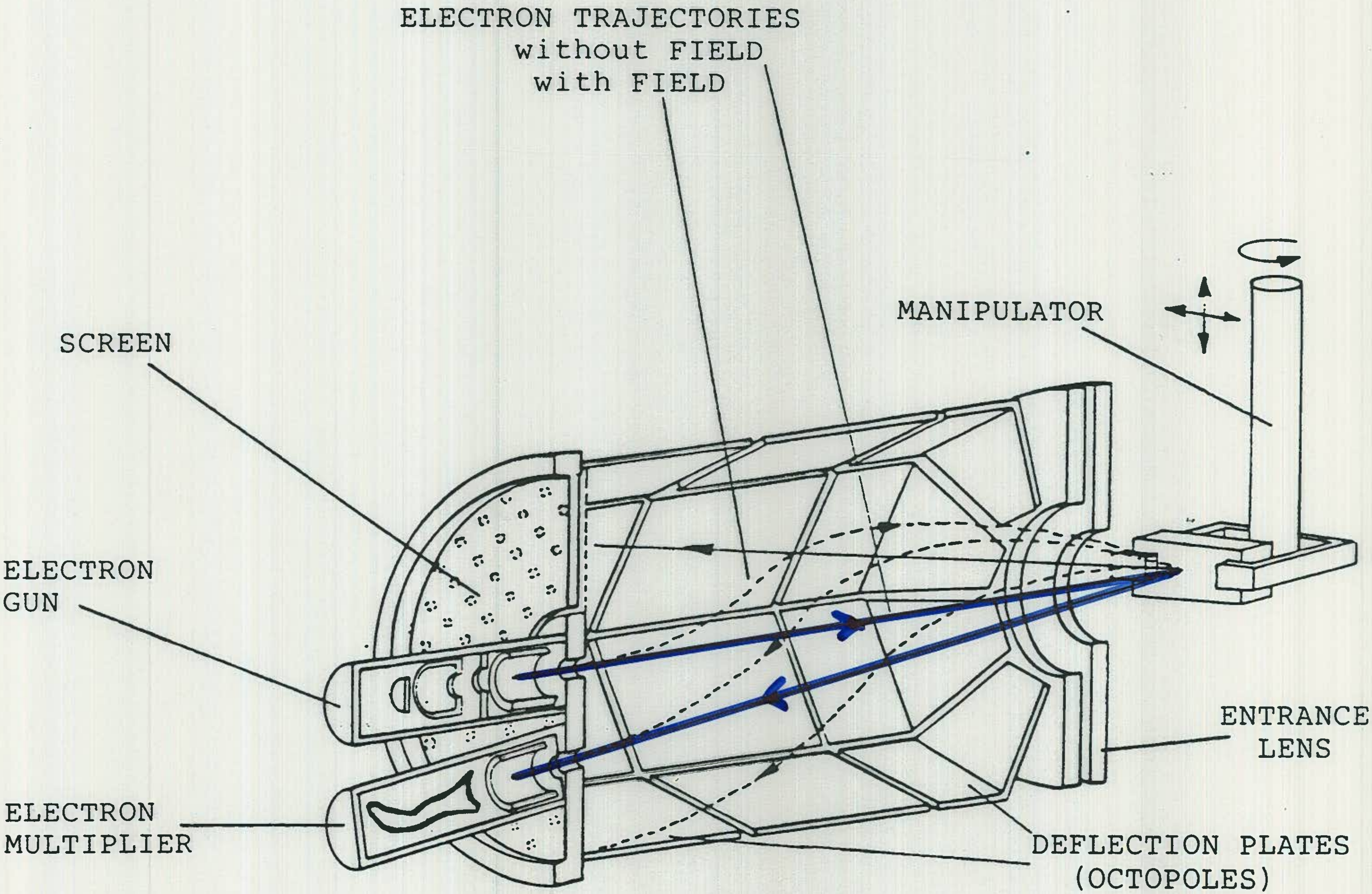
At room temperature silver forms continuous, flat, epitaxial films with small mosaic spread (max. 0.15°) due to steps on the Si(111) substrate



SPA-LEED-Optics



SPA-LEED Optics



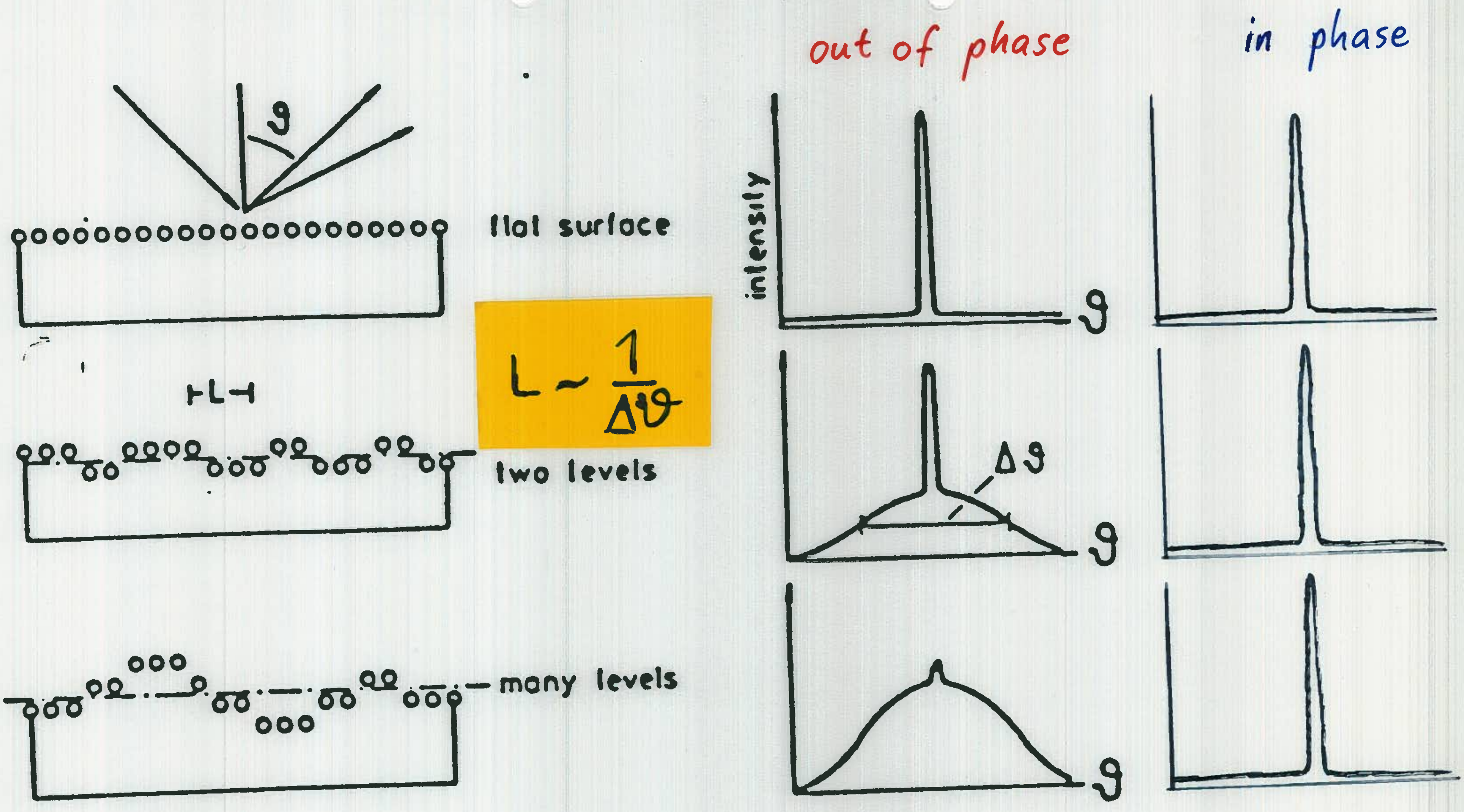
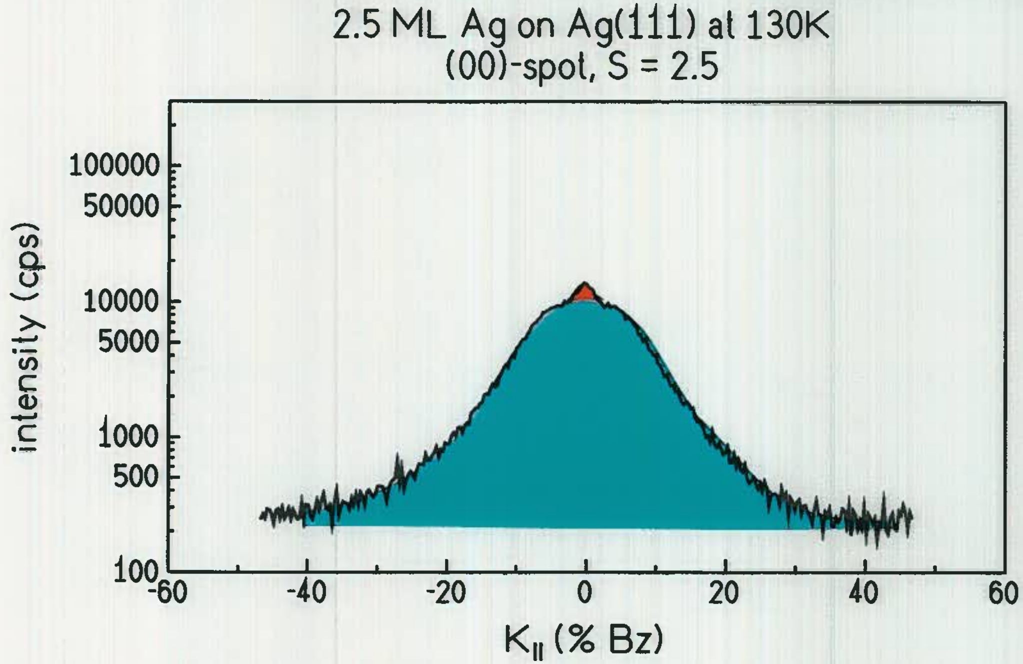
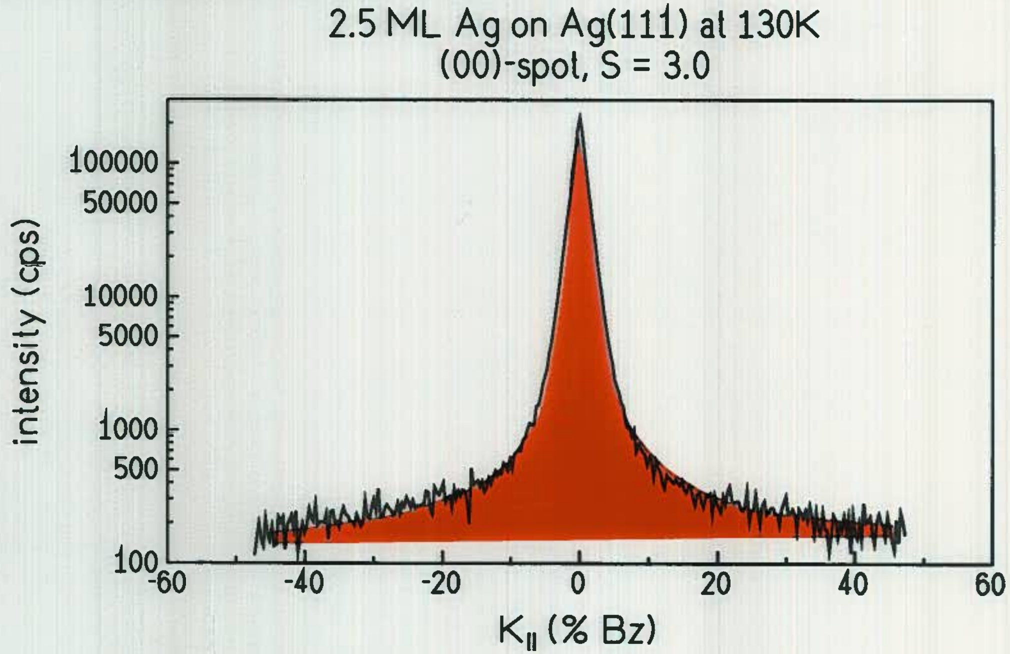


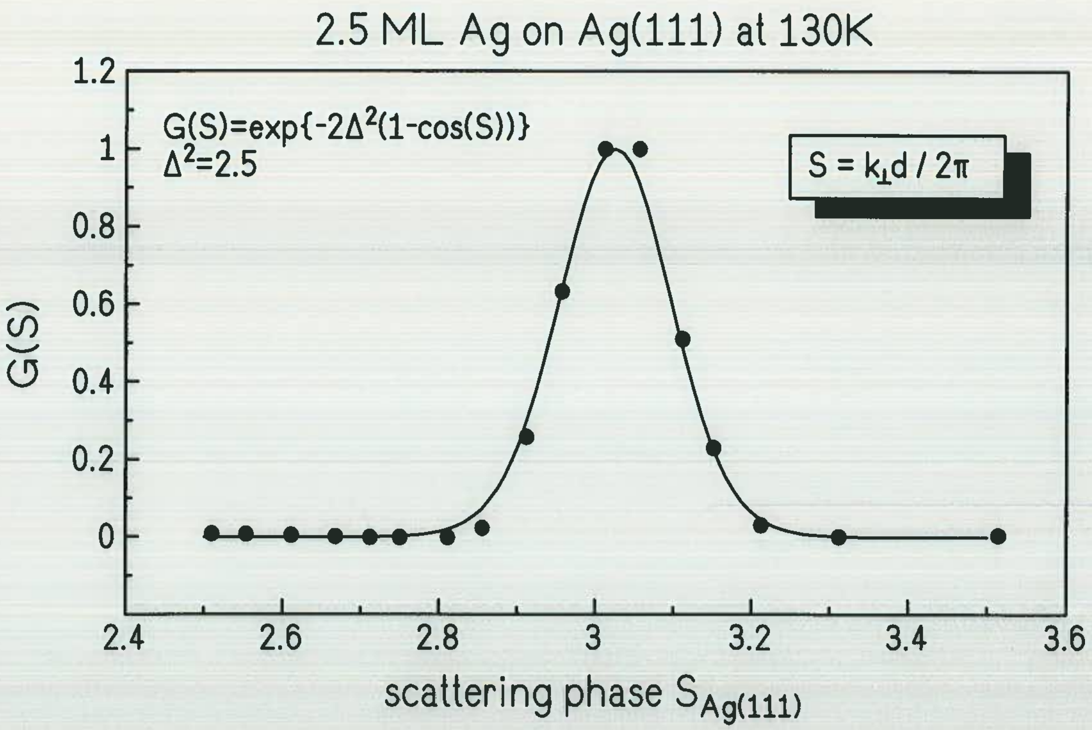
Fig. 1: Observed spot profile (central spike and shoulder for a flat and stepped surface within two and with many levels

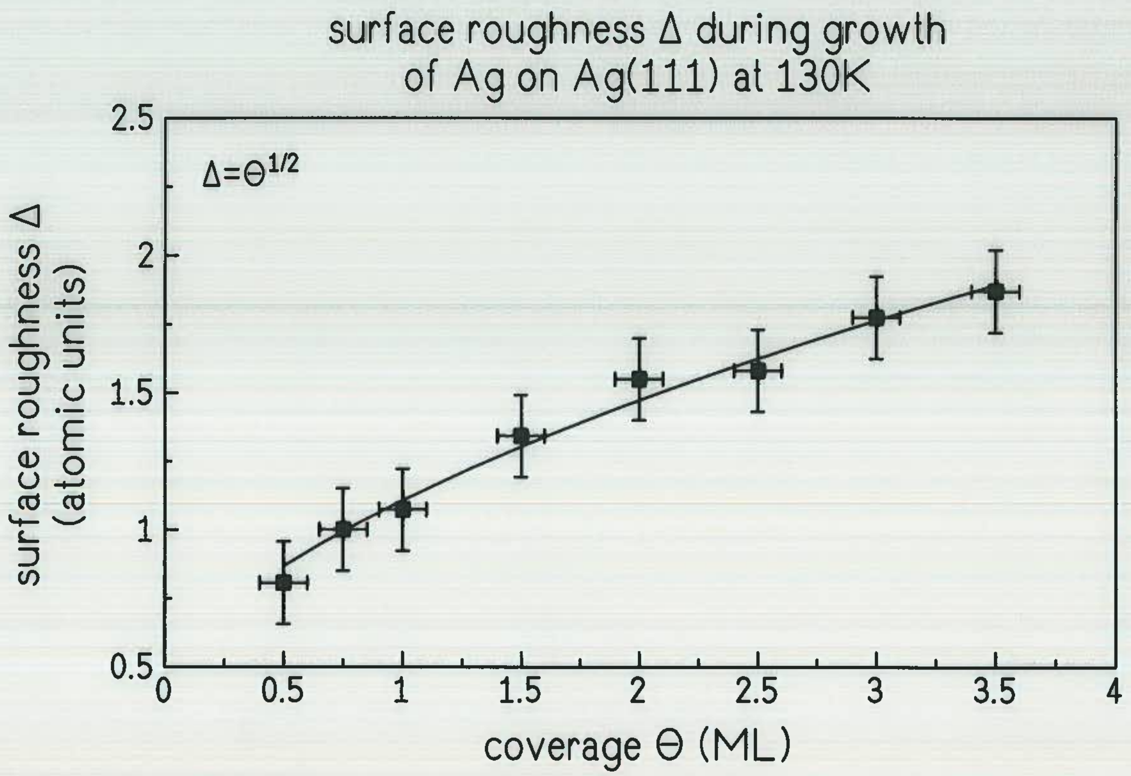
determination of surface roughness





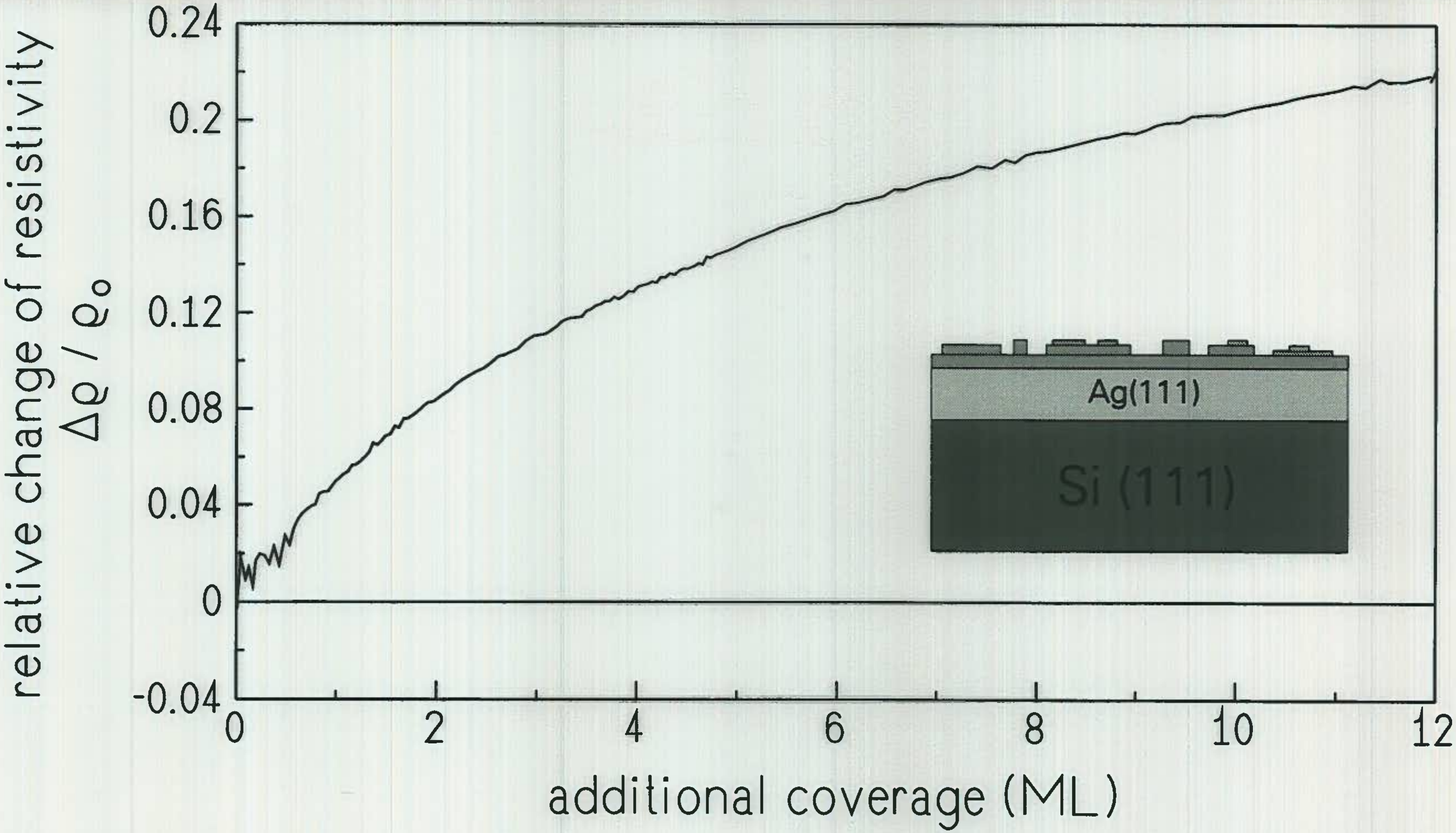
$$G(S) = \frac{I_{Peak}}{I_{Peak} + I_{Shoulder}}$$

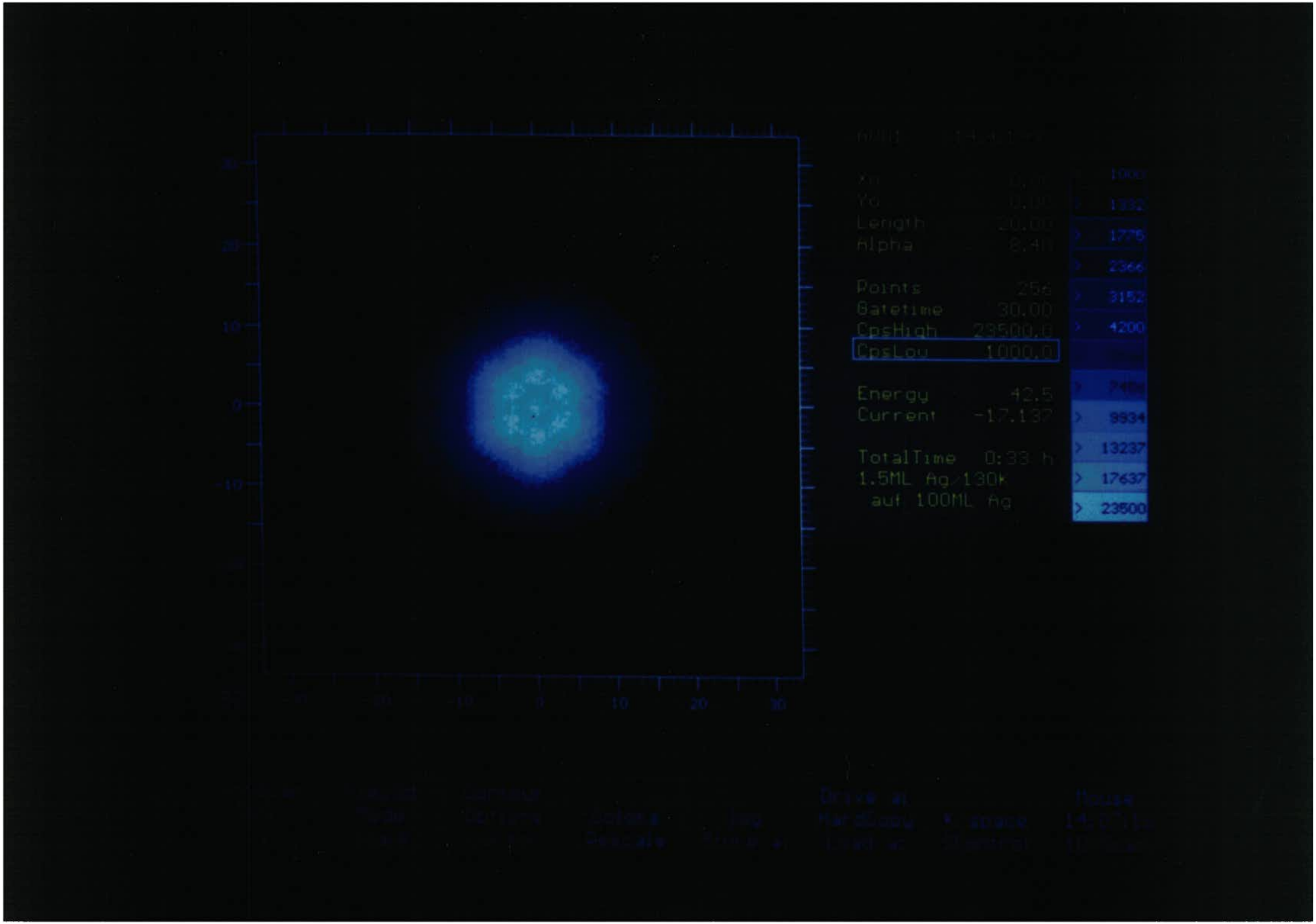




--> statistical growth at 130K

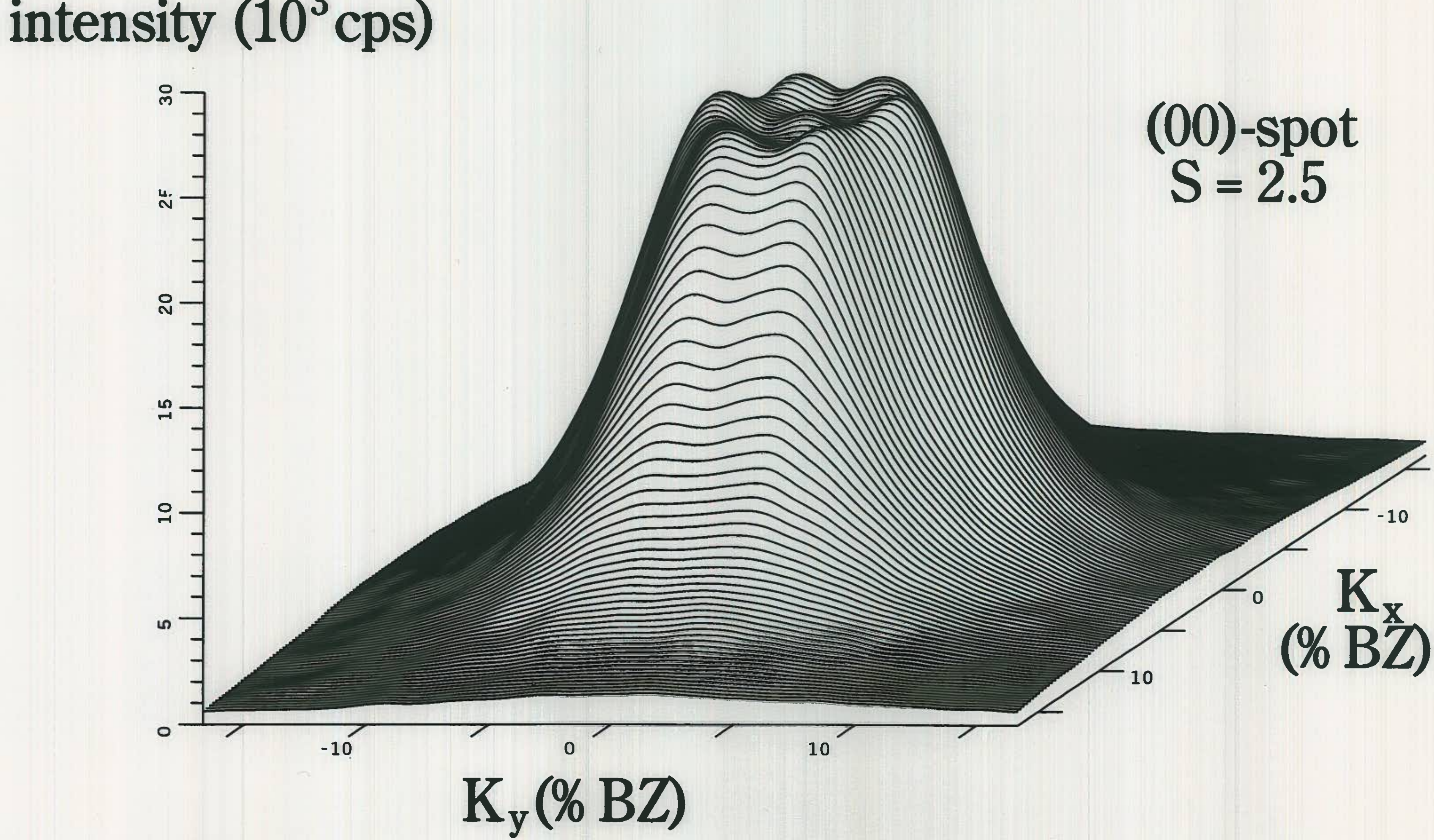
increase of resistivity due to surface roughness scattering by additional deposition of Ag on Ag(111) at low temperature (130K)





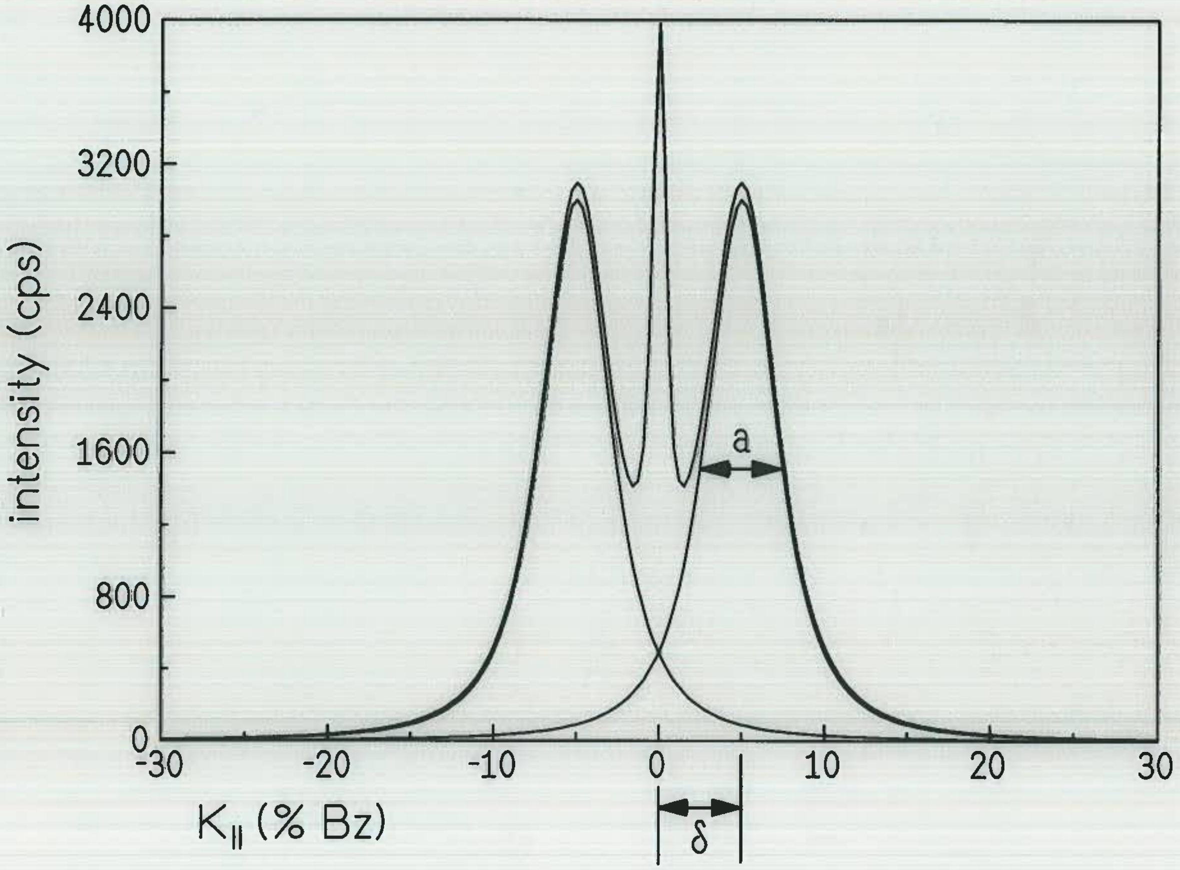
Length 20.00
Points 256
Gatetime 30.00
CpsHigh 23500.0
CpsLow 1000.0
Energy 42.5
Current -17.137
TotalTime 0:33 h
1.5ML Ag/130k
auf 100ML Ag
1000
1332
1776
2366
3152
4200
9934
13237
17637
23500

1.5 ML Ag on Ag(111) at 130K



Wollschläger's model

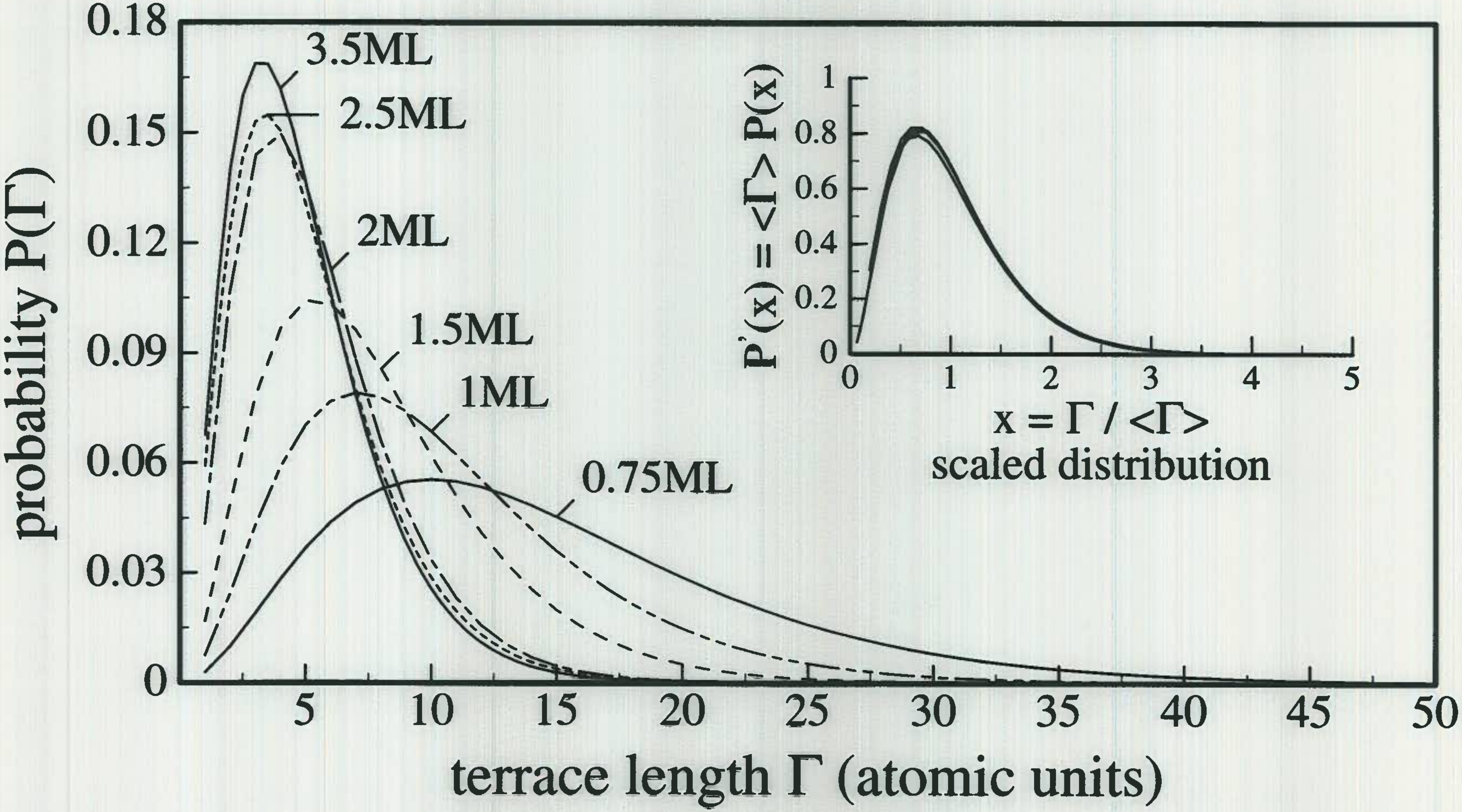
for a stepped surface and
for the out-of-phase condition:



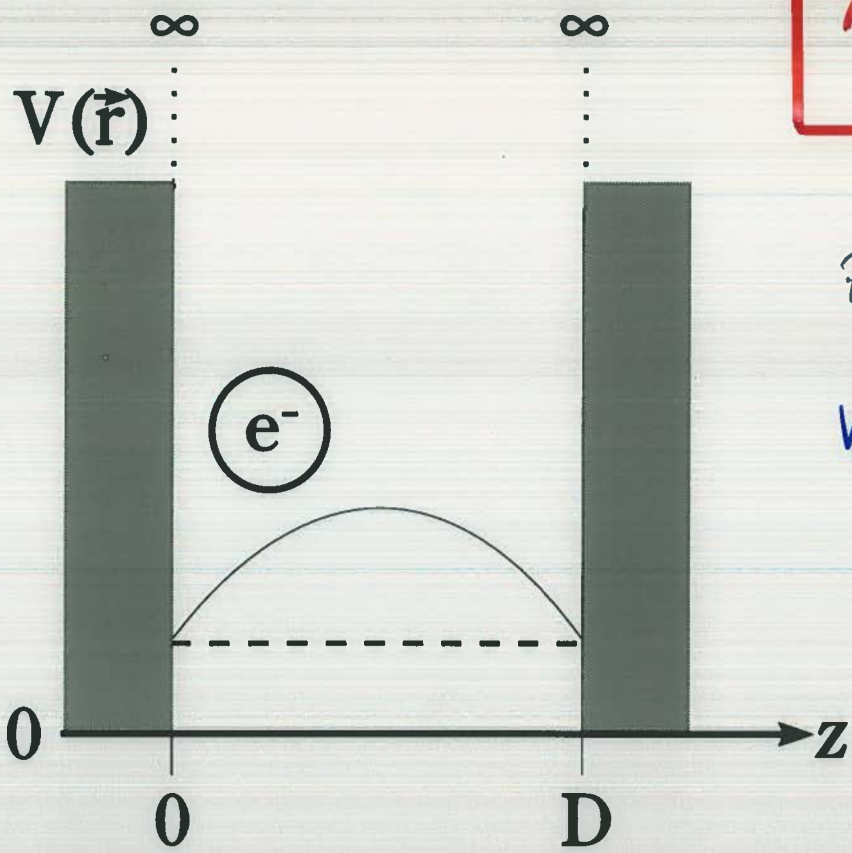
from a, δ follows

Γ	(average terrace length)
σ	(standard deviation of Γ)

terrace length distribution for different coverages
Ag on Ag(111) at 130K

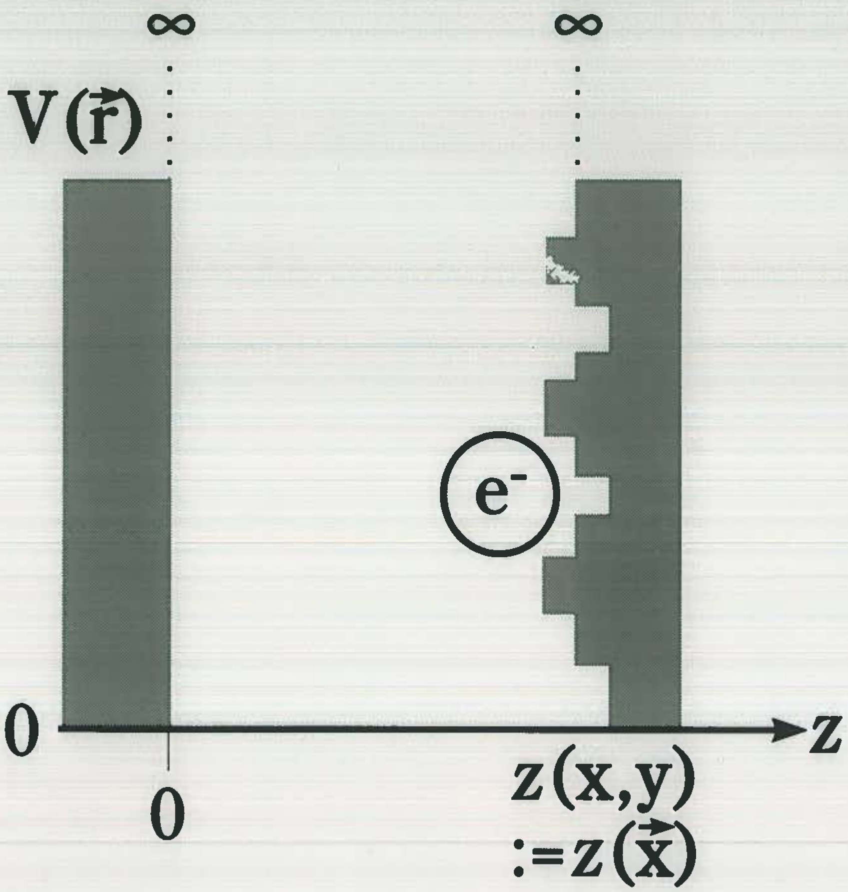


Teilchen im Kasten



Potential

$$V_0(\vec{r}) = \begin{cases} 0 & \text{für } 0 \le z \le D \\ \infty & \text{sonst} \end{cases}$$



Potential

$$V(\vec{r}) = V_0(\vec{r}) + V' z(\vec{x})$$

$\rightarrow$ $H = H_0 + H'$ mit $H_0 = -\frac{\hbar^2}{2m}\vec{\nabla}^2 + V_0(\vec{r})$

und $H' = V' z(\vec{x})$

Modell freier Elektronen:

$$\langle \vec{x} | \vec{k} \rangle \propto e^{i\vec{k}\cdot\vec{x}}$$

Übergangsmatrixelement:

$$M_{\vec{k},\vec{k}'} \propto \langle \vec{k} | H' | \vec{k}' \rangle$$

$$\propto V' \int d^2x \; z(\vec{x})\, e^{i(\vec{k}-\vec{k}')\cdot\vec{x}}$$

Verweildauer im Zustand $|\vec{k}\rangle$:

$$\tau^{-1}_{\vec{k},\vec{k}'} \propto |\langle \vec{k} | H' | \vec{k}' \rangle|^2$$

$$\propto |V'|^2 \int d^2x \; f(\vec{x})\, e^{i\vec{Q}\cdot\vec{x}}$$

mit $\vec{Q} = \vec{k} - \vec{k}'$

und $f(\vec{x}) = \int d^2x' \; z(\vec{x}')\, z(\vec{x}' + \vec{x})$

$$:= \Delta^2 \exp\{-x/\xi\}$$

integriere über Fermikugel $\rightarrow \tau^{-1}$

$$\rho \propto \tau^{-1} \sim (\Delta \xi)^2 \, F(\xi)$$

Theoretische Ansätze

① Fuchs / Sondheimer

② Leung

Gerlach / Kaser

$$\Delta\rho \propto \Delta^2 \xi^2 F(k_F \xi) \xrightarrow{k_F \xi \gg 1} \Delta^2/\xi$$

mit Korrelationslänge ξ aus Autokorrelation

$$a(\rho) = \langle H(\rho+\rho')\, H(\rho') \rangle =: \Delta^2 e^{-\rho/\xi}$$

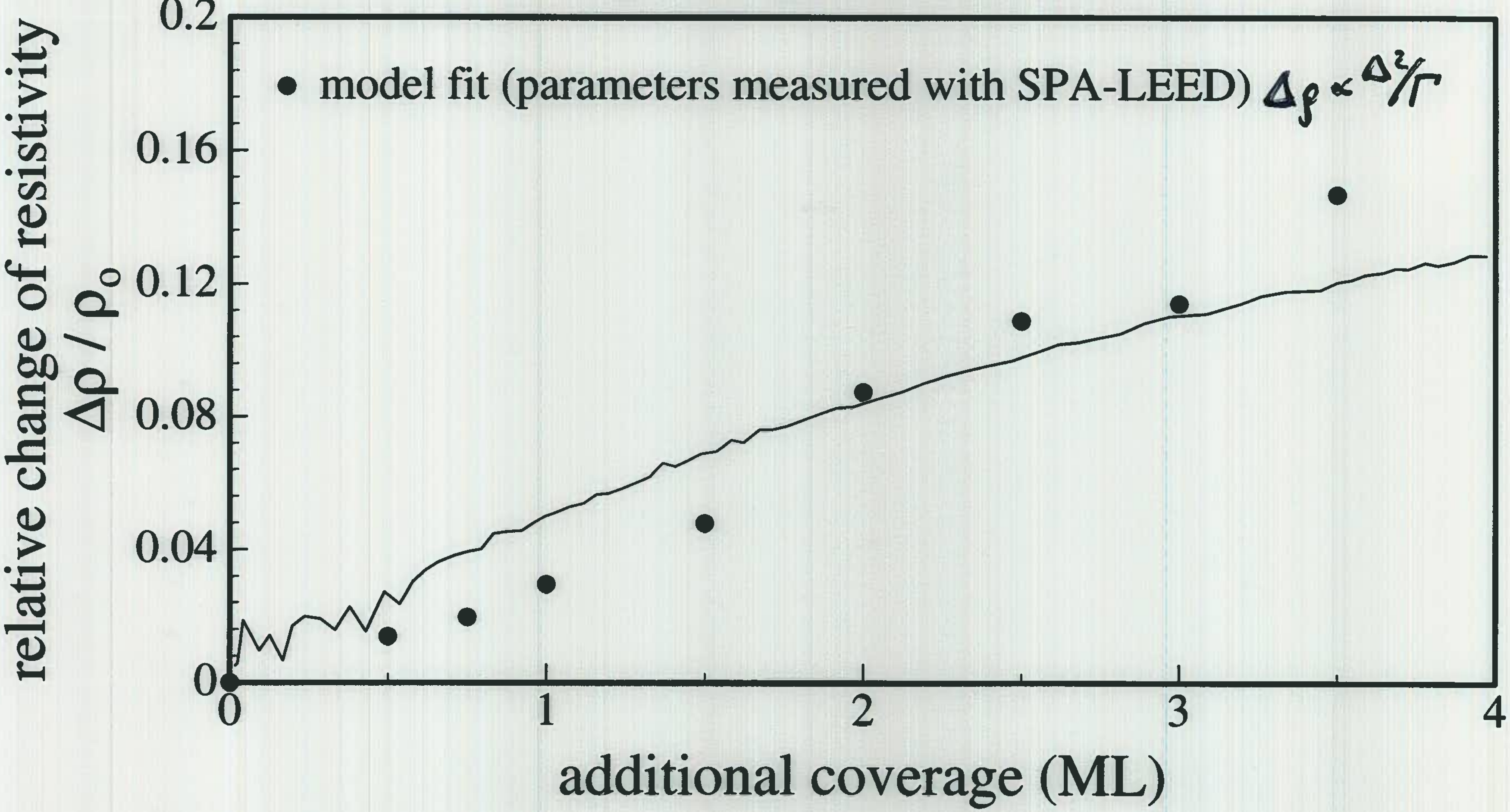
③ Wißmann: Springer Tracts Mod. Phys. **77** (1975) 1

$$\Delta\rho \propto \Omega \cdot n_{\text{Streuer}} \propto 1/\Gamma$$

↳ Streuquerschnitt

$$\Gamma = \xi / 4\Delta^2 \xrightarrow{②} \Delta\rho \propto 1/\Gamma$$

comparison between measurement and theory
Ag on Ag(111) at 130K



Beitrag zur allgemeinen Begriffsverwirrung
(Dr. J. Wollschläger)

Autokorrelation $a(\rho) = \langle H(\rho+\rho') H(\rho') \rangle =: \Delta^2 e^{-\rho/\xi}$

$= \mathcal{F}\{|\mathcal{F}\{H(\rho)\}|^2\} \rightarrow \xi$

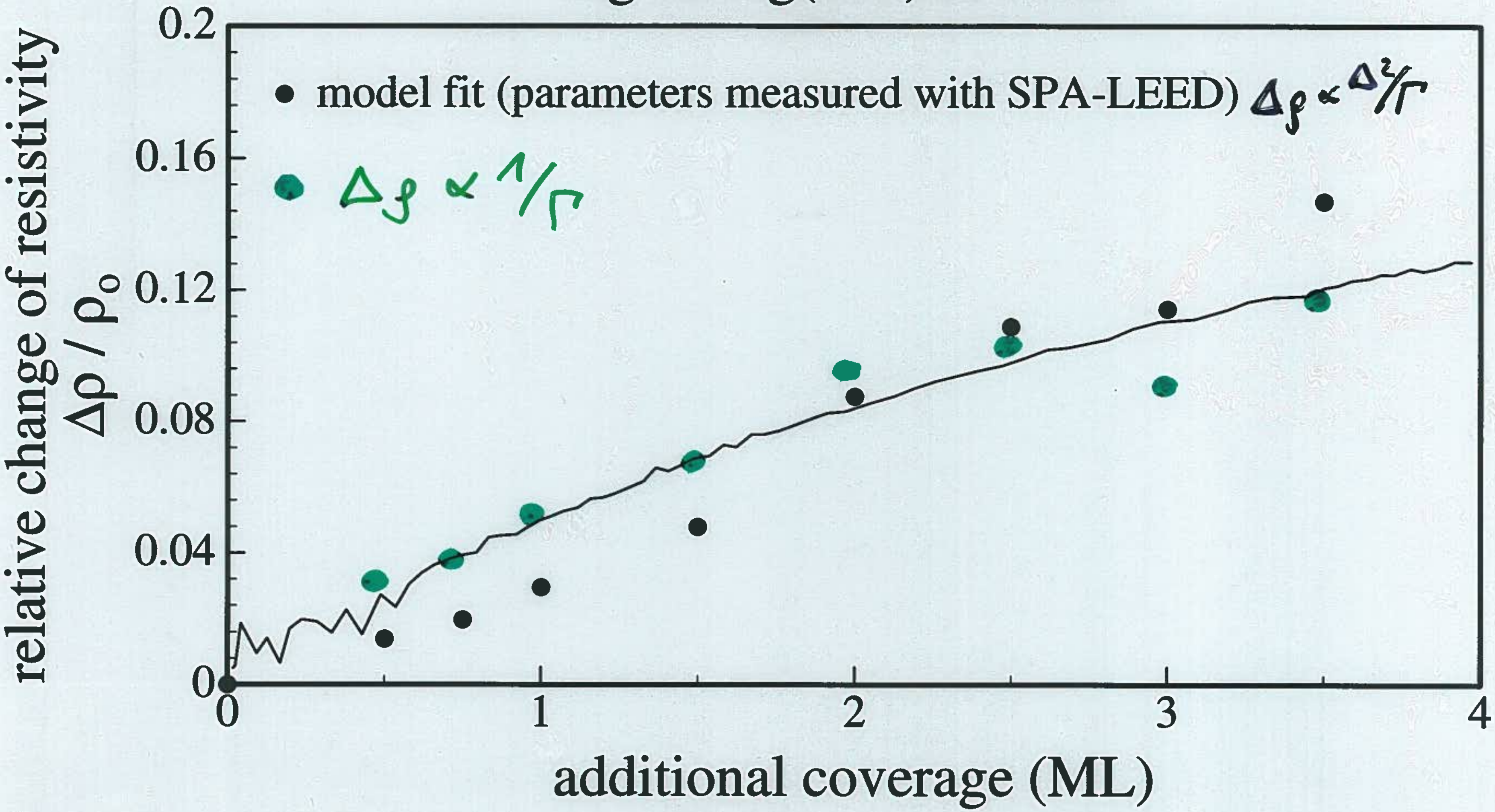
Phasenkorrelation (SPA-LEED) $\phi(\rho, S) = \langle e^{2\pi i \cdot S [H(\rho+\rho') - H(\rho')]} \rangle$

$\rightarrow \Gamma$

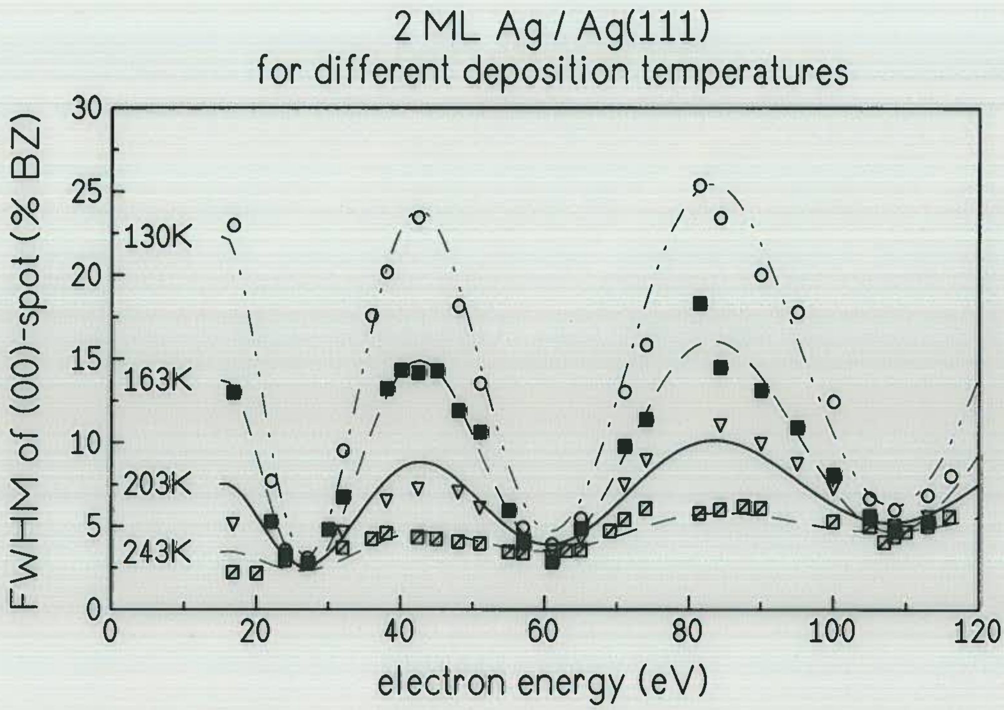
2

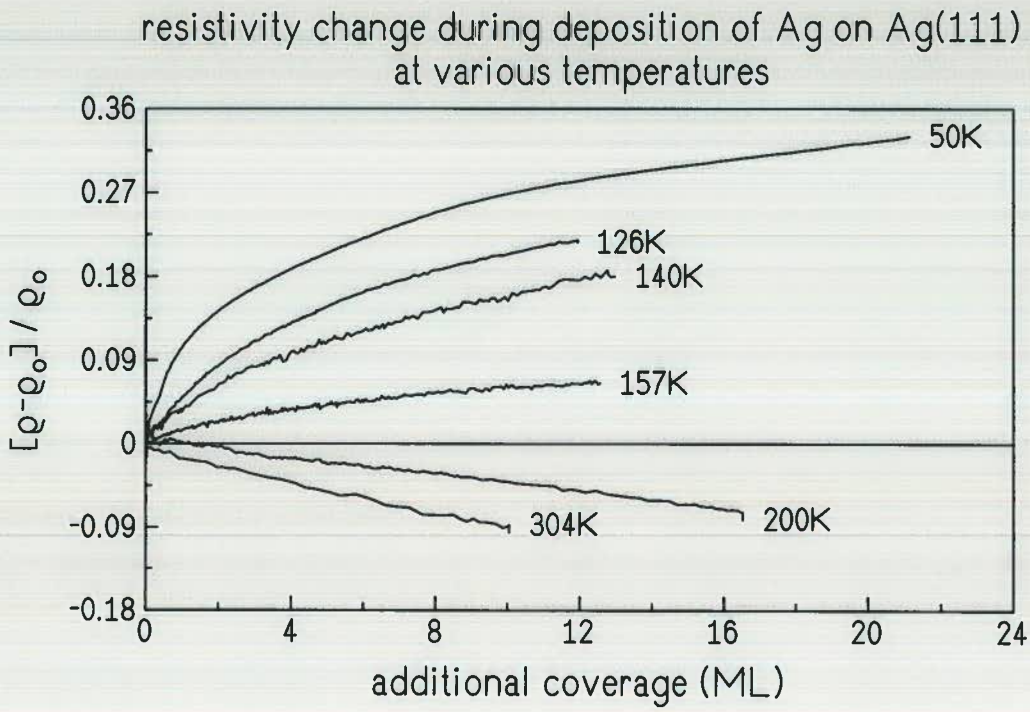
$$\Gamma = \xi / \not{4} \Delta^2$$

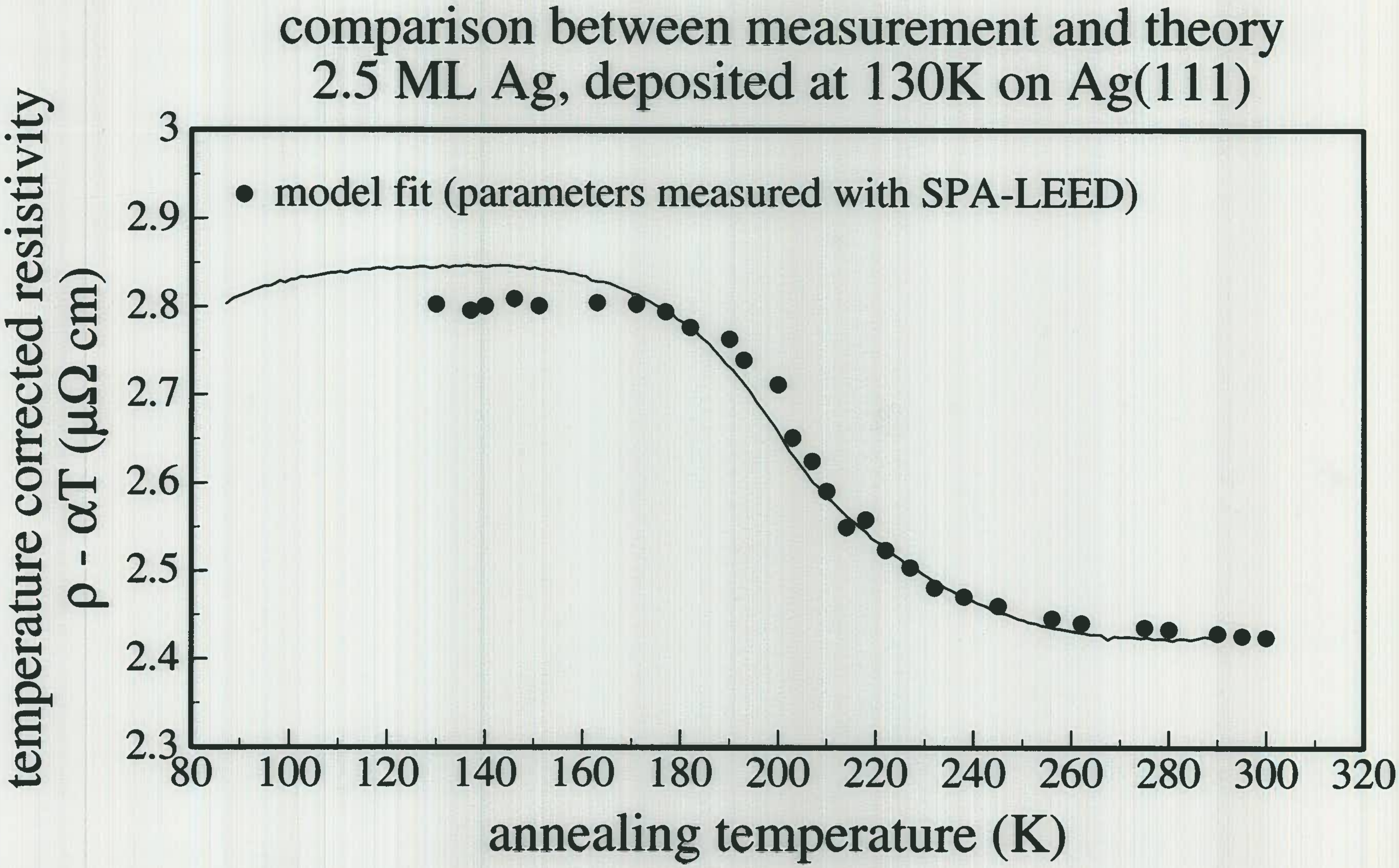
comparison between measurement and theory
Ag on Ag(111) at 130K



influence of deposition temperature



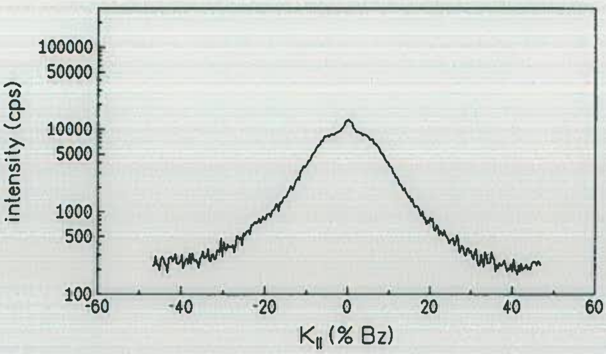


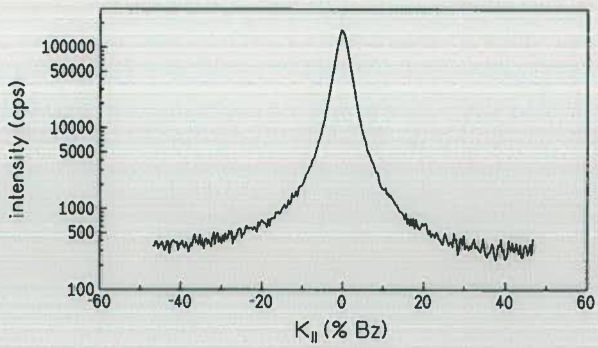

comparison between measurement and theory
2.5 ML Ag, deposited at 130K on Ag(111)
model fit (parameters measured with SPA-LEED)
temperature corrected resistivity
ρ - αT (μΩ cm)
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
80
100
120
140
160
180
200
220
240
260
280
300
320
annealing temperature (K)

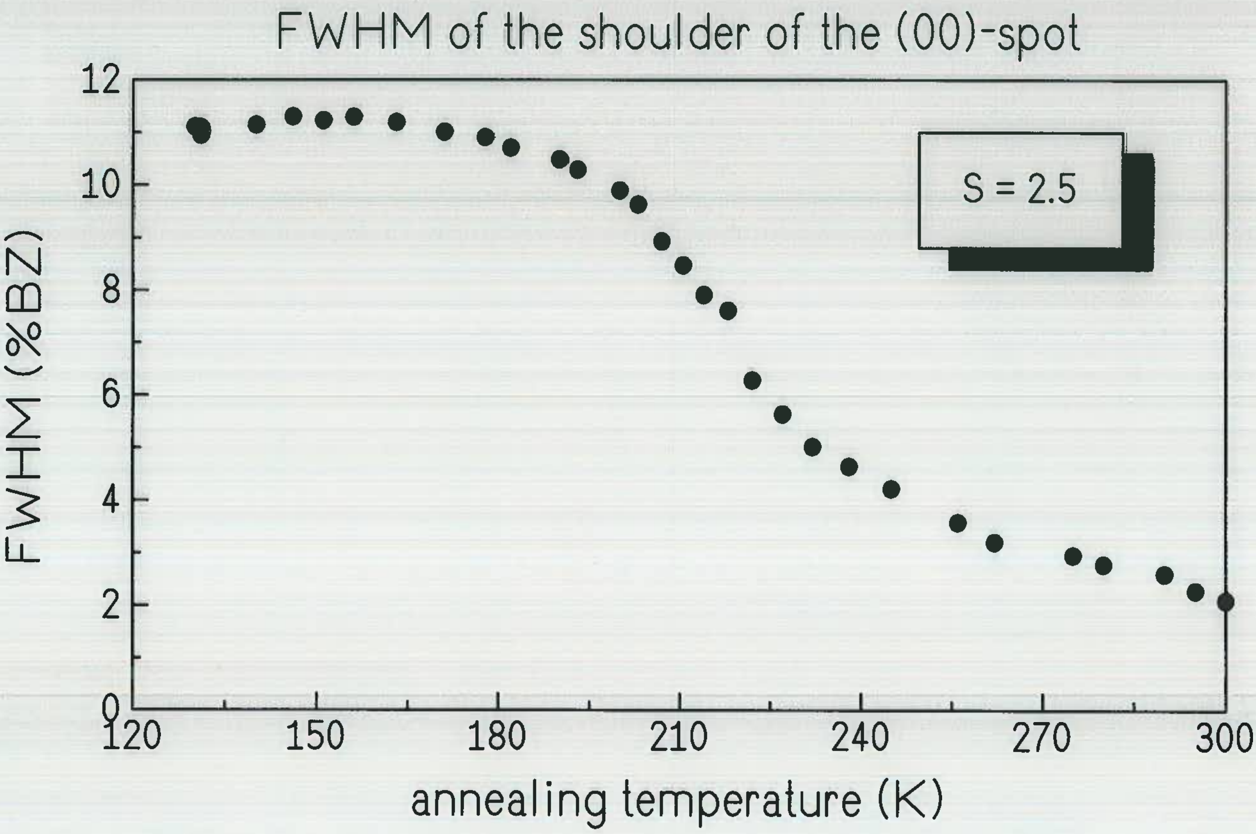
annealing experiment

2.5 ML Ag on Ag(111)

as deposited at 130K   after annealing to 260K

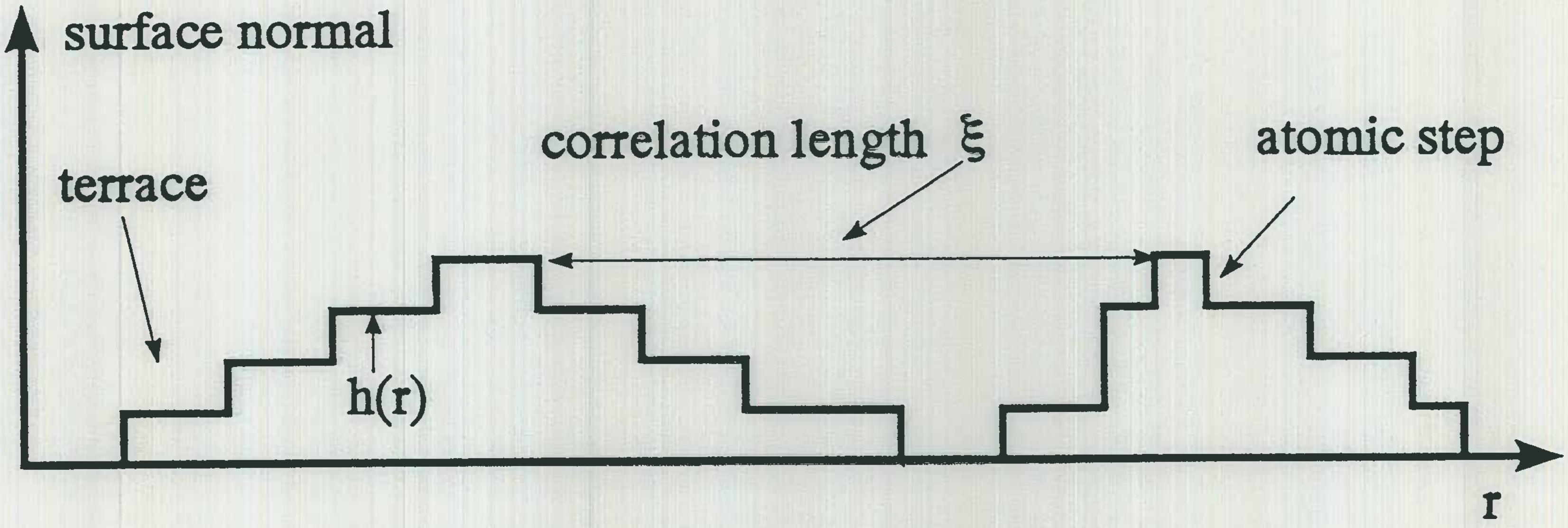


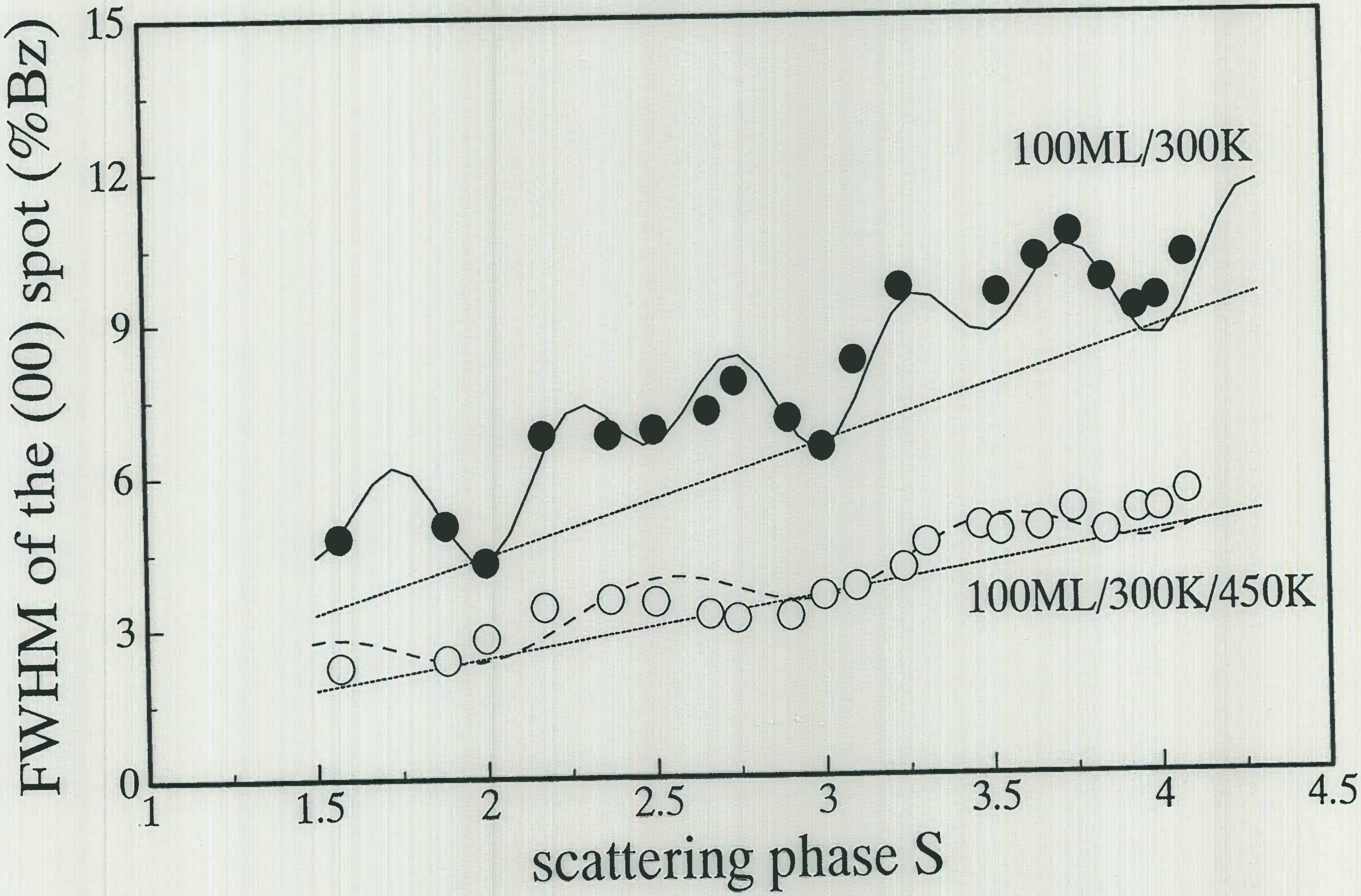




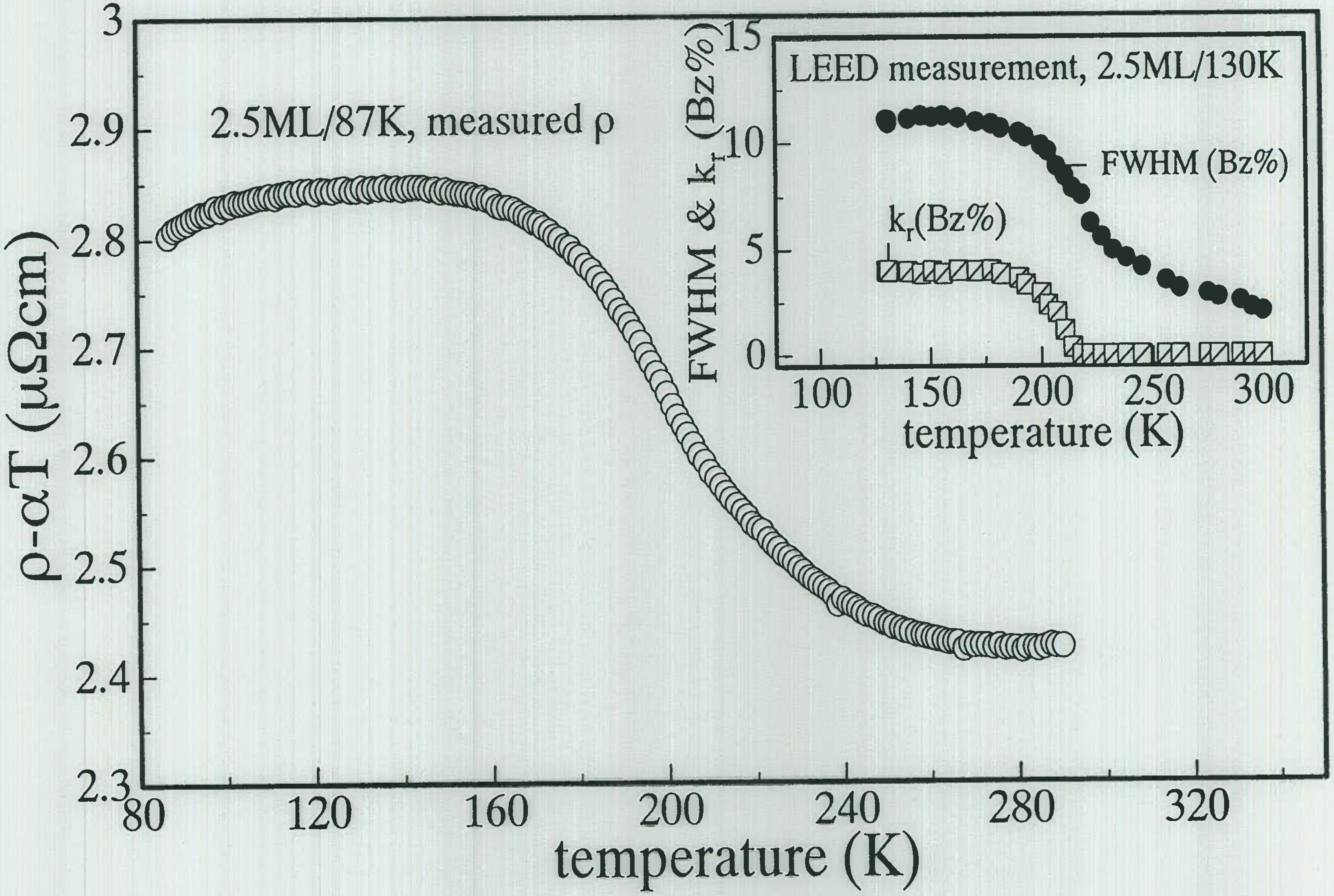
1. measuring surface morphology. SPA-LEED yields statistical informations like
   - surface roughness Δ
   - terrace length distribution Γ, σ
2. measurement of the corresponding change in resistivity ρ
3. comparison of both results, using the the **<u>measured</u>** structural data to explain resistivity measurements

aim: a deeper understanding of electronic scattering processes on interfaces

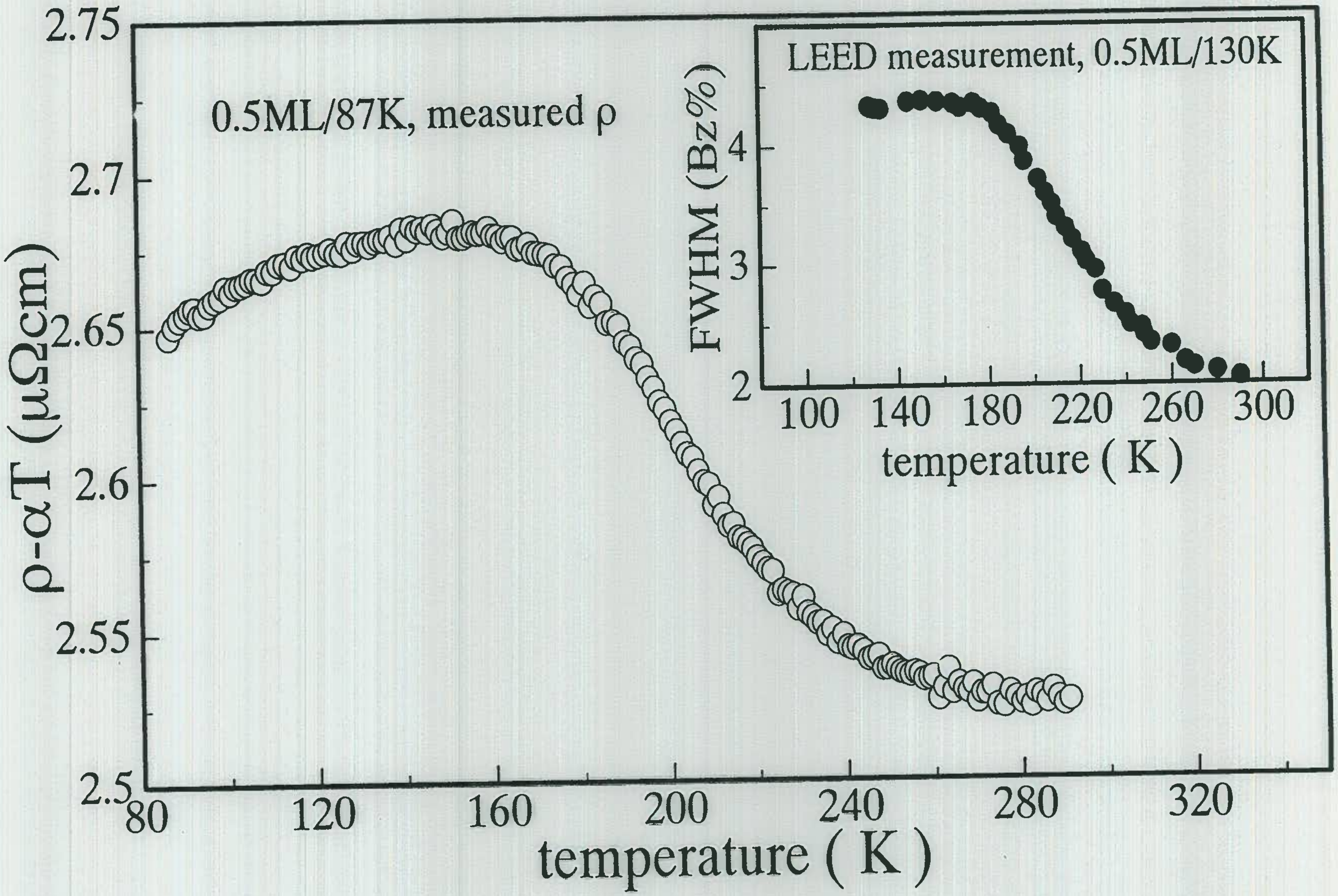

surface normal
correlation length ξ
atomic step
terrace
h(r)
r



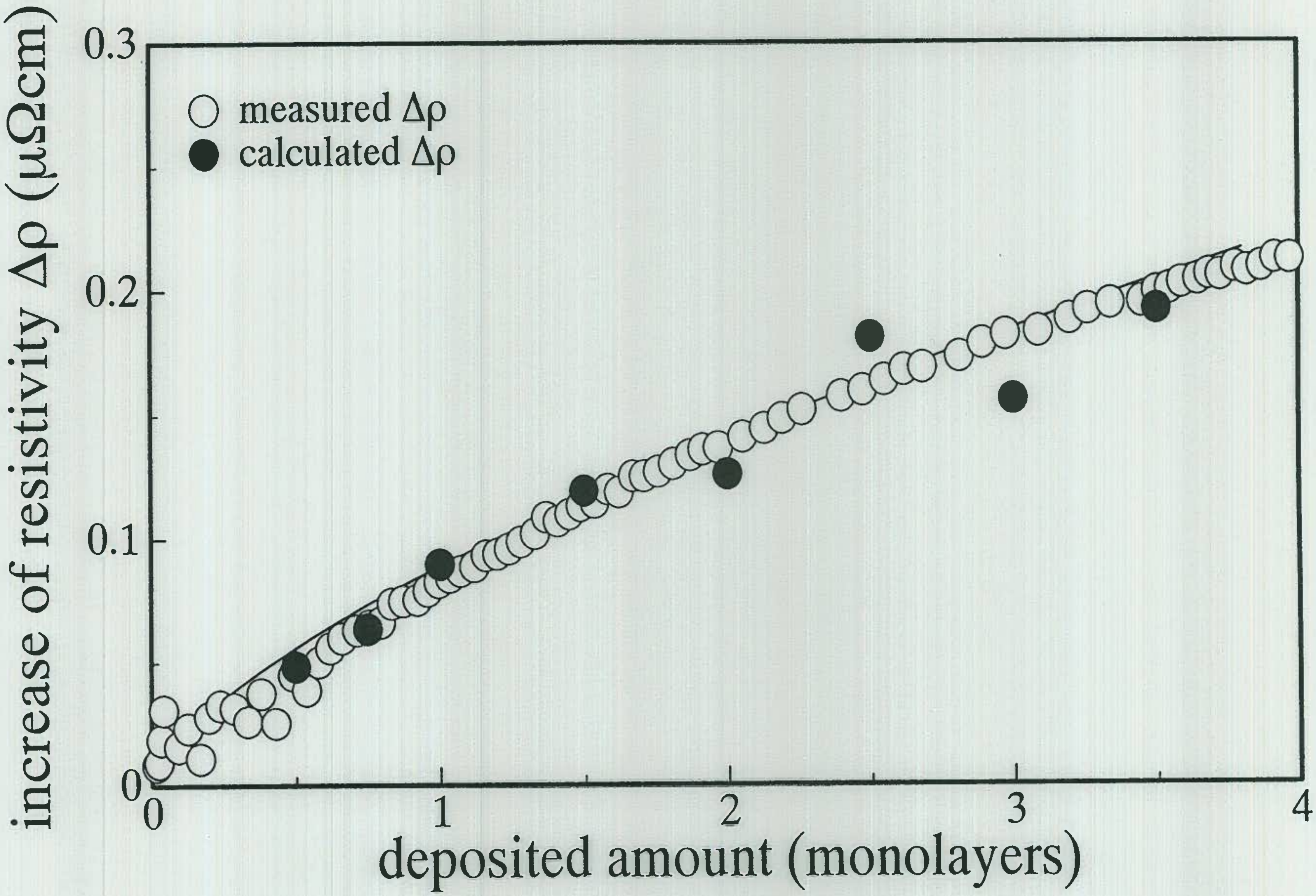
FWHM of the (00) spot (%Bz)
15
12
9
6
3
0
1
1.5
2
2.5
3
3.5
4
4.5
scattering phase S
100ML/300K
100ML/300K/450K



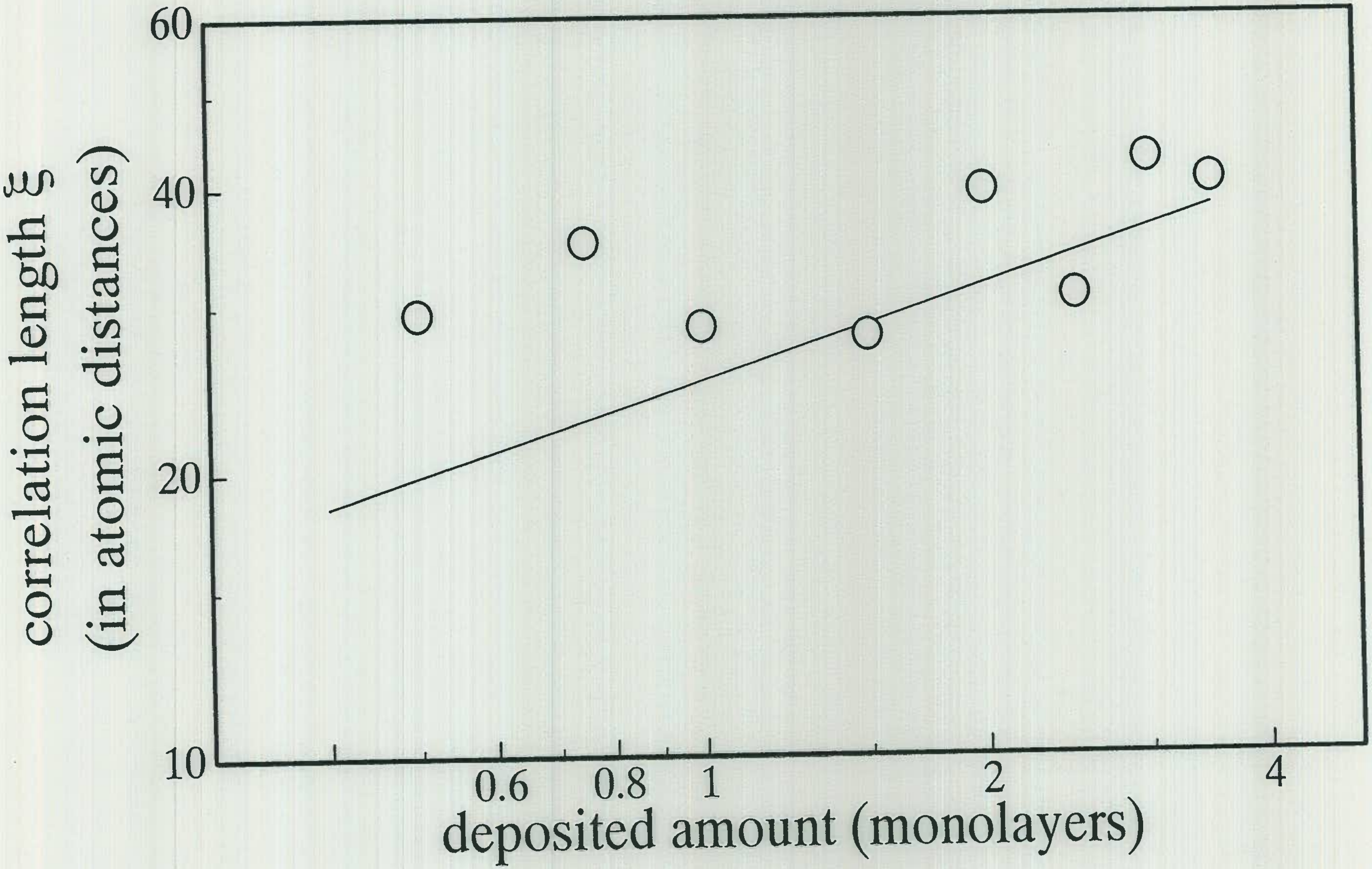
2.5ML/87K, measured ρ
ρ-αT (μΩcm)
temperature (K)
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
80
120
160
200
240
280
320
LEED measurement, 2.5ML/130K
FWHM (Bz%)
k_r(Bz%)
FWHM & k_r (Bz%)
temperature (K)
15
10
5
0
100
150
200
250
300

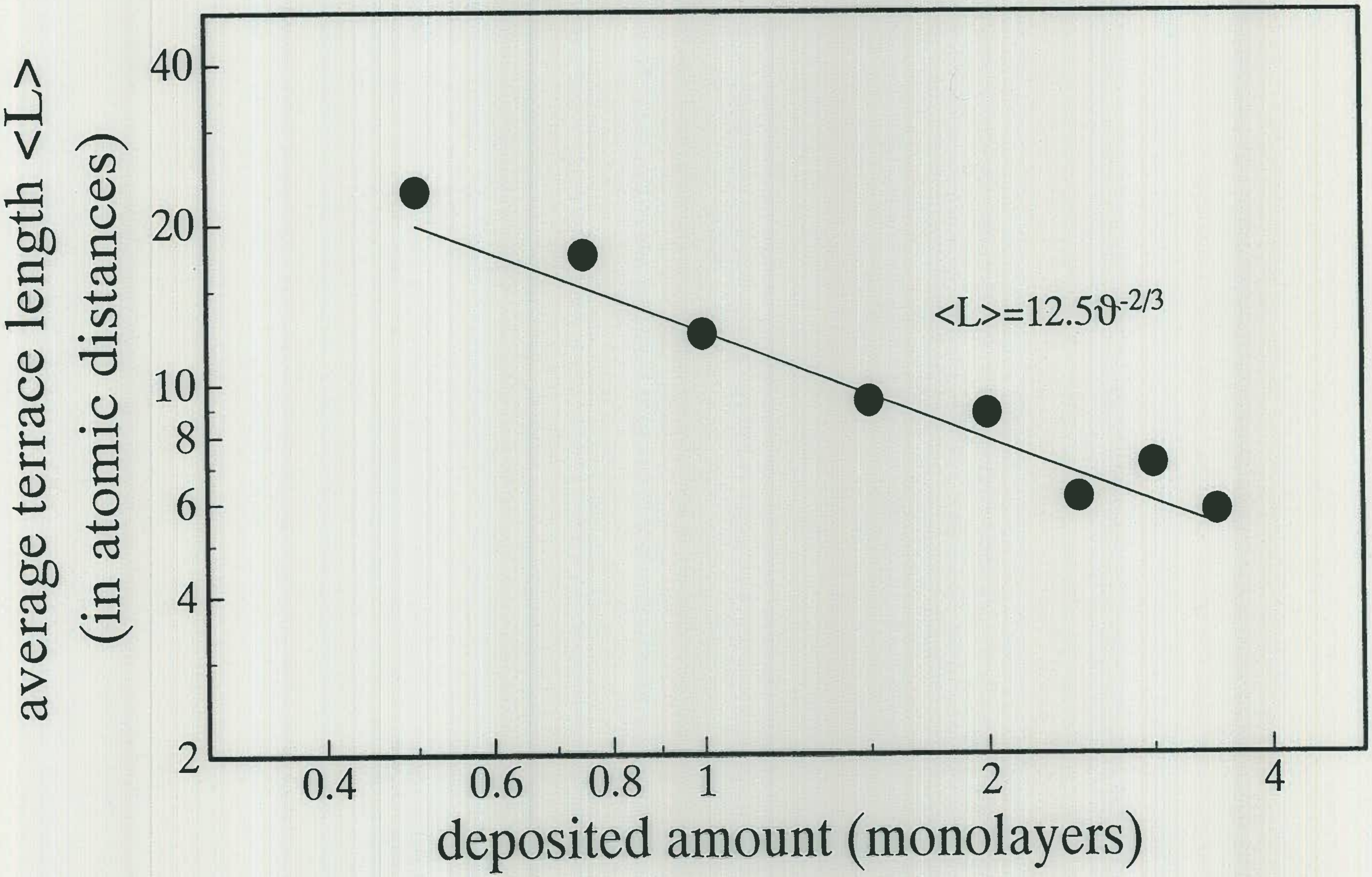


0.5ML/87K, measured ρ
ρ-αT (μΩcm)
2.75
2.7
2.65
2.6
2.55
2.5
80
120
160
200
240
280
320
temperature (K)
LEED measurement, 0.5ML/130K
FWHM (Bz%)
4
3
2
100
140
180
220
260
300
temperature (K)

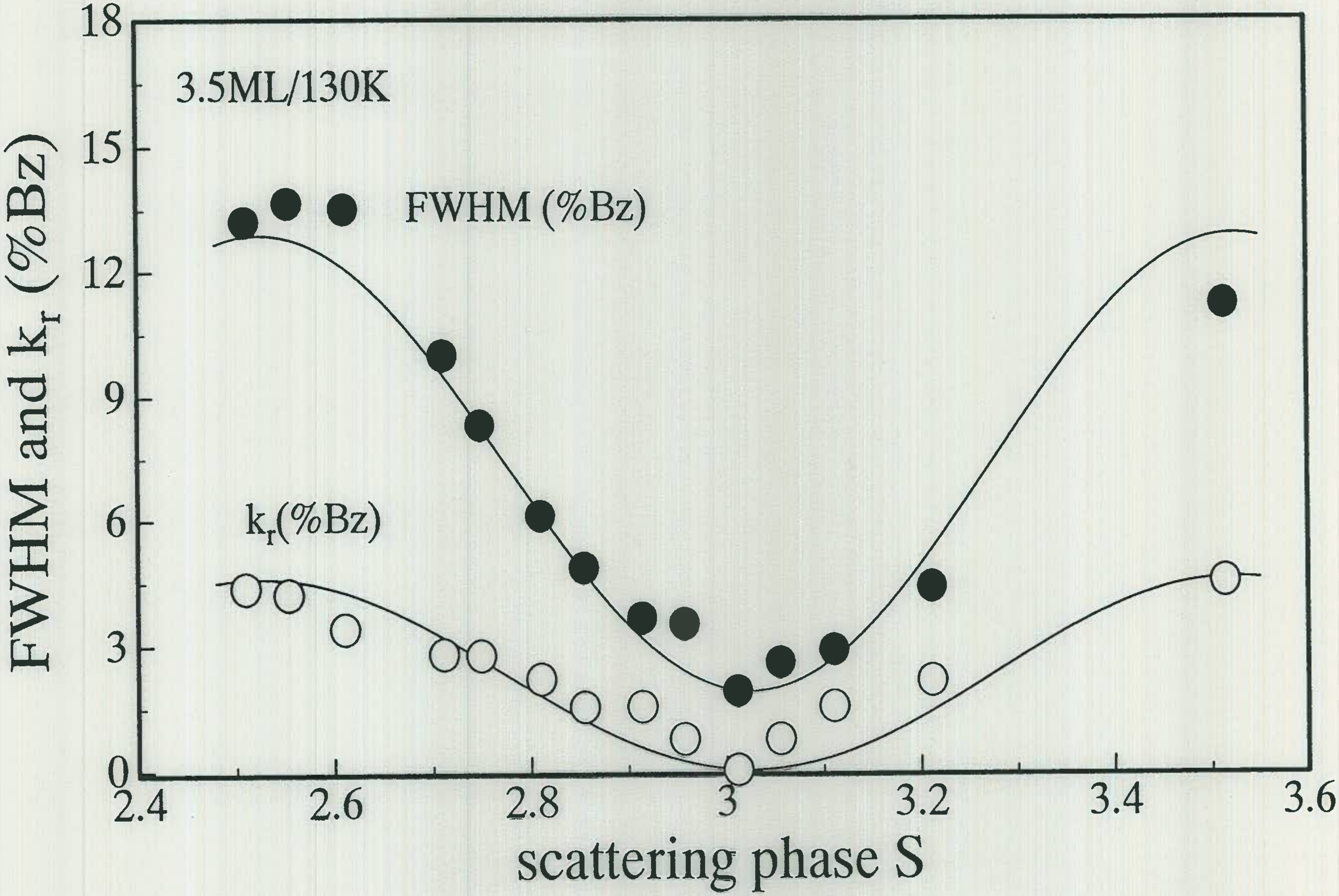


measured Δρ
calculated Δρ
increase of resistivity Δρ (μΩcm)
deposited amount (monolayers)
0
0.1
0.2
0.3
0
1
2
3
4

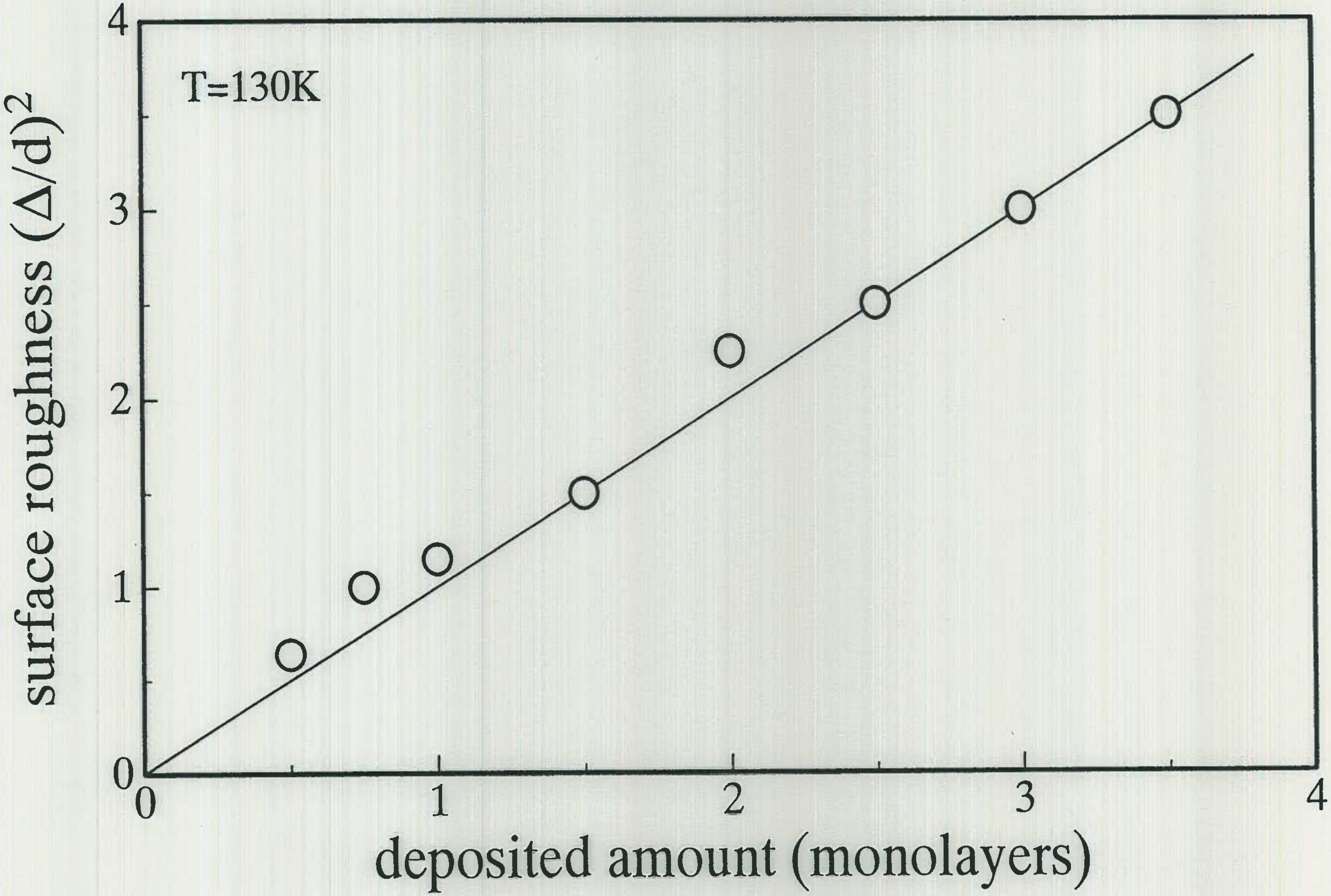

60
40
20
10
correlation length ξ
(in atomic distances)
0.6
0.8
1
2
4
deposited amount (monolayers)

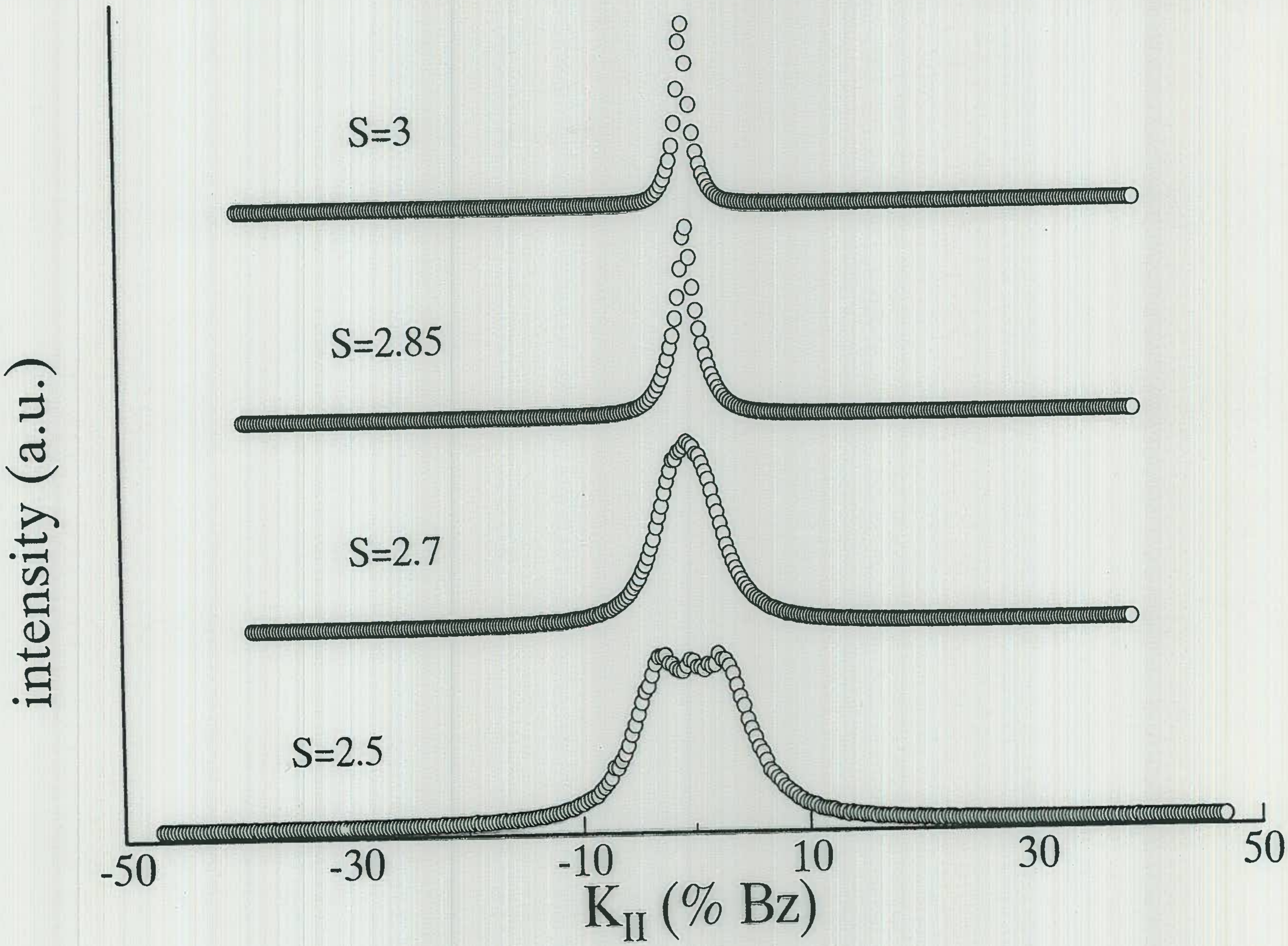


average terrace length <L>
(in atomic distances)
40
20
10
8
6
4
2
0.4
0.6
0.8
1
2
4
deposited amount (monolayers)
<L>=12.5ϑ-2/3



3.5ML/130K
FWHM (%Bz)
k_r(%Bz)
FWHM and k_r (%Bz)
scattering phase S
0
3
6
9
12
15
18
2.4
2.6
2.8
3
3.2
3.4
3.6


T=130K
surface roughness (Δ/d)²
deposited amount (monolayers)
0
1
2
3
4
0
1
2
3
4



S=3
S=2.85
S=2.7
S=2.5
intensity (a.u.)
-50
-30
-10
10
30
50
K_II (% Bz)