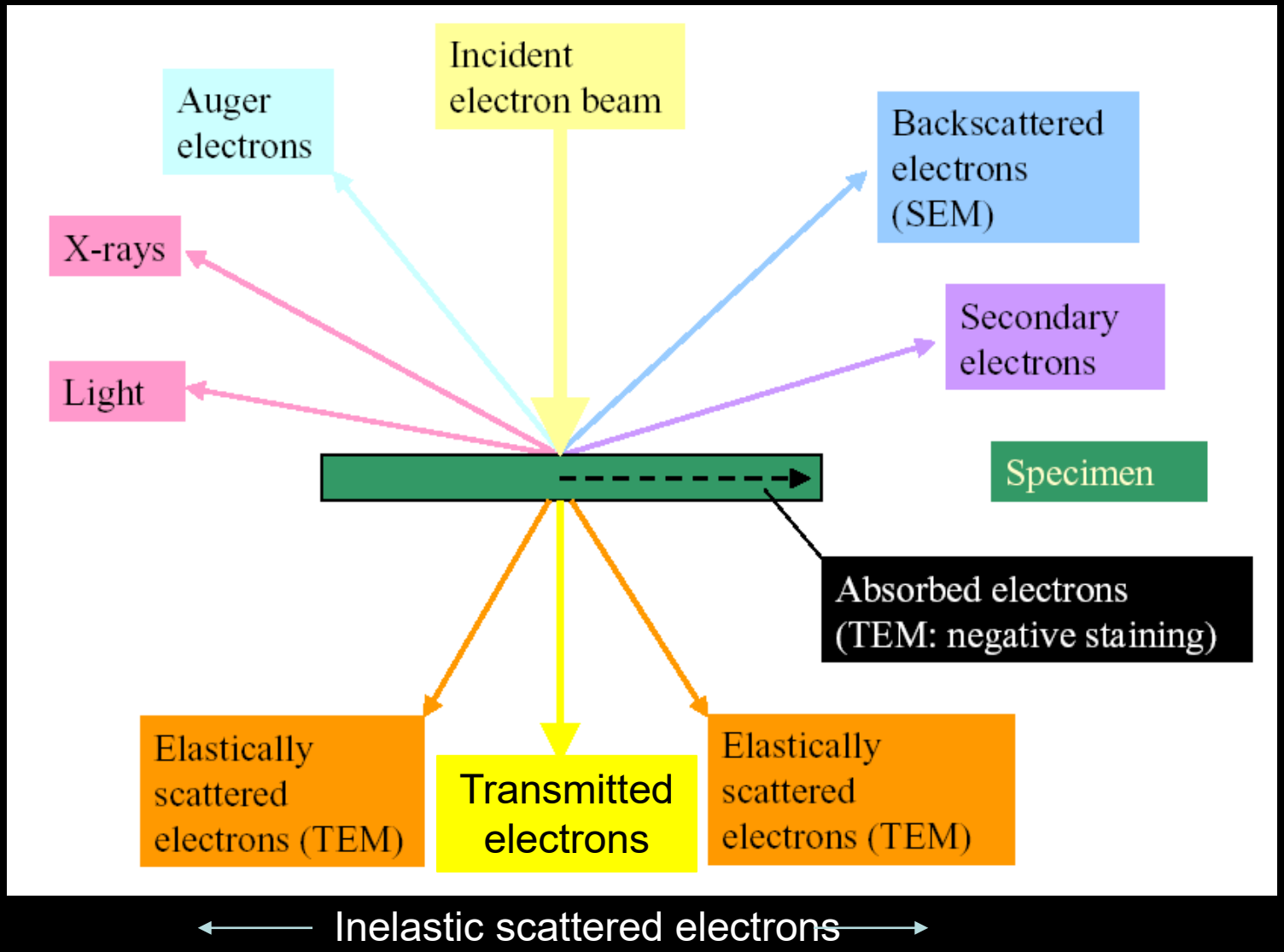
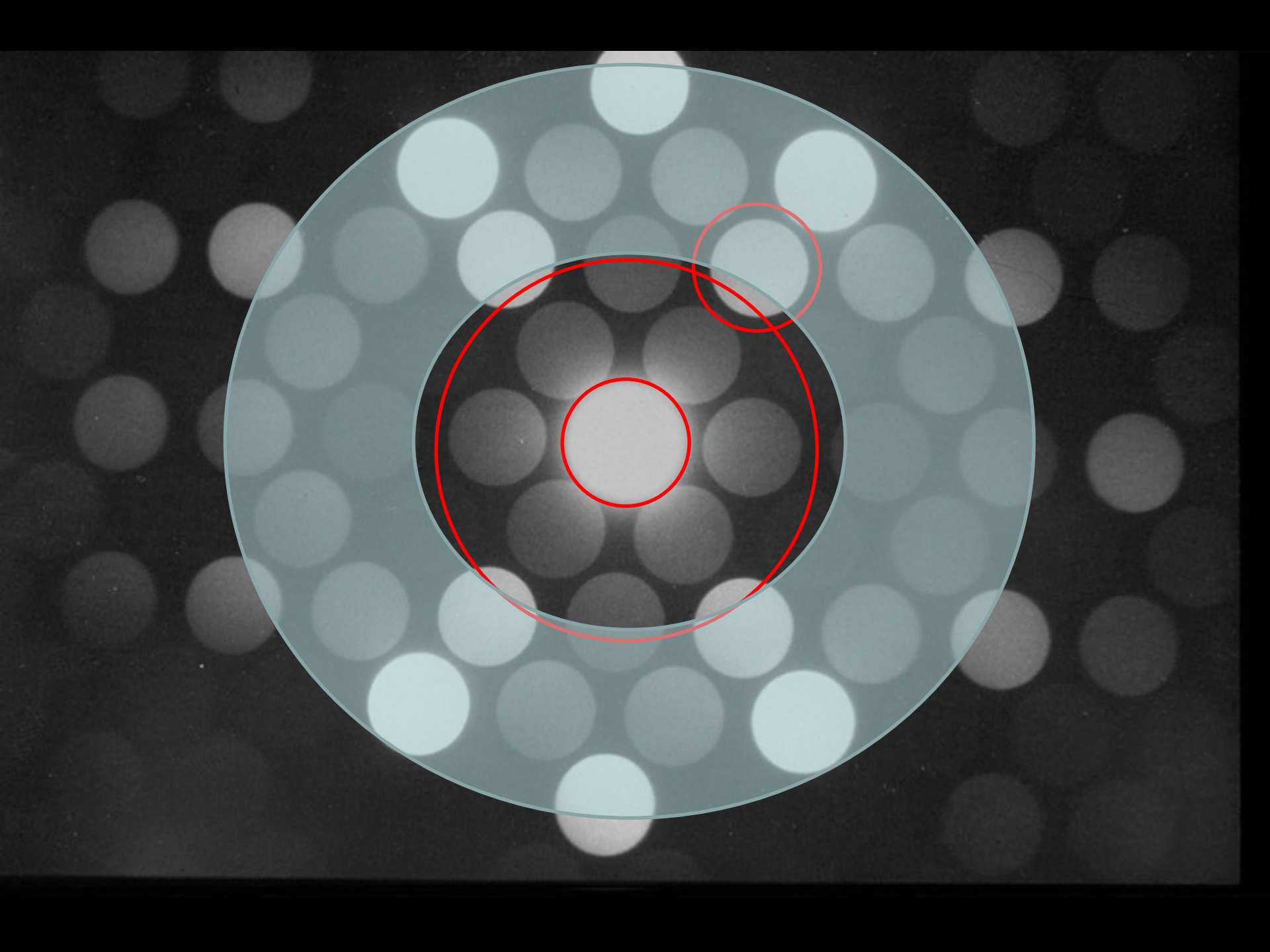
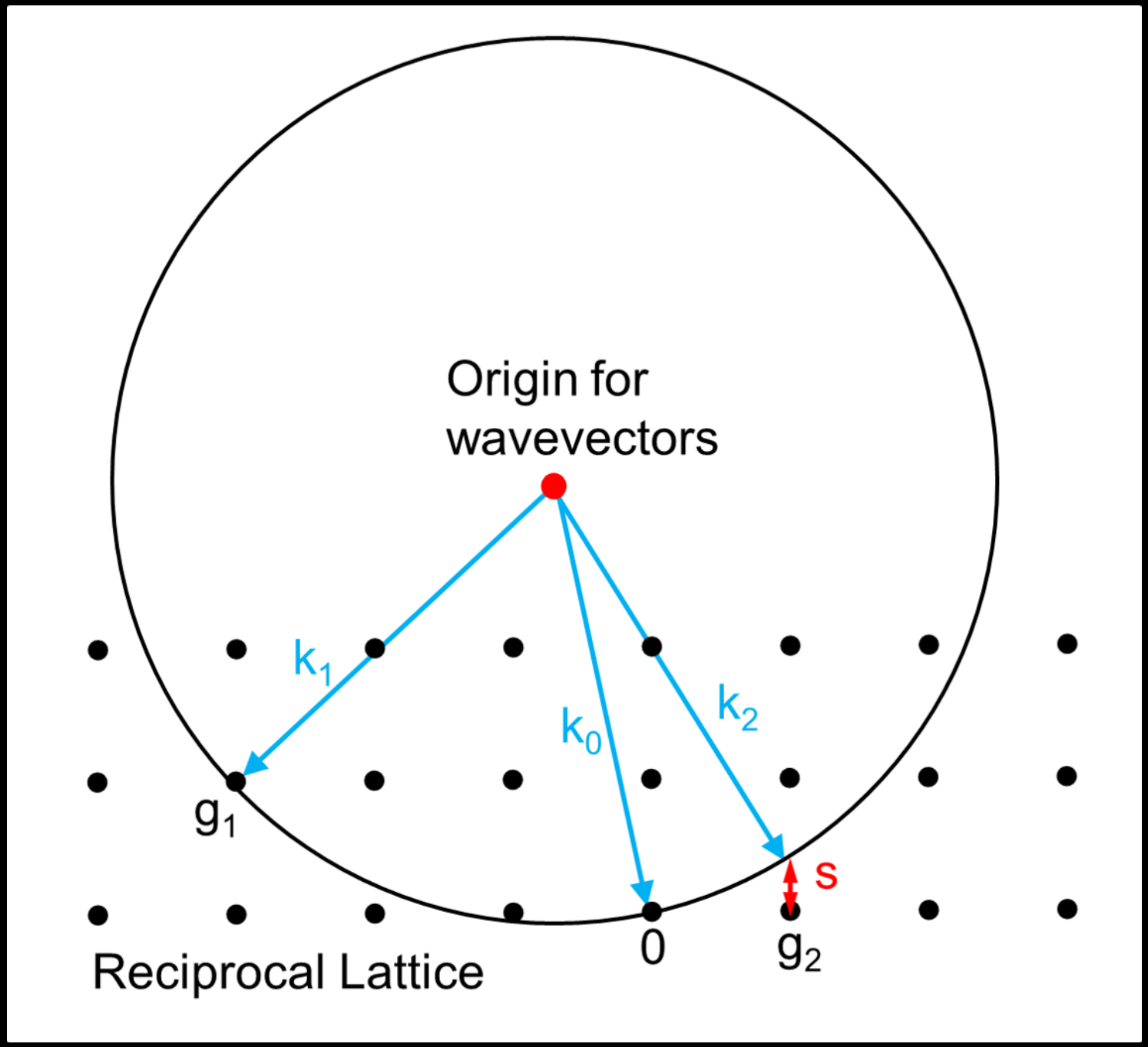
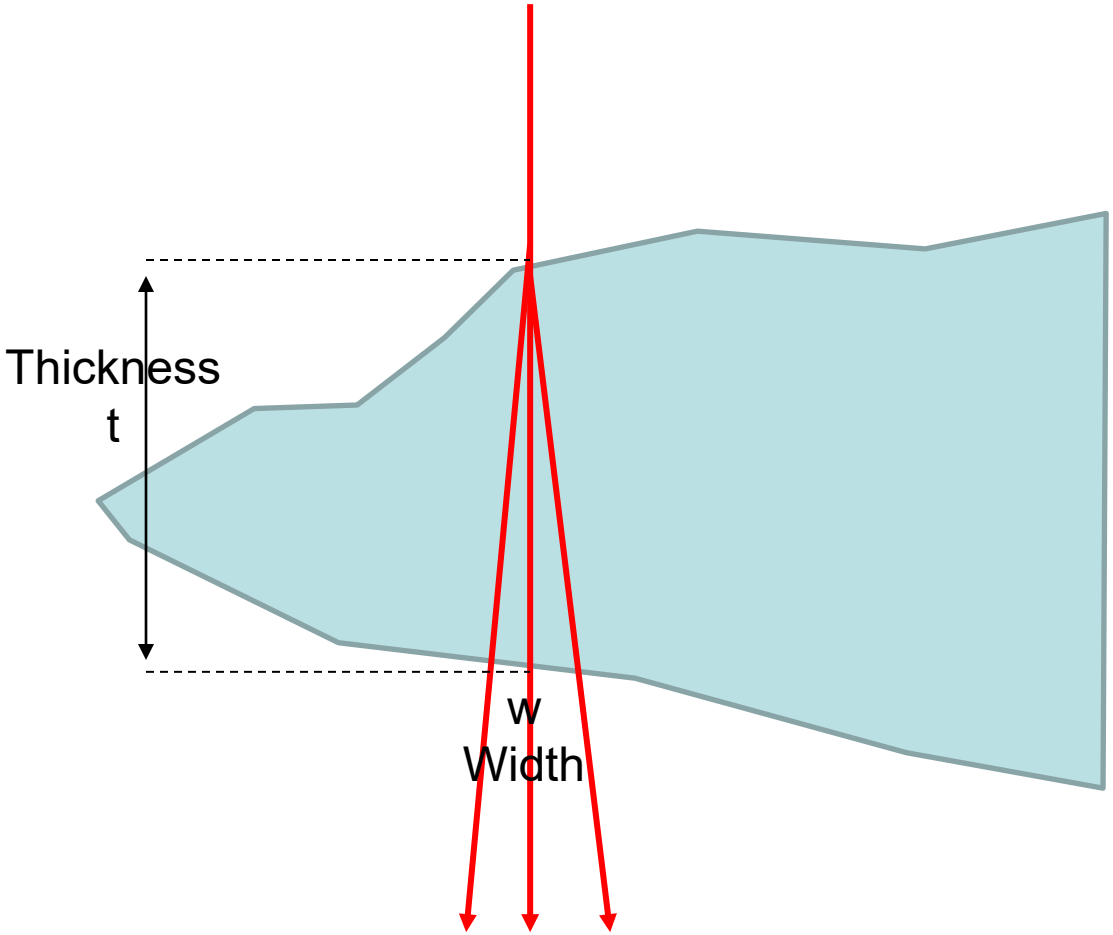
2-slit experiment; single electrons form interference statistically (Tonamura)


Incident electron beam
Auger electrons
Backscattered electrons (SEM)
X-rays
Secondary electrons
Light
Specimen
Absorbed electrons (TEM: negative staining)
Elastically scattered electrons (TEM)
Transmitted electrons
Elastically scattered electrons (TEM)
Inelastic scattered electrons




Origin for
wavevectors
k_1
k_0
k_2
g_1
s
0
g_2
Reciprocal Lattice

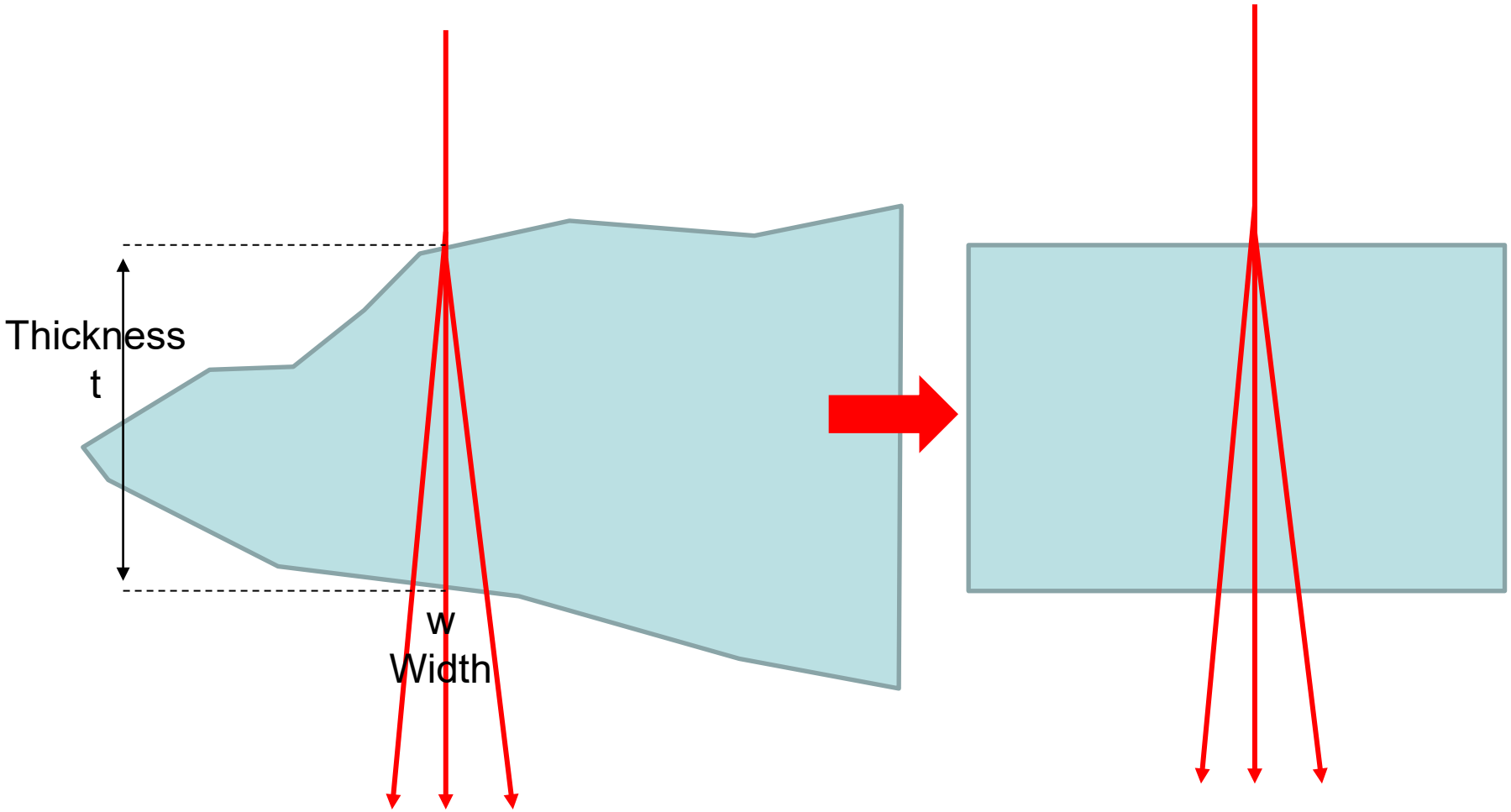


$$w = tTan(\theta)$$

$$w = t\theta$$

Thickness ~ 50nm
Angle ~ 10 mRad
Width ~ 0.5nm

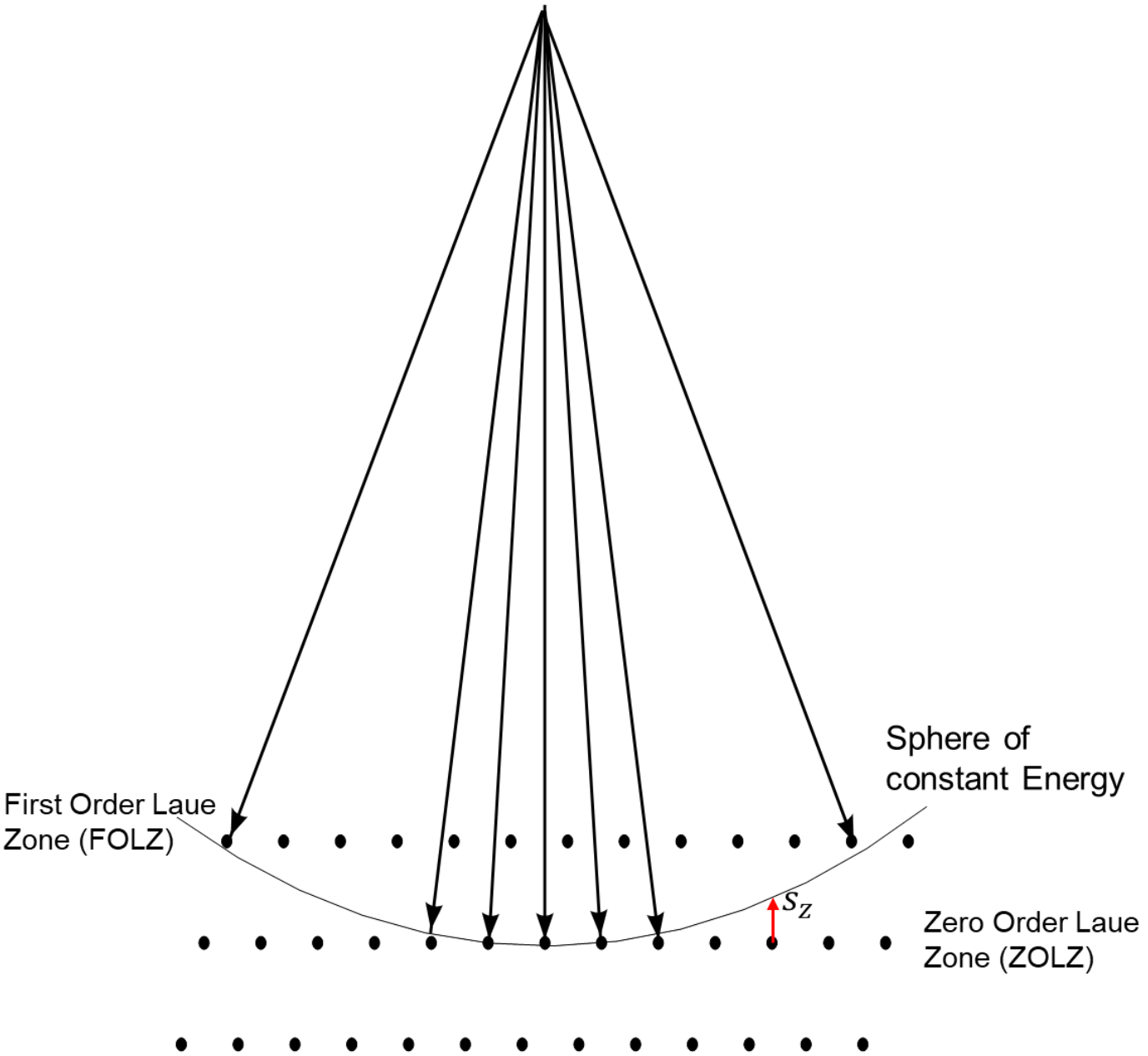
For low resolution work, 0.5nm is “a point”

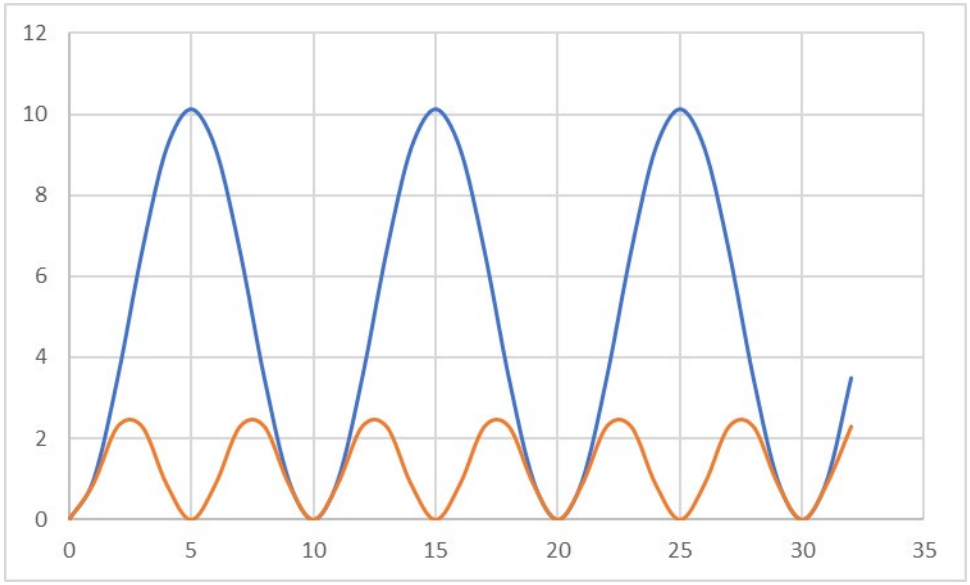


$$\phi(g) = \int_0^t \exp(2\pi i s_z z)\, dz$$

$$|\phi(g)|^2 = |\sin(\pi t s_z)\,/\pi s_z|^2$$

Column Approximation

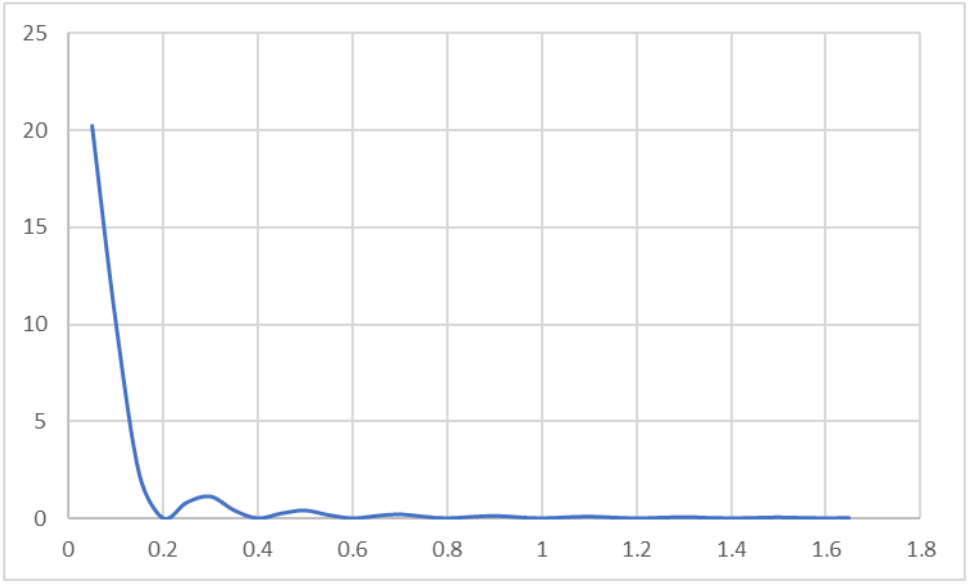

Sphere of
constant Energy
First Order Laue
Zone (FOLZ)
s_z
Zero Order Laue
Zone (ZOLZ)



Variation with thickness

$$|\phi(g)|^2 = |\sin(\pi t s_z)\,/\pi s_z|^2$$

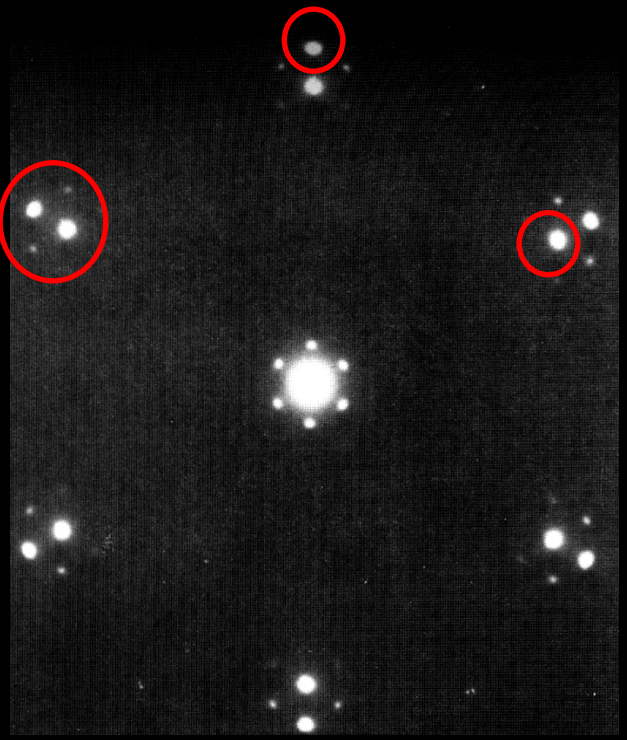
Variation with s_z

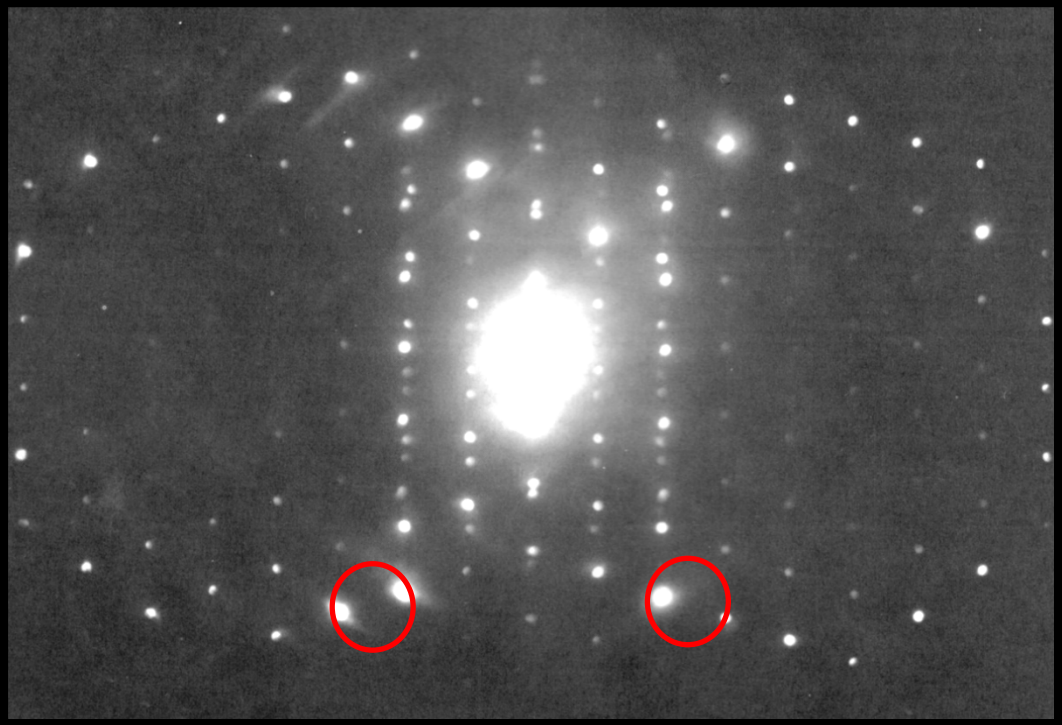


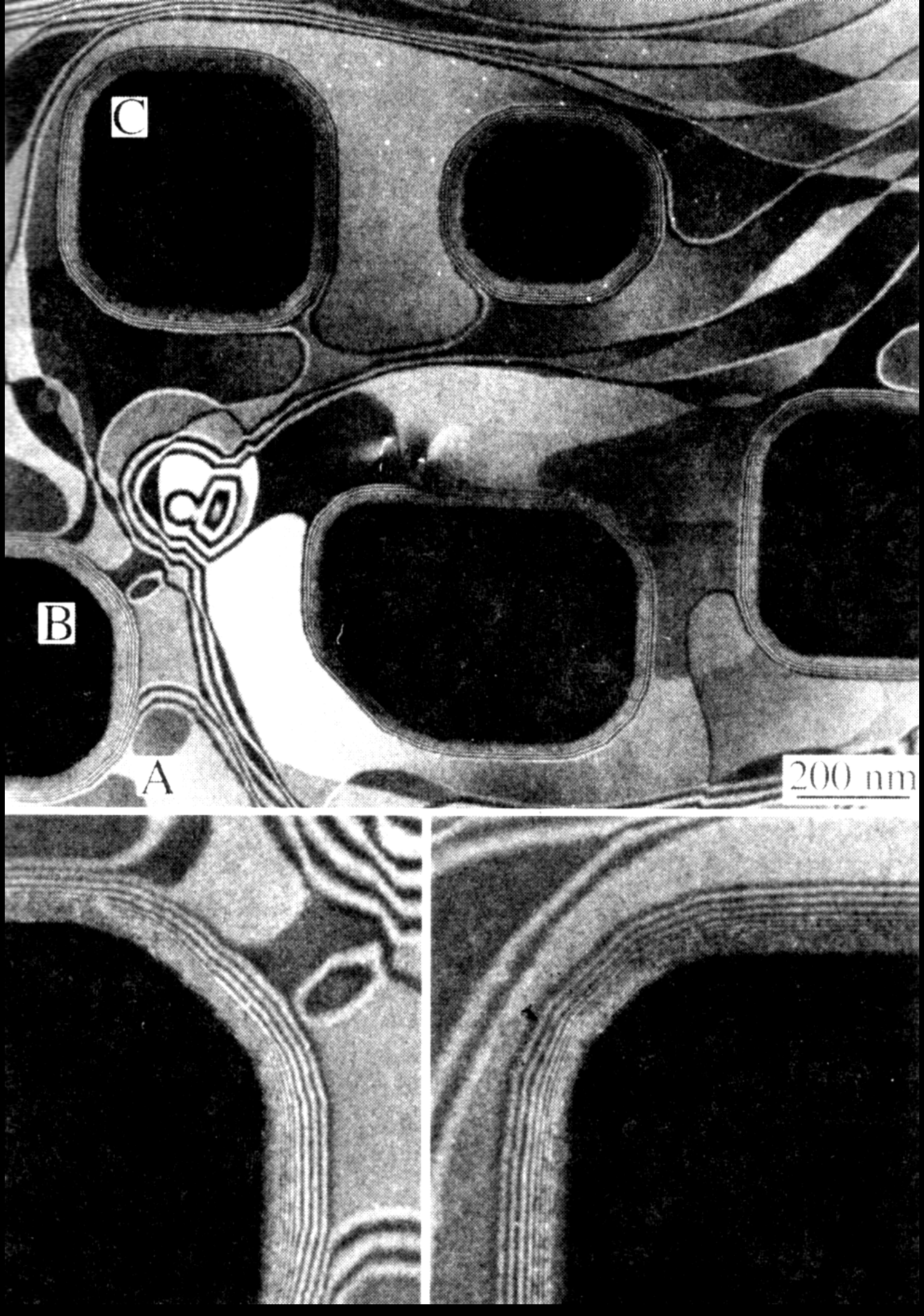
Simple Imaging in BF/DF

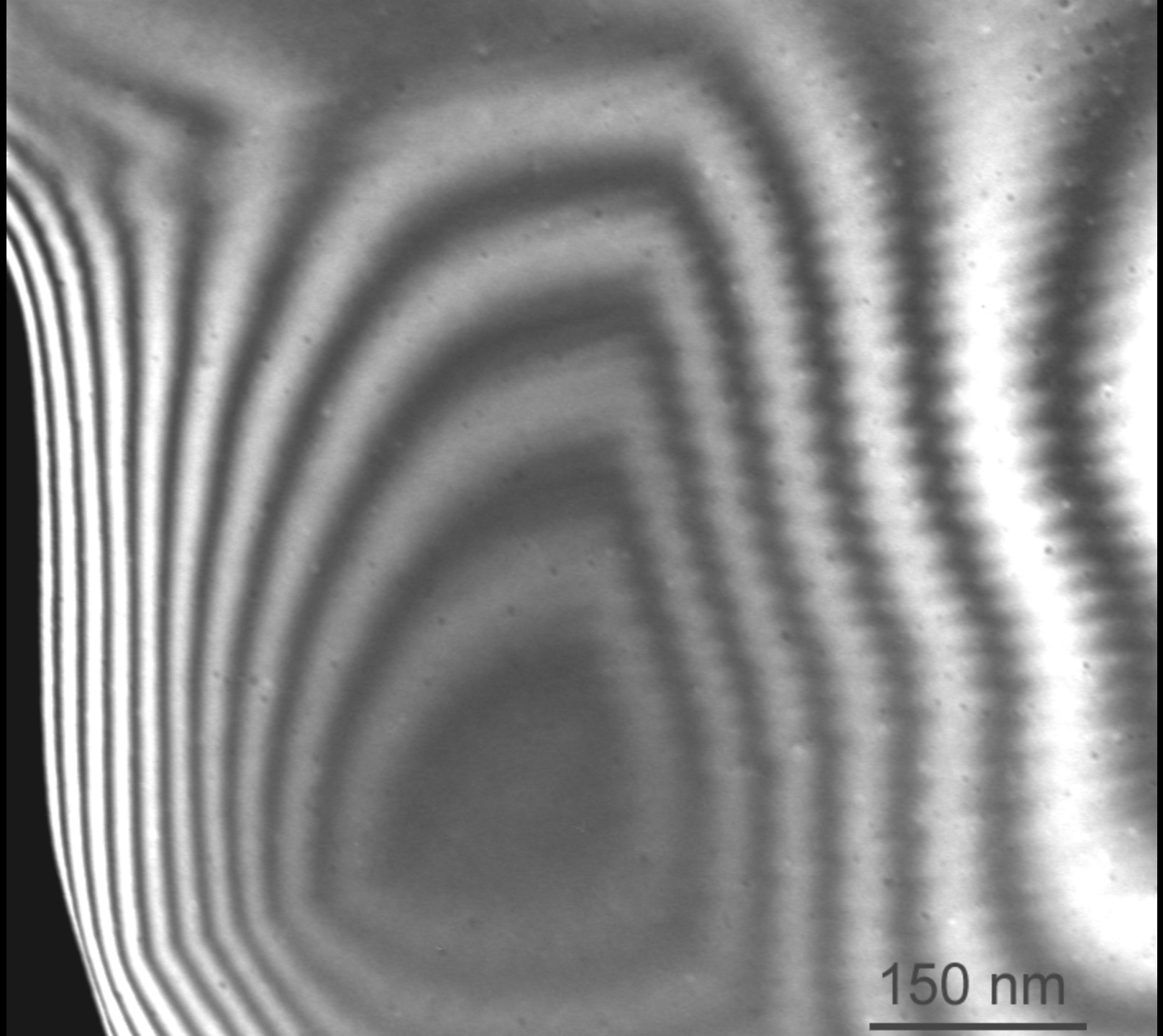
- $I_g = c|Sin(\pi t s_z)/(\pi s_z)|^2$
- Oscillates with thickness; changes with tilt
- Need to combine understanding of DP, s_z and where the aperture is with imaging
- Use “materials” knowledge – samples are almost always sensible
- Forensic work
- Beware of prejudices/assumptions

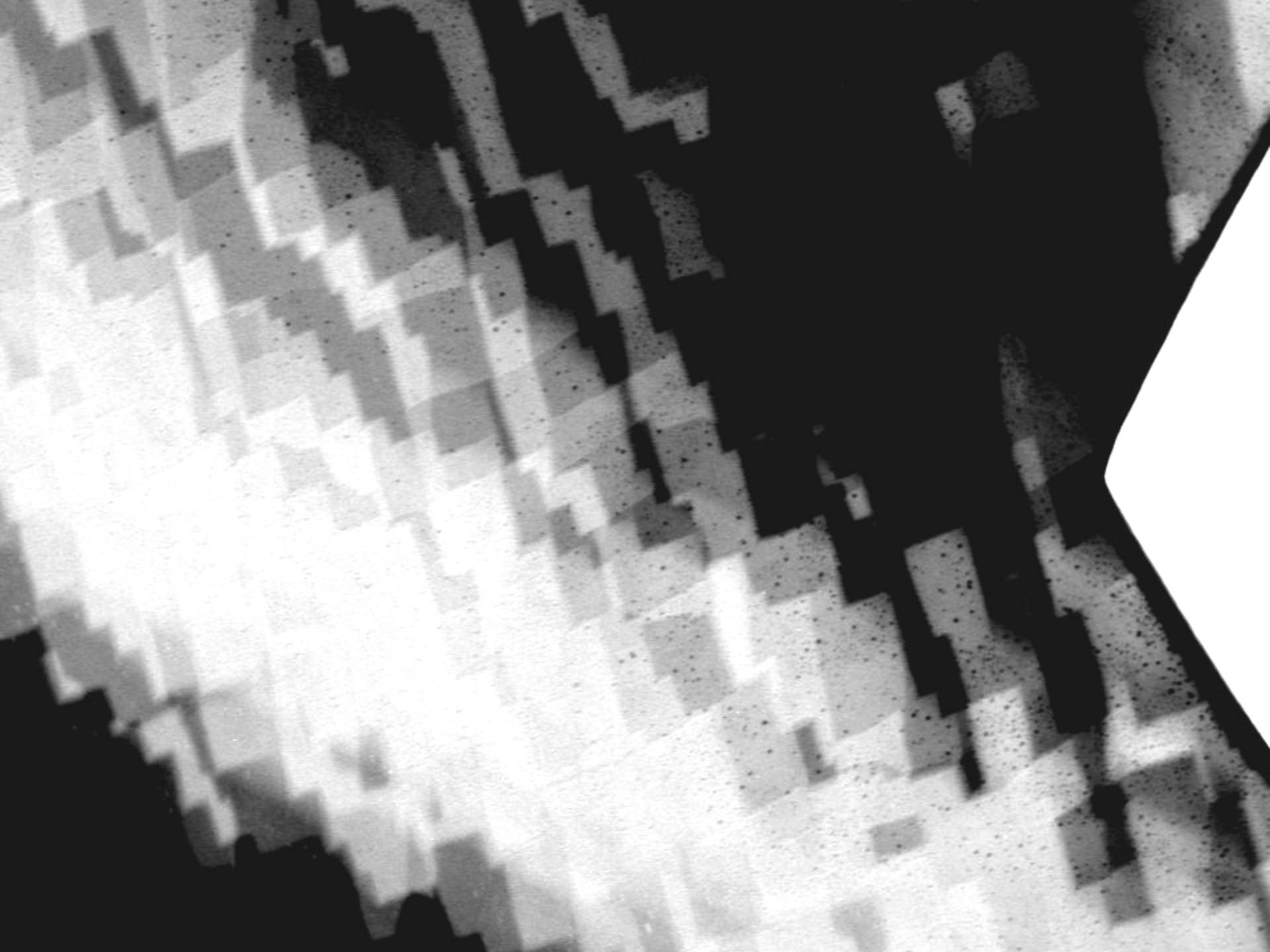
Apertures at different locations will give different images

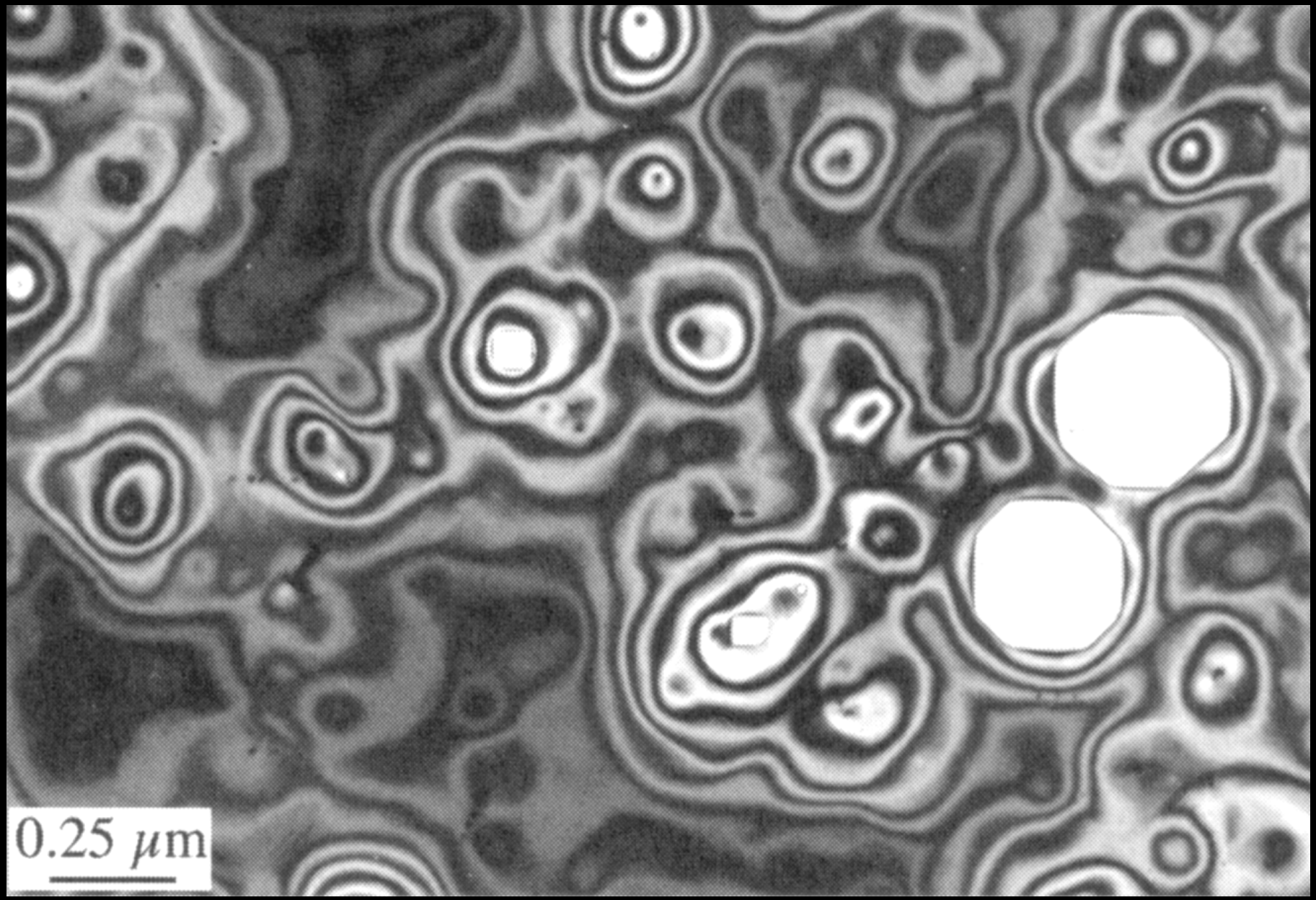


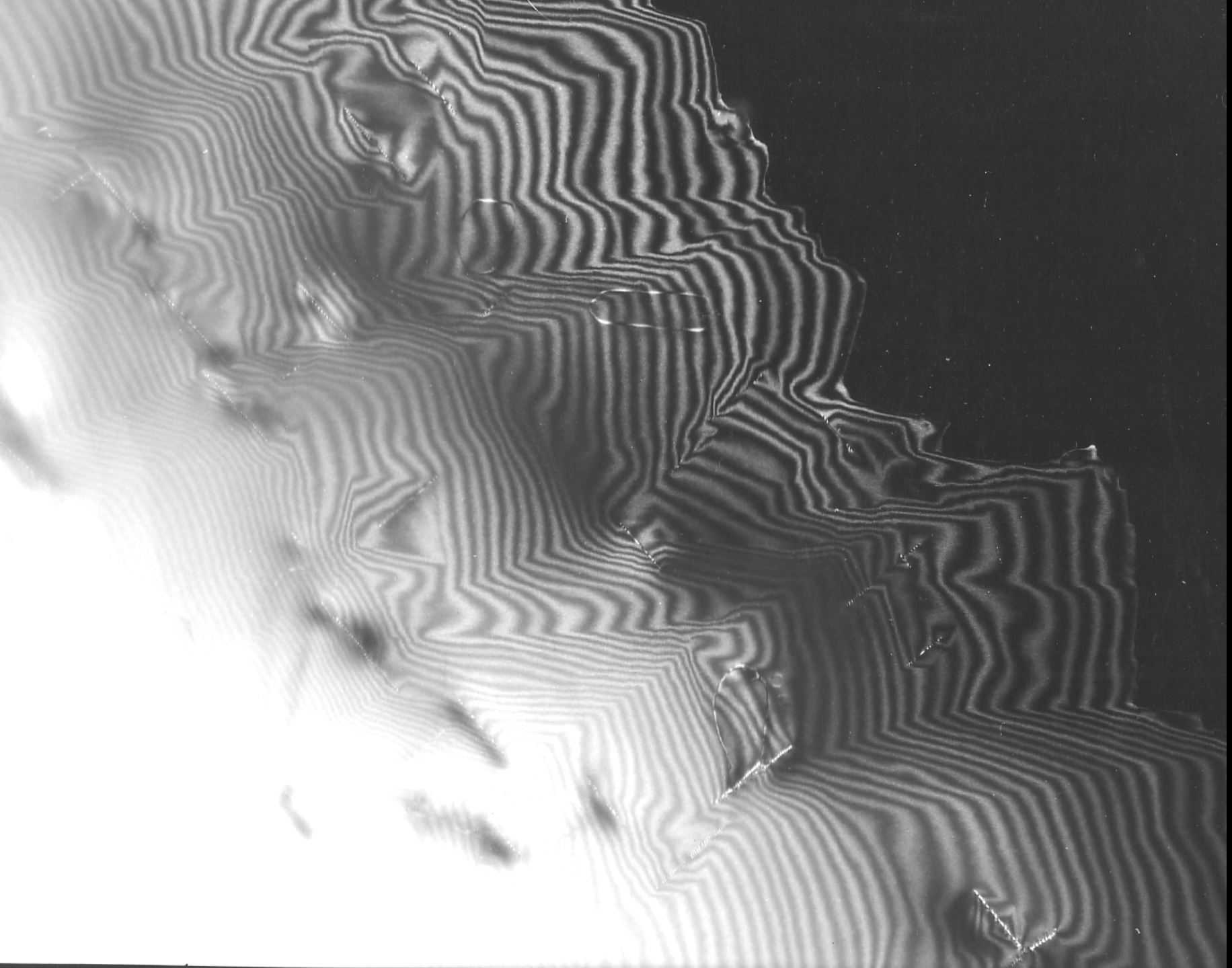


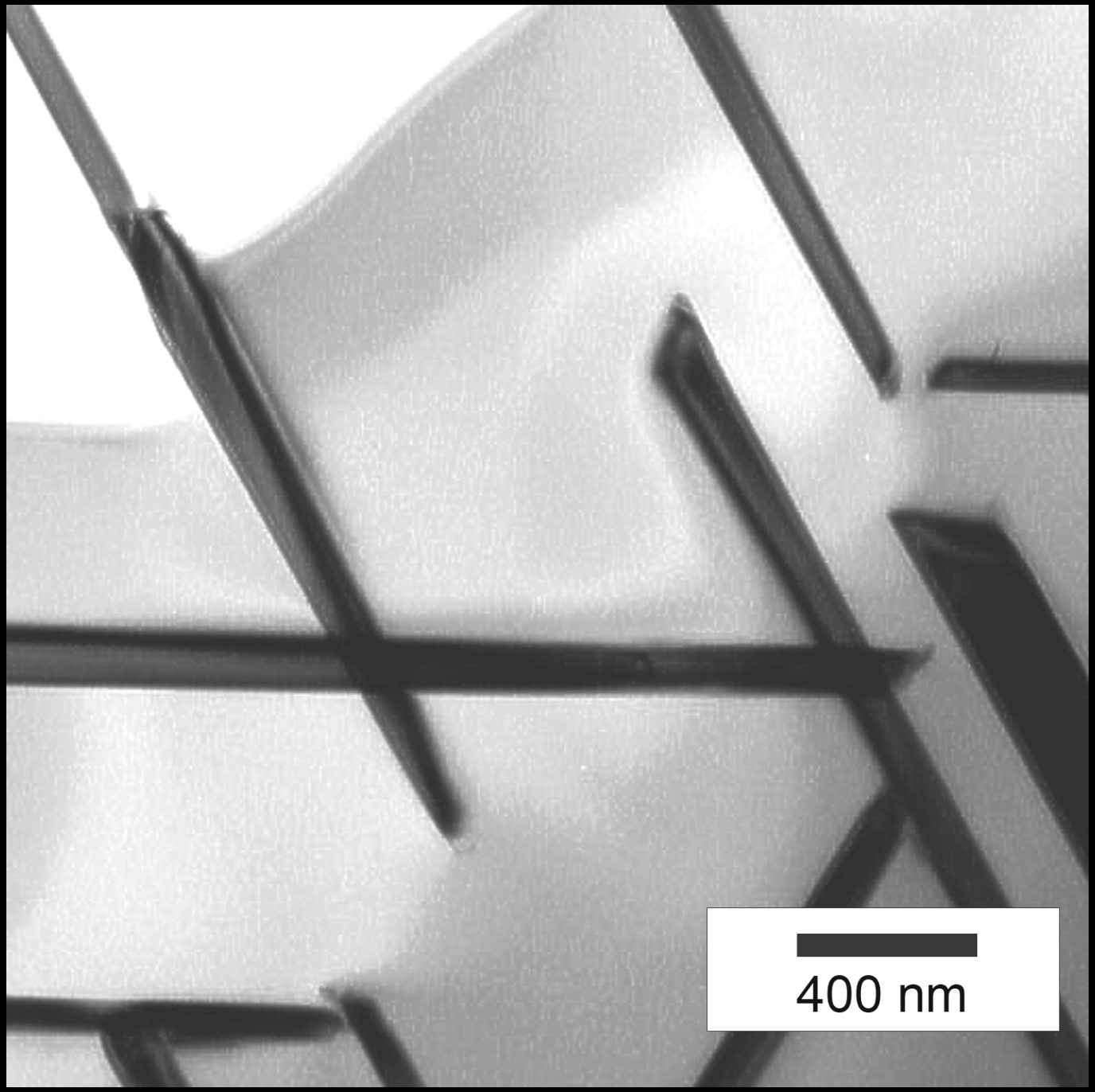

C
B
A
200 nm

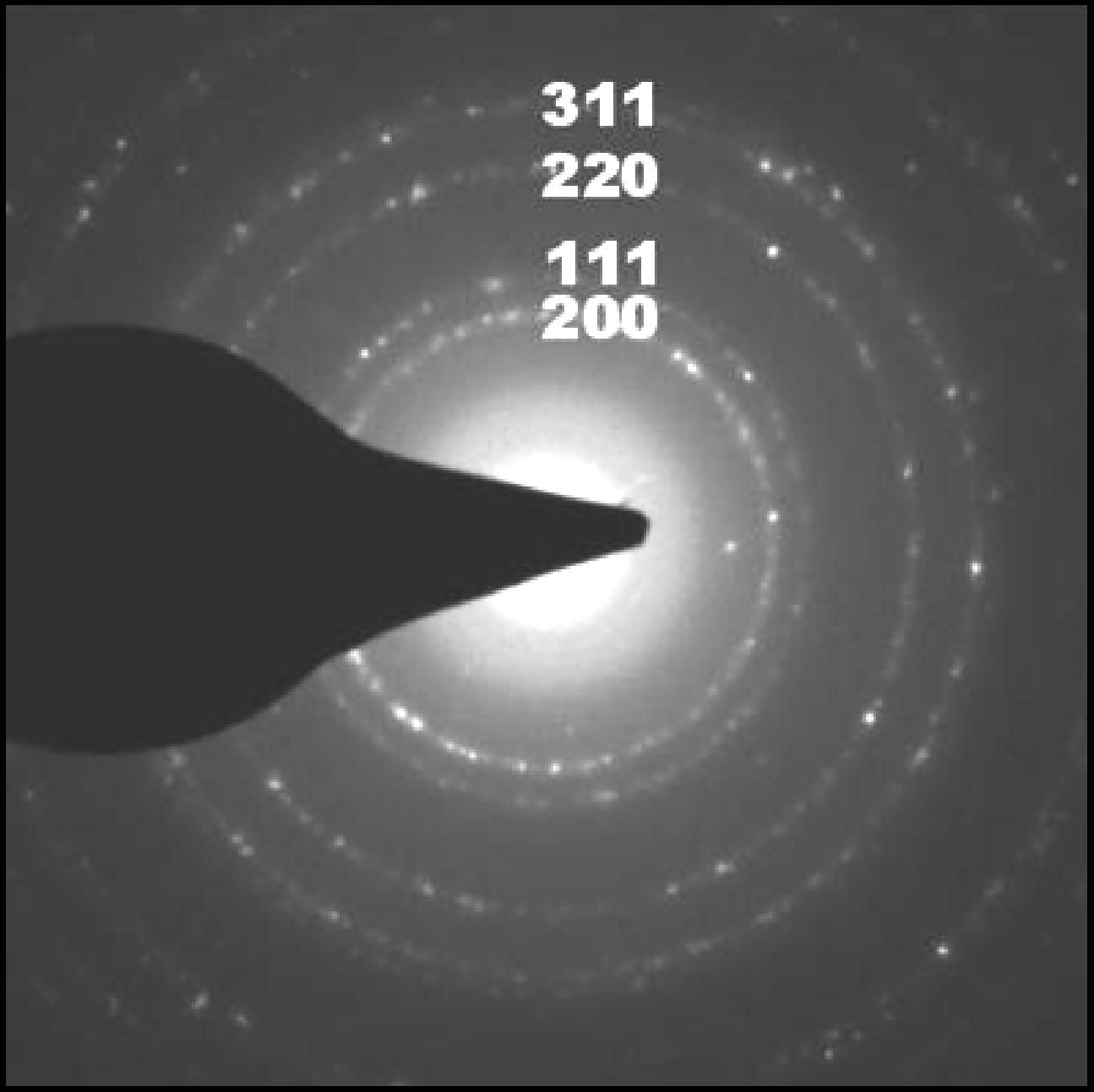

150 nm

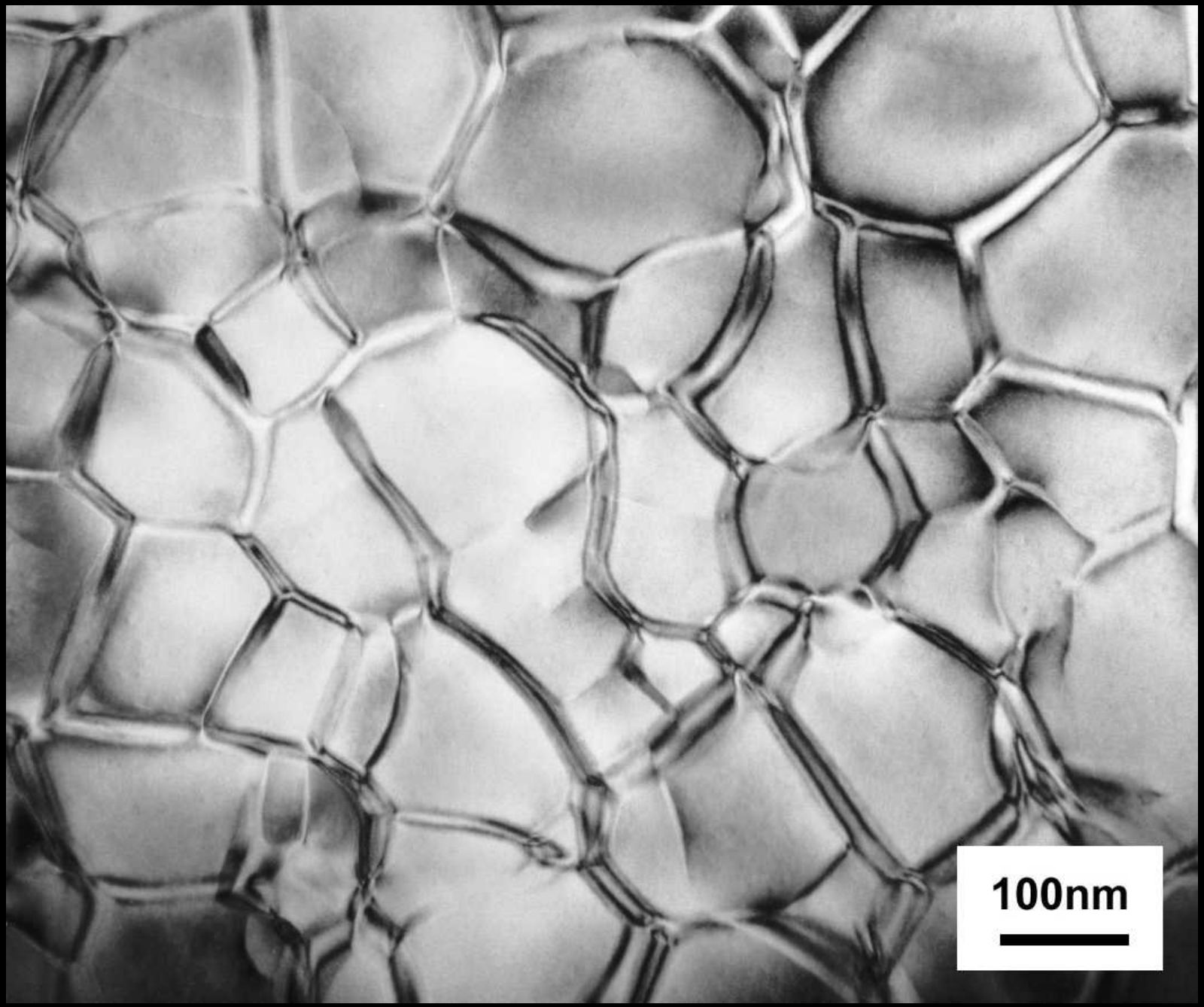


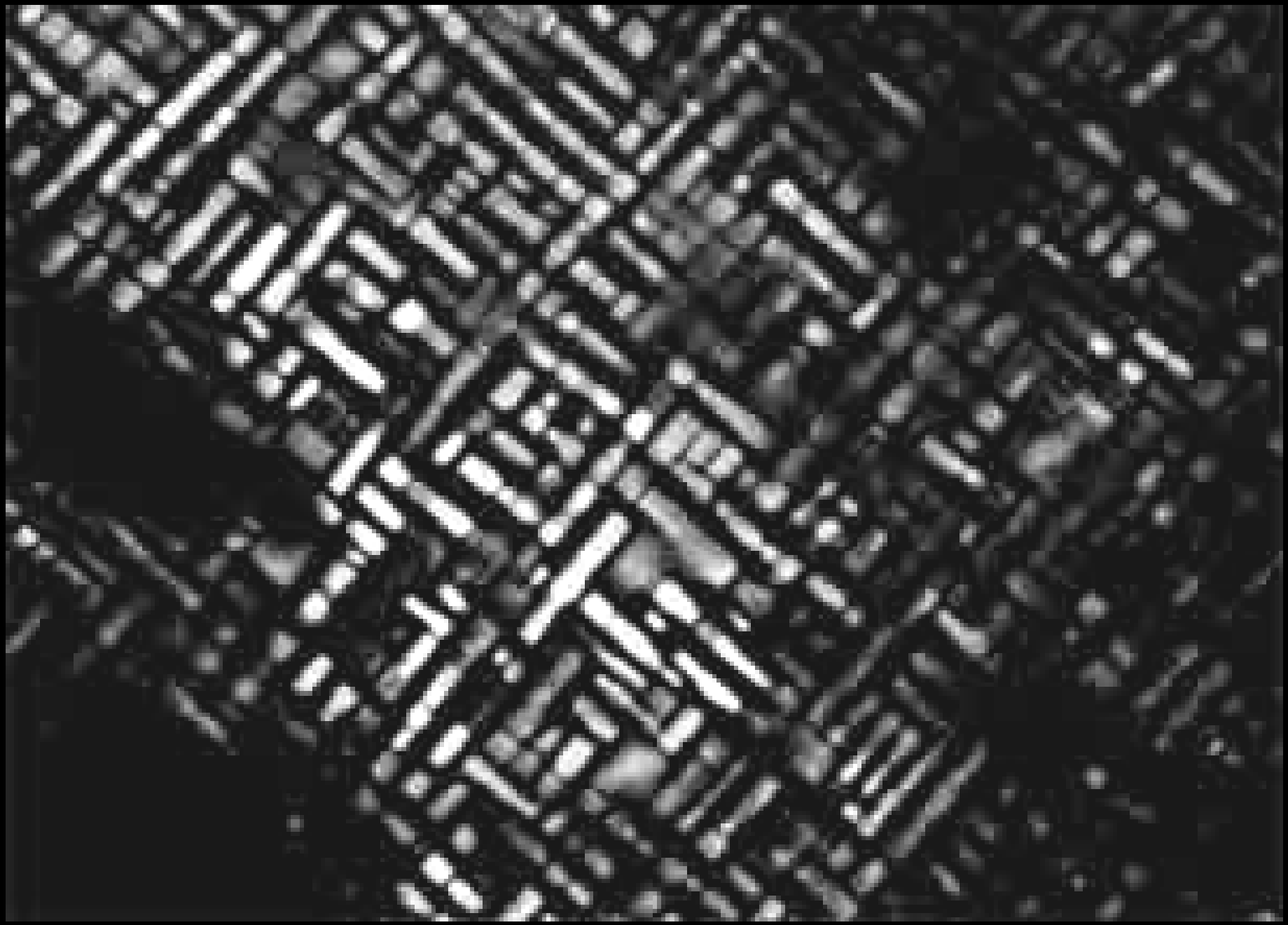

0.25 μm

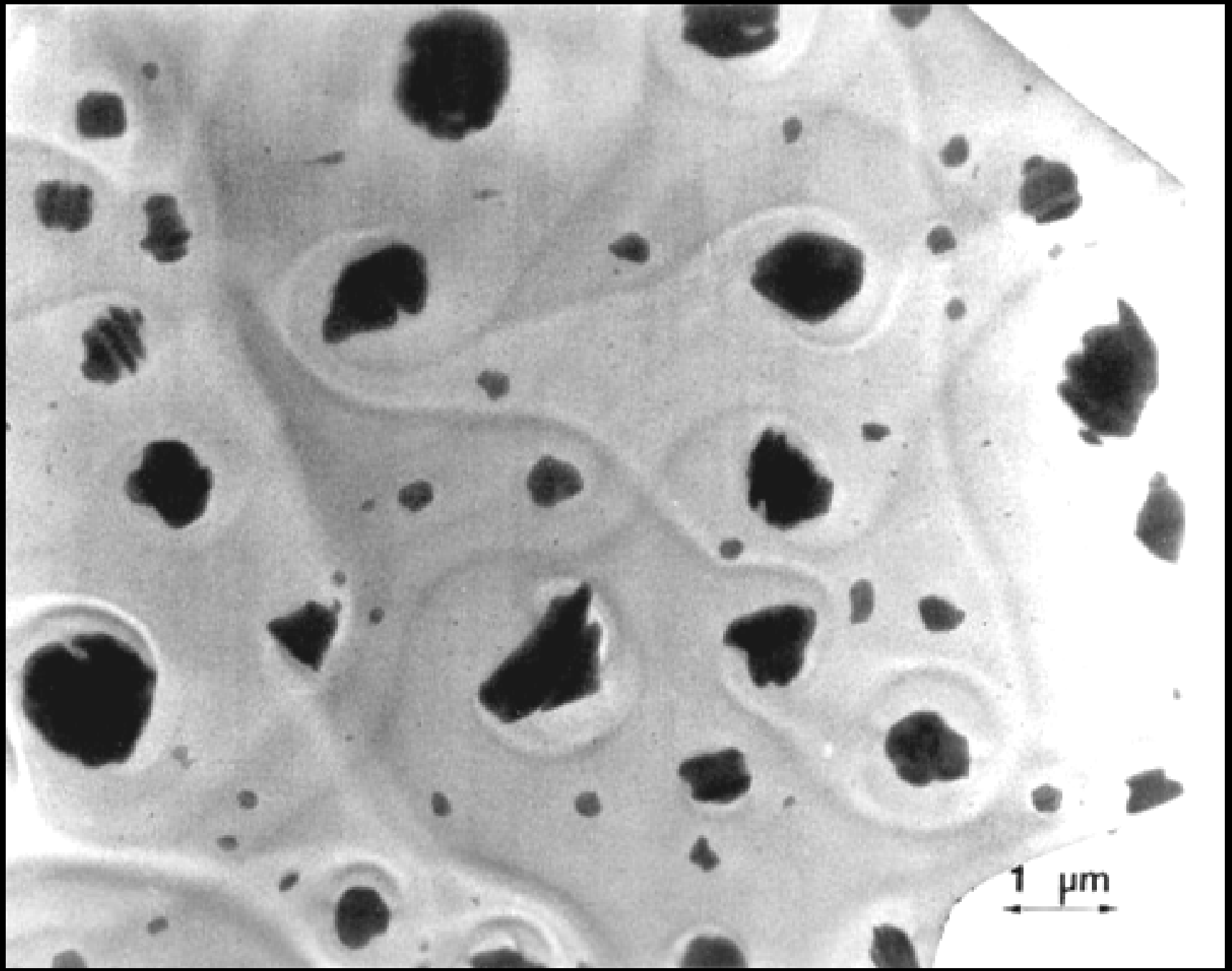


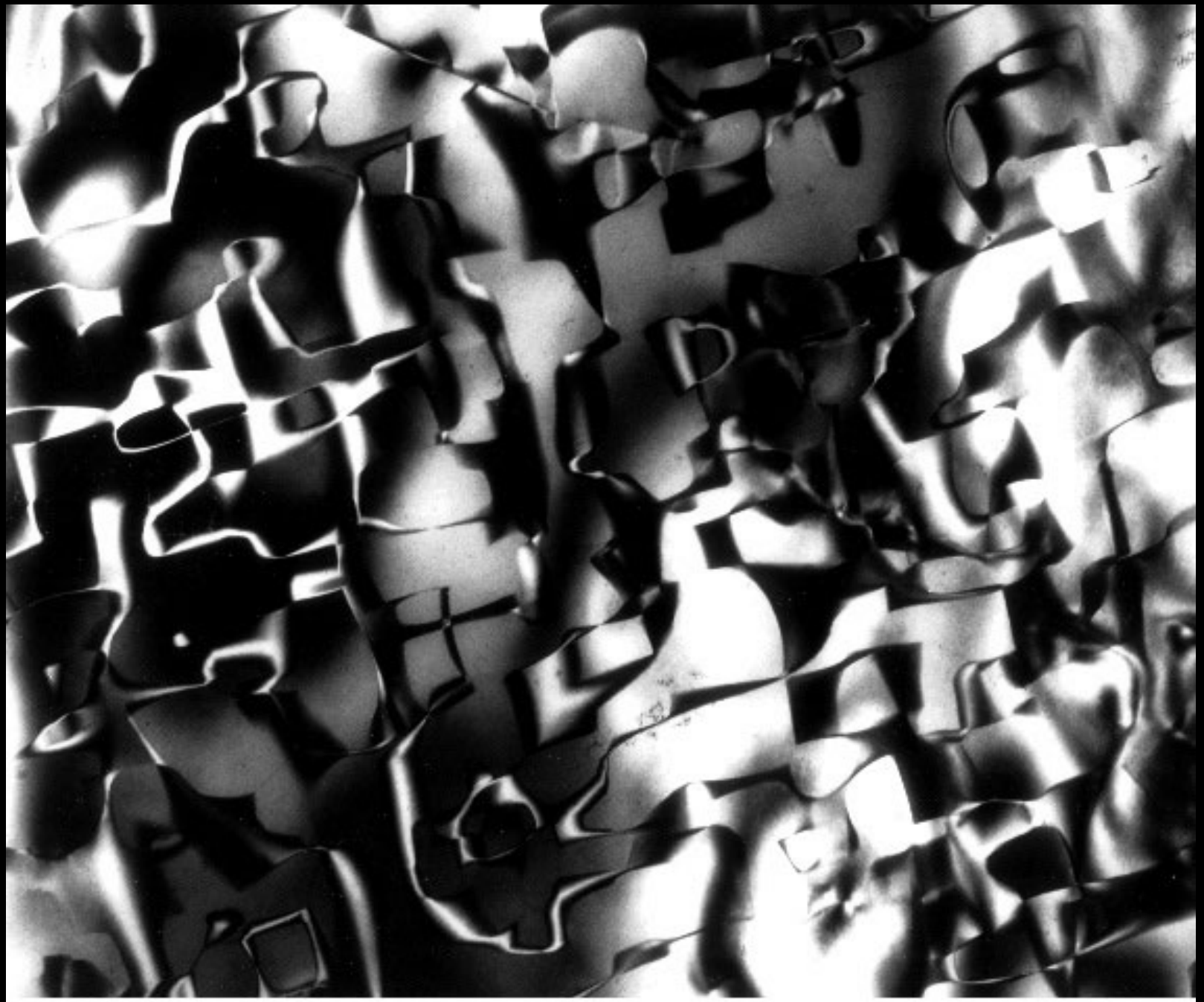

400 nm

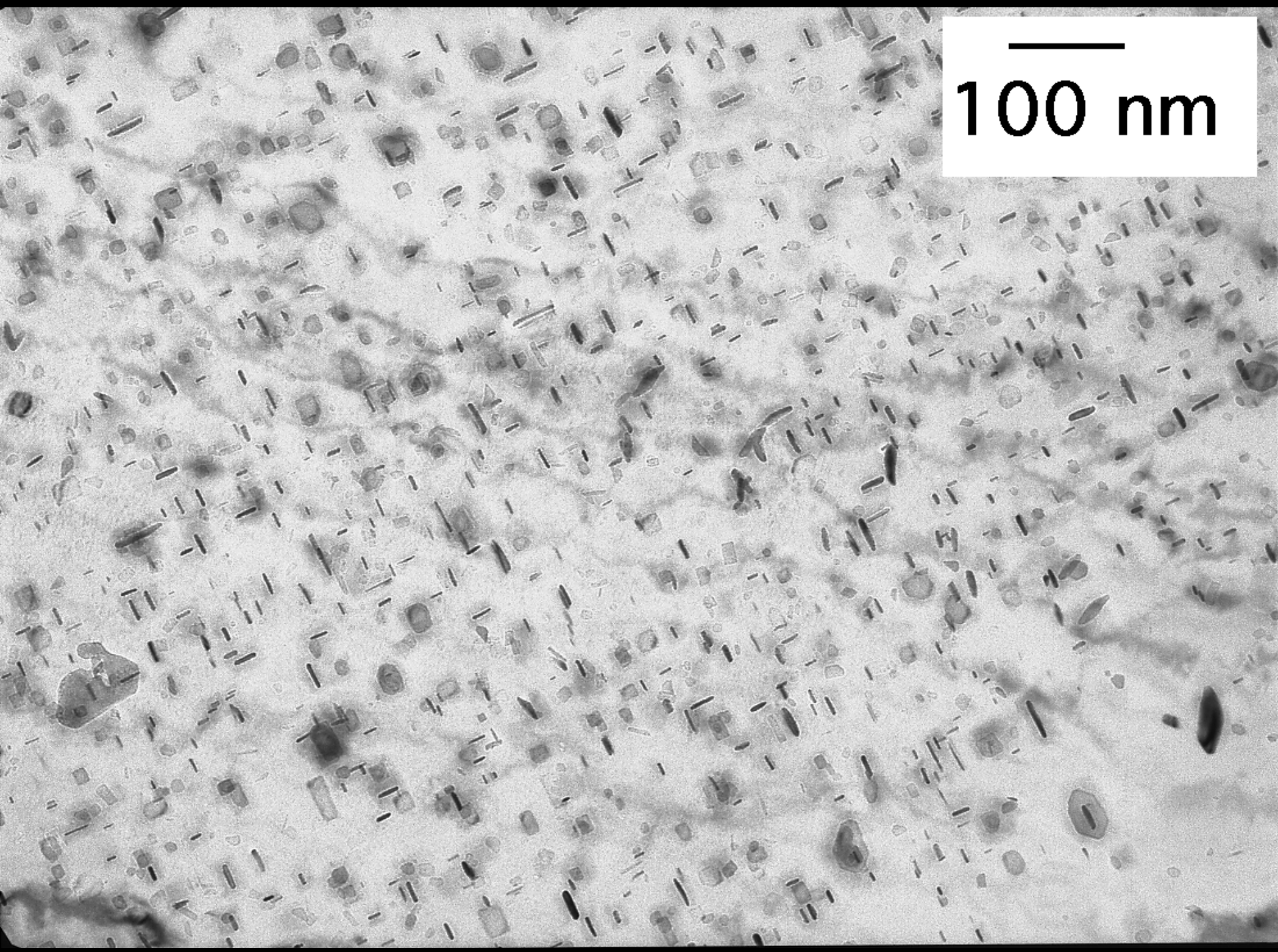

311
220
111
200

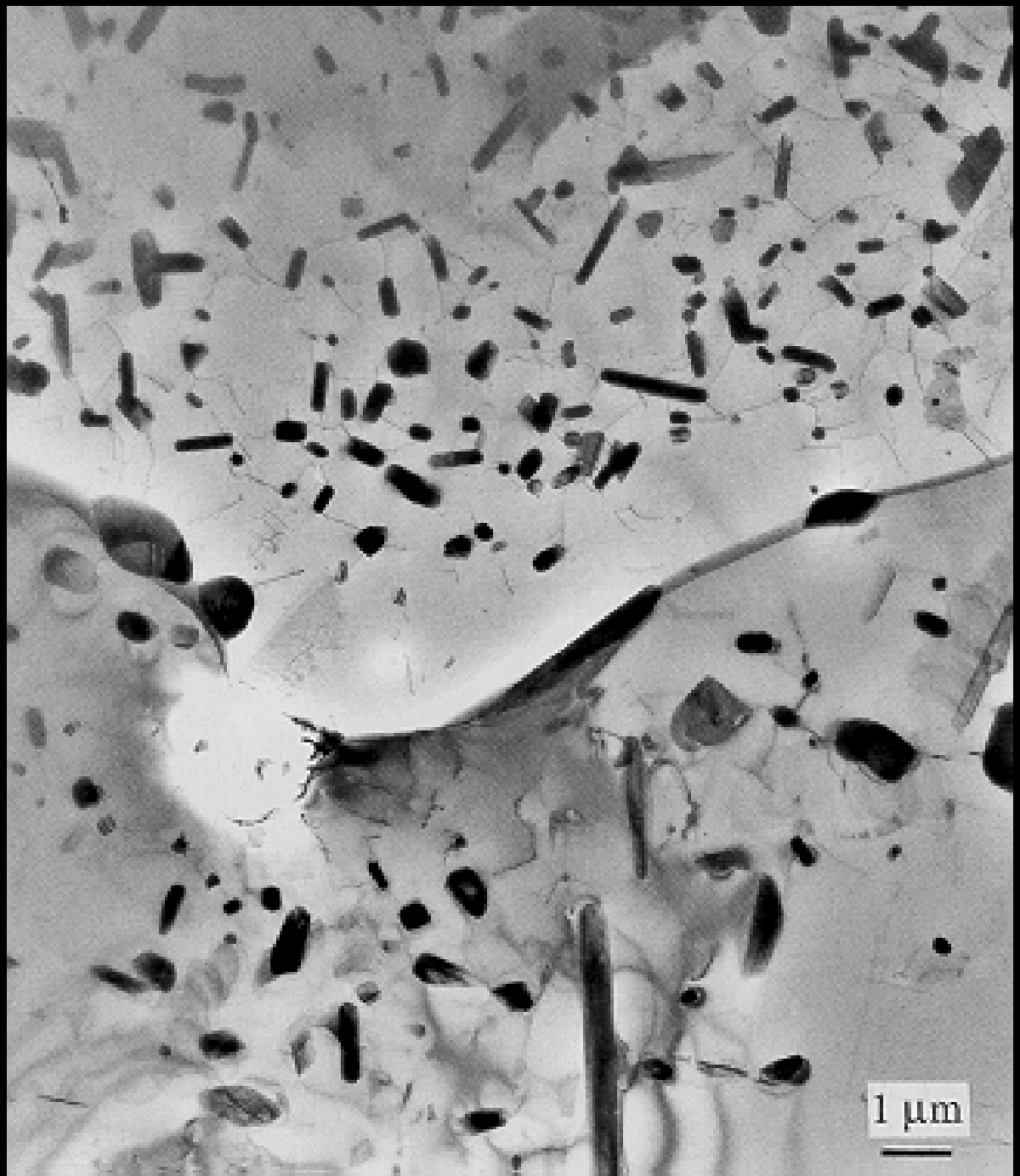

100nm

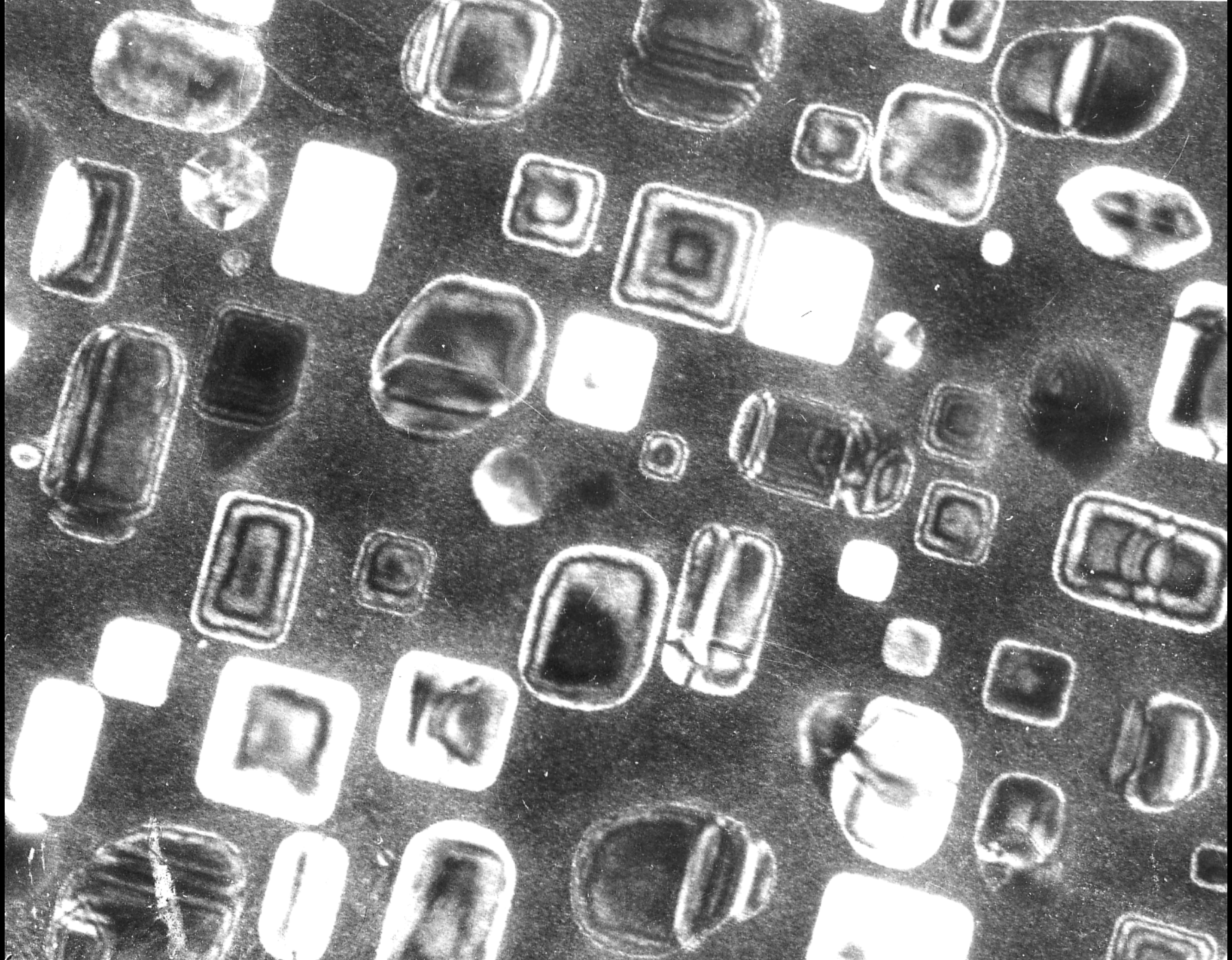



1 µm

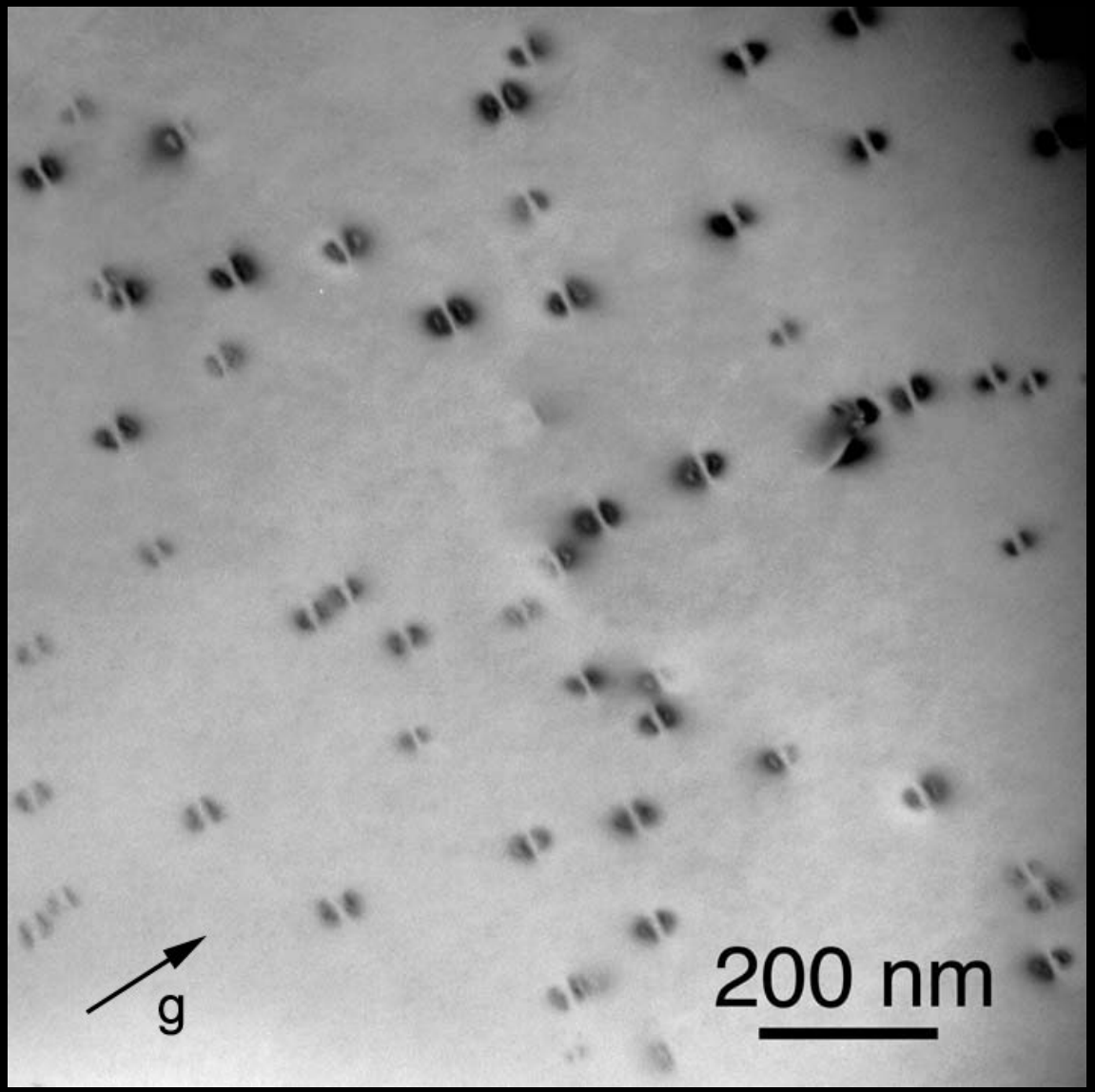



100 nm


1 µm

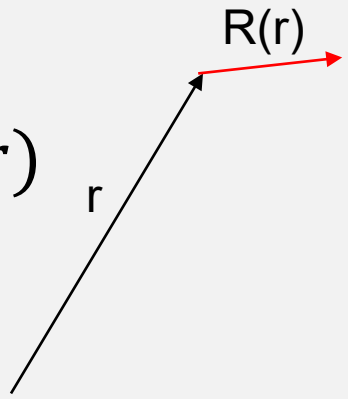


Coherency of Al_3Sc Precipitates[1]



[1]E.A. Marquis, D.N. Seidman, Acta Mater. **49** (2001) 1909-1919.

Defects

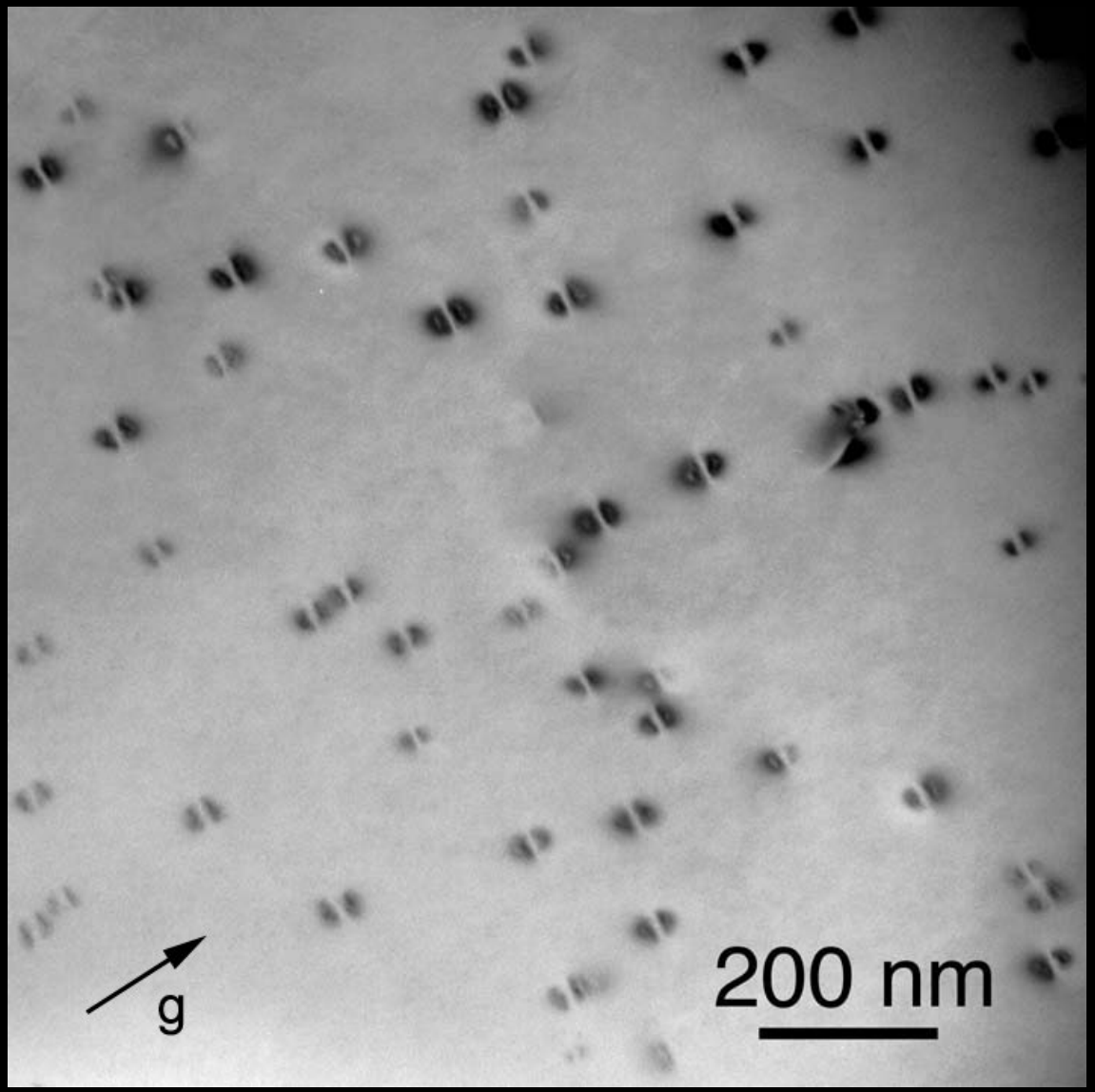


- Fourier series $V(r) = \sum V_g \exp(2\pi i g.r)$
- Defect, position r → R(r)
- $V(r+R) = \sum V_g \exp(2\pi i g.(r+R))$
- $V(r+R) = \sum V_g \exp(2\pi i g.r) \exp(2\pi i g.R)$
- If g.R=0, $V(r+R) = V(r)$ → No contrast

Quick Summary

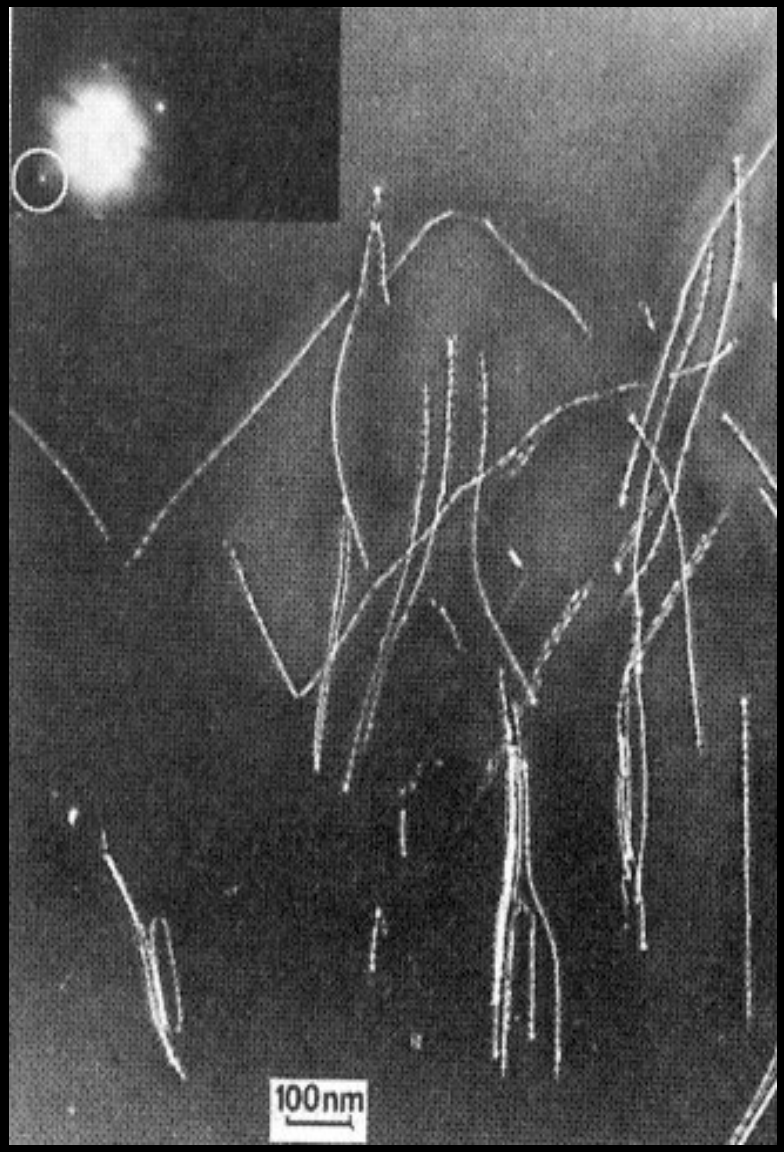
- Diffraction Contrast
  - $|\mathrm{Sin}(\pi t s_z)/\pi s_z|^2$ in DF, 1- in BF
  - Change of t or s_z gives thickness/bend contours
  - Width of features scales as $1/s_z$
  - Contrast scales as $1/s_z$
  - Which spots are in aperture matters
  - Change of s_z due to strain – g.R term

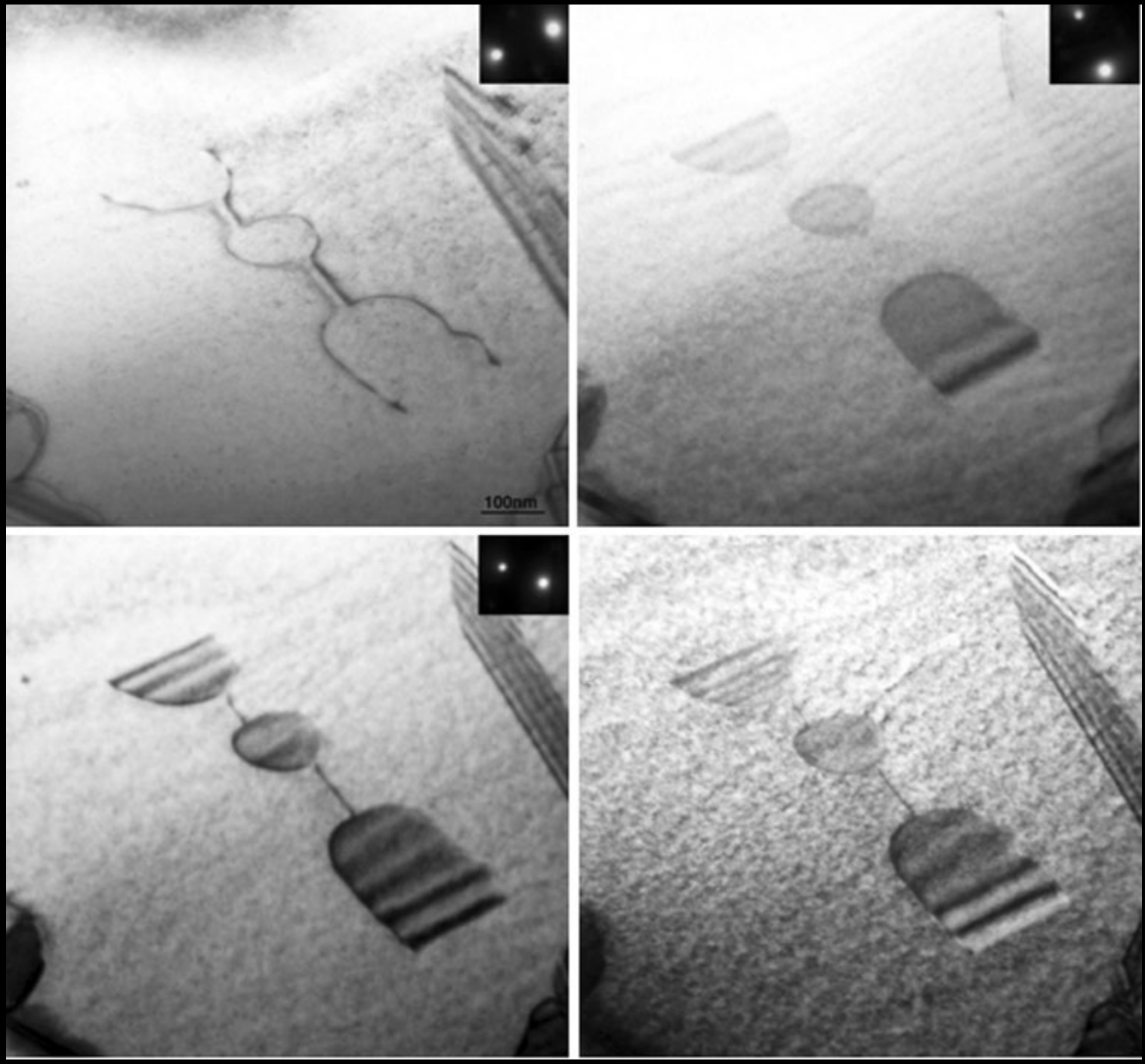
Coherency of Al_3Sc Precipitates[1]

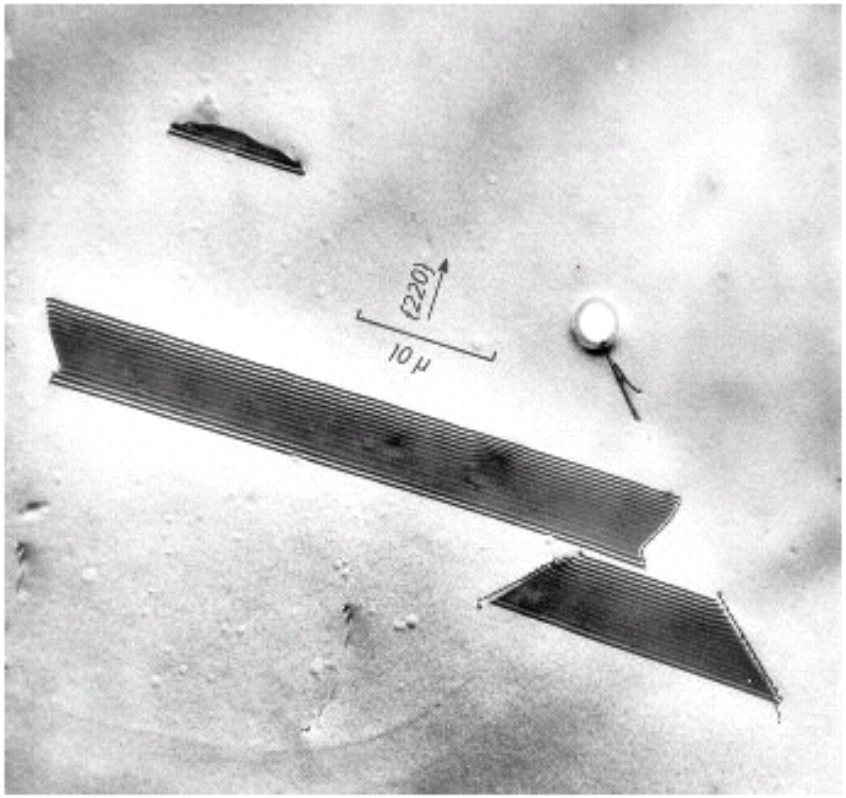


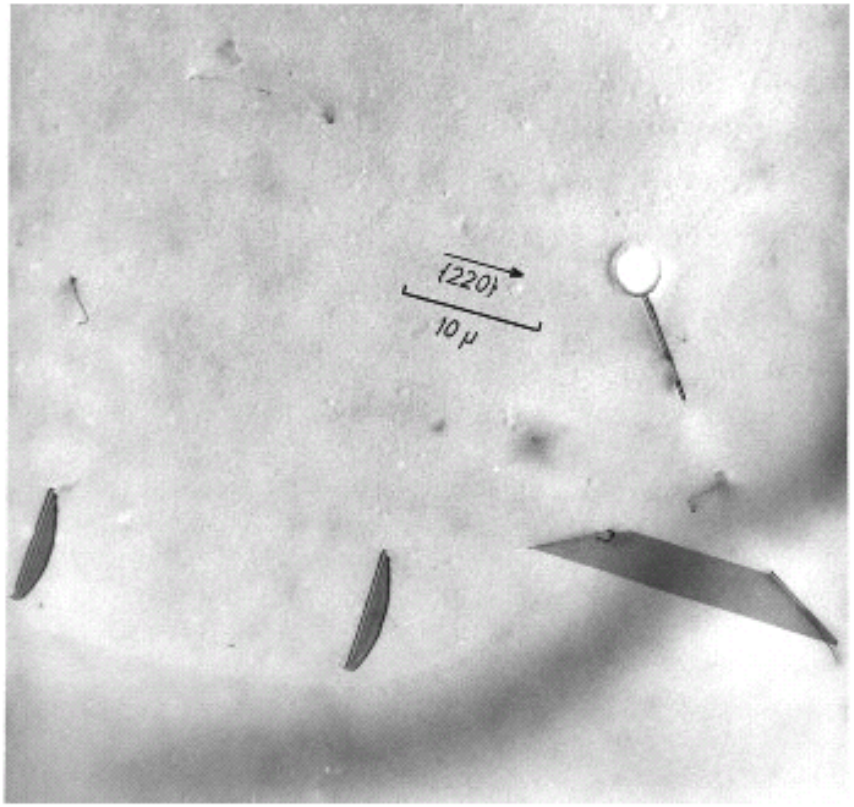
[1]E.A. Marquis, D.N. Seidman, Acta Mater. **49** (2001) 1909-1919.

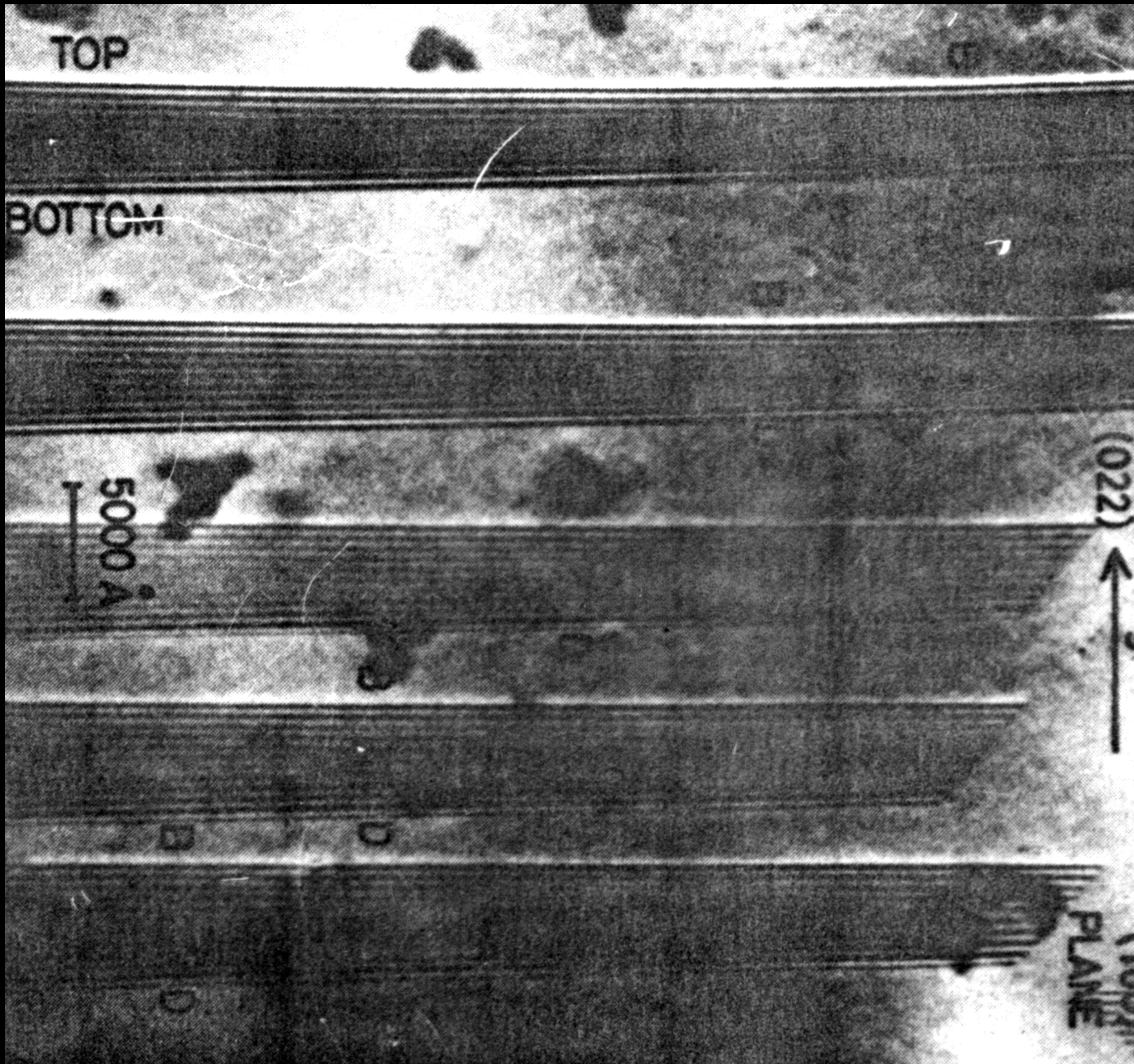

100nm

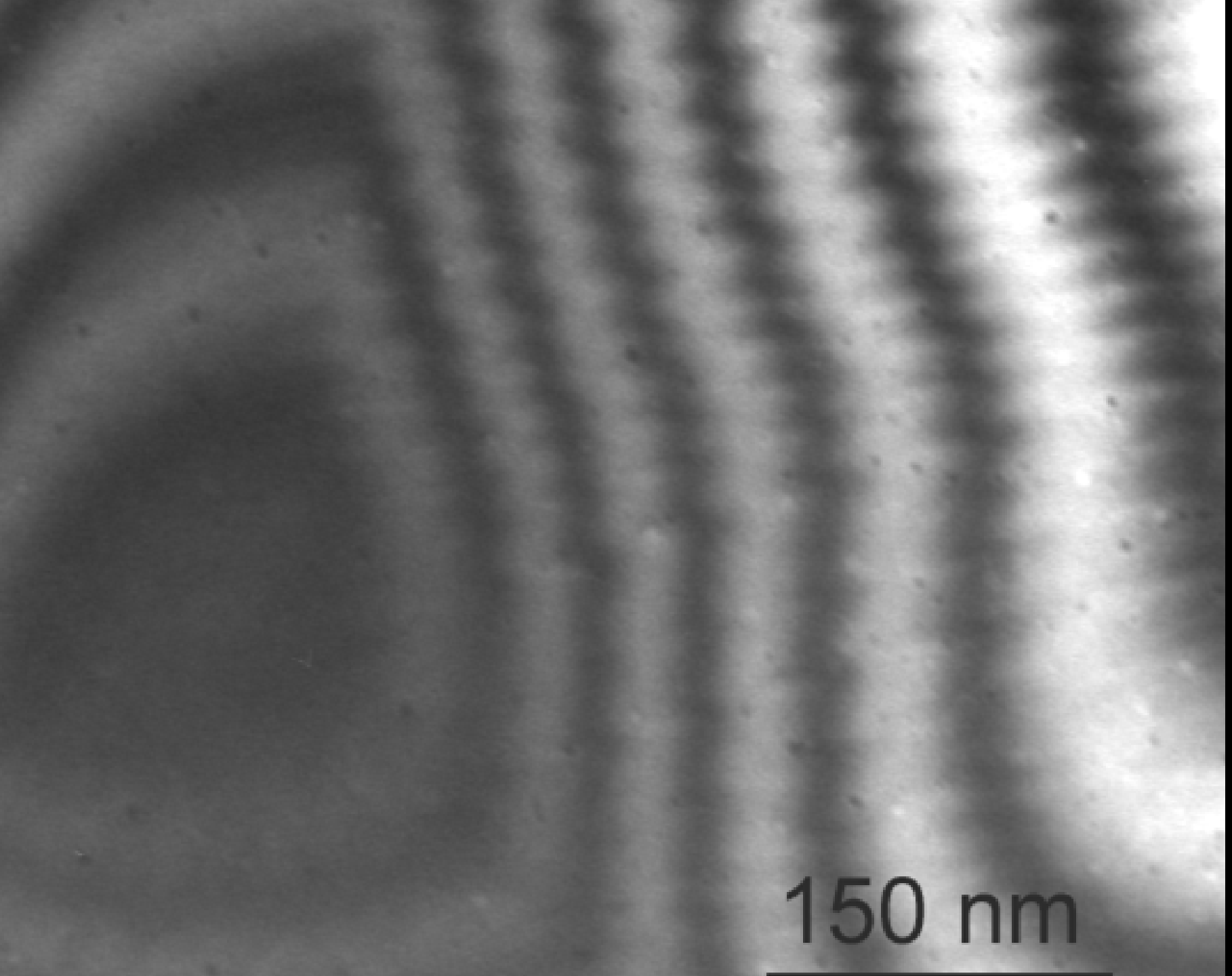

100nm

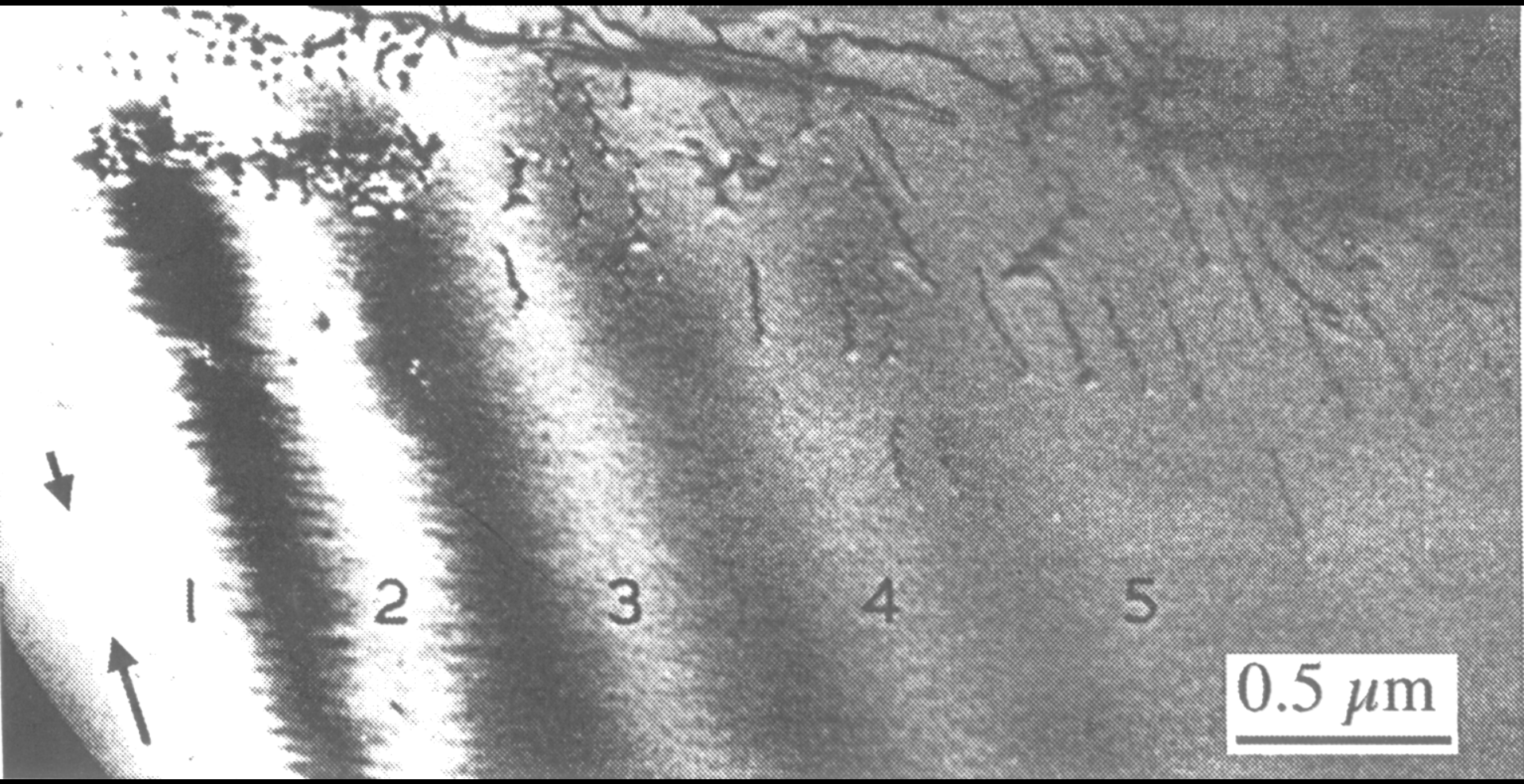

100nm


(220)
10 μ

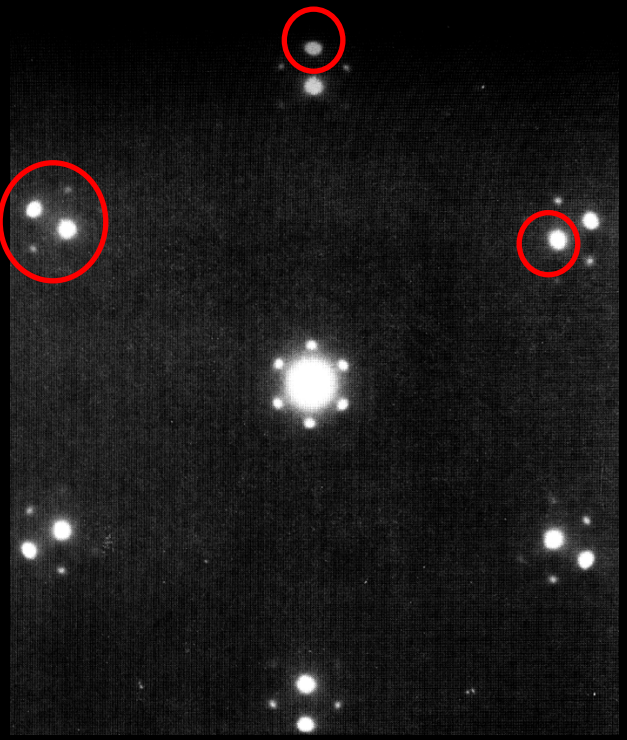

(220)
10 μ

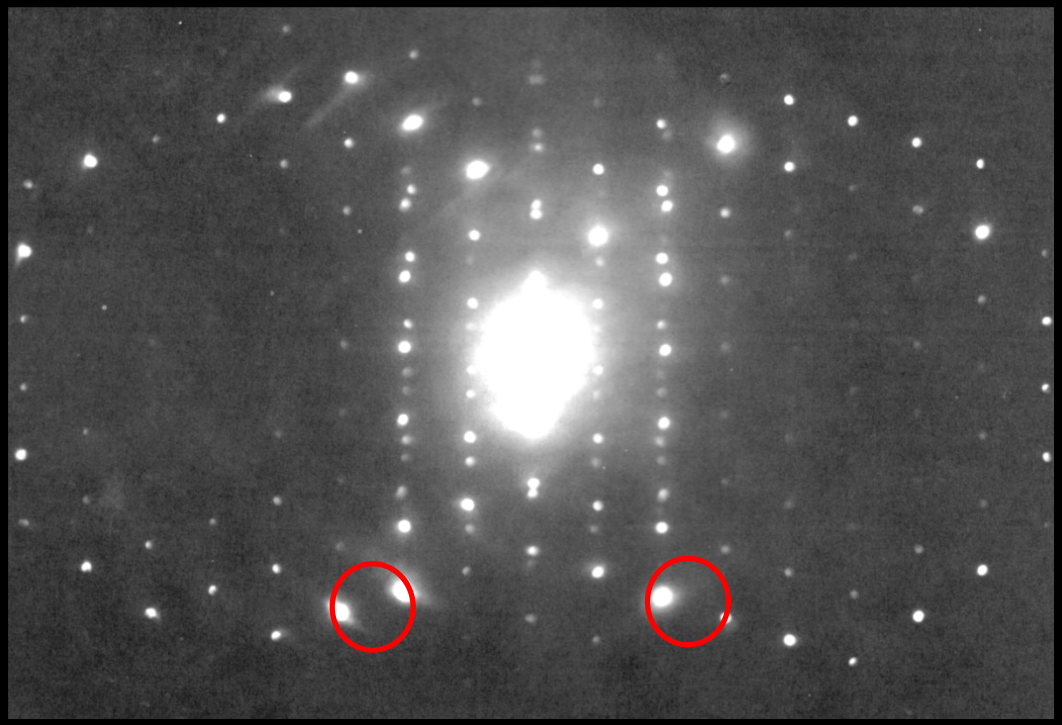

TOP
BOTTOM
5000 Å
(02$\bar{2}$)
g
(100) PLANE


150 nm


1
2
3
4
5
0.5 μm

Apertures at different locations will give different images





Moire Patterns See Wolfram Demo Page

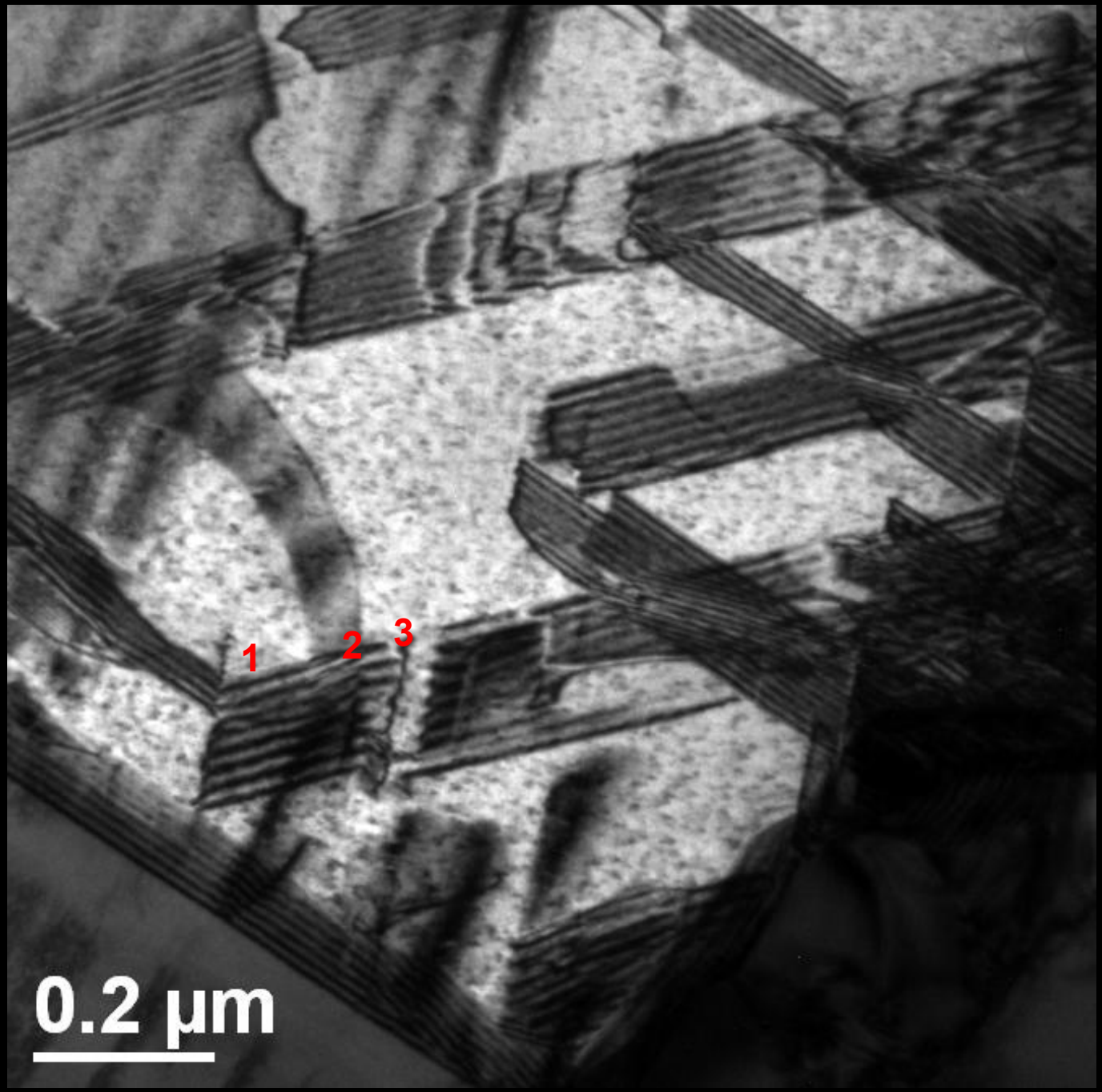
1D Case

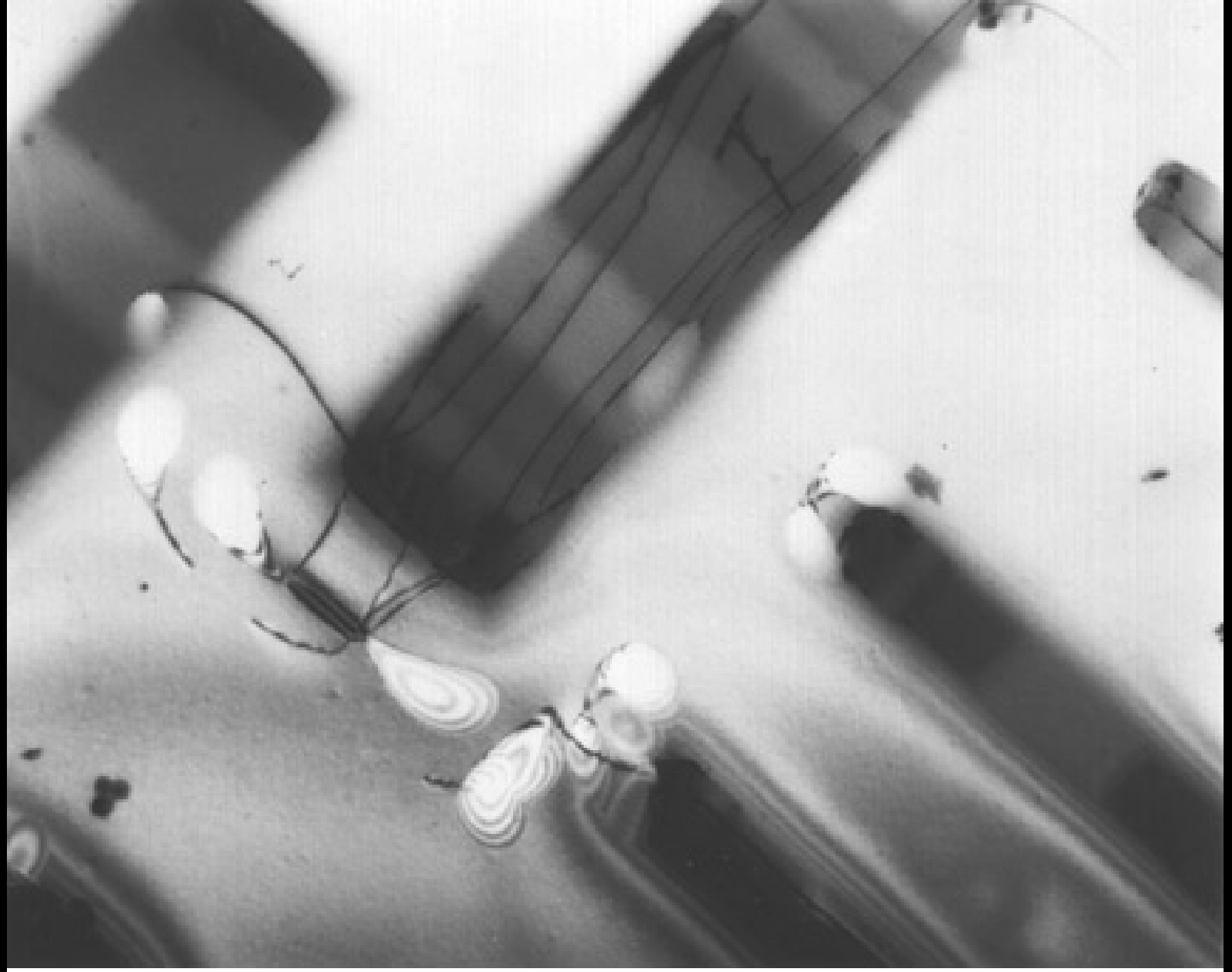
MoirePatternOfTwoStraightLinePatterns.nbp

2D Case

MoirePatterns.nbp


200 nm


1
2
3
0.2 µm

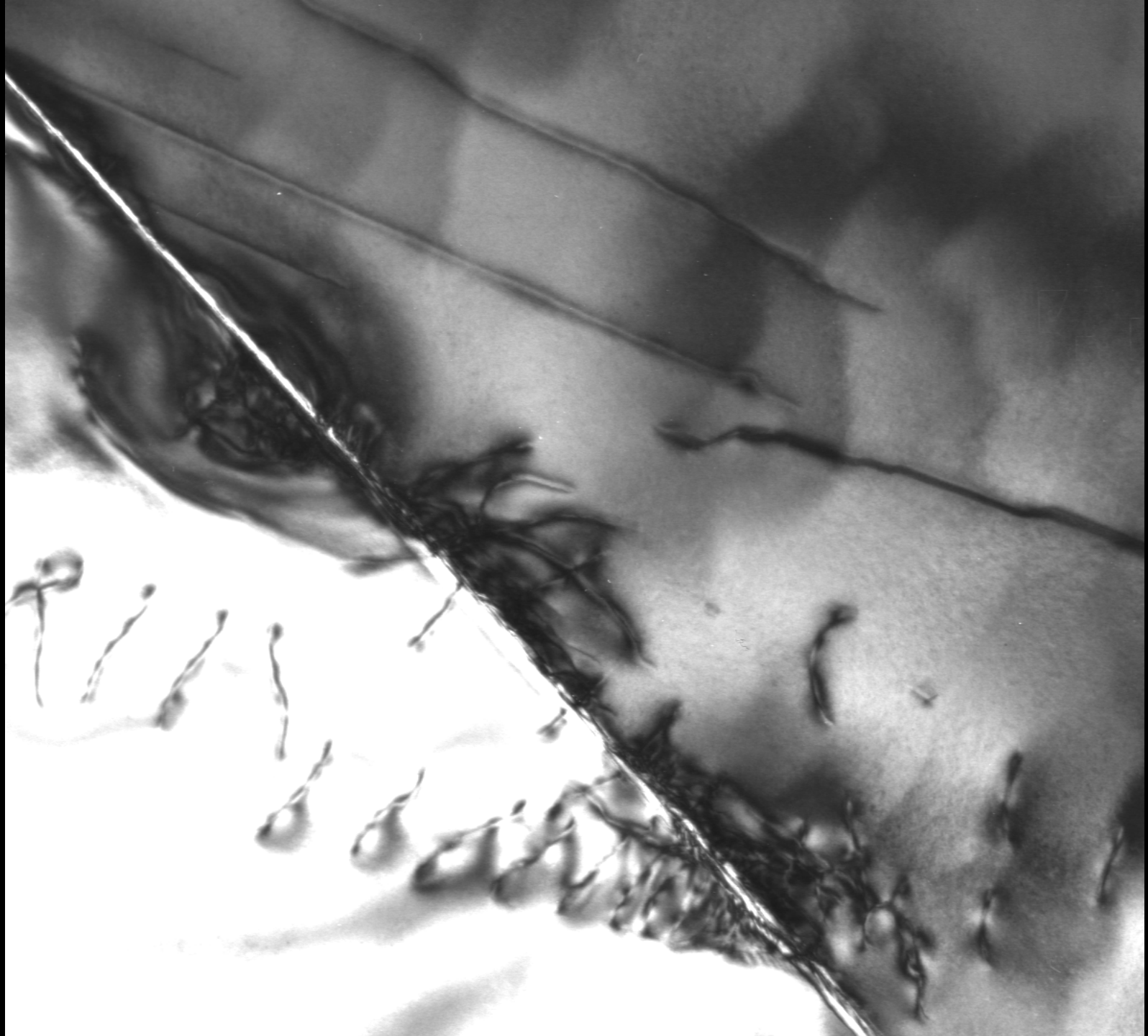


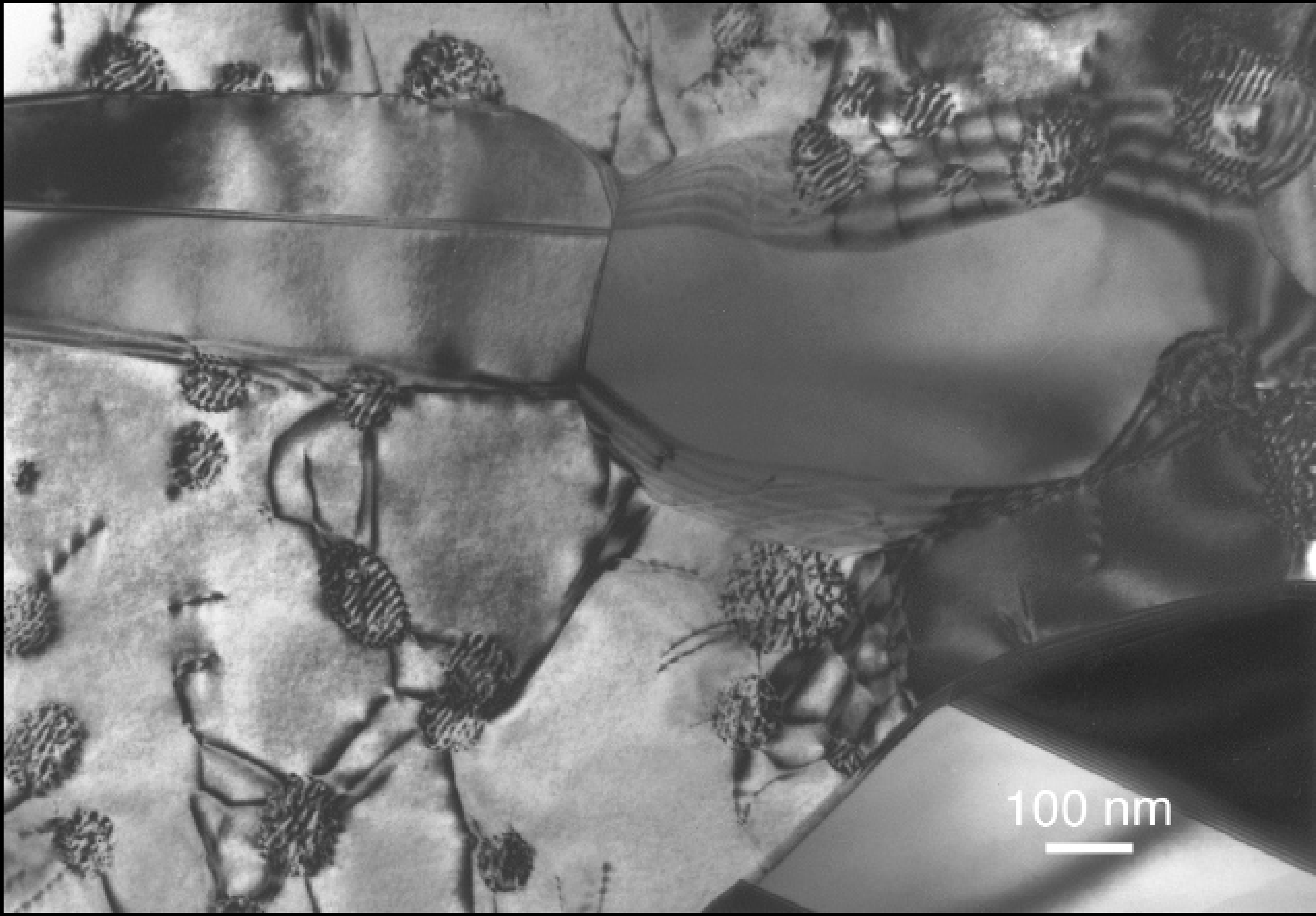
High voltage micrograph of aluminum contact lines on silicon device showing failure due to

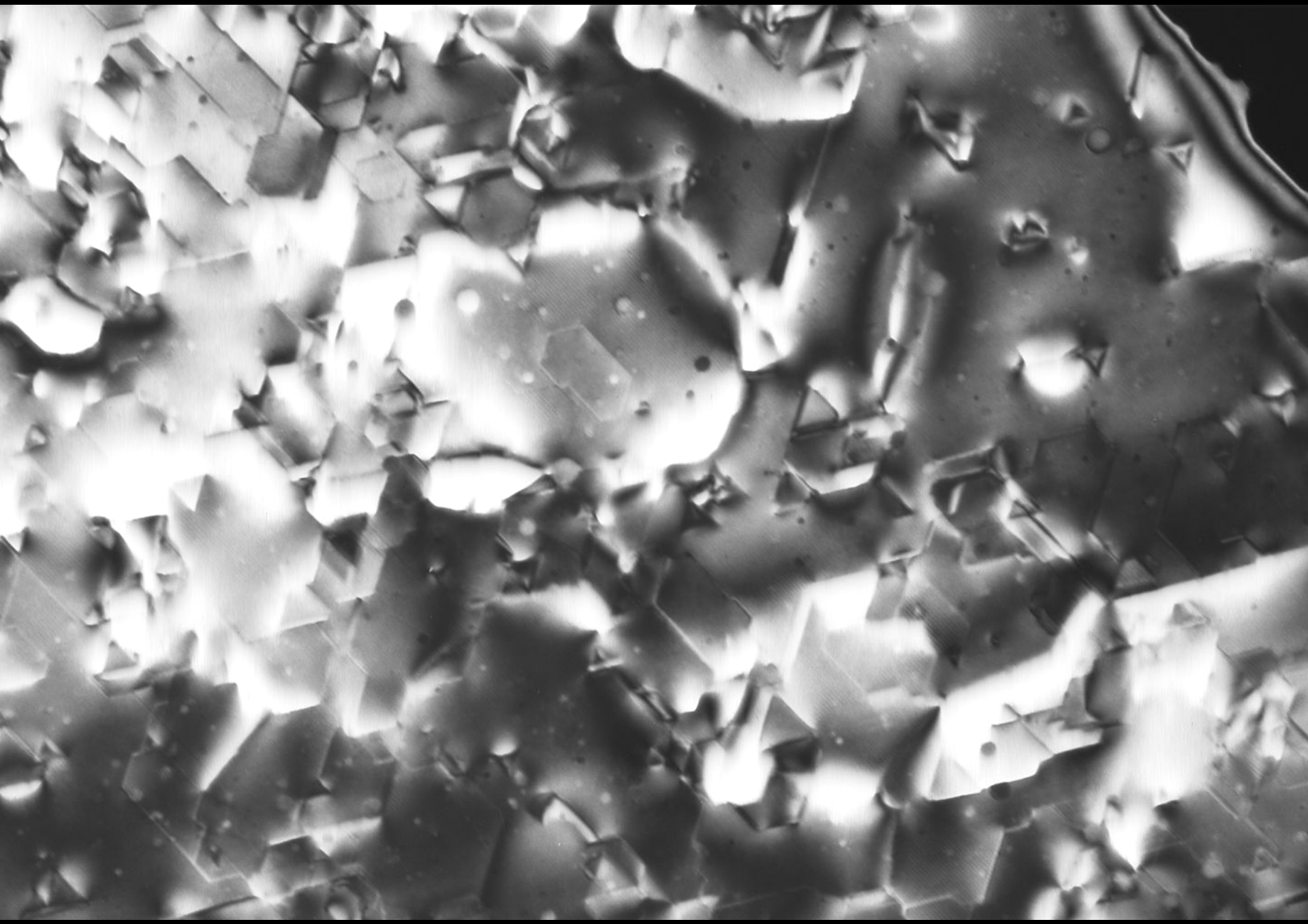
Quick Summary

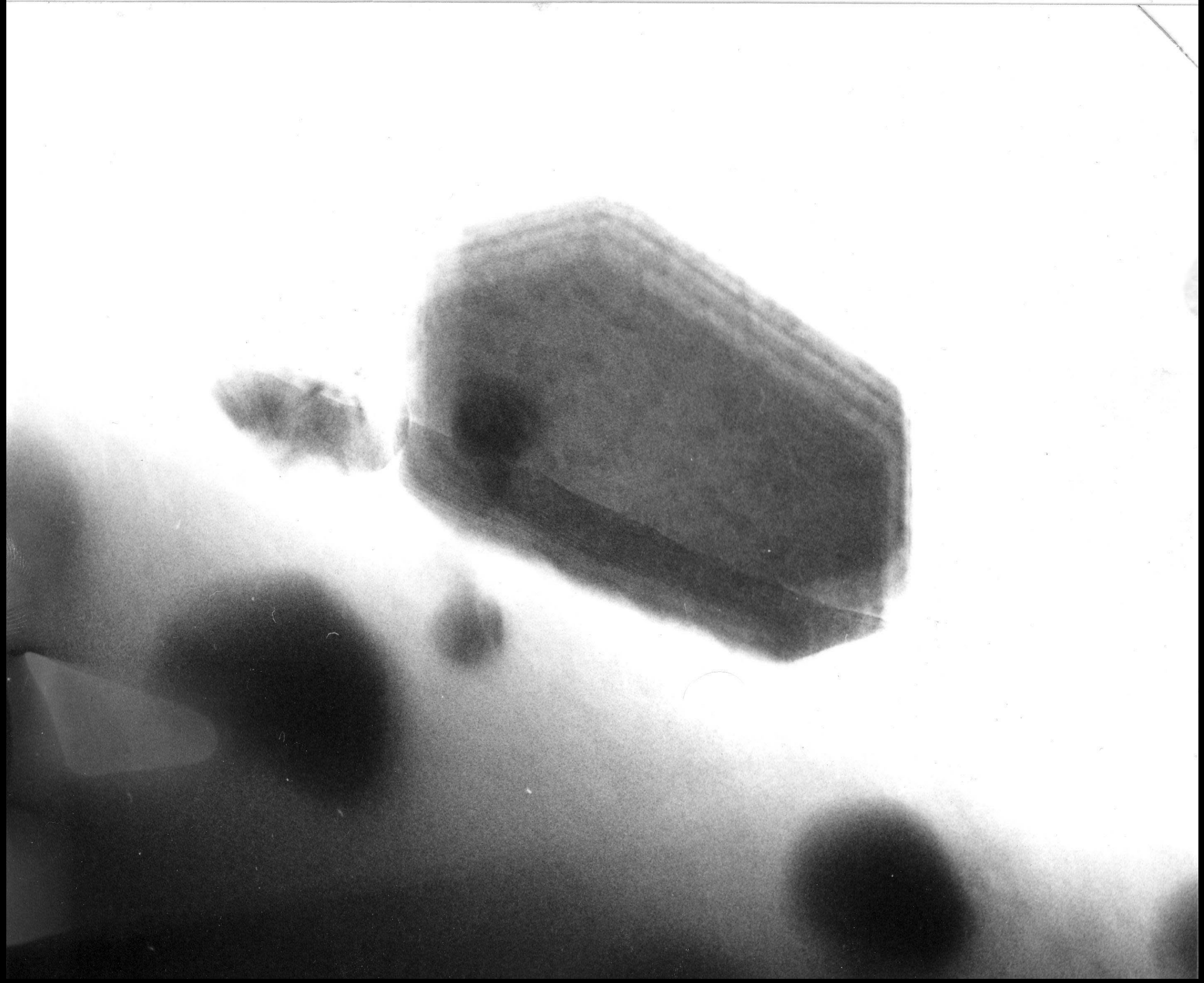
- Diffraction Contrast
  - $|\mathrm{Sin}(\pi t s_z)/\pi s_z|^2$ in DF, 1- in BF
  - Change of t or s_z gives thickness/bend contours
  - Change of s_z due to strain – g.R term
  - Width of features scales as $1/s_z$
  - Contrast scales as $1/s_z$
  - Which spots are in aperture matters

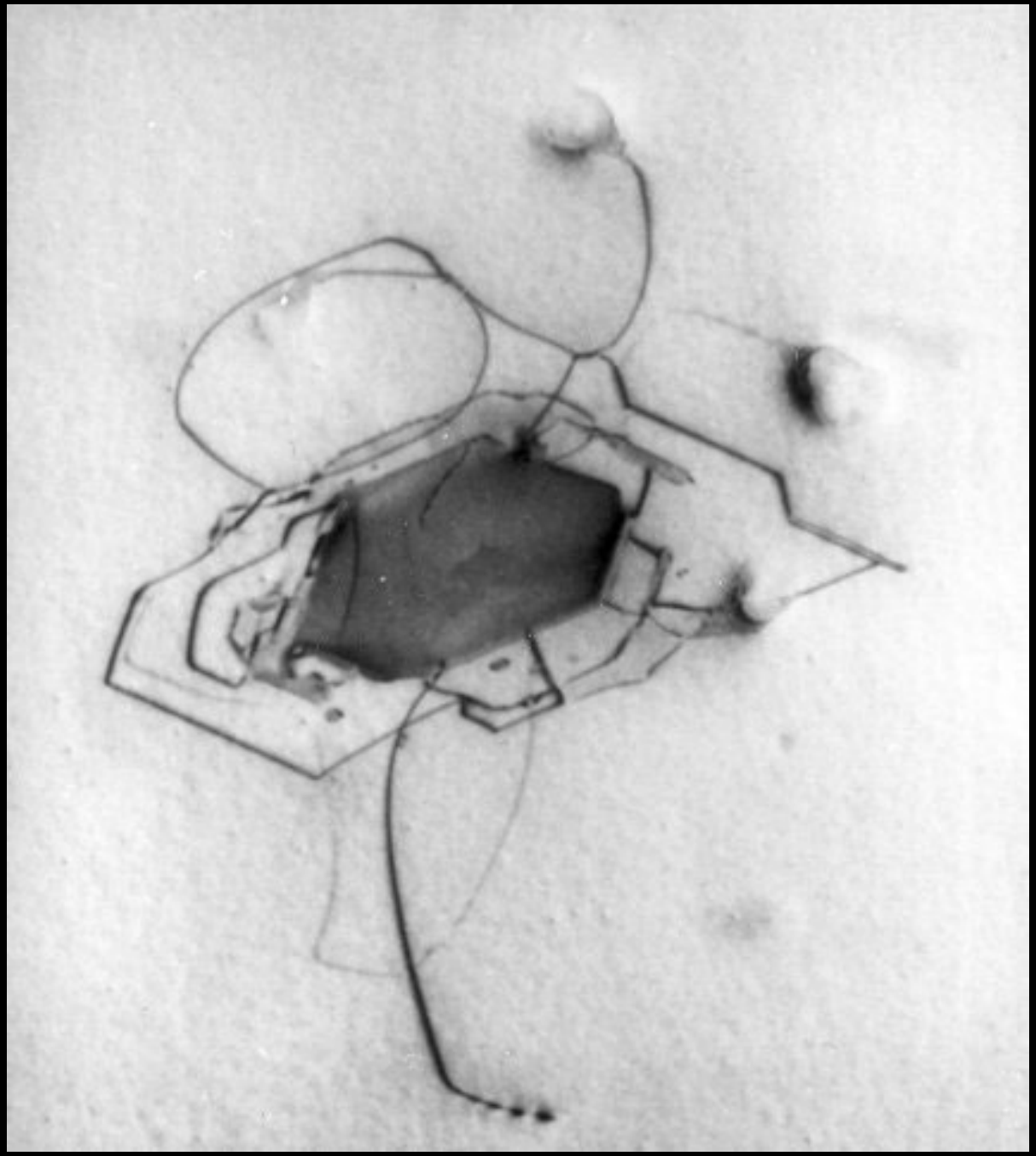
- Extra Slides if needed….

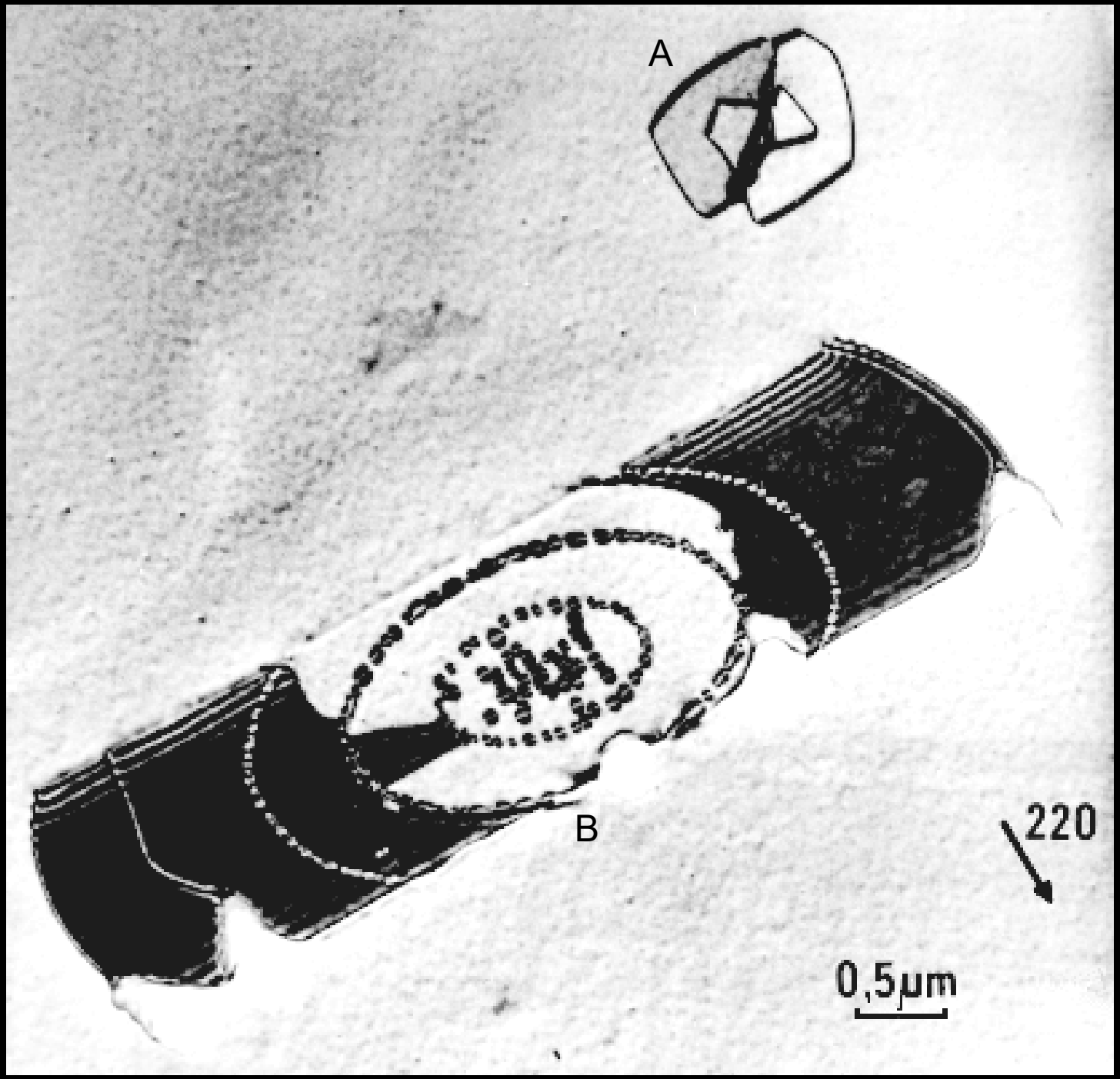


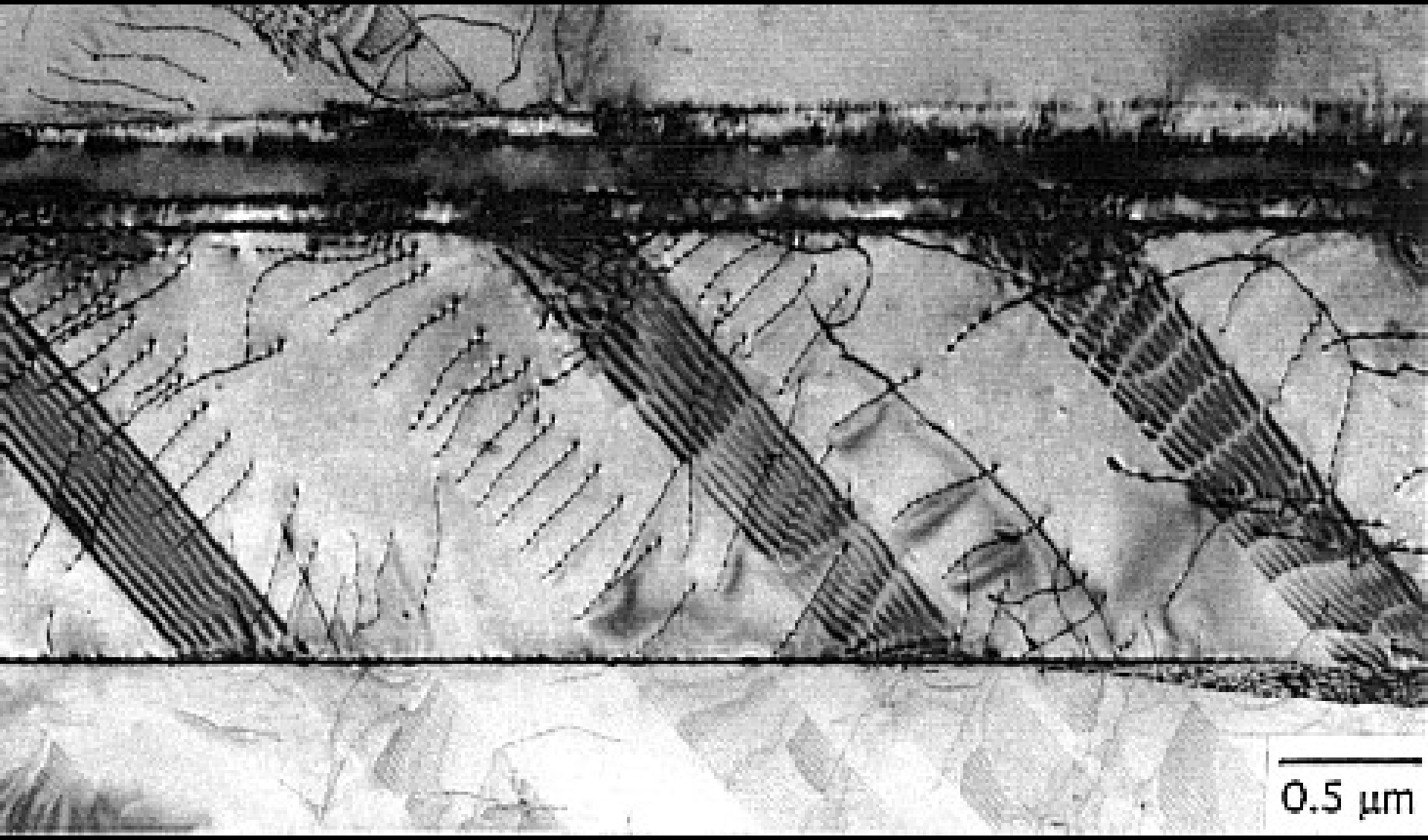

100 nm

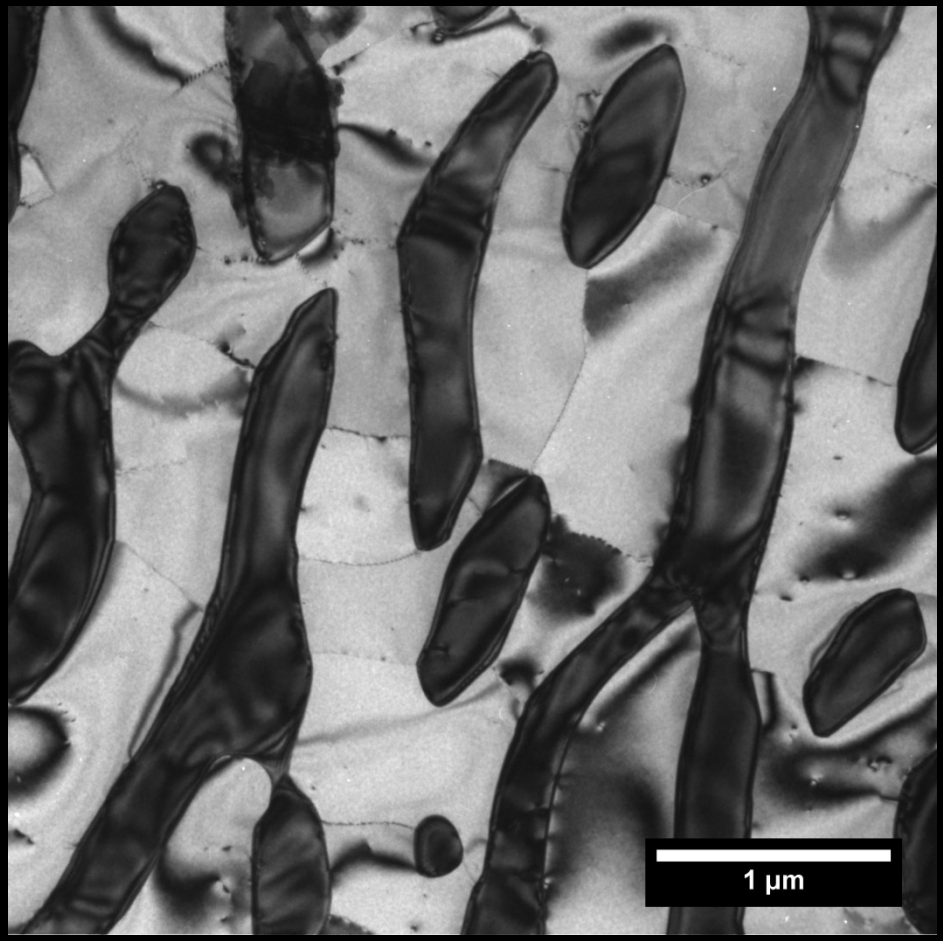


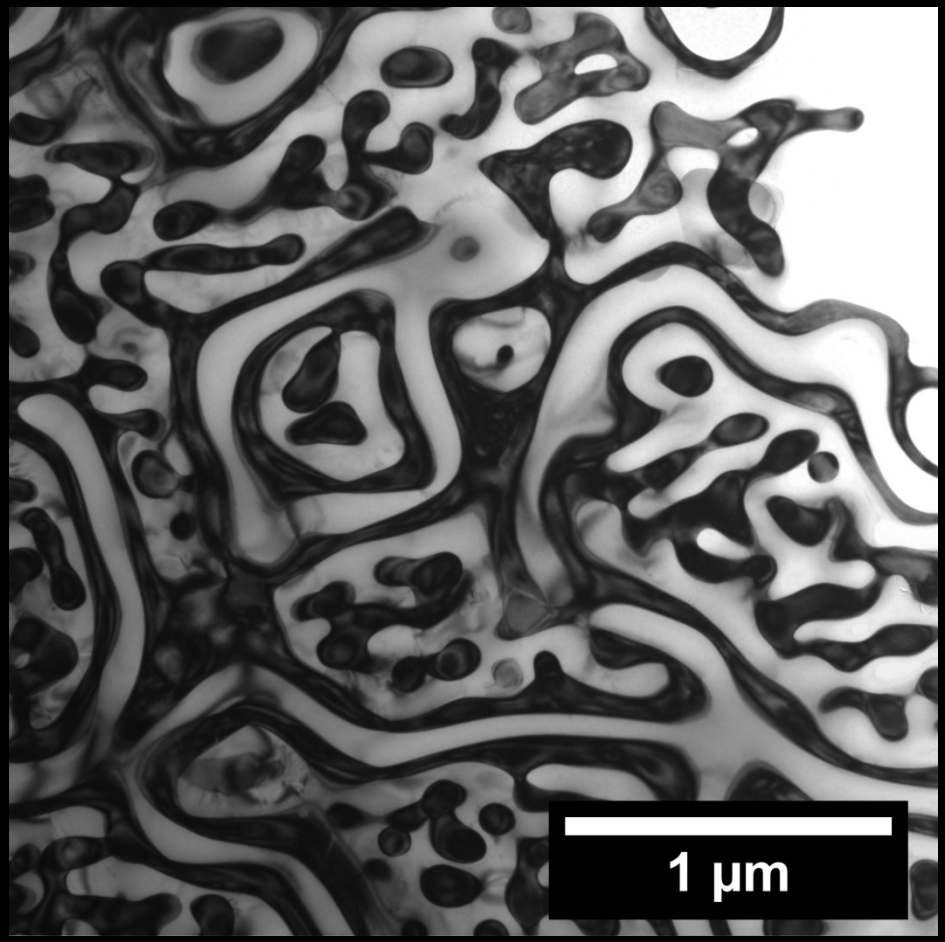


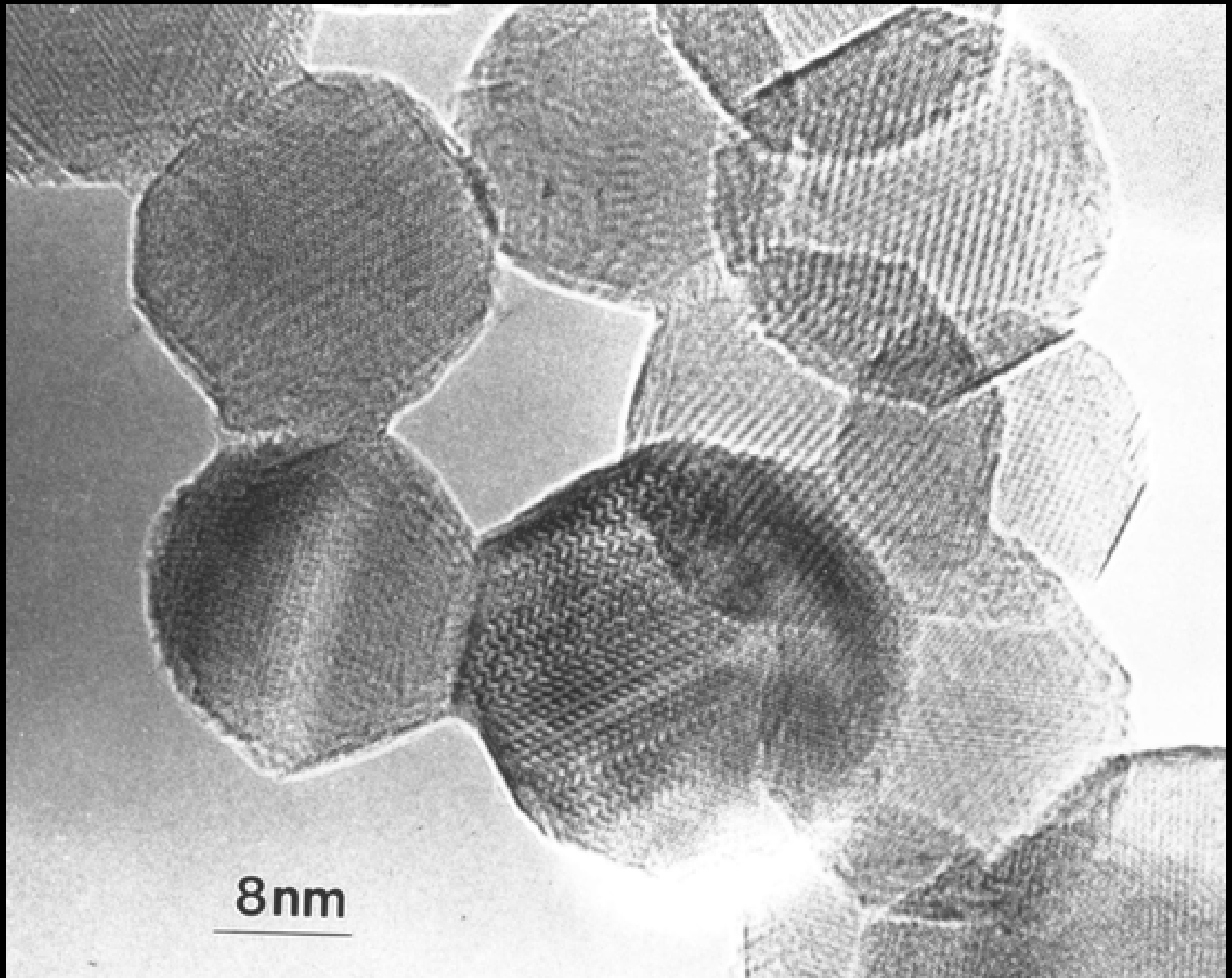


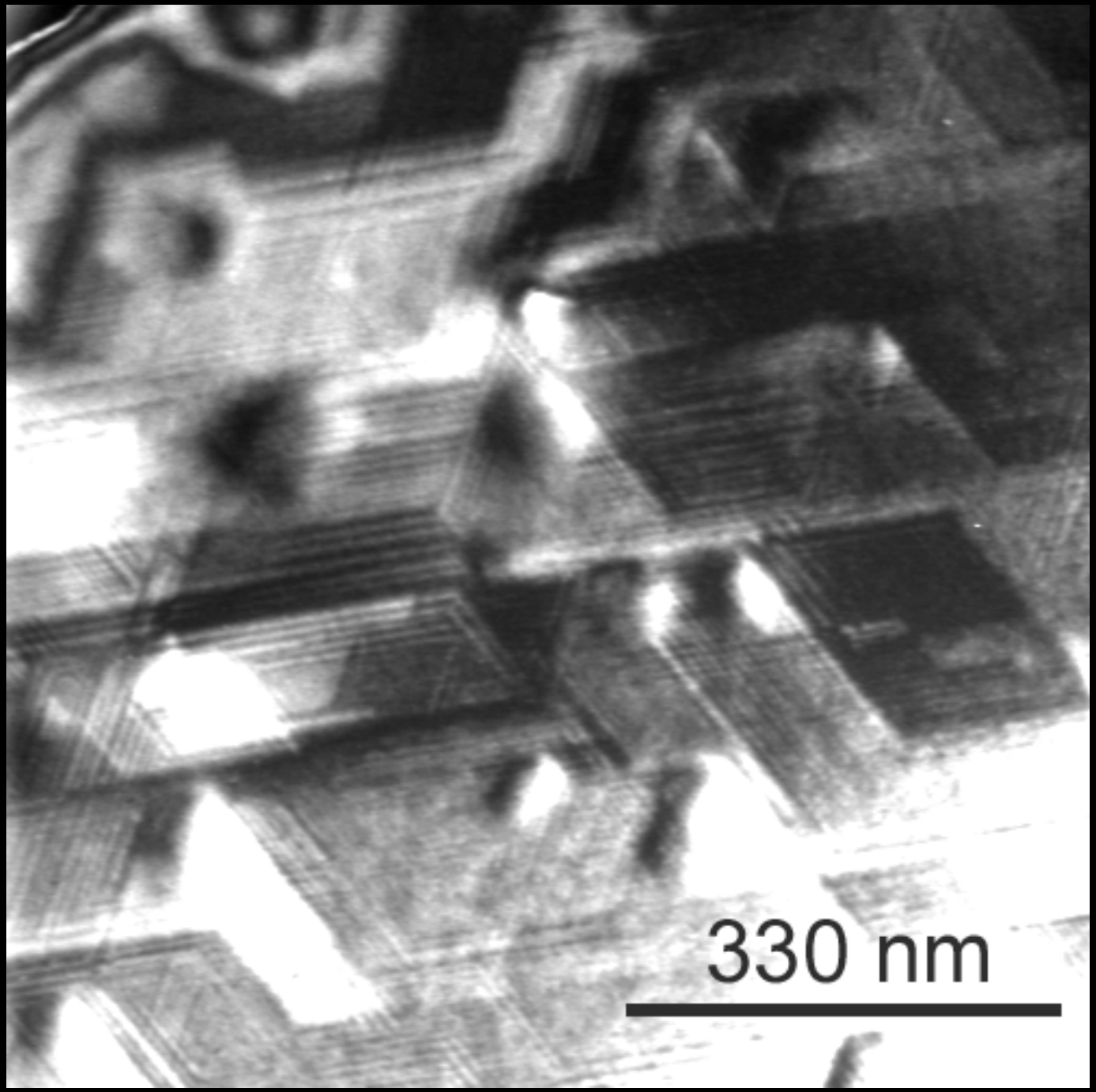

A
B
220
0,5µm

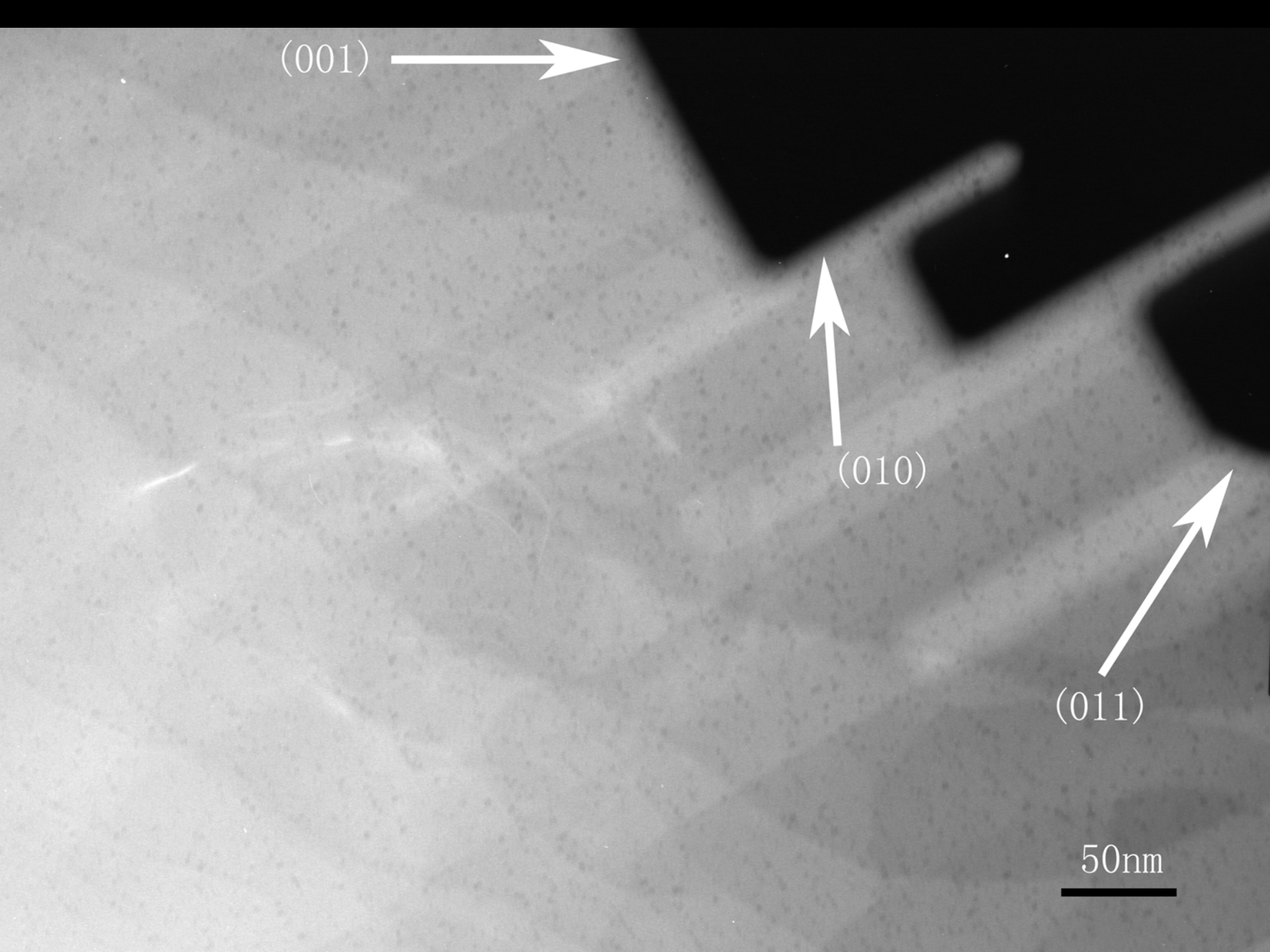

0.5 µm

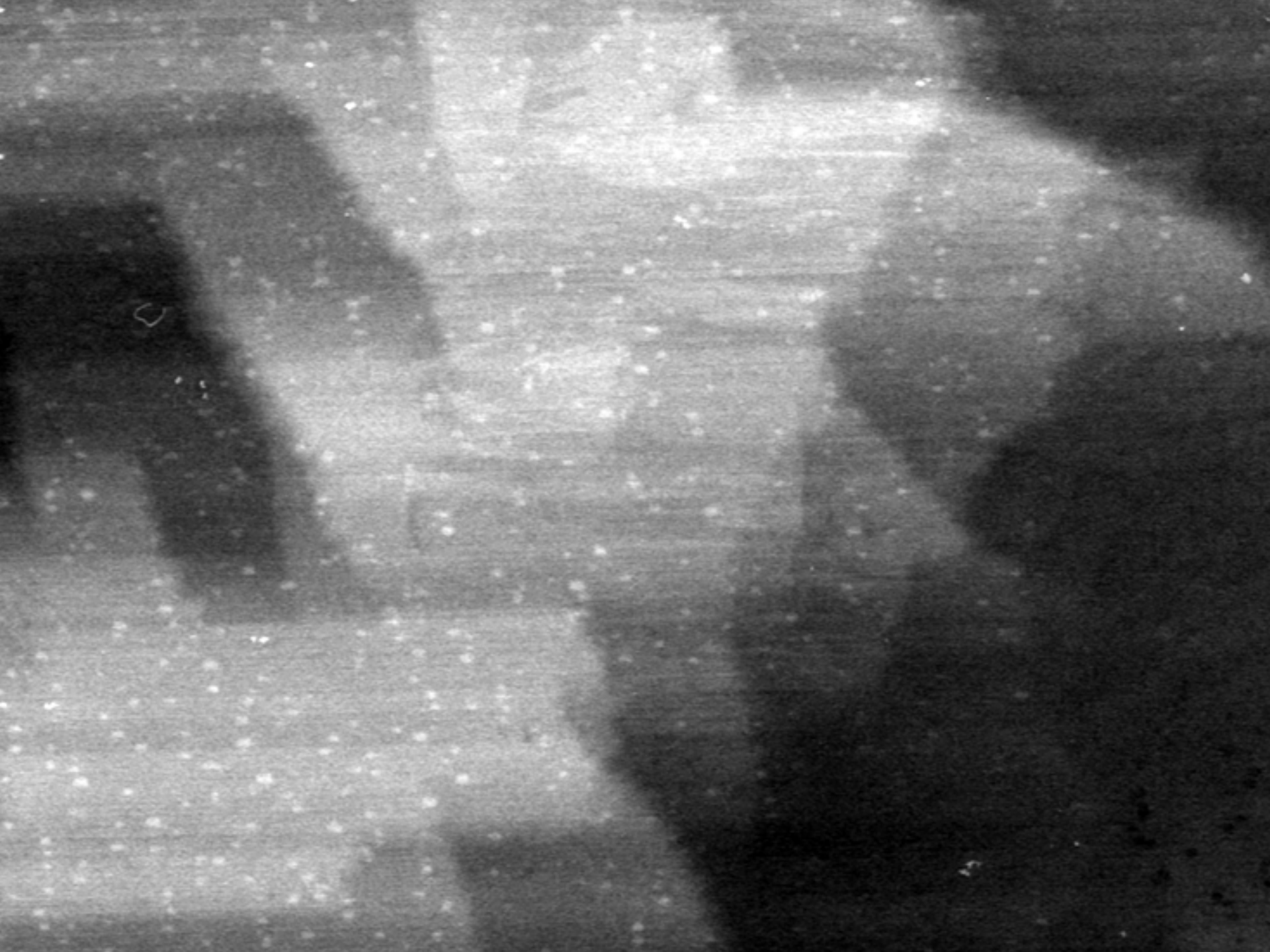

1 µm

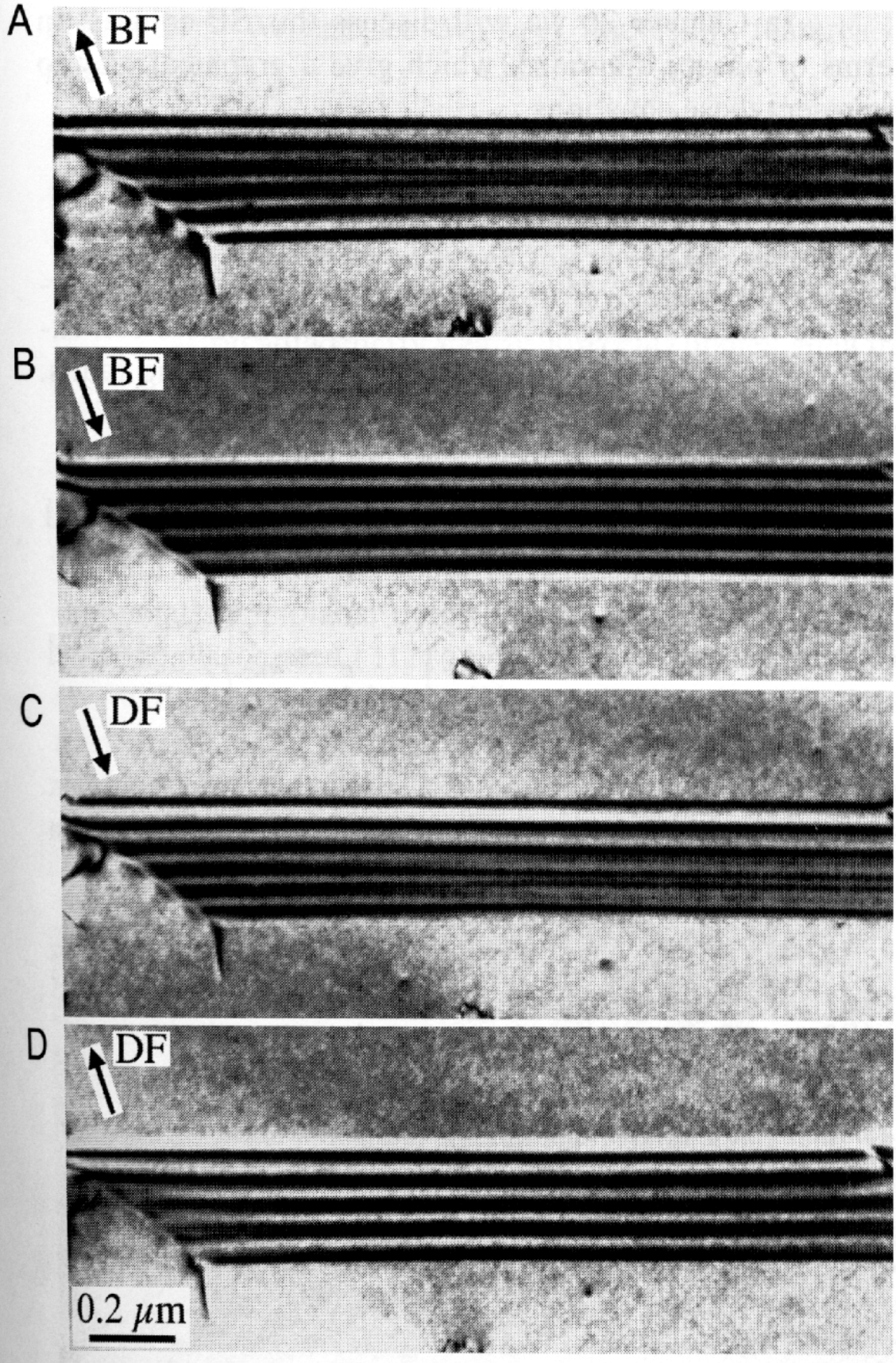

1 µm

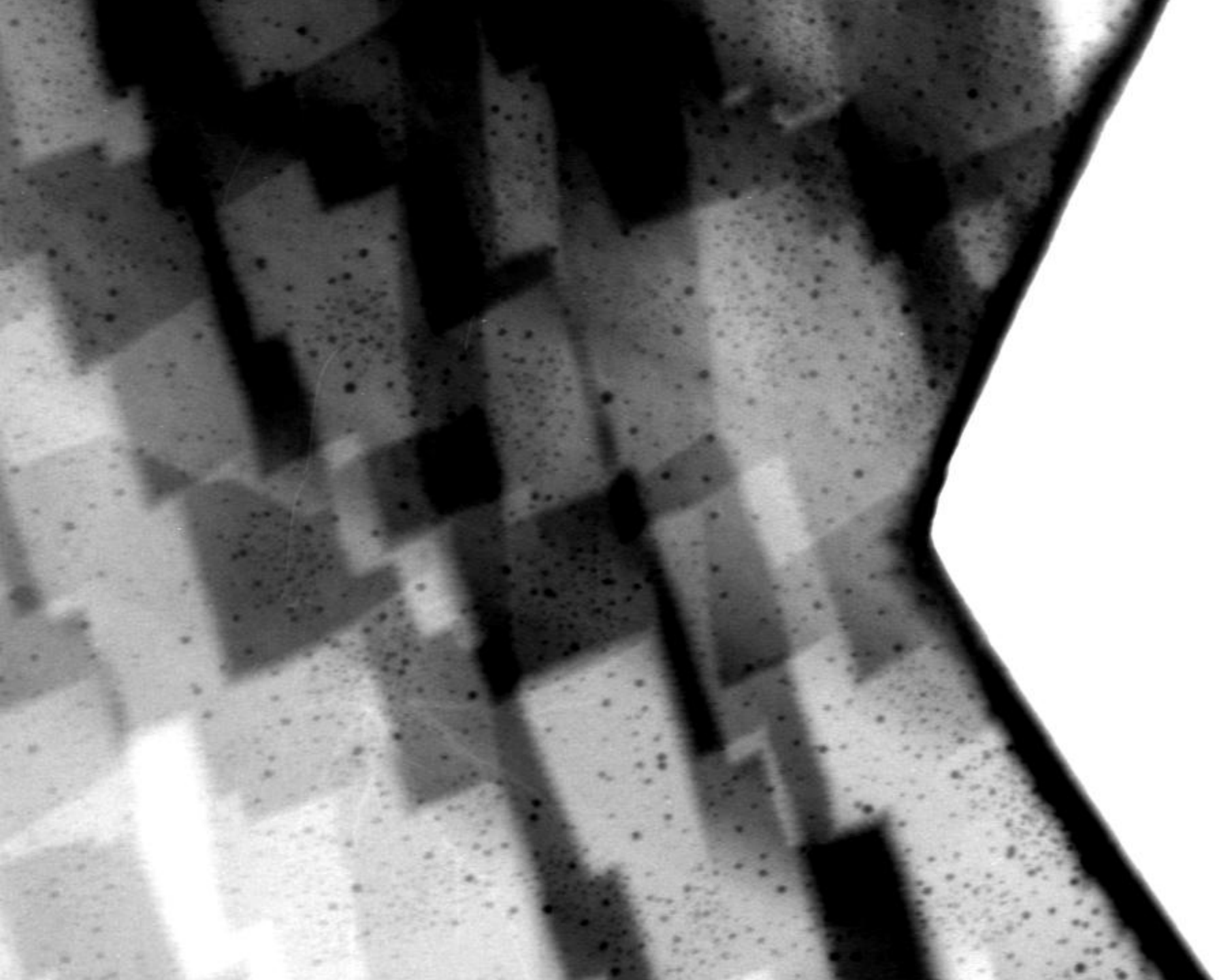

8nm

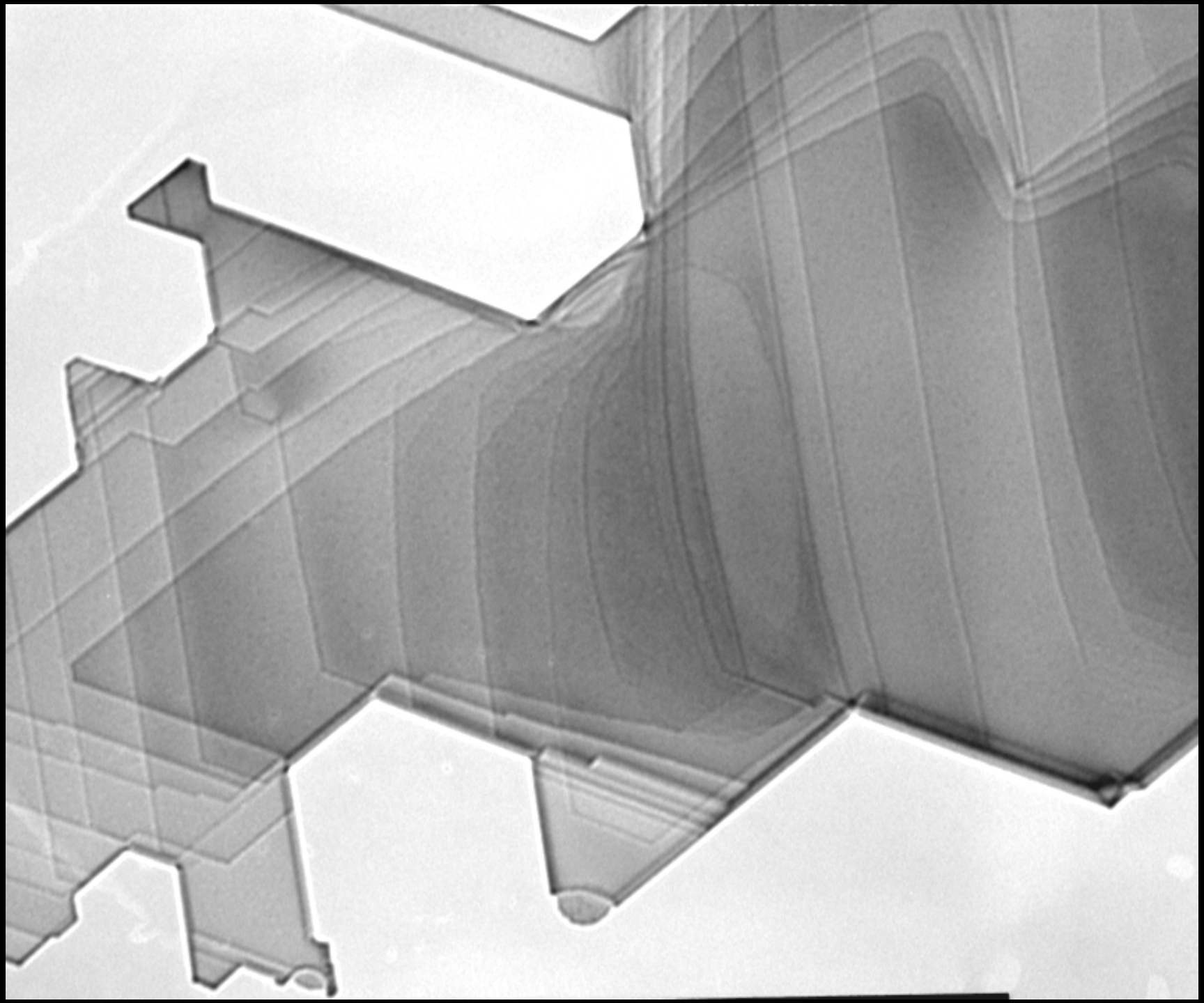

330 nm

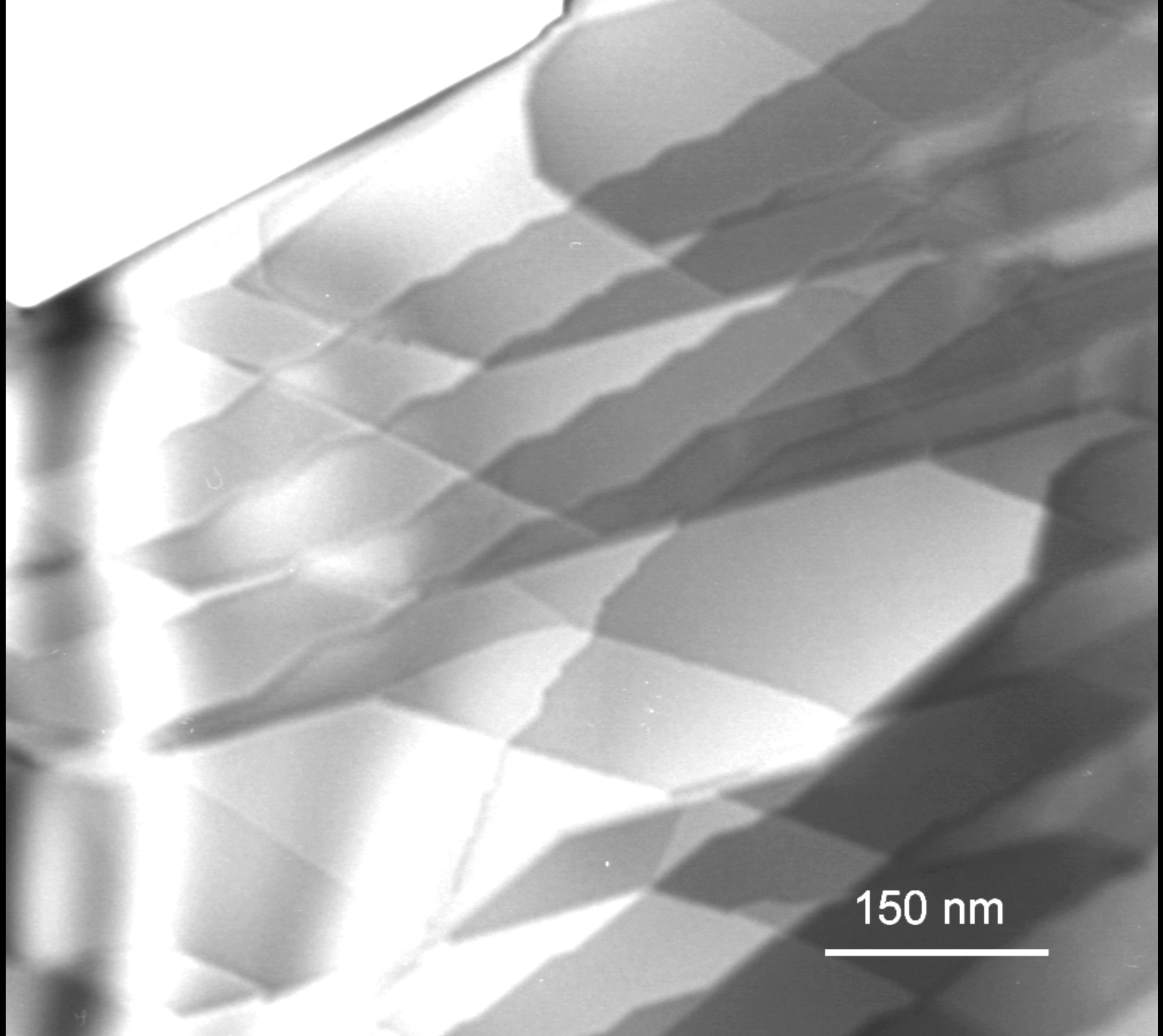

(001)
(010)
(011)
50nm




A
BF
B
BF
C
DF
D
DF
0.2 μm



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