Silver Halide Emulsion as a Tool for High Energy and Nuclear Physics

Tadaaki Tani and Kenichi Kuwabara
Ashigara Research Laboratories, Fuji Photo Film Co., Ltd.
210 Minami-Ashigara, Kanagawa, 250-0193, Japan

1. **Introduction for Nuclear Emulsion**

2. **Structure and Formation of Silver Halide Grains**

3. **Mechanisms and Sensitivity of Photographic Processes**

4. **Summary**

2nd International Workshop on Nuclear Emulsion Technology
March 7-9, 2002, Nagoya University, Nagoya, Japan

References

Photographic Processes

Tadaaki Tani, "Photographic Sensitivity: Theory and Mechanisms",
Oxford University Press, New York, 1995

Prediction of Future of AgX Photography

1. *T.Tani, J.Imaging Sci., 29, 93 (1995).*
2. *T.Tani, J.Imaging Sci., Technol., 39, 1 (1994)*
3. *T.Tani, J.Imaging Sci., Technol., 43,in press (1998)*

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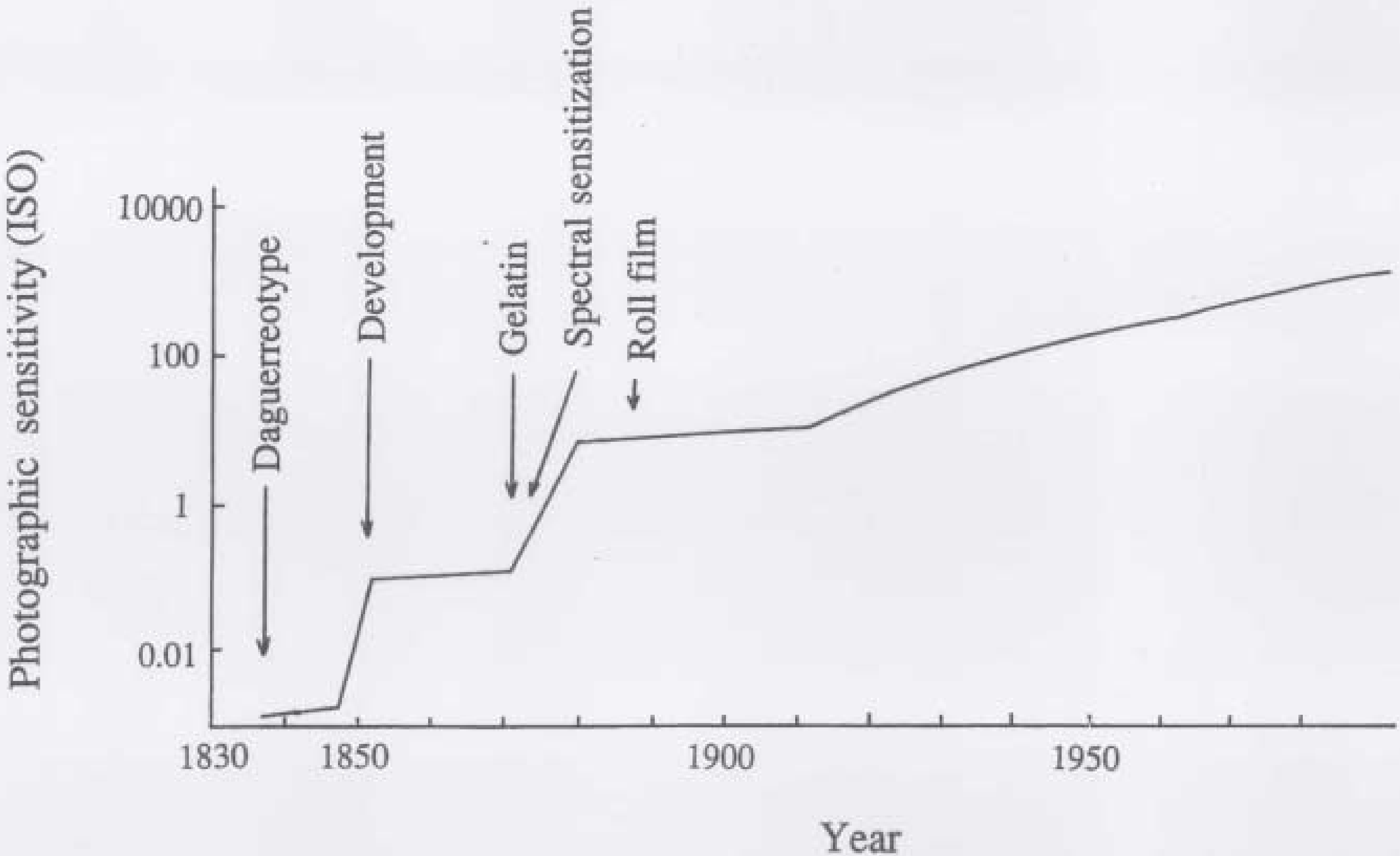
W.H. Fox Talbot
1800-1877

L. J. Mandé Daguerre
1787-1851

Commemorating 150 years of Photography 1839-1989

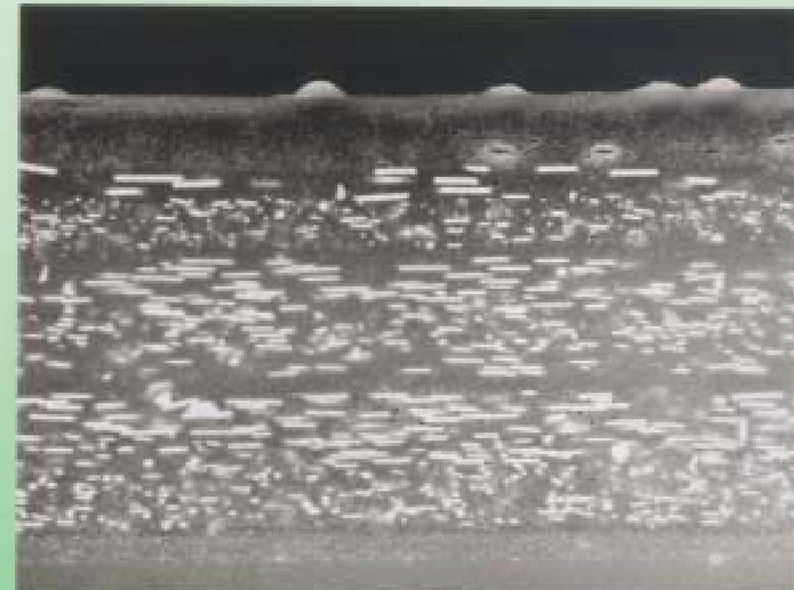


Change in sensitivity of silver halide photographic materials.[5]

FUJIFILM
I&I - Imaging & Information

Recent progress of the color negative film

HR400(1983)



Zoom Master 800(2000)

Faster speed, finer image quality and color fidelity
4th layer technology (layer to give inter-image effect)

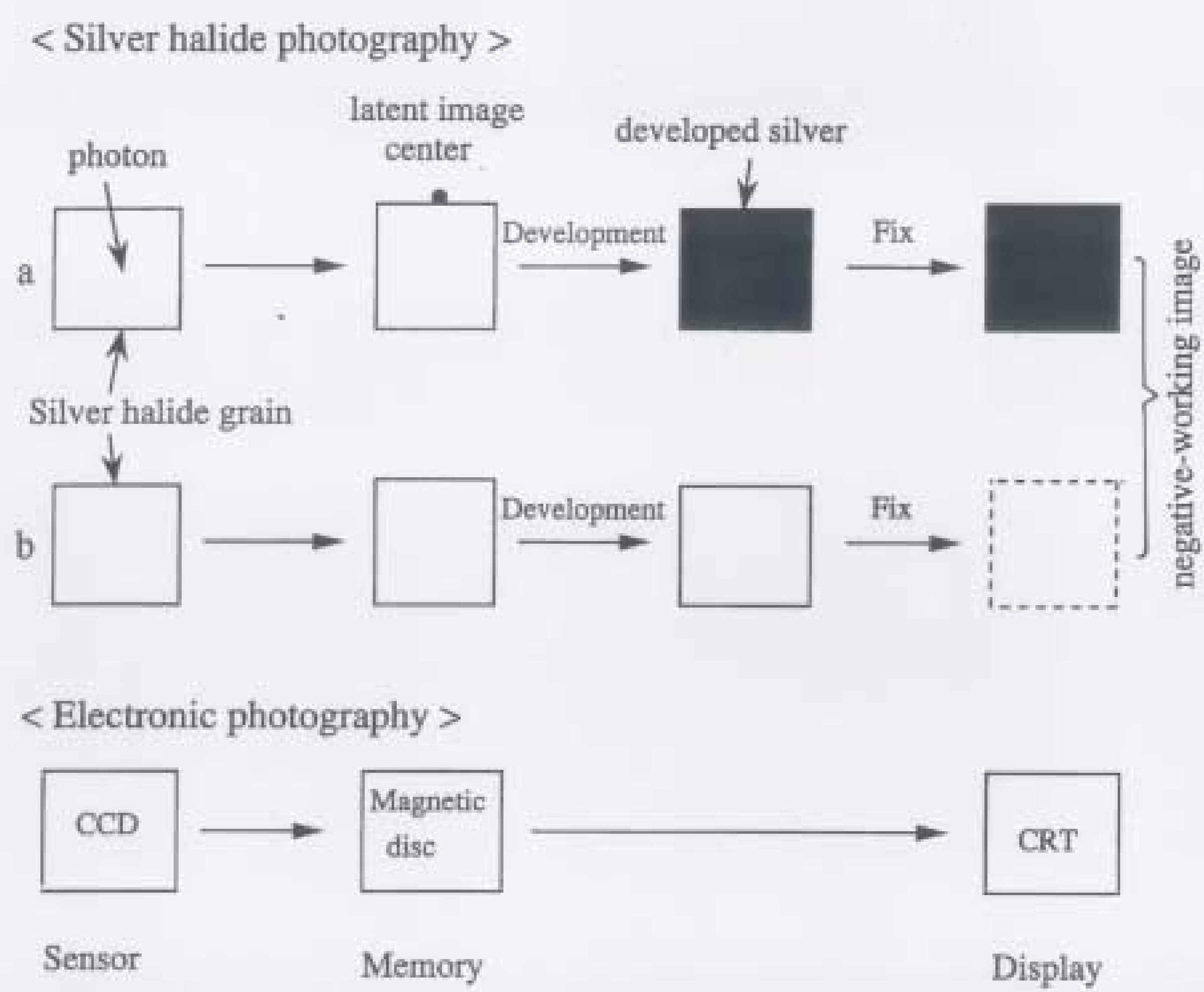
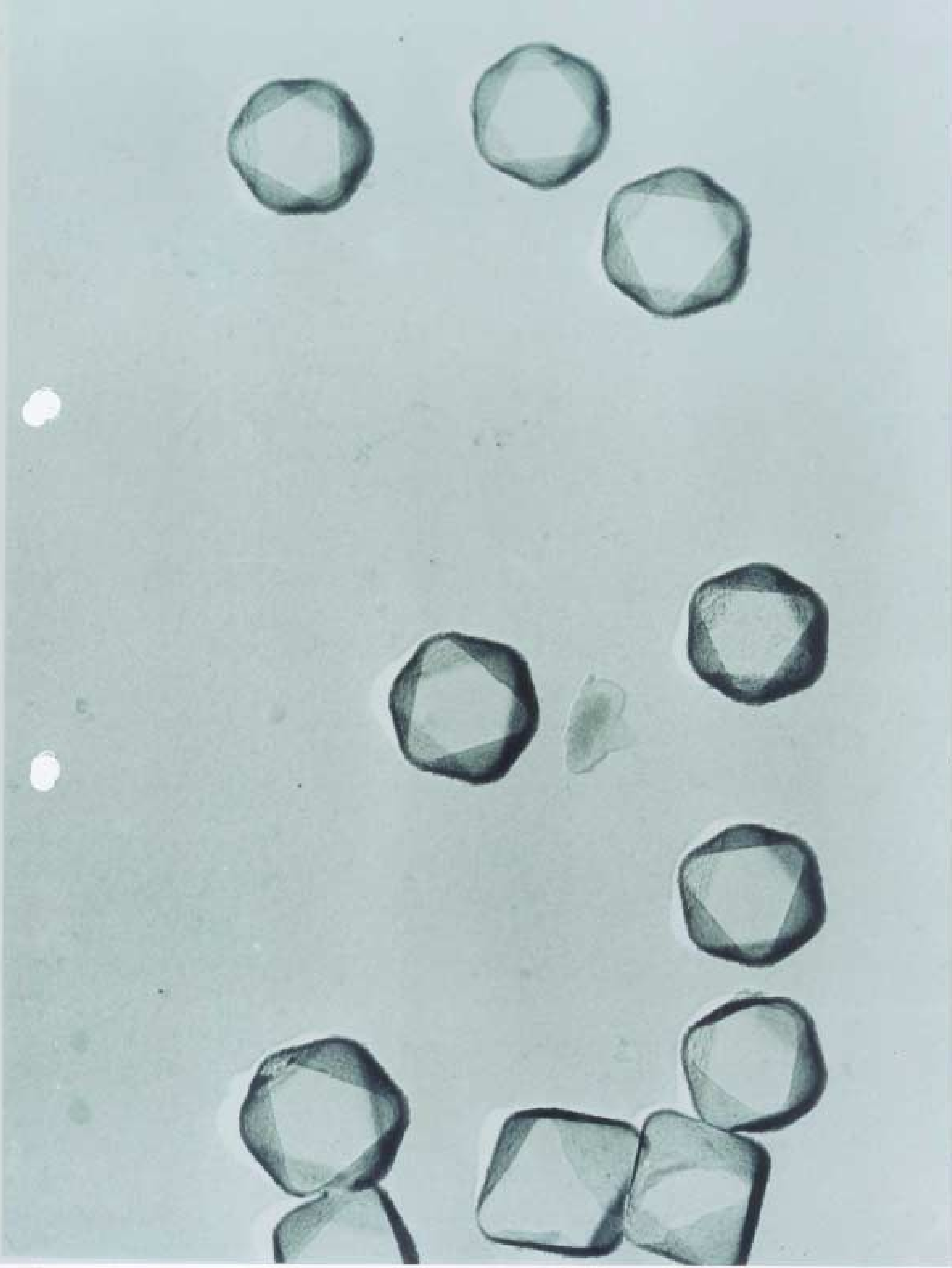
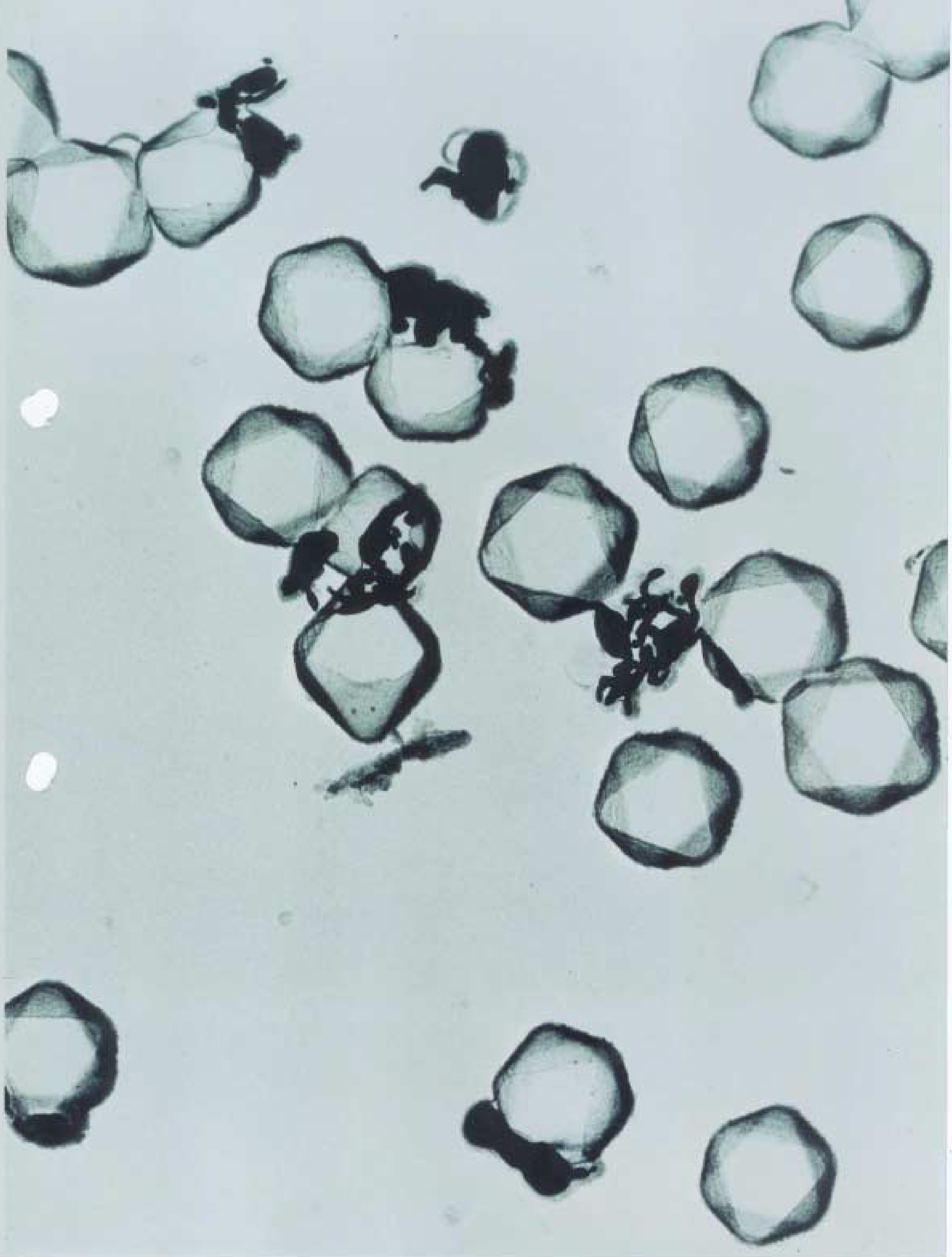
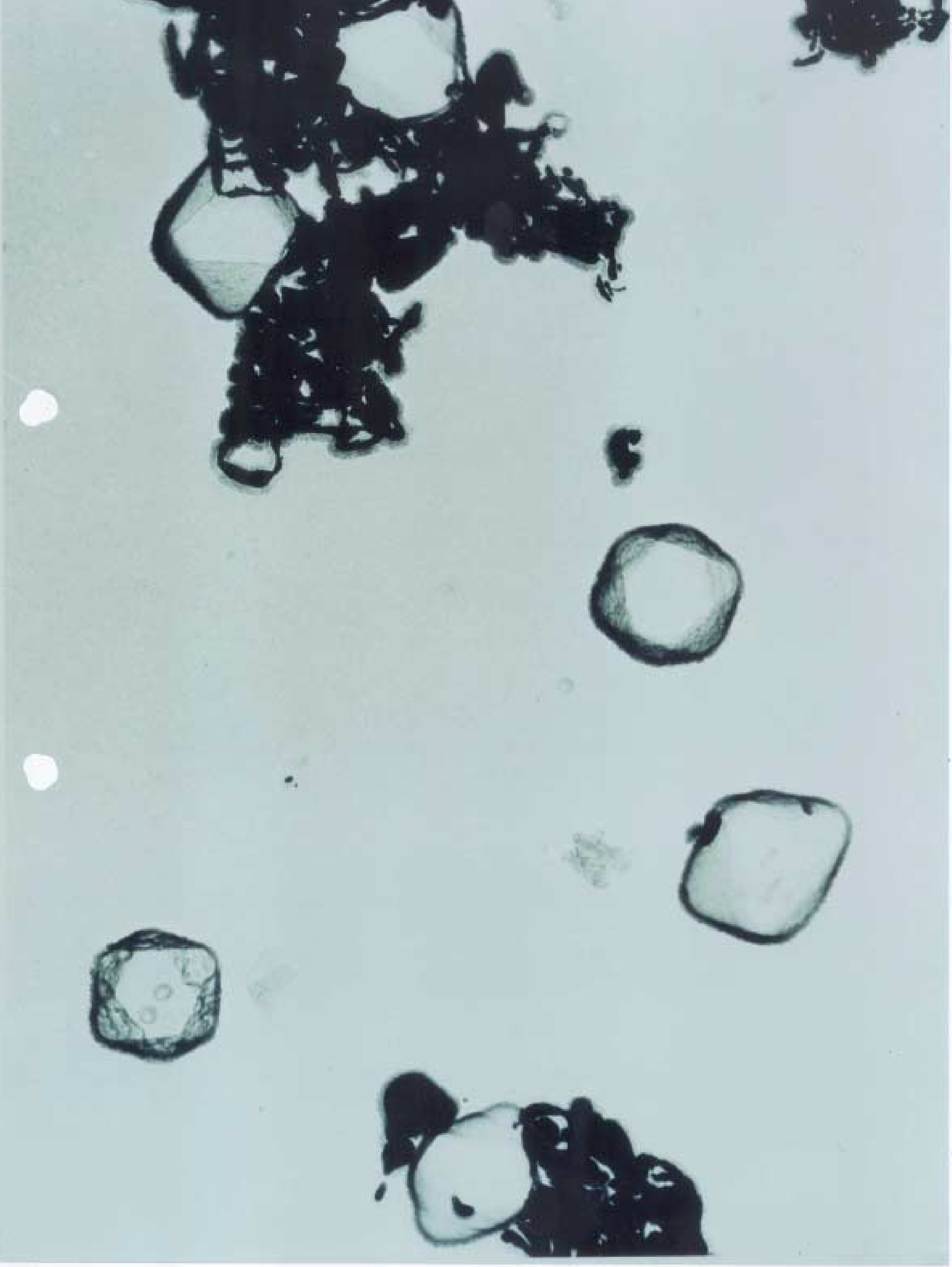
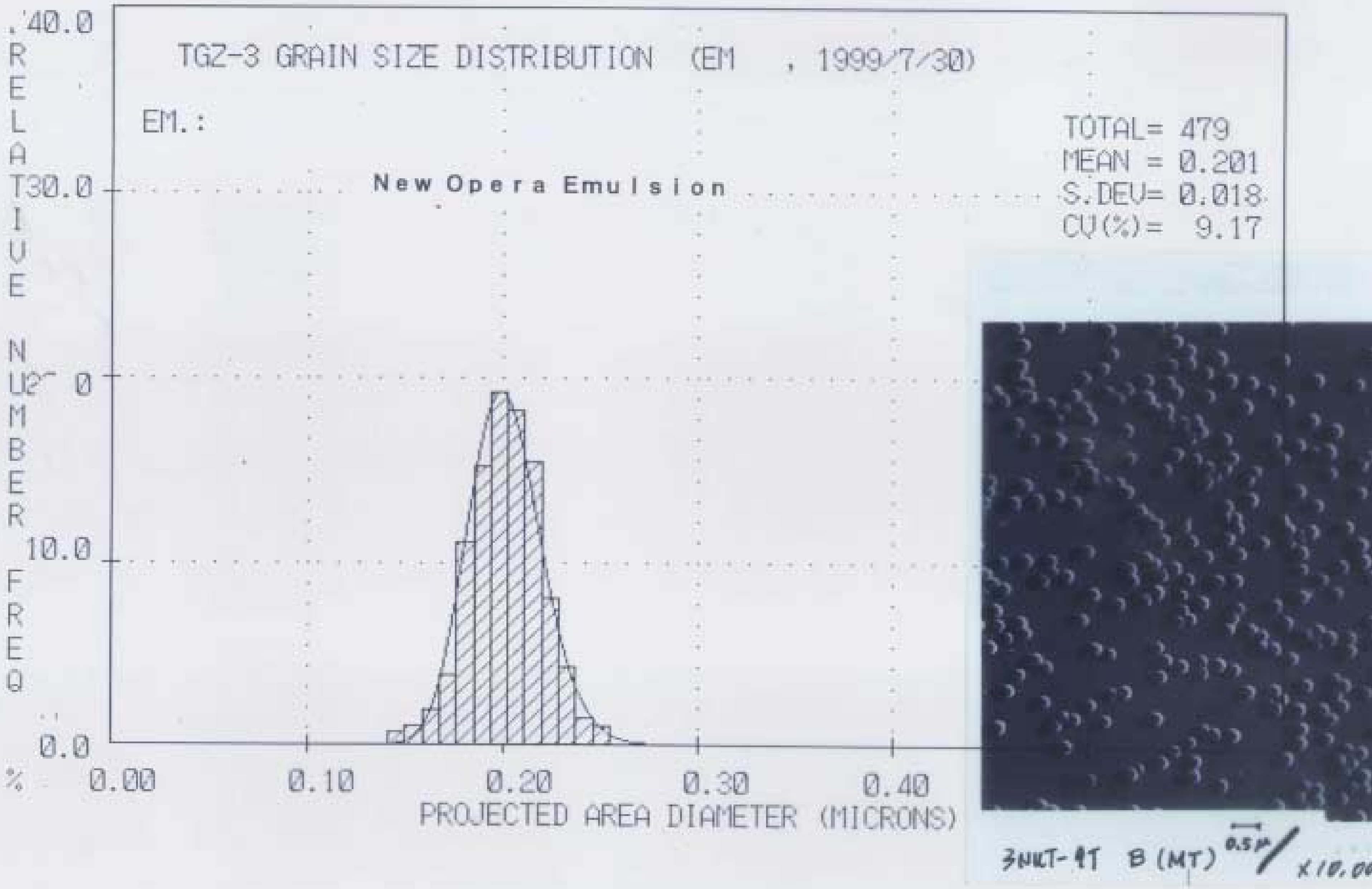


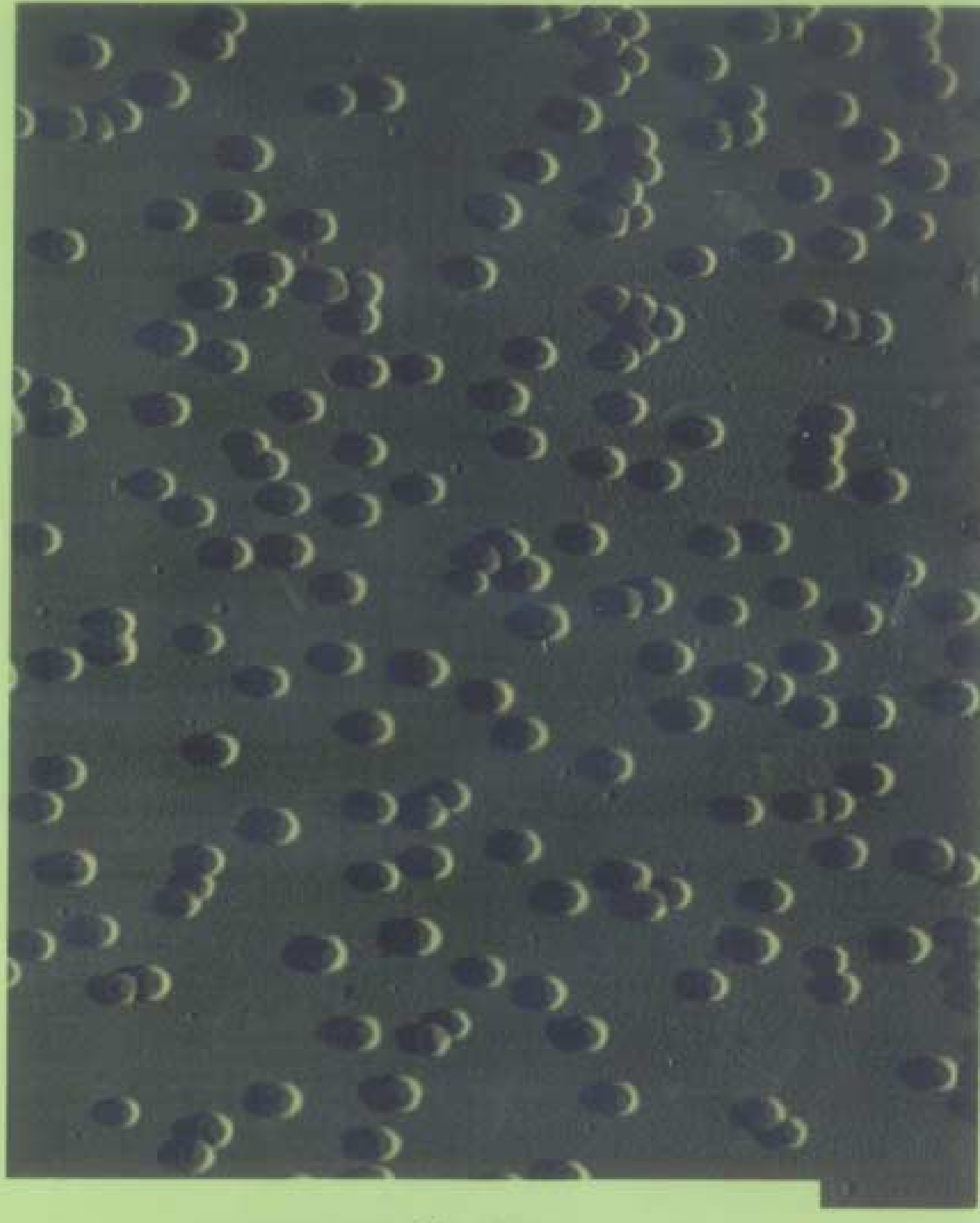
Illustration showing imaging processes in silver halide photography and electronic photography. In the former, a and b show the changes of exposed and unexposed silver halide grains during the processes.








TGZ-3 GRAIN SIZE DISTRIBUTION (EM , 1999/7/30)
EM.:
New Opera Emulsion
TOTAL= 479
MEAN = 0.201
S.DEV= 0.018
CV(%)= 9.17
RELATIVE NUMBER FREQ %
40.0
30.0
20.0
10.0
0.0
0.00
0.10
0.20
0.30
0.40
PROJECTED AREA DIAMETER (MICRONS)
3NKT-4T B (MT) 0.5μ



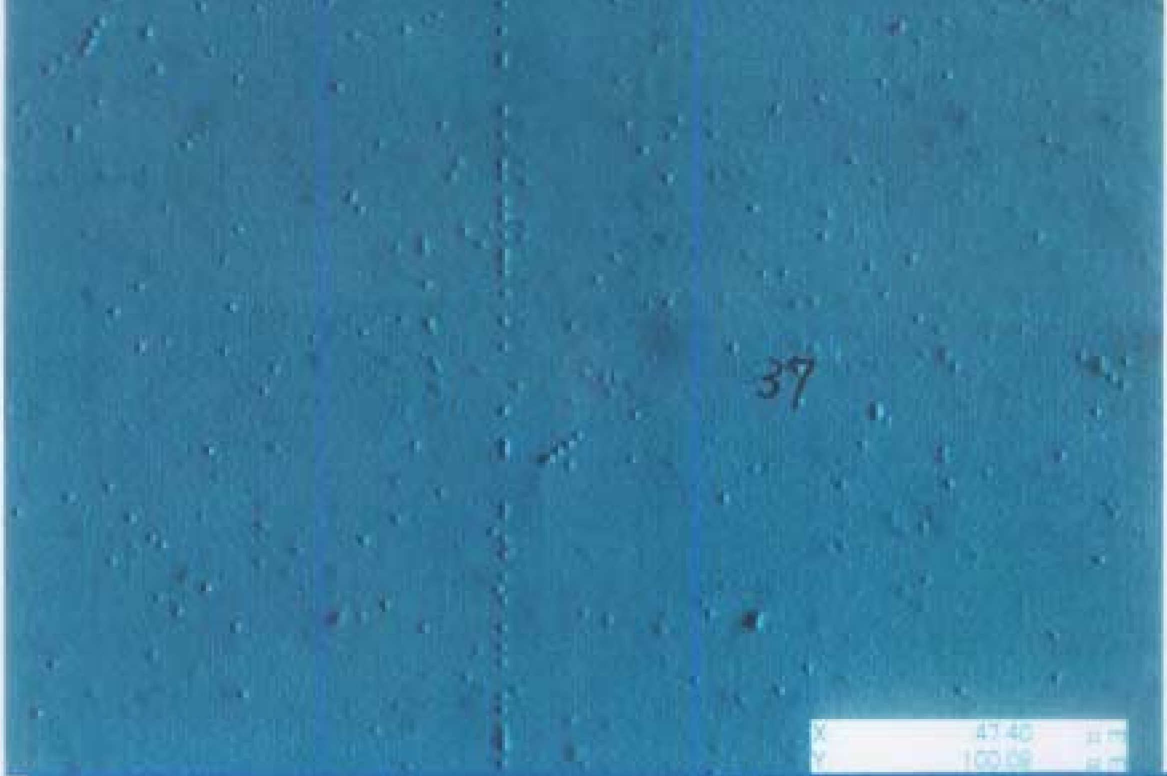
結晶の写真

0958

3.9×10^{13} grains / 4*5 inch^2

40.000 grains / $(10\mu m)^3$

2~4 tagged grains / $(10\mu m)^3$

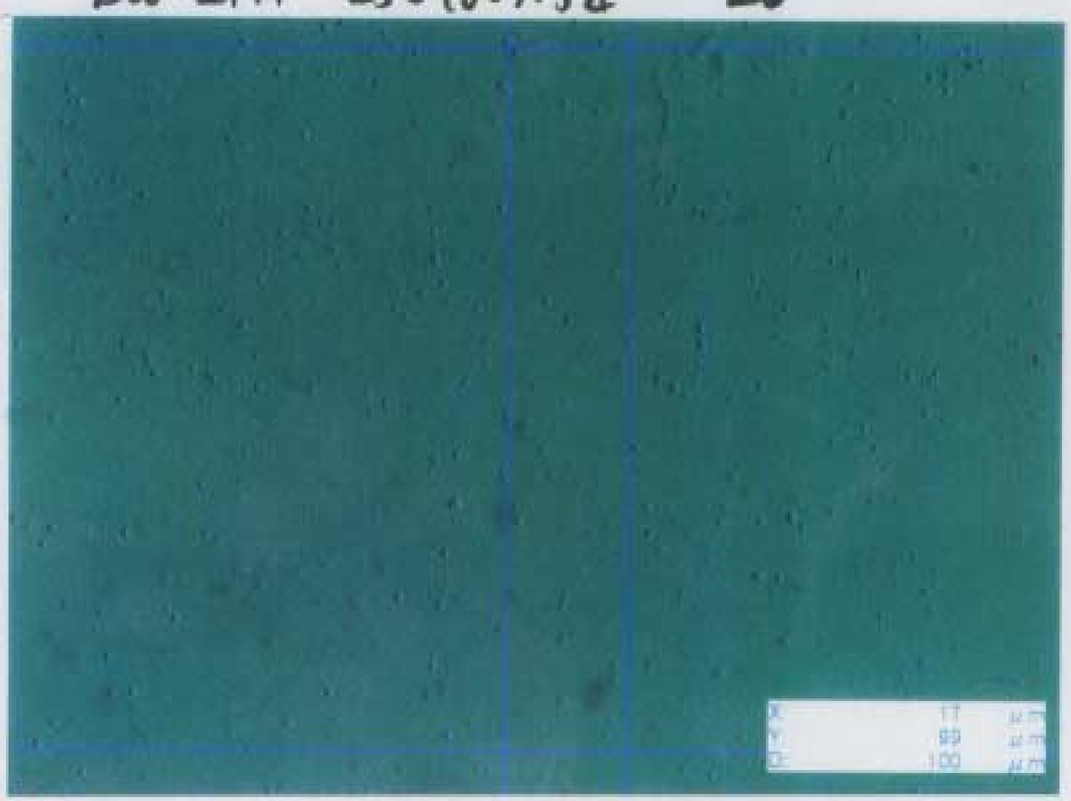

37
X 47.40 µm
Y 100.09 µm


32
X 47.40 µm
Y 100.09 µm


28

SU-21H なし 25'

SU-21H 25C100%.3d 26'



Requirements for nuclear emulsions include

1. large frame area
2. three dimensions
3. high sensitivity
4. high stability on storage
5. high resolution. and
6. ability to be reset before use

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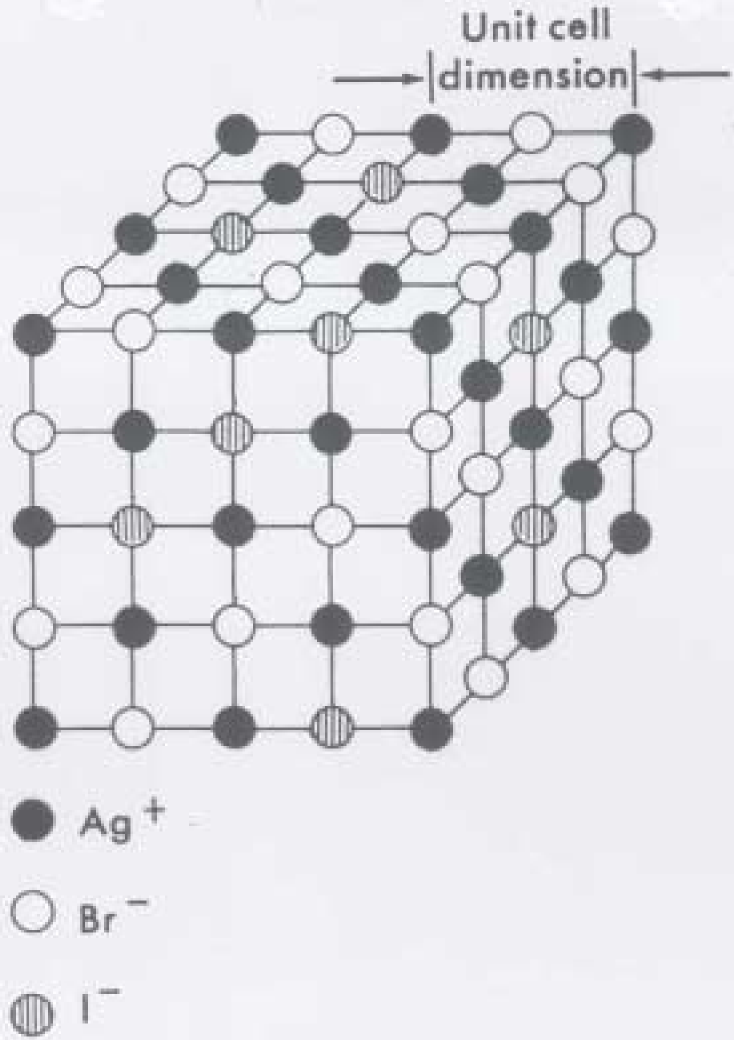
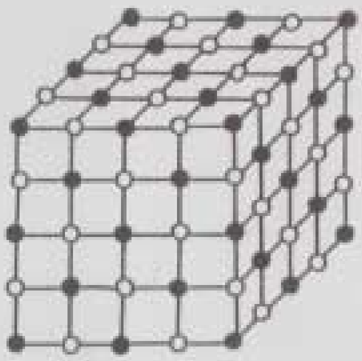
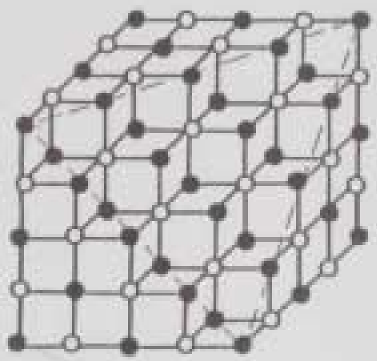
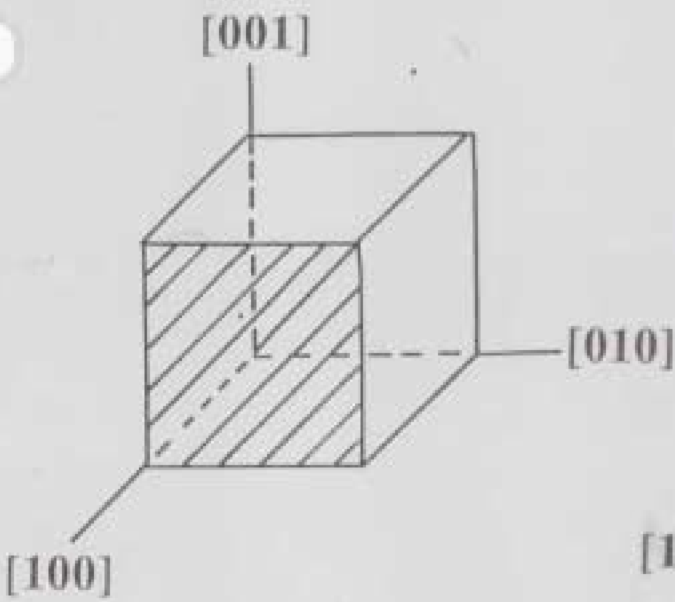


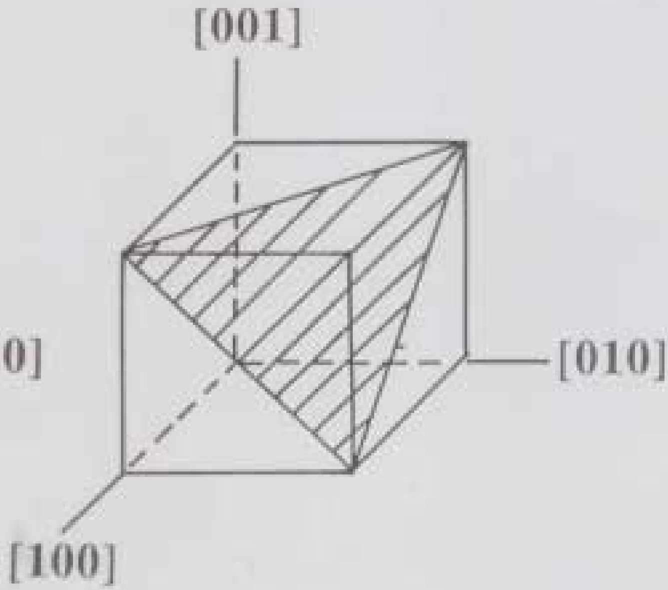
Fig. 1.1. *A schematic representation of a random solid solution of AgI in AgBr, where 25% of the bromide-ion sites are occupied by iodide ions.*



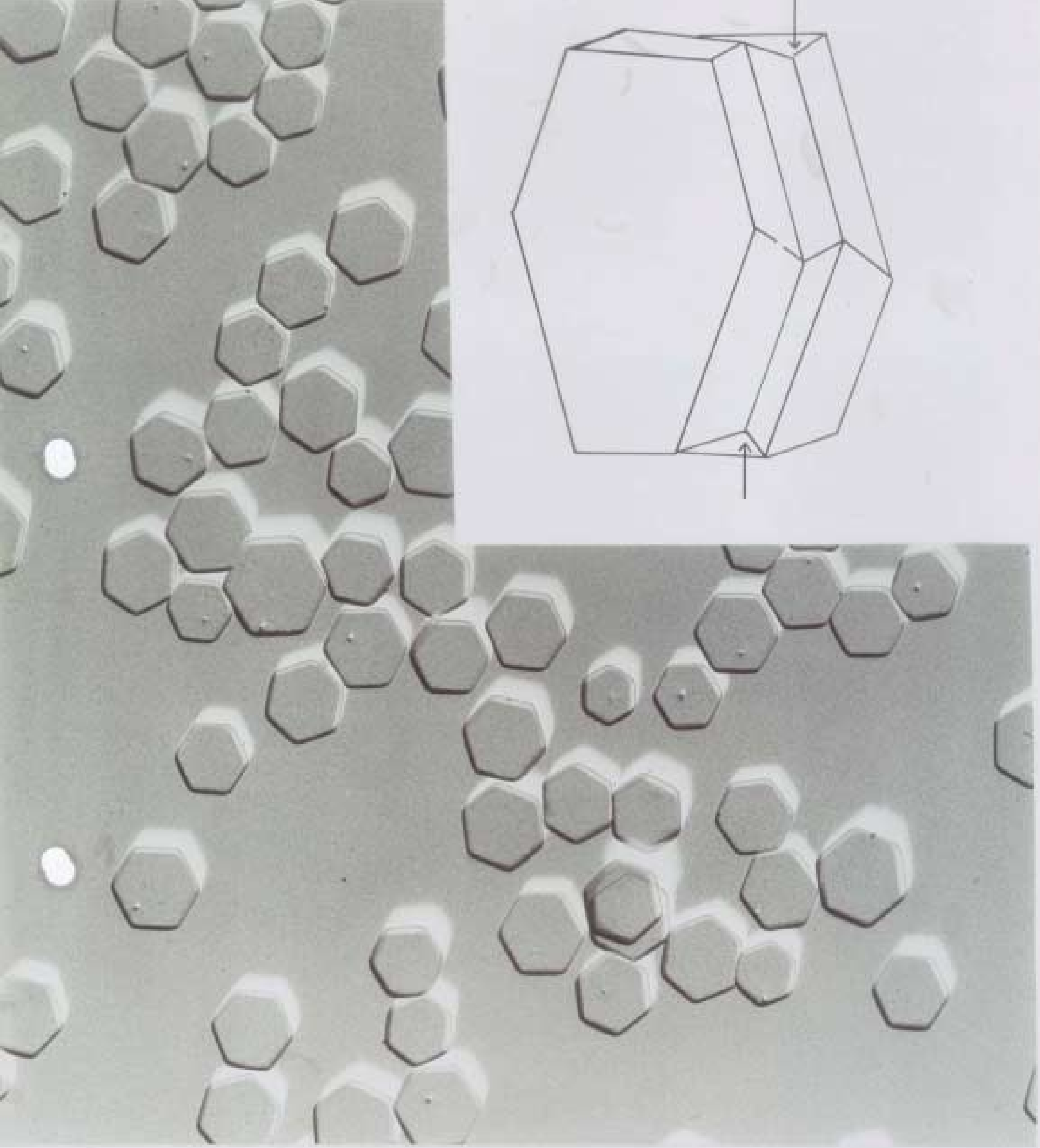


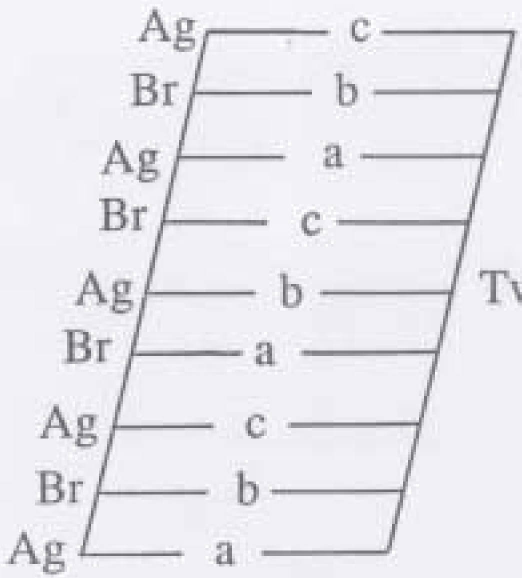


(100)

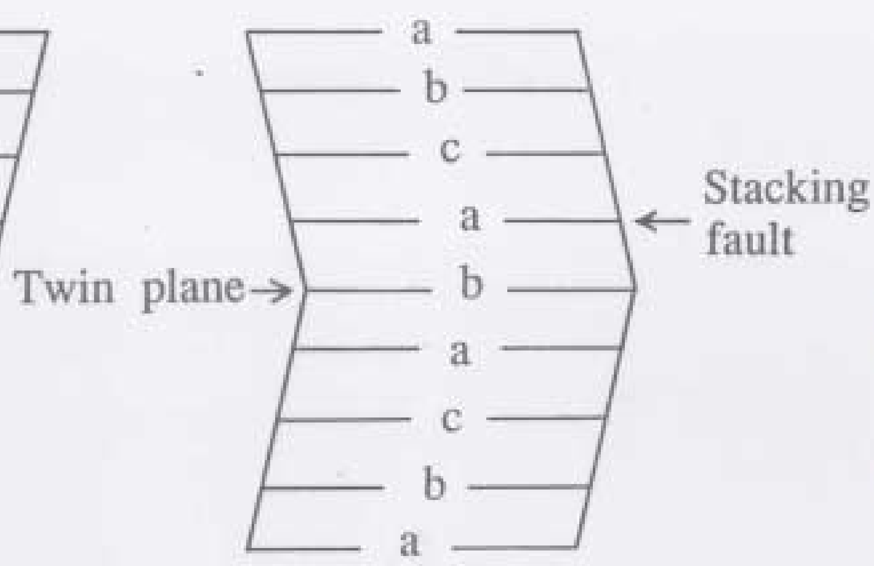


(111)

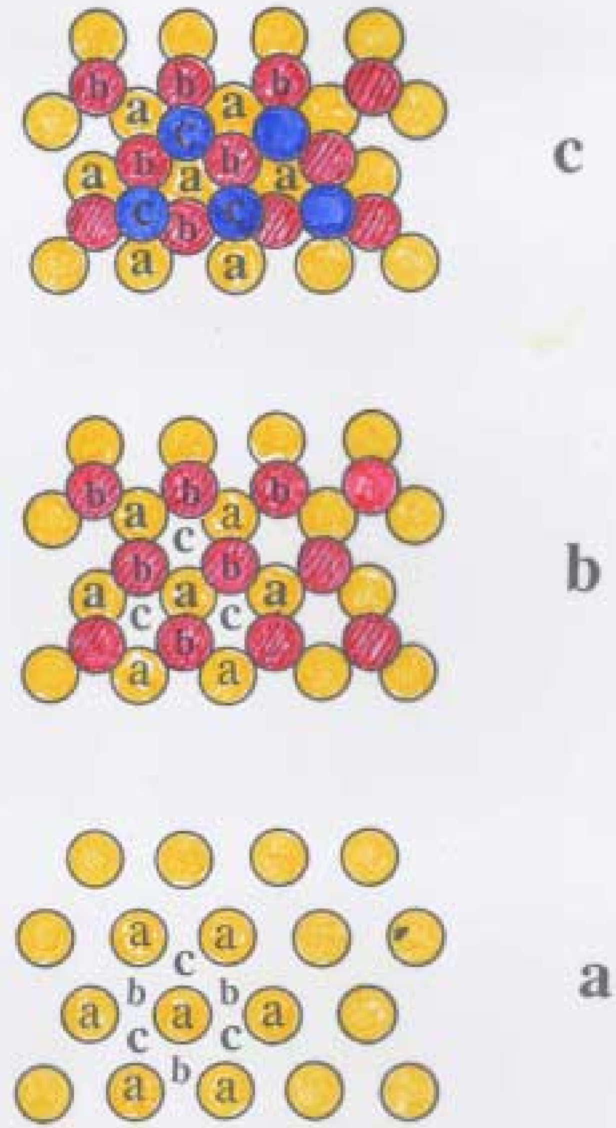


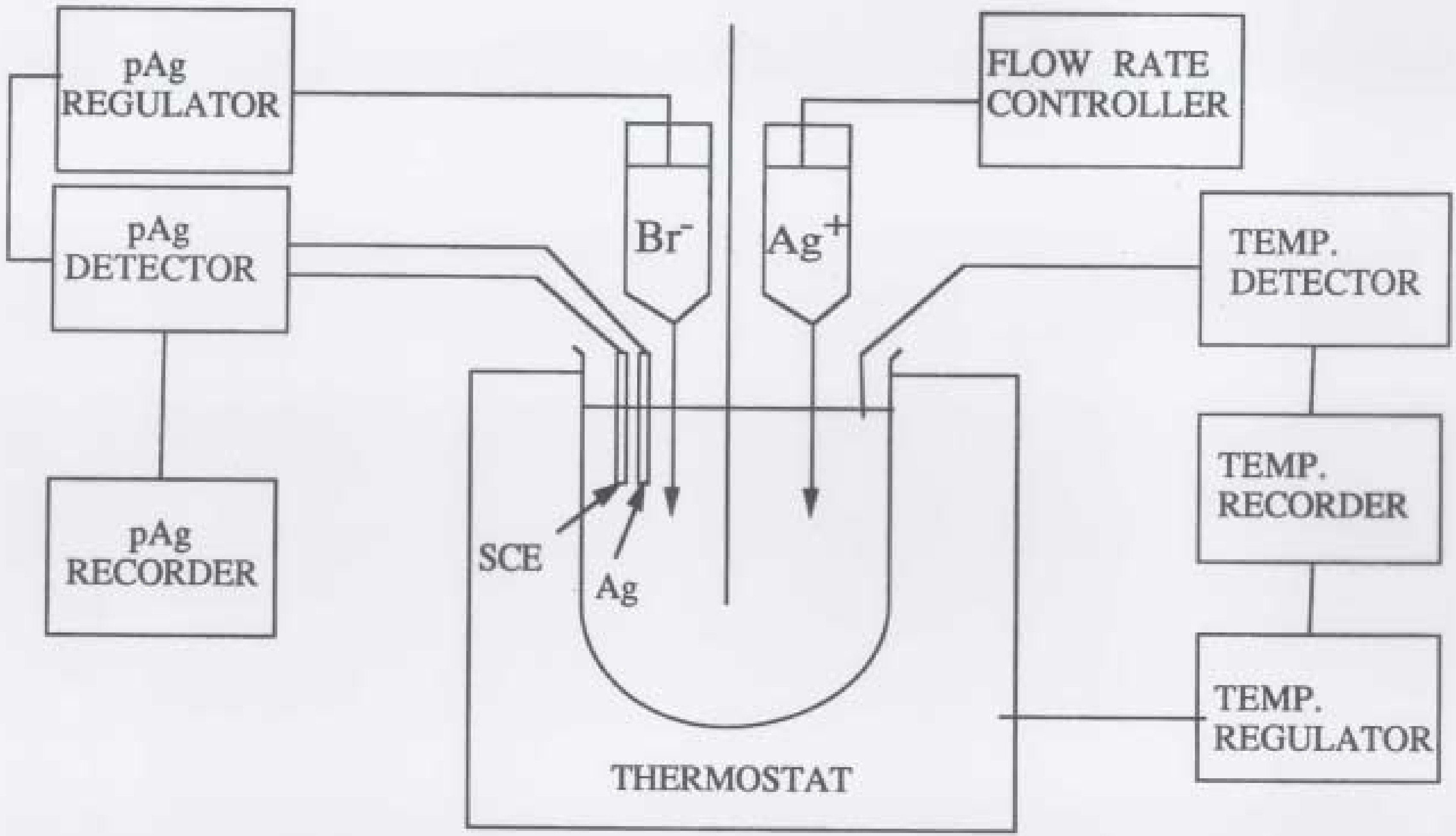


Layer structure of AgBr



Layer structure of a (111) twin





Block diagram of an apparatus for controlled double-jet precipitation.

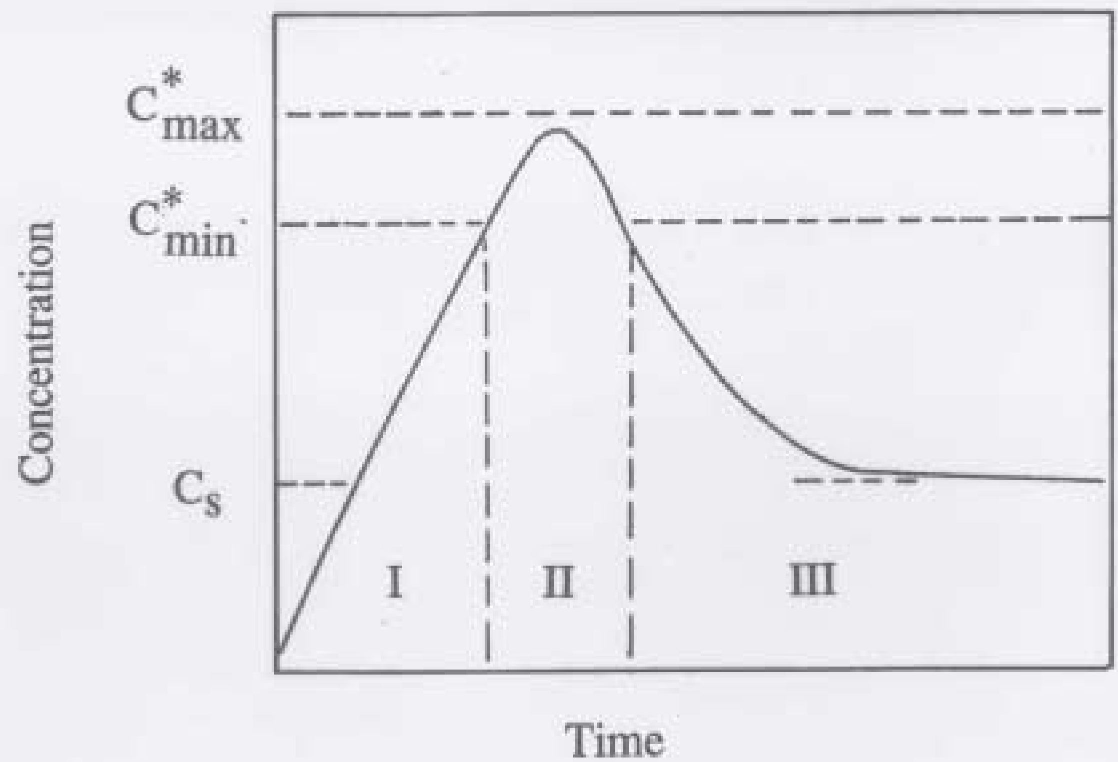
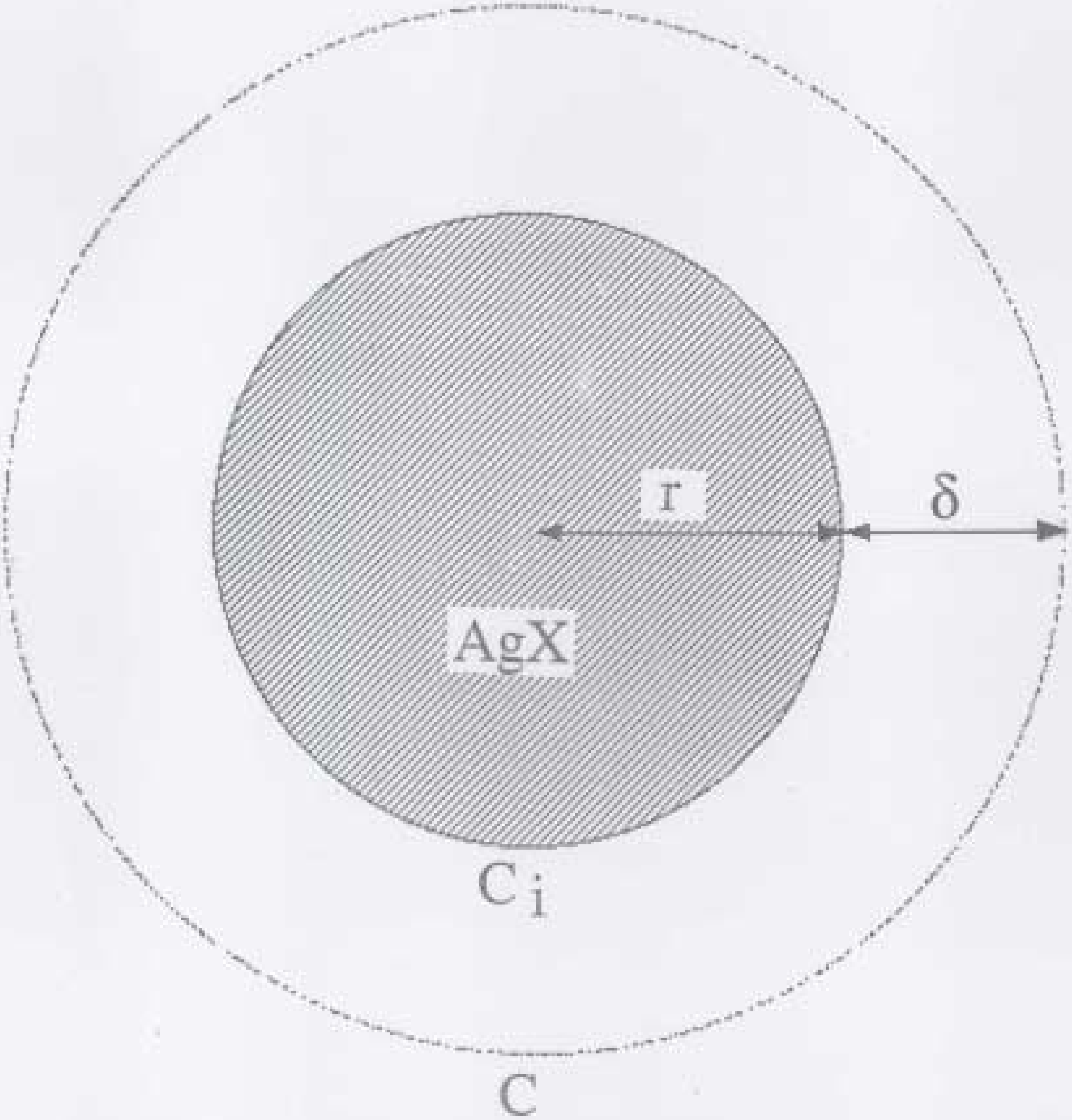


Illustration showing the nucleation and growth of silver halide grains during precipitation, where C_s is solubility and C^*_{min} and C^*_{max} are the minimum and maximum concentration for nucleation, respectively. Regions I, II, and III indicate the period before nucleation, nucleation, and growth, respectively.

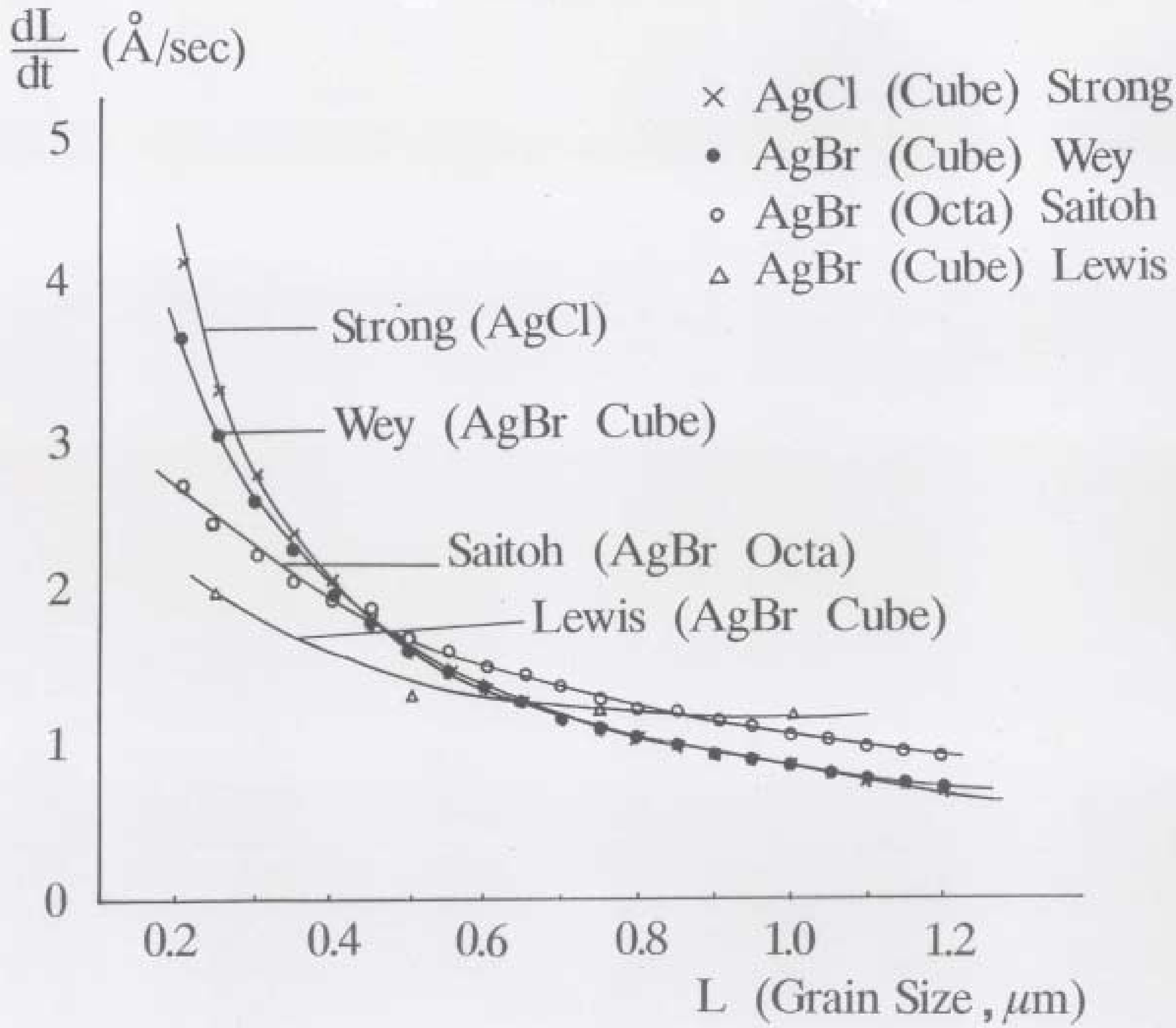


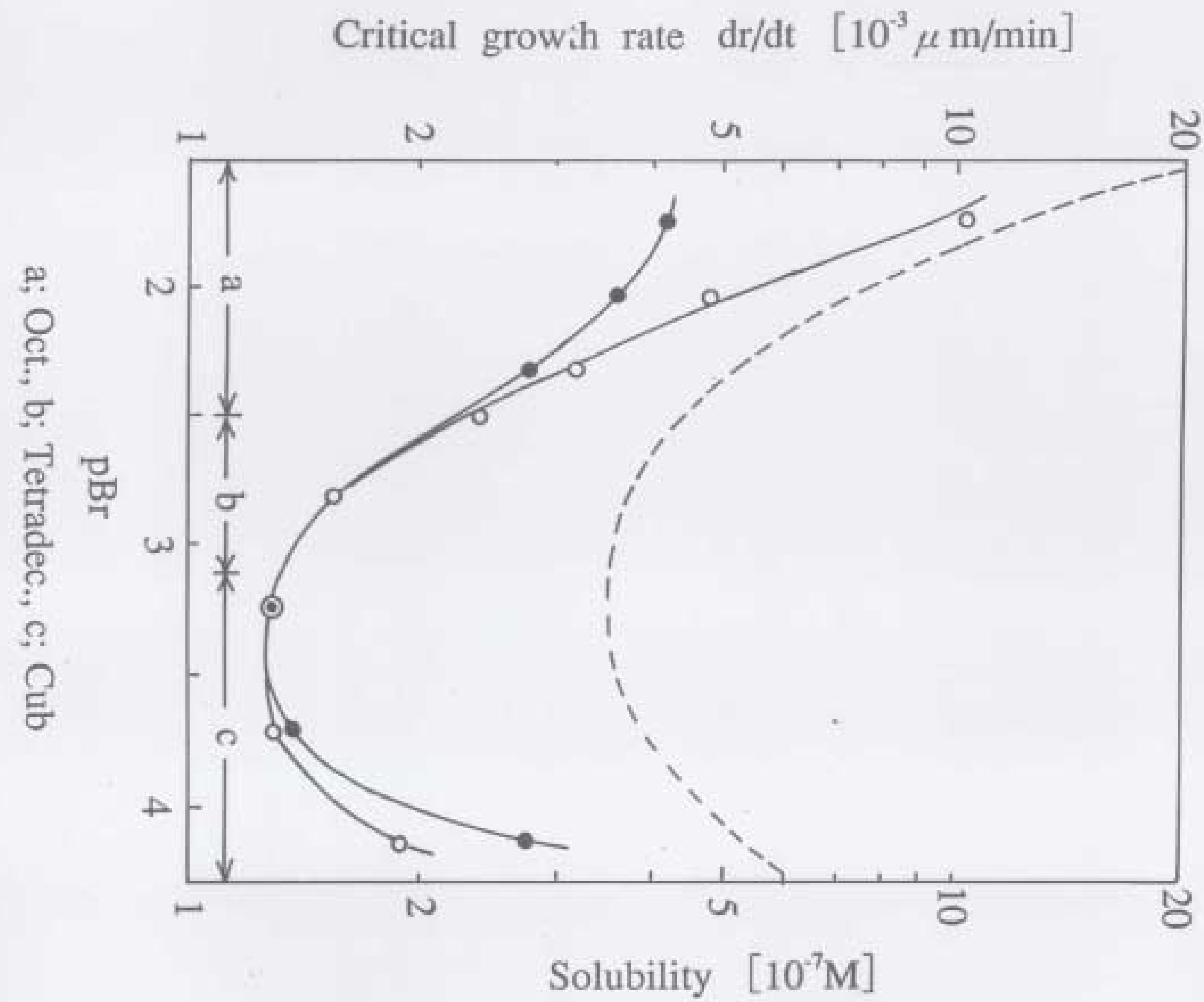
$$\frac{dr}{dt} = DV_m \left(\frac{1}{r} + \frac{1}{\delta}\right)(C - C_i)$$

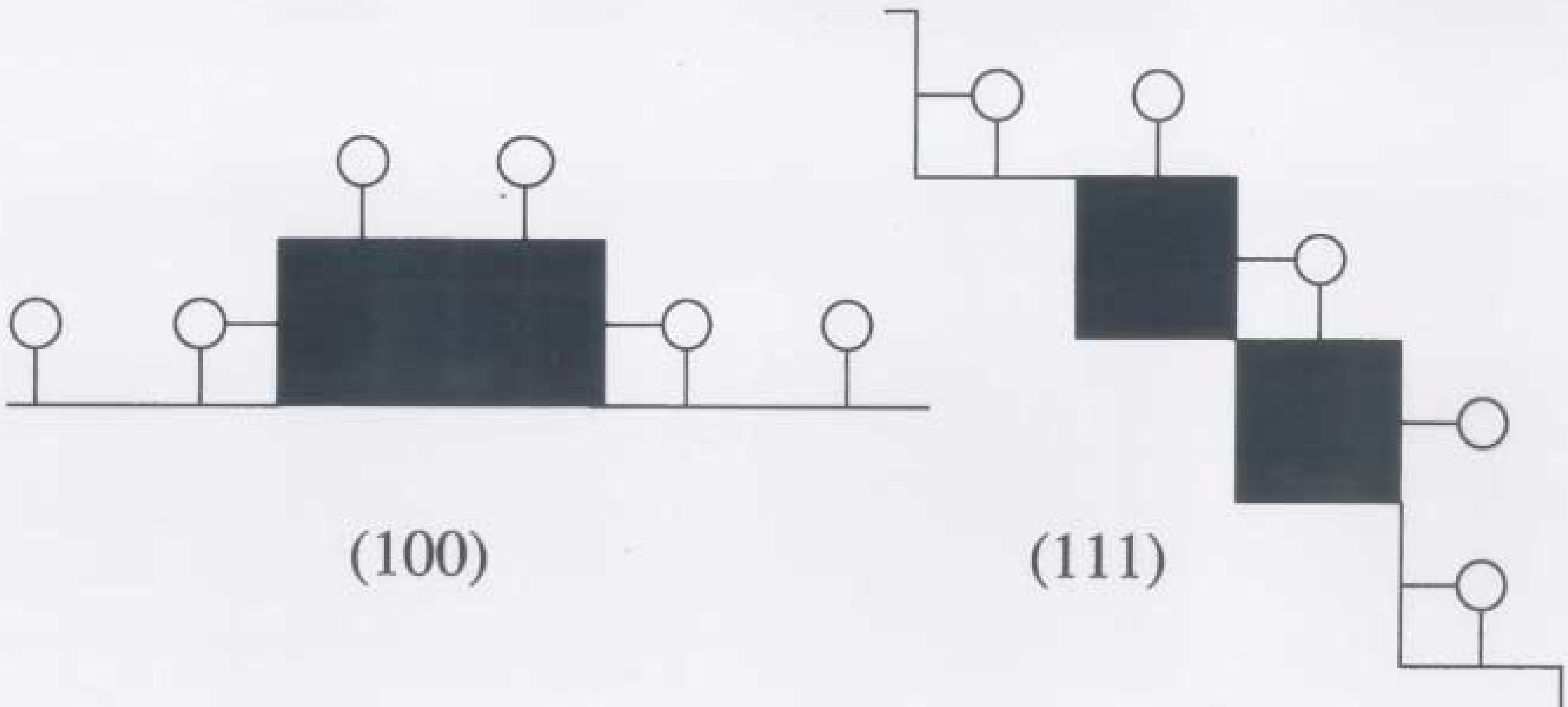
$$[Ag^+][X^-] = K_{sp}$$

$$pAg = -\log[Ag^+], \quad pX = -\log[X^-]$$

$$pAg + pX = pK_{sp}$$


dL/dt (Å/sec)
× AgCl (Cube) Strong
• AgBr (Cube) Wey
∘ AgBr (Octa) Saitoh
▵ AgBr (Cube) Lewis
Strong (AgCl)
Wey (AgBr Cube)
Saitoh (AgBr Octa)
Lewis (AgBr Cube)
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
L (Grain Size, μm)


Critical growth rate dr/dt [10-3 μ m/min]
1
2
5
10
20
pBr
2
3
4
a
b
c
a; Oct., b; Tetradec., c; Cub
Solubility [10-7M]



Two-dimensional nuclei (shaded areas) on (100) and (111) faces and adsorbed bromide ions (○).

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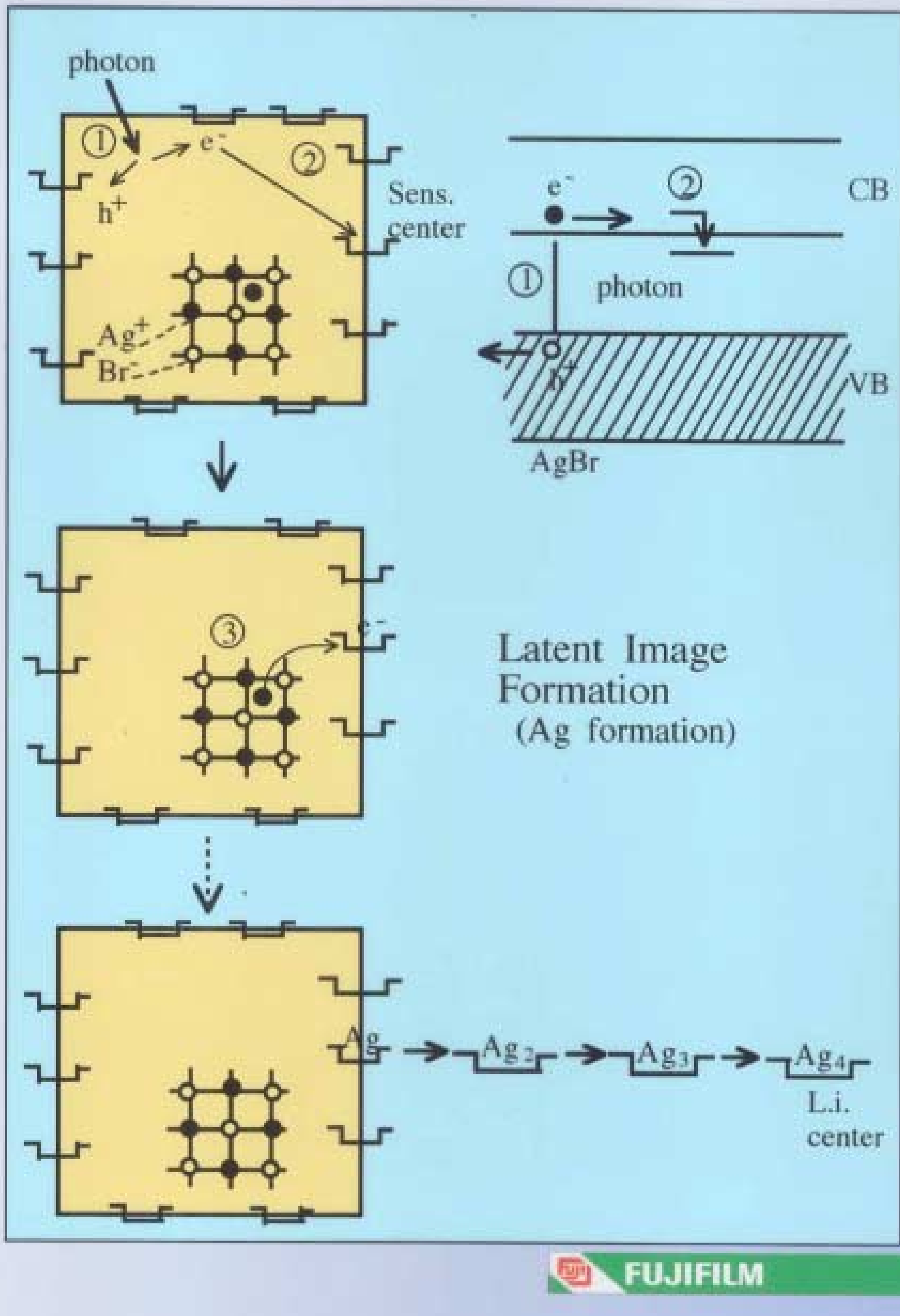
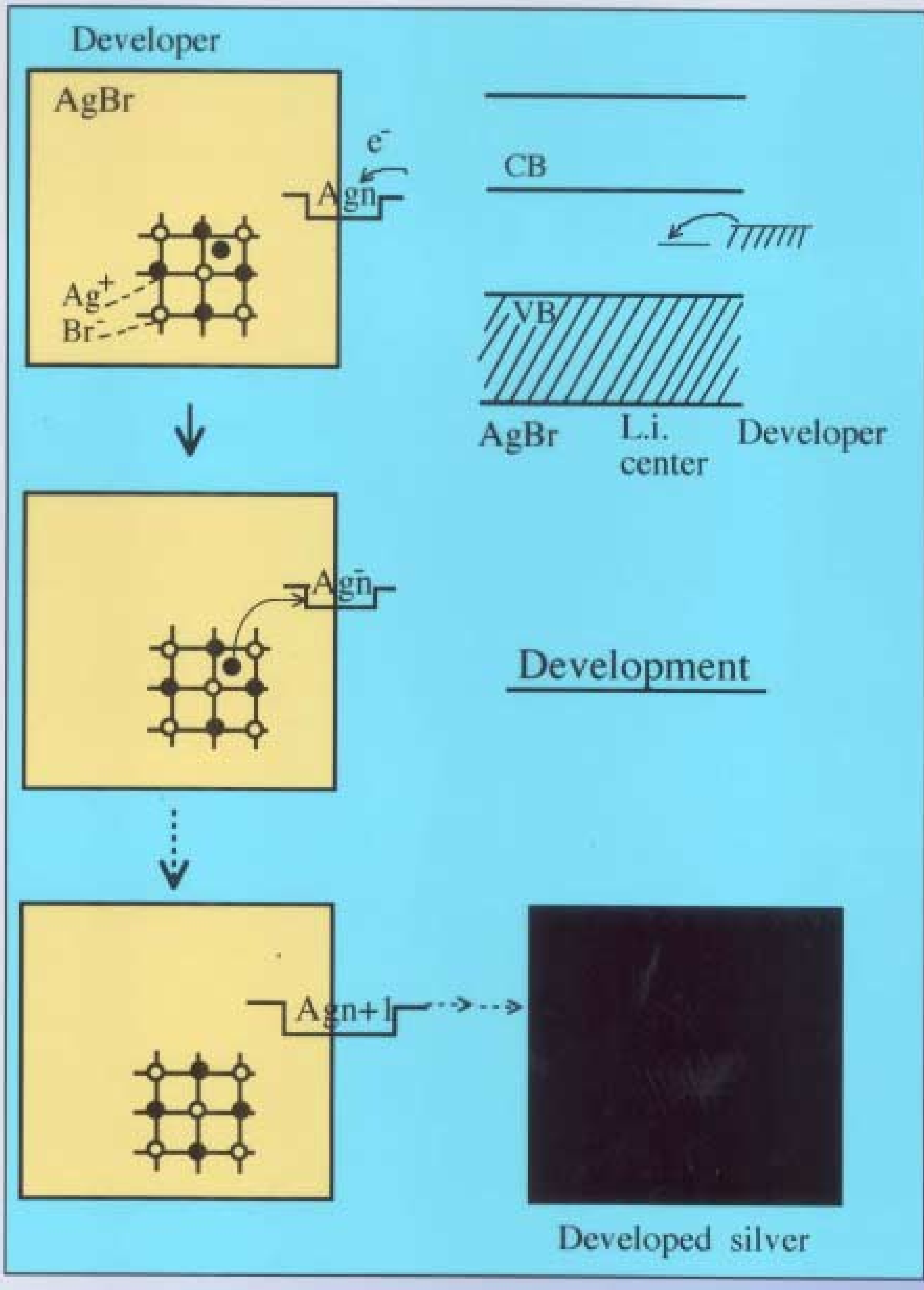
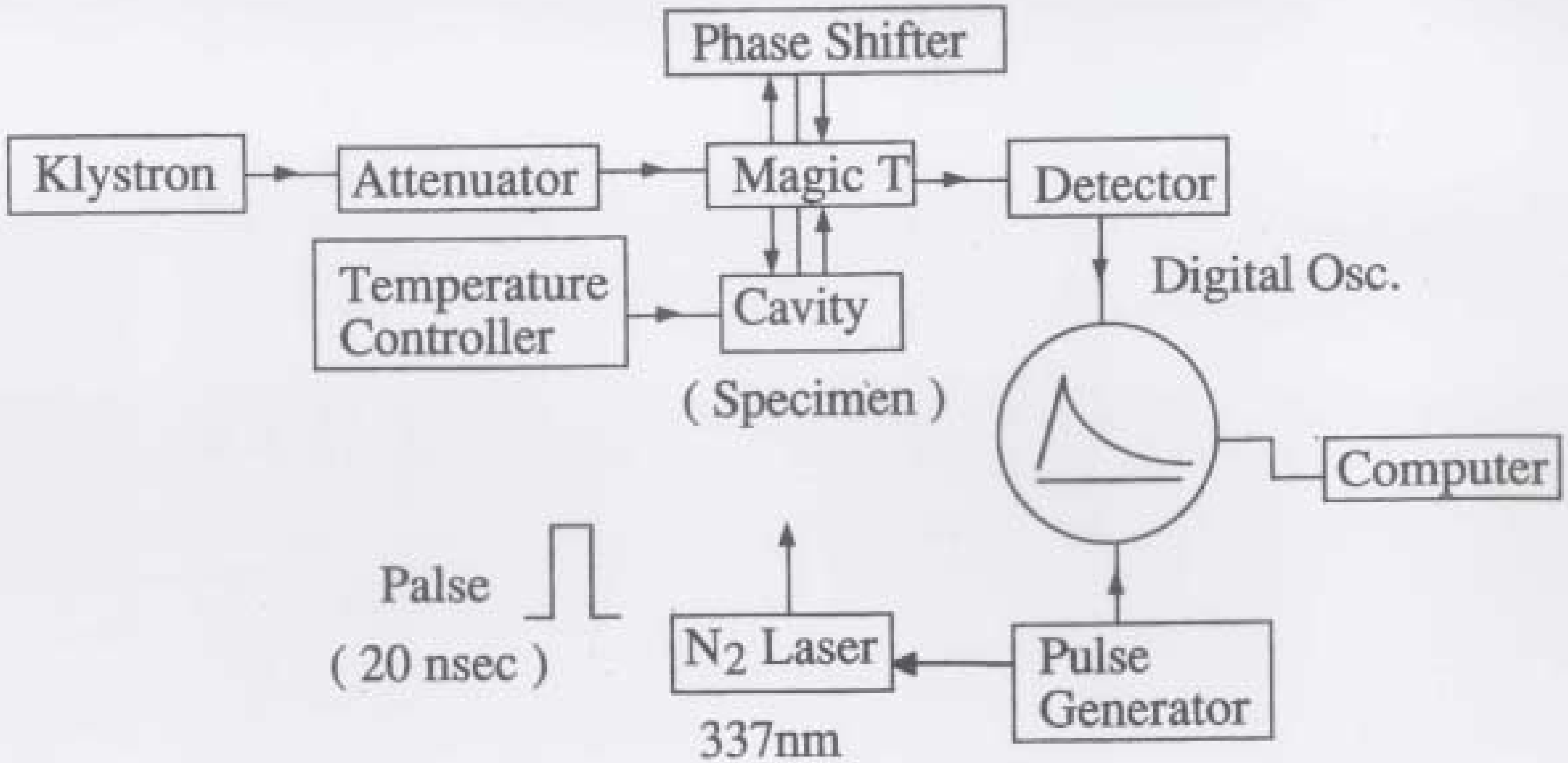
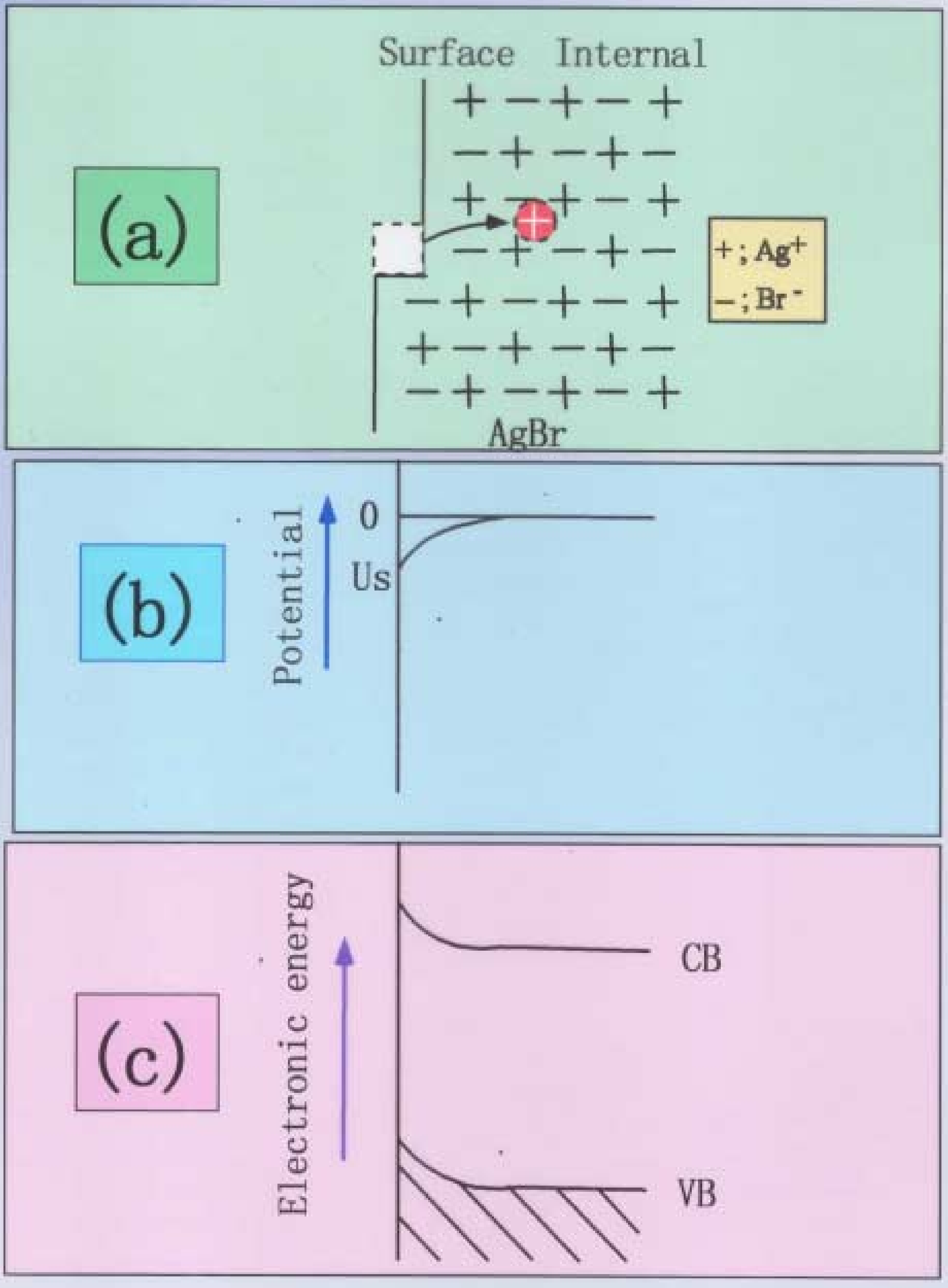

photon
①
e⁻
②
h+
Sens. center
Ag+
Br-
e-
②
CB
①
photon
h+
VB
AgBr
③
e-
Latent Image Formation
(Ag formation)
Ag
Ag2
Ag3
Ag4
L.i. center

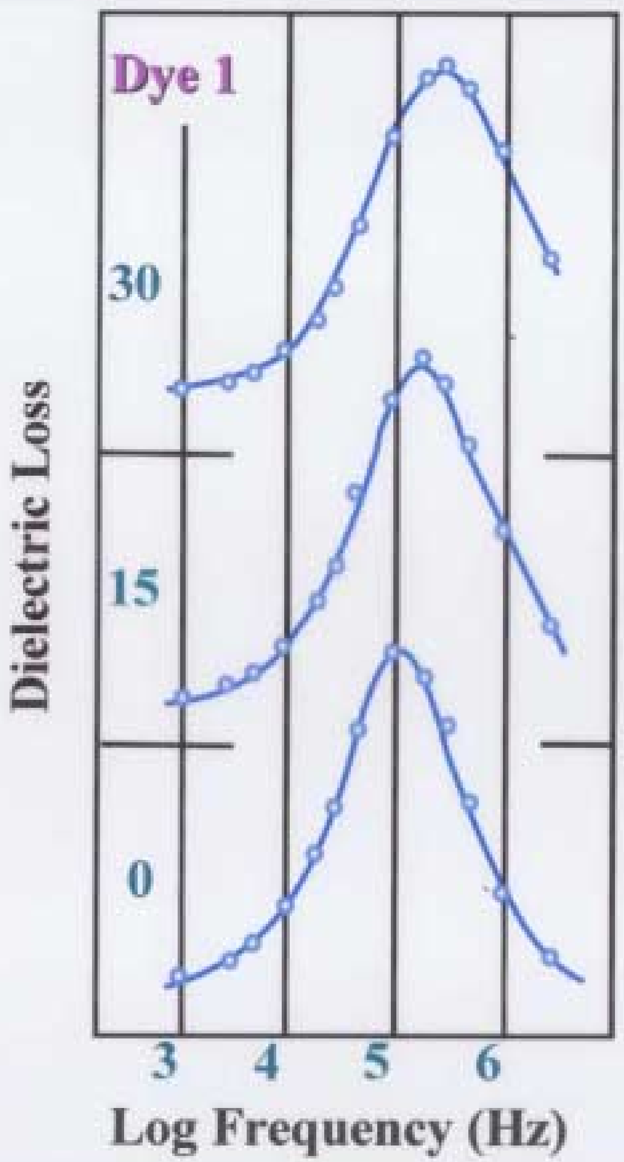

Developer
AgBr
e-
Agn
Ag+
Br-
CB
VB
AgBr
L.i. center
Developer
Agn
Development
Agn+1
Developed silver

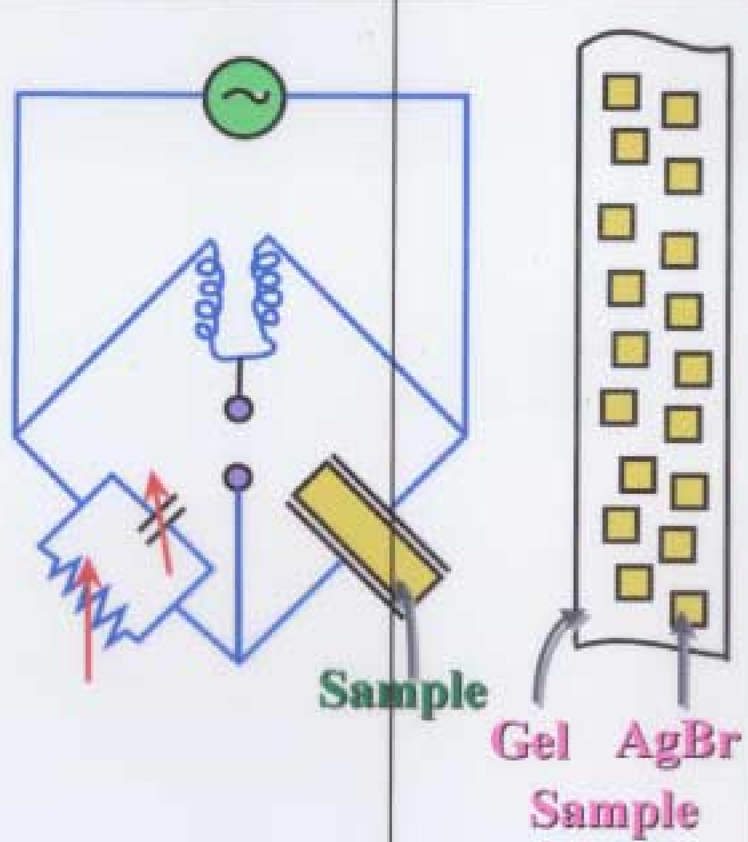


Block diagram of an apparatus for microwave photoconductivity measurements.


(a)
Surface Internal
+ ; Ag+
− ; Br−
AgBr
(b)
Potential
0
Us
(c)
Electronic energy
CB
VB

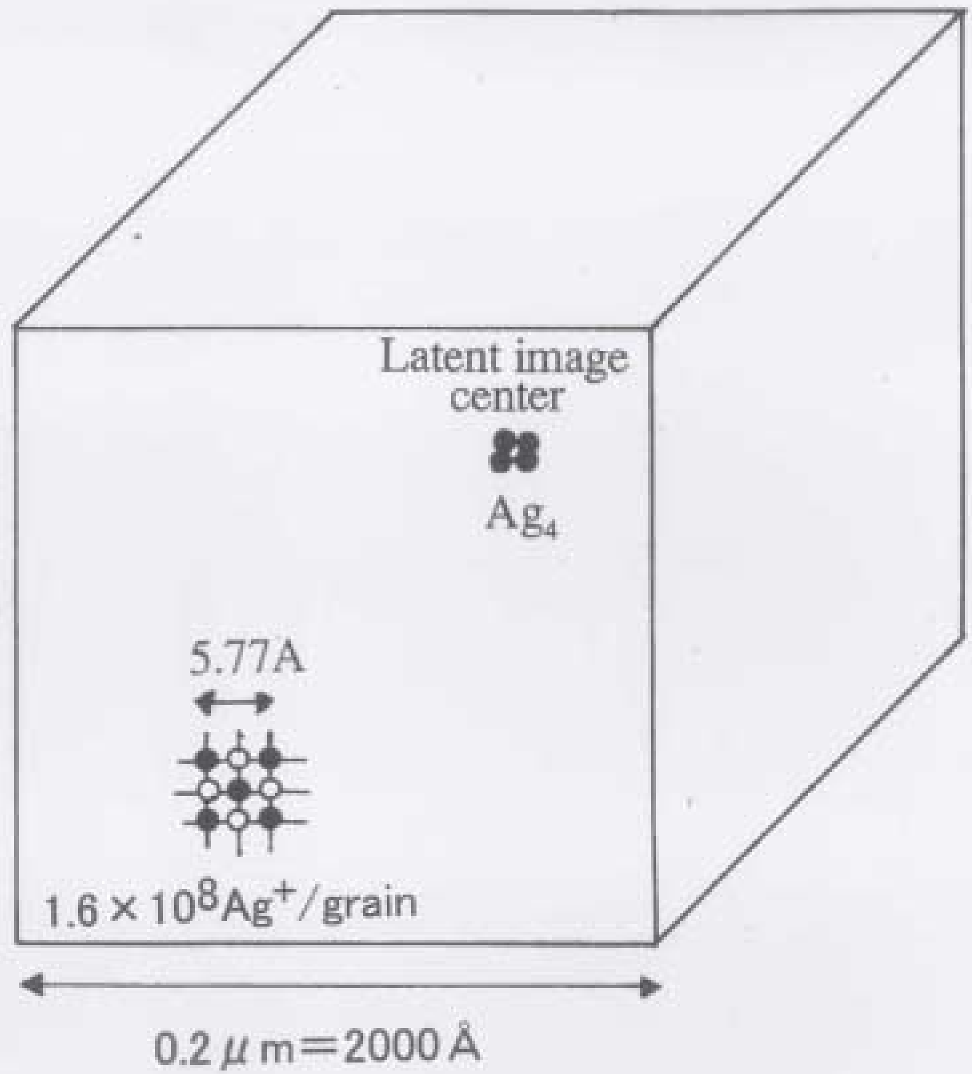
FUJIFILM



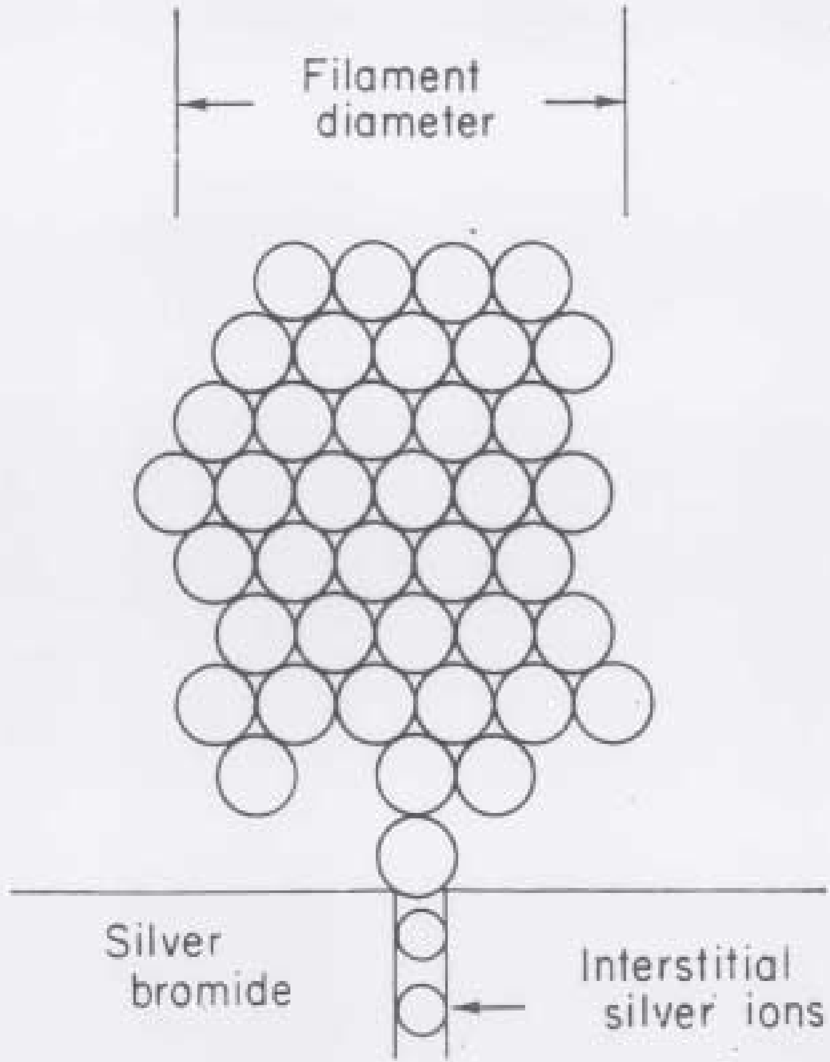


$$\delta_2 = f_{max} \frac{\{\varepsilon_\infty + (N-1)\,\varepsilon'_1\}^2}{2\,q\varepsilon'_1 N}$$

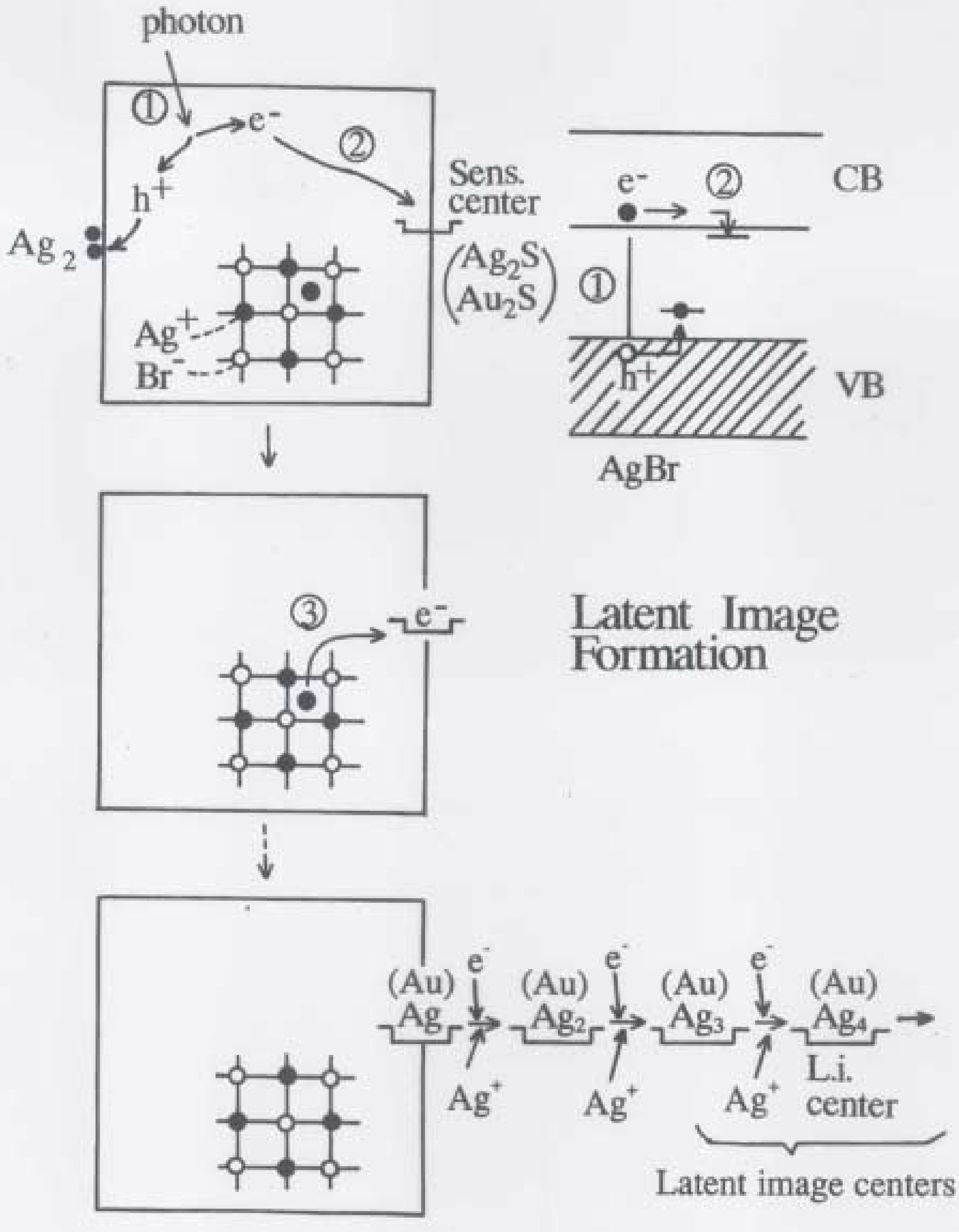
FUJIFILM


Latent image center
Ag4
5.77A
1.6×10^8 Ag+/grain
0.2 μm=2000 Å

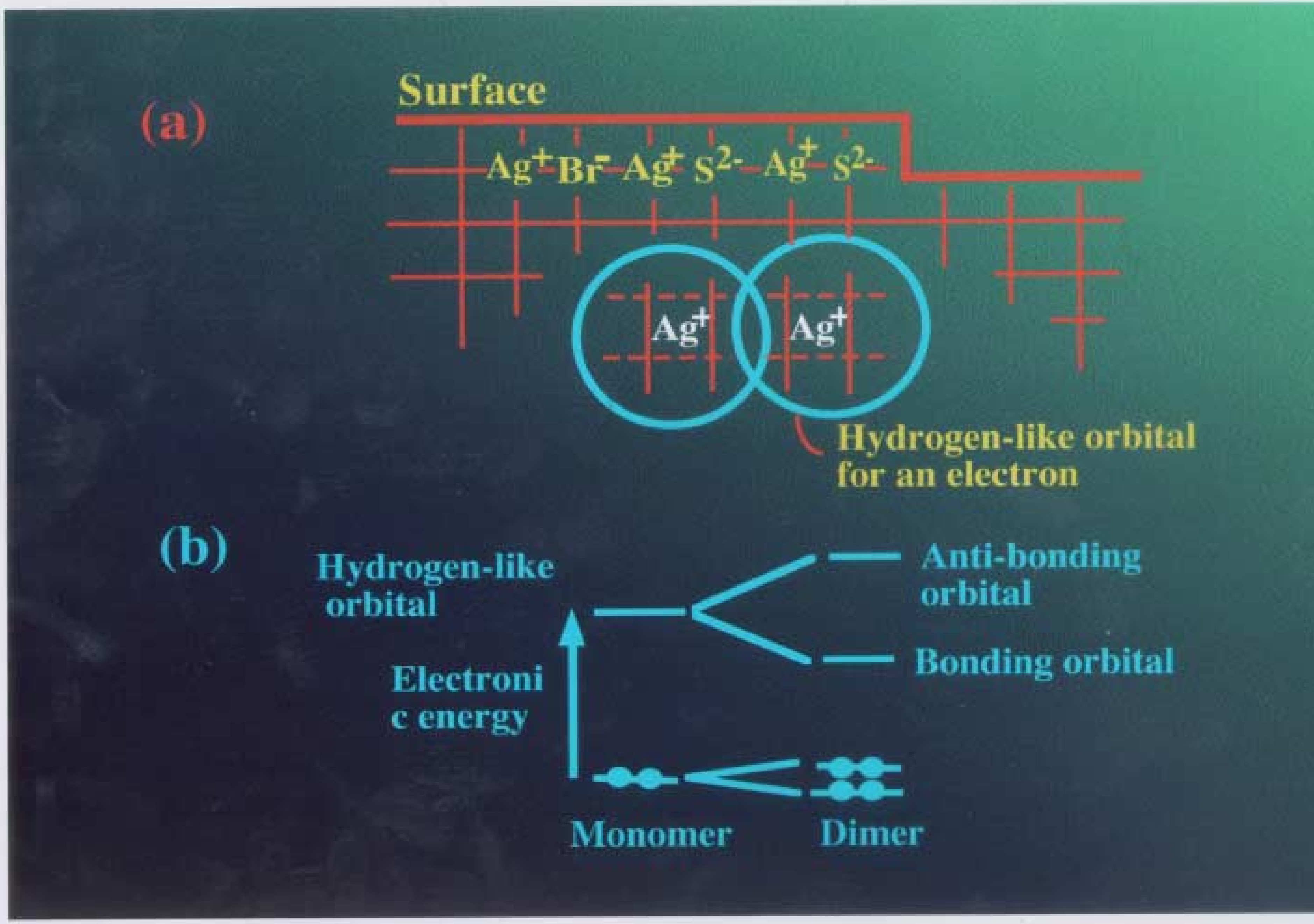
Filamentary silver produced by developing a photographic emulsion.



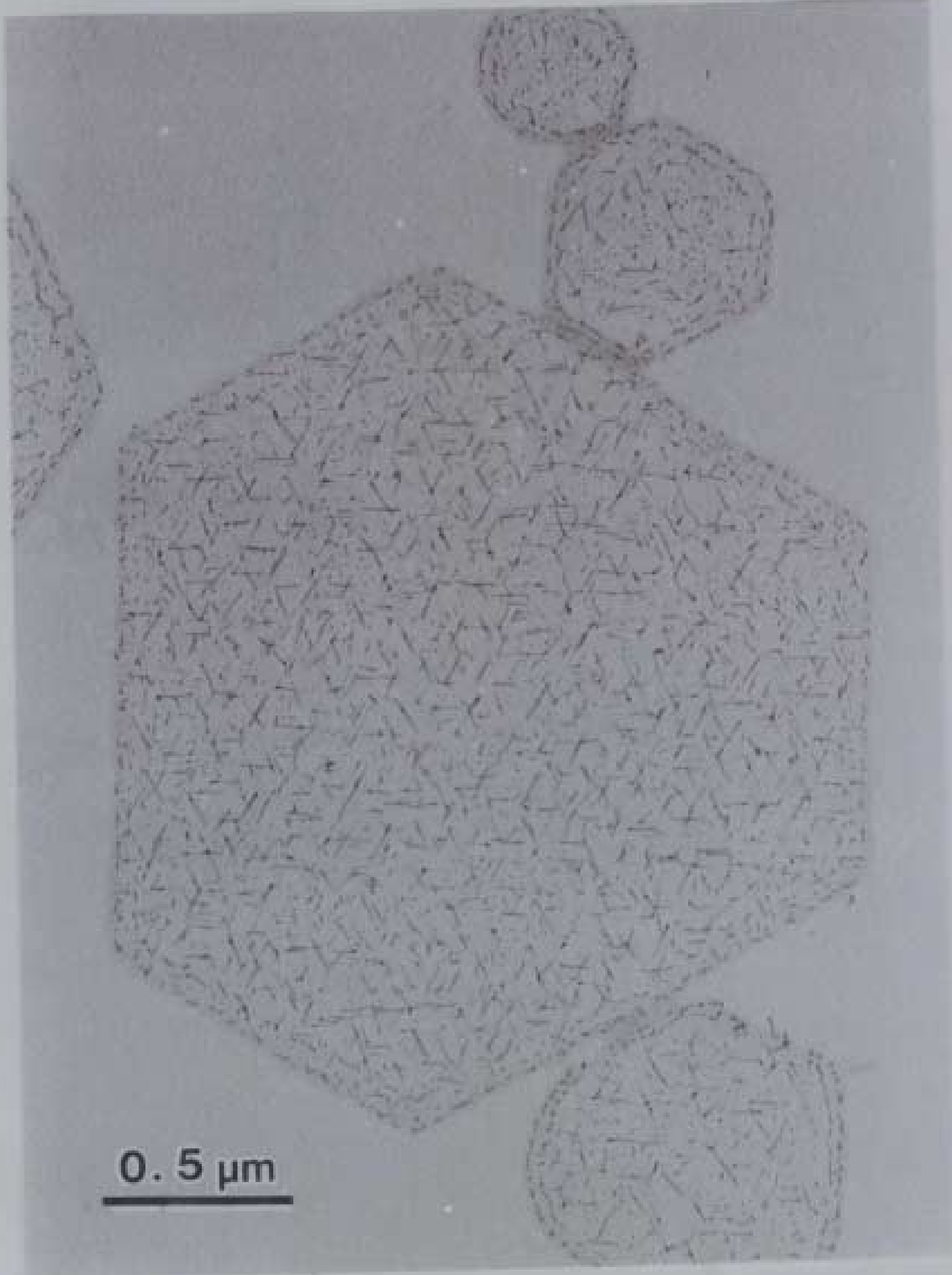
Metallic silver growing at an AgBr surface. The spherical particle becomes elongated when the diameter of the sphere grows too large for the silver to diffuse over the whole sphere in the time available. Typical 200 A filaments are about 70 atoms wide.

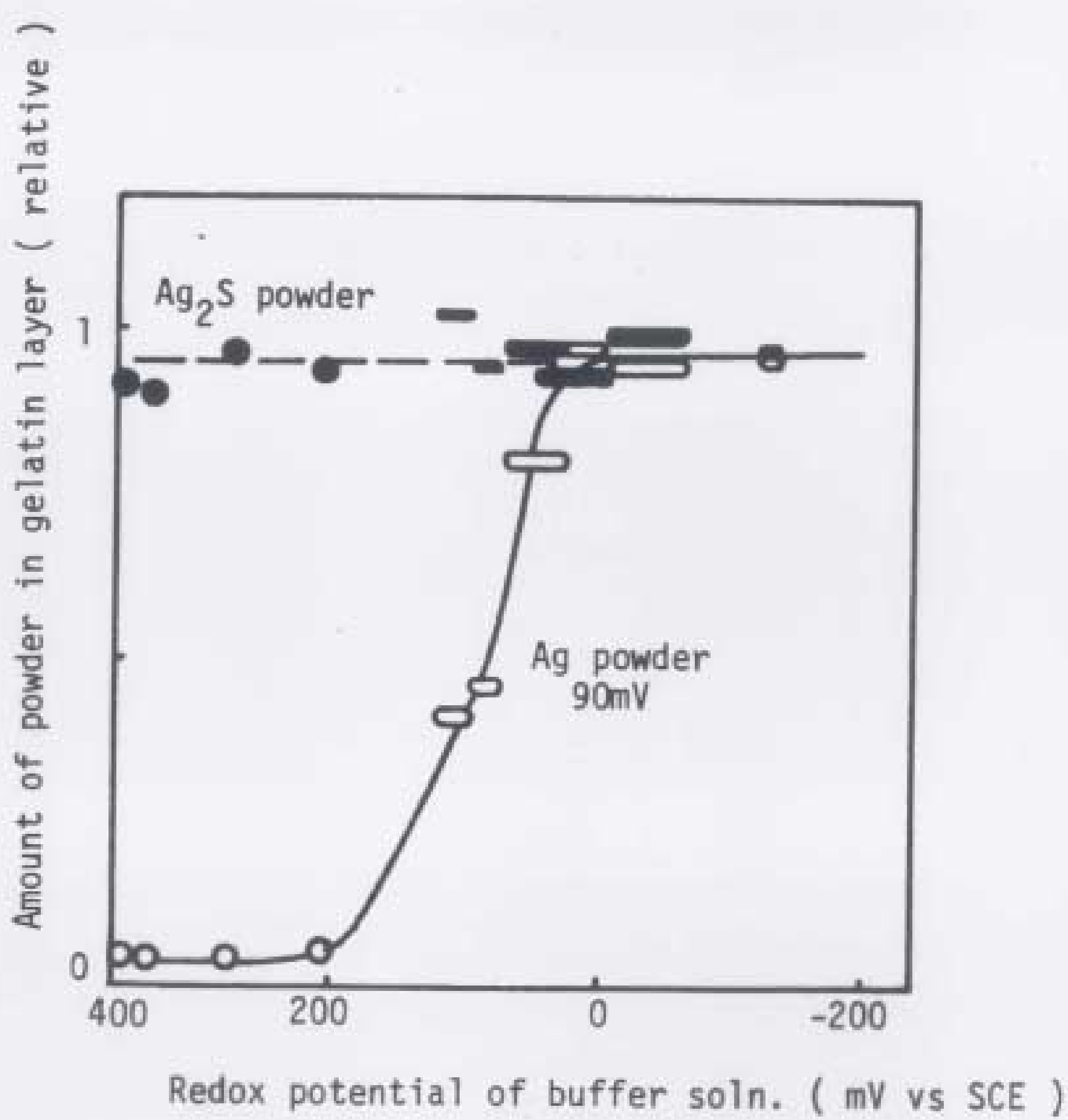


photon
①
e⁻
②
h⁺
Ag 2
Sens.
center
$\left(\begin{matrix}Ag_2S\\Au_2S\end{matrix}\right)$
Ag^+
Br^-
e^-
②
CB
①
h^+
VB
AgBr
③
e^-
Latent Image
Formation
(Au) Ag
(Au) Ag_2
(Au) Ag_3
(Au) Ag_4
e^-
Ag^+
L.i.
center
Latent image centers



(a)
Surface
Ag+ Br- Ag+ S2- Ag+ S2-
Ag+
Ag+
Hydrogen-like orbital
for an electron
(b)
Hydrogen-like
orbital
Electroni
c energy
Anti-bonding
orbital
Bonding orbital
Monomer
Dimer


0. 5 µm


Amount of powder in gelatin layer (relative)
1
0
Ag$_2$S powder
Ag powder
90mV
400
200
0
-200
Redox potential of buffer soln. (mV vs SCE)

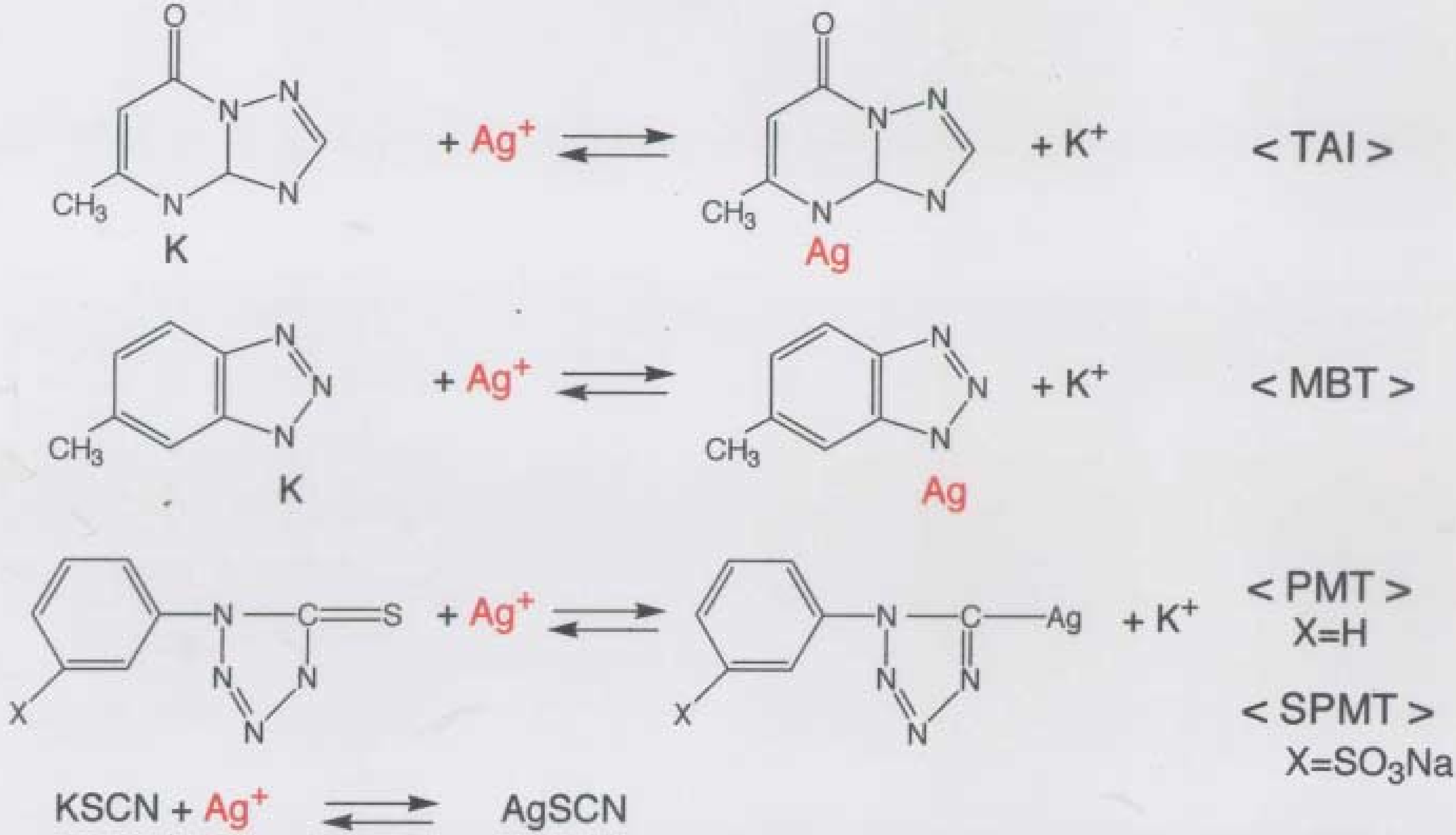
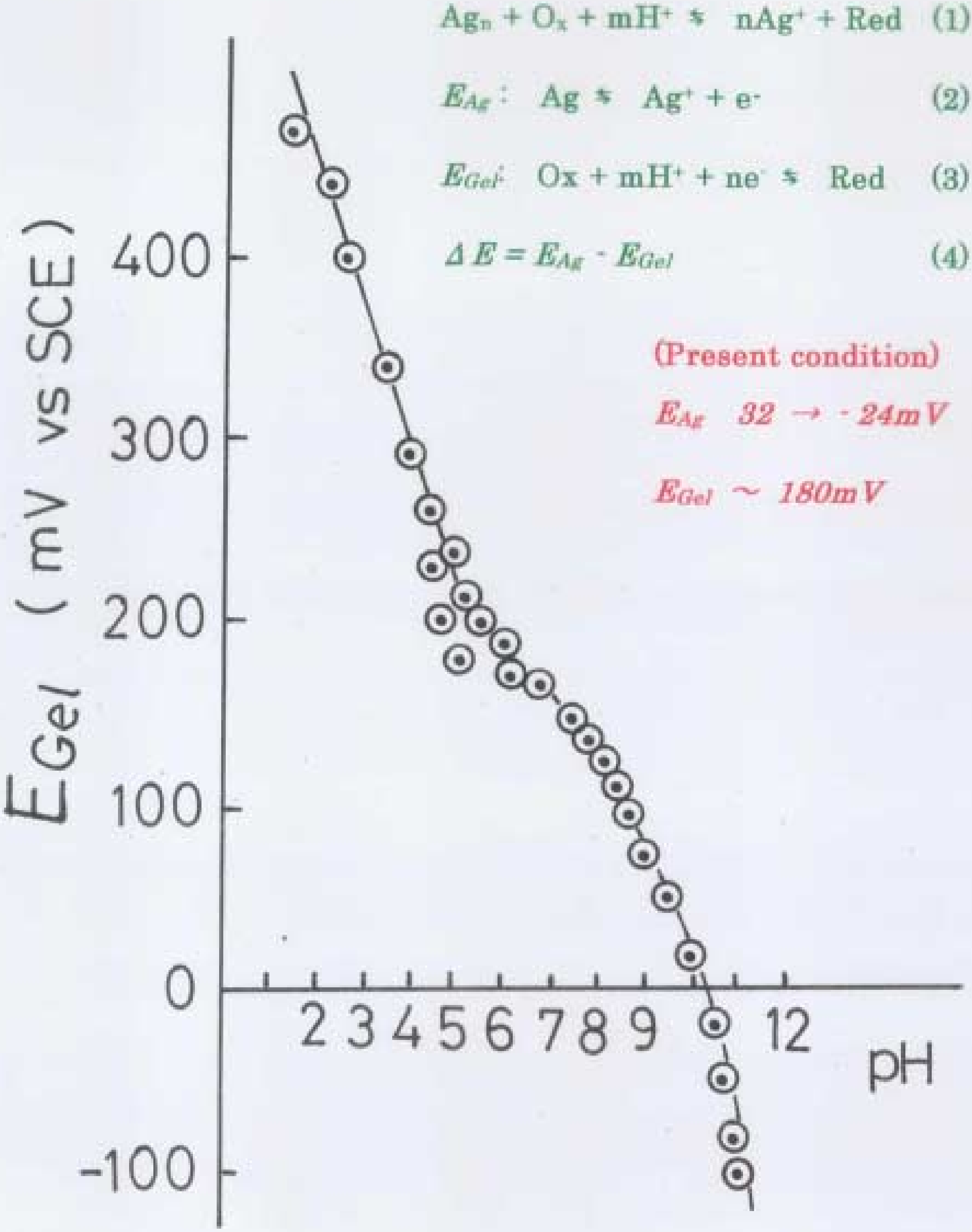


Fig. 3 Molecular structures and silver salt formation of campounds studied.



Ag_n + O_x + mH⁺ ⇆ nAg⁺ + Red (1)
E_Ag : Ag ⇆ Ag⁺ + e⁻ (2)
E_Gel: Ox + mH⁺ + ne⁻ ⇆ Red (3)
ΔE = E_Ag - E_Gel (4)
(Present condition)
E_Ag 32 → -24mV
E_Gel ~ 180mV
E_Gel (mV vs SCE)
400
300
200
100
0
-100
2 3 4 5 6 7 8 9 12
pH

The Smallest Latent Image Center

<Evaluation>3 atoms

Babcock & James (1975) with $S+Au+H_2$

Mitchell (1978) with theoretical calc.

Granzer,Moisar,Woeste et al. (1985) with Ag_4^+

Hailstone & Hamilton (1985-88) with simulation.

<Ultimate limit>2 atoms(Au_2)

Mitchell (1978) with theoretical calc.

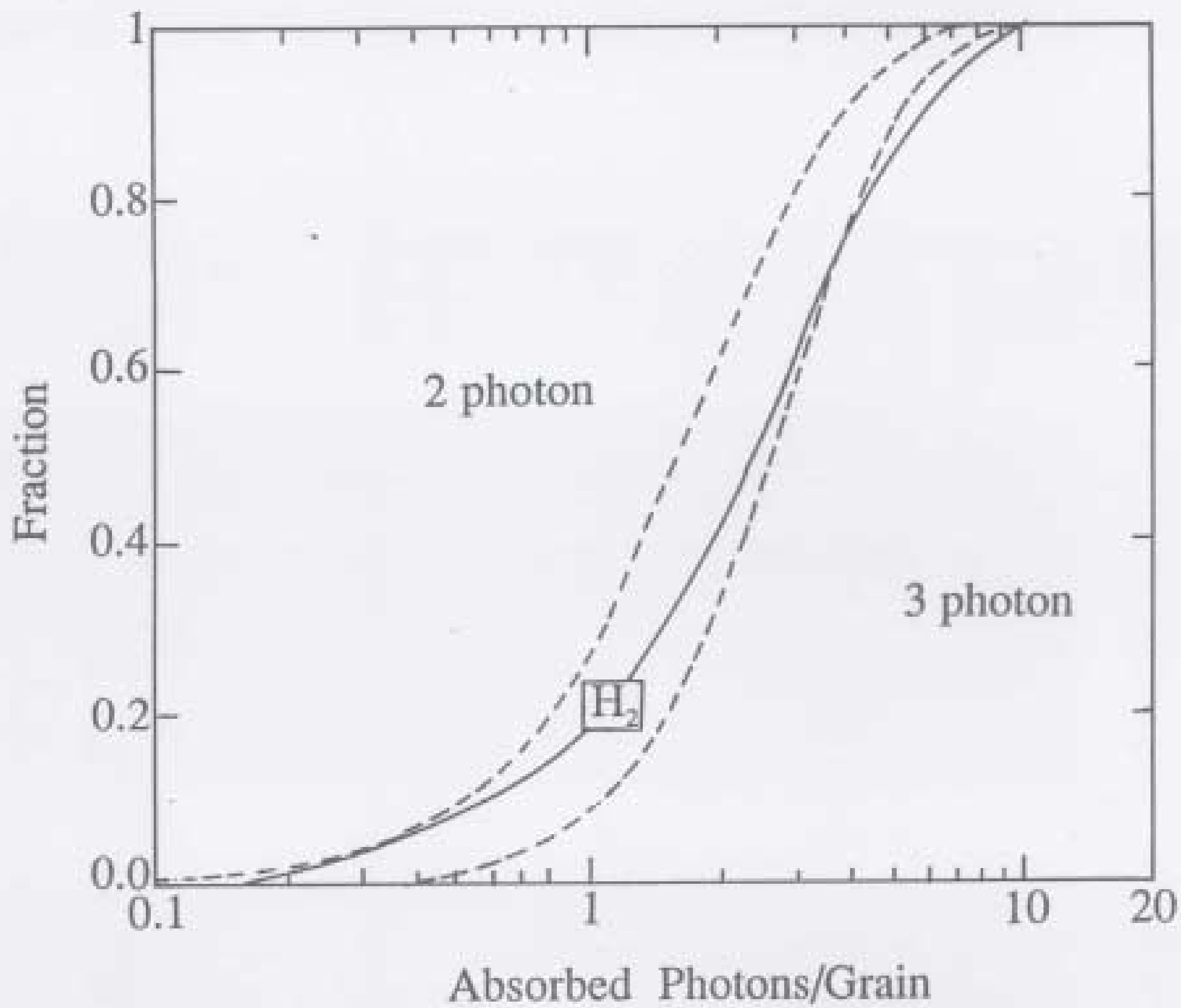
Tani et al. (1995) with gold-latensified Ag_2.

<Single-photon system>

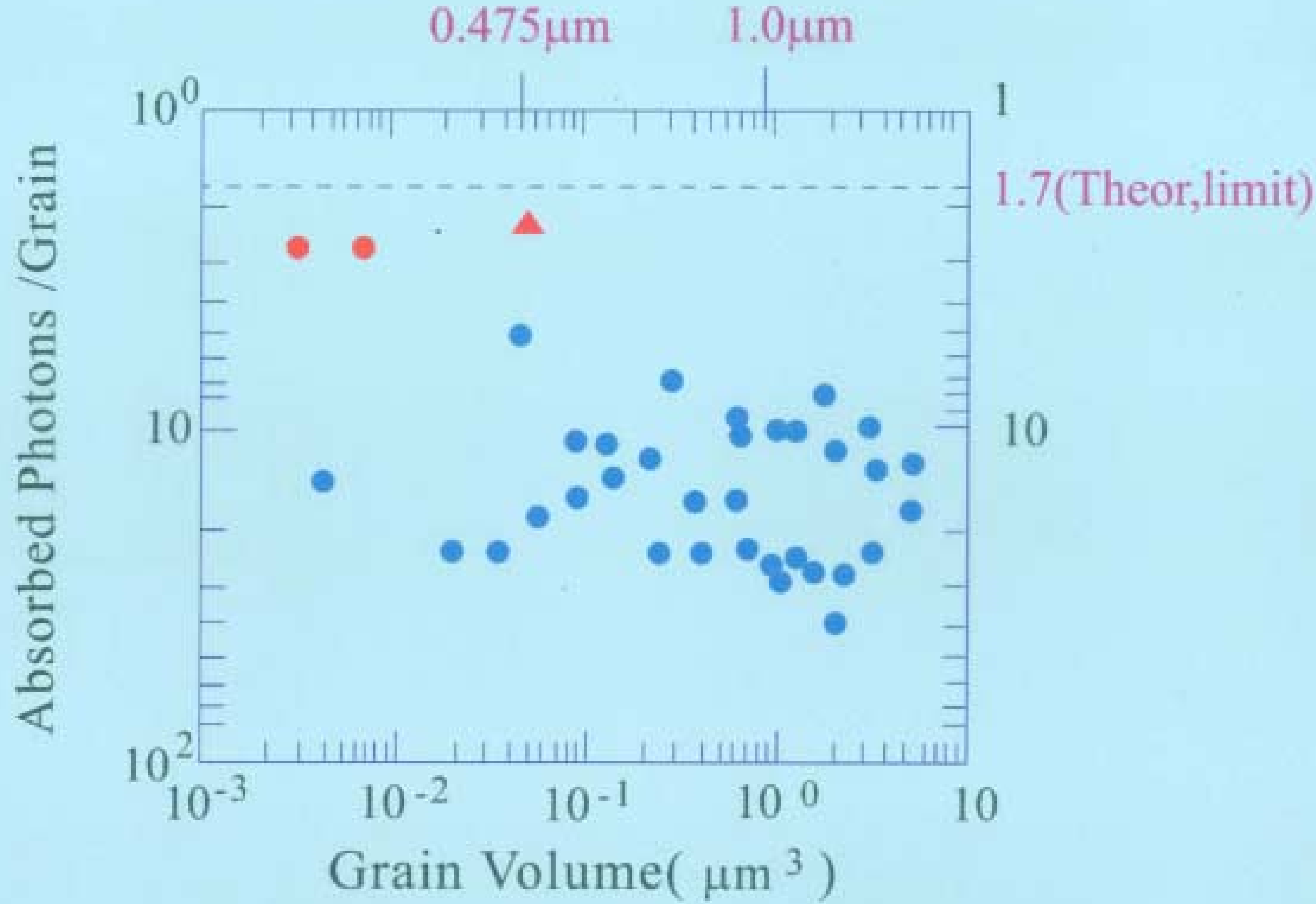
Formation of Au_2 by a single photon absorption and Lowe's process

Hailstone (1994)

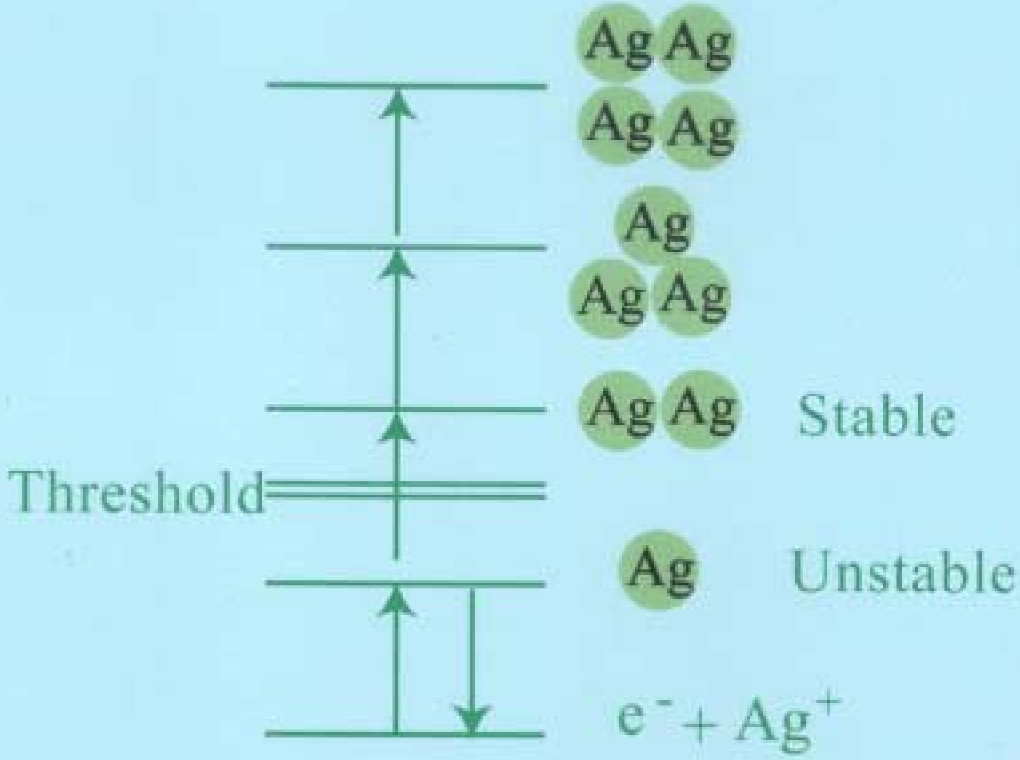
Takada (1997)

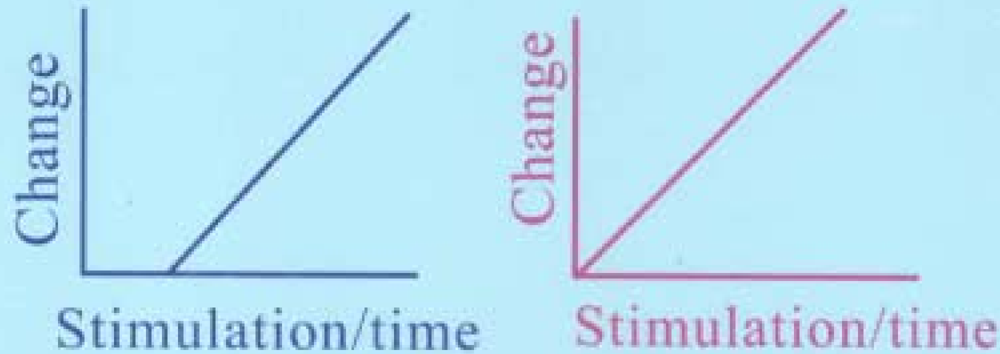


Fraction
1
0.8
0.6
0.4
0.2
0.0
0.1
1
10
20
Absorbed Photons/Grain
2 photon
3 photon
H2



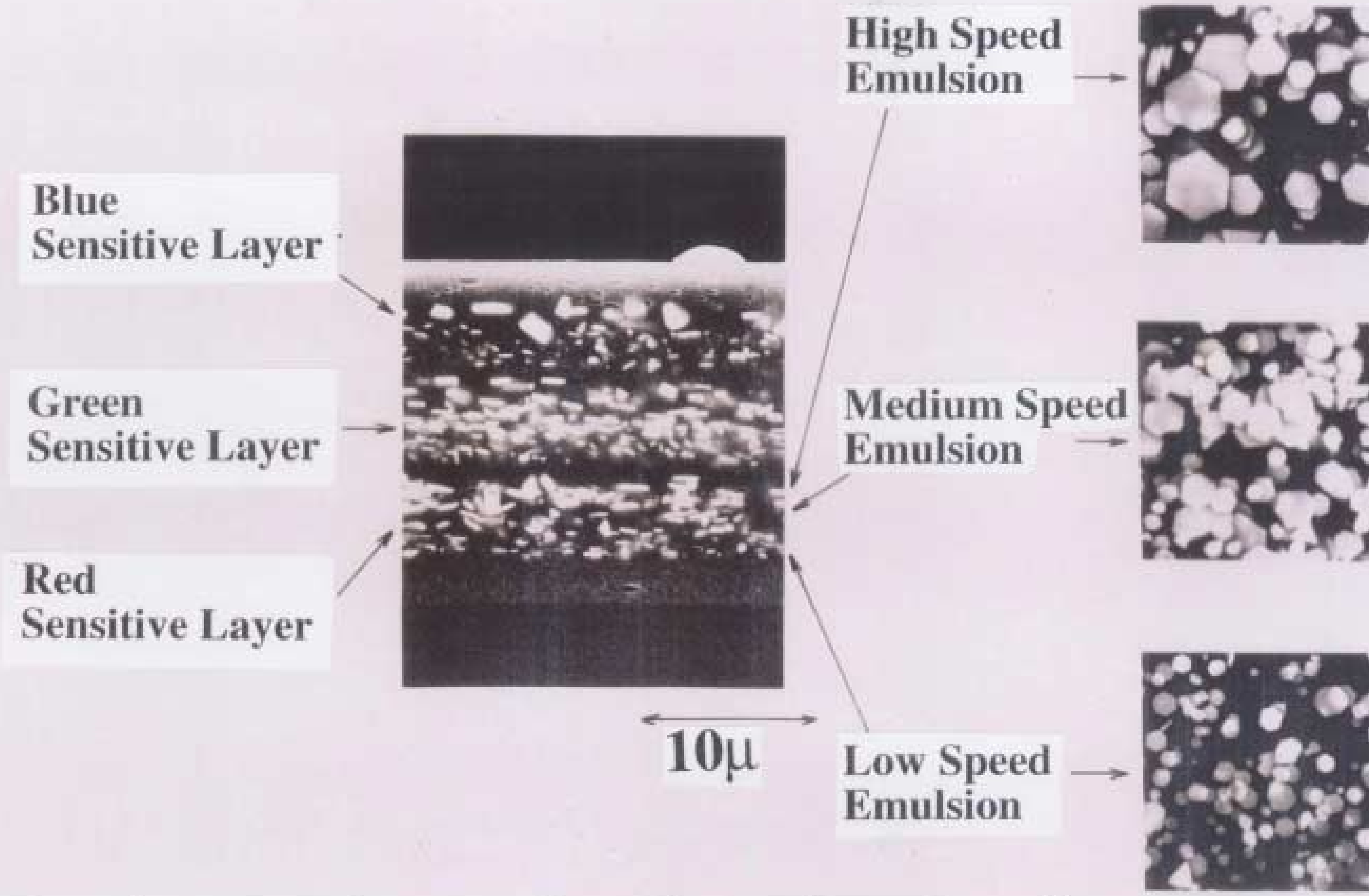
R.K.Hailstone et al.,1988





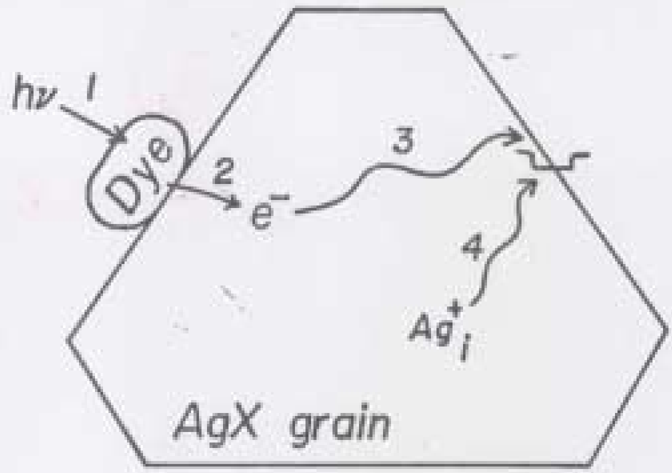
<Silver halide photo.> <Non-silver photo>

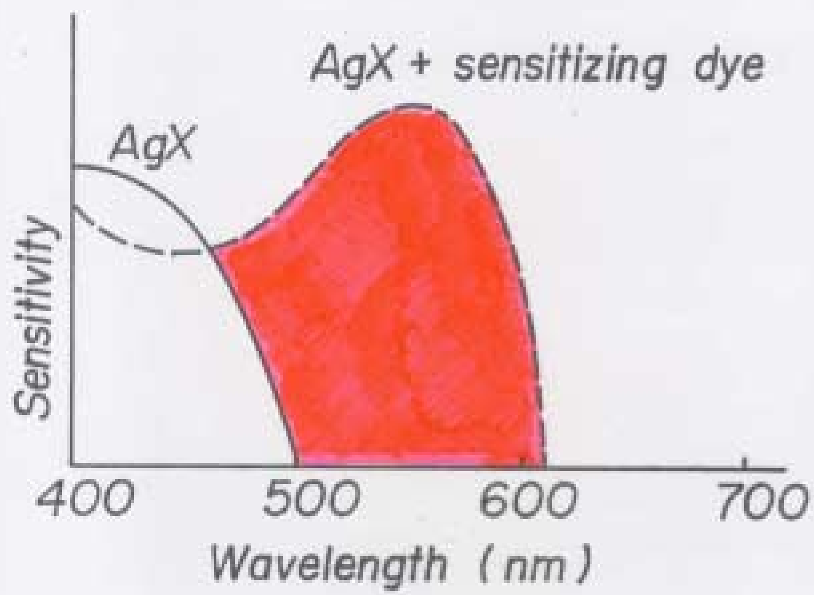
Threshold for Latent Image Formation



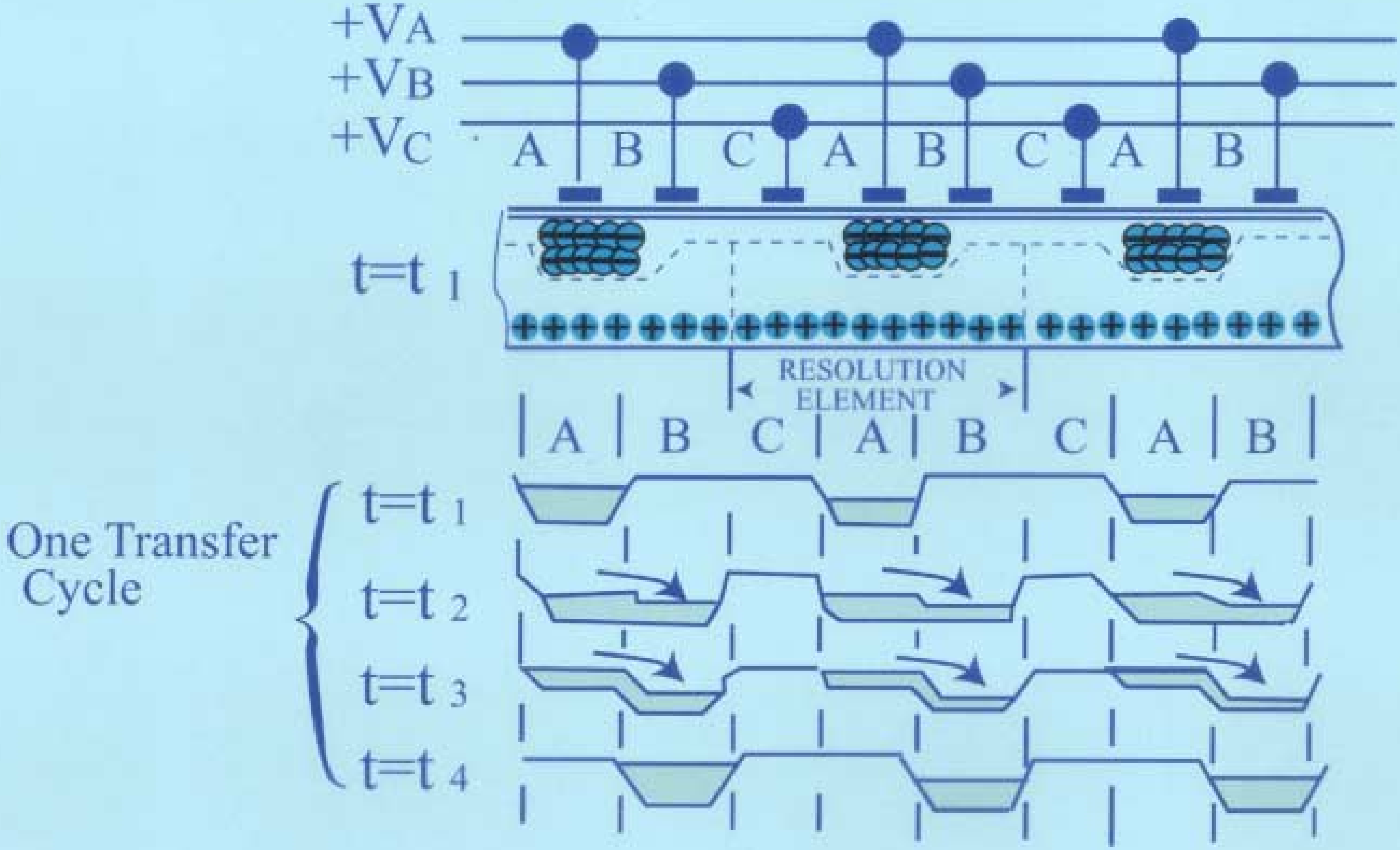
Scanning electron micrographys of a section of a color negative film (Super G400) and some halide grains used in it.

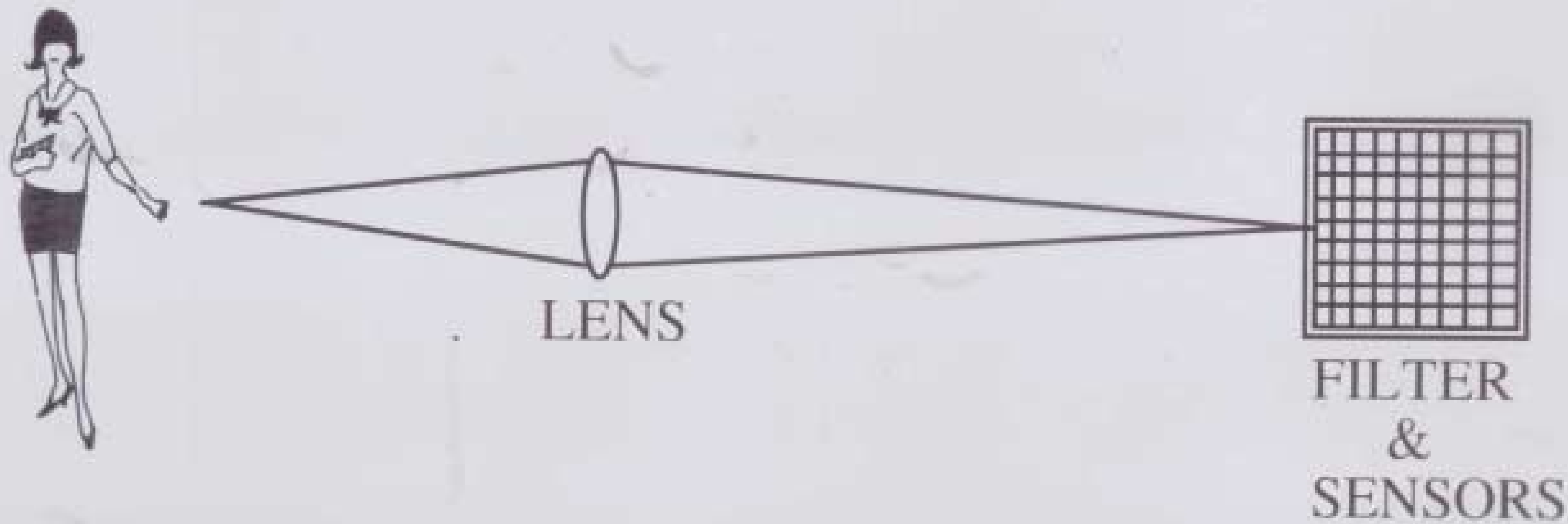
Spectral Sensitization



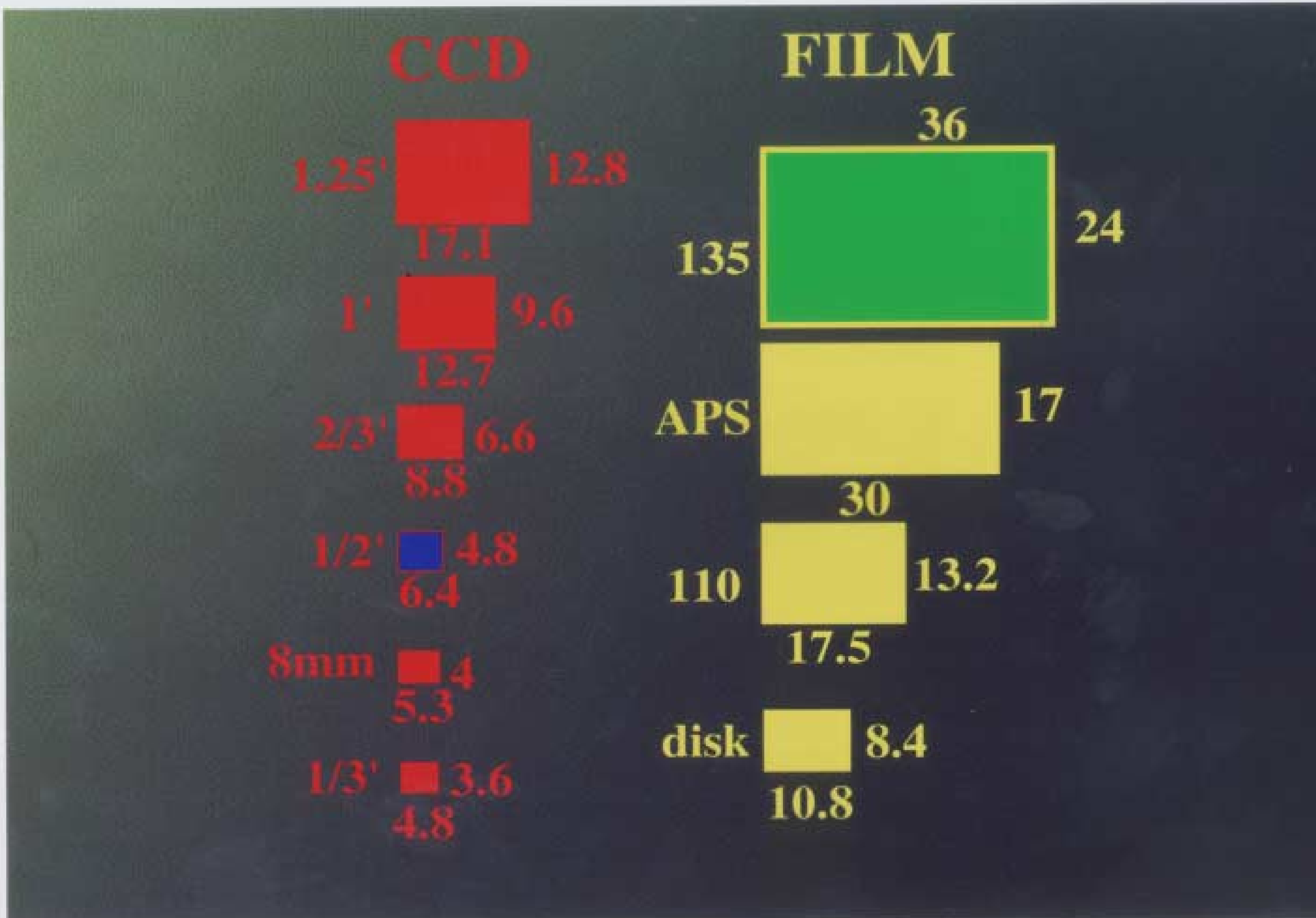


CHARGE COUPLED DEVICE





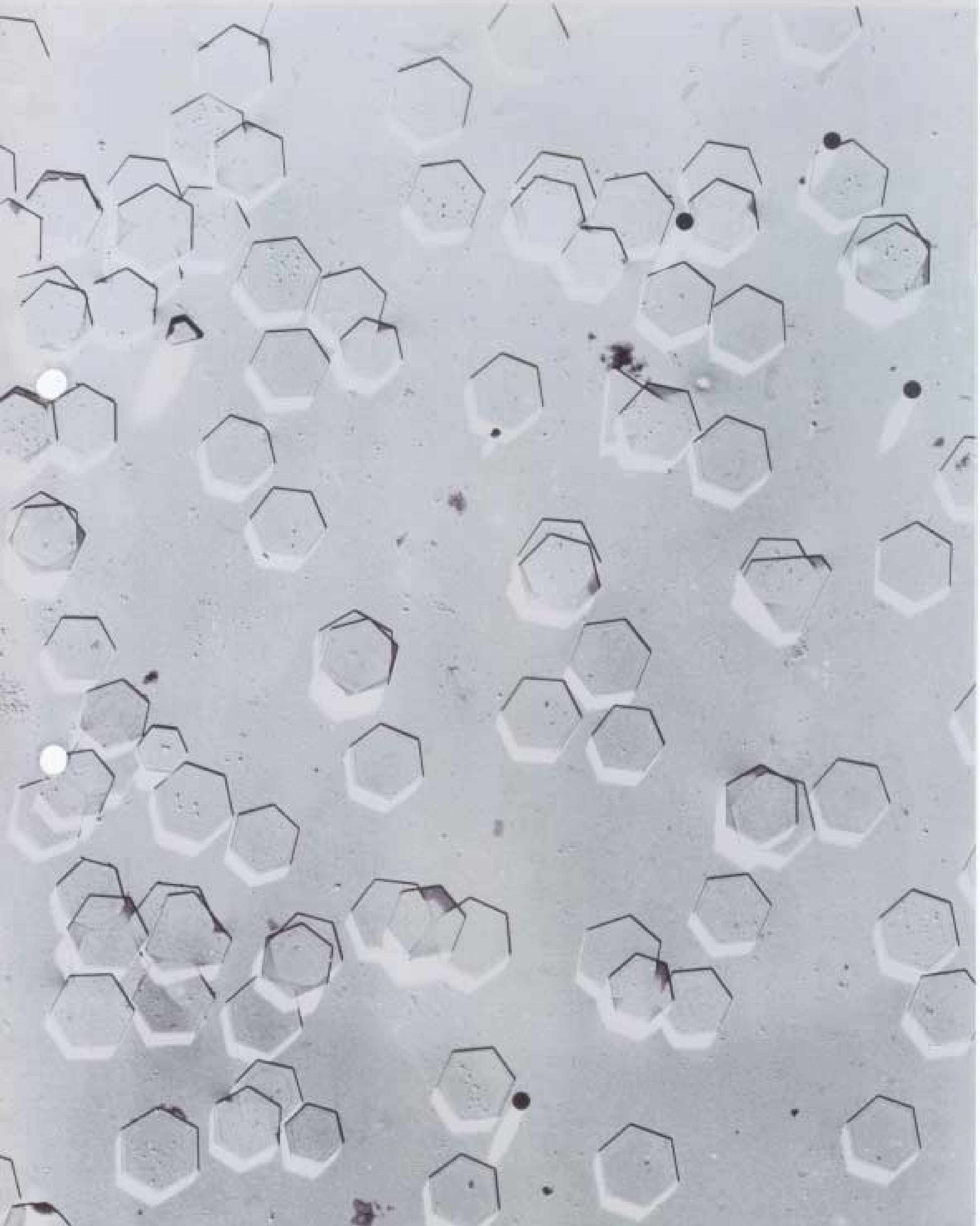
The sensor and filter geometry will be assumed to be a pattern such as :



CCD
1.25'
12.8
17.1
1'
9.6
12.7
2/3'
6.6
8.8
1/2'
4.8
6.4
8mm
4
5.3
1/3'
3.6
4.8
FILM
36
135
24
APS
17
30
110
13.2
17.5
disk
8.4
10.8

The reduction of the sensitivity to high-energy radiations without deteriorating light sensitivity is one of the most important problems for the development of color films, and should be achieved

(1) by using large amount of sensitizing dyes,
(2) by using AgX grains with large specific surface area such as tabular grains,
(3) by using AgX grains with appropriate high-intensity reciprocity law failure such as heavily sulfur-sensitized grains and grains without transient traps for photoelectrons, and
(4) by using AgX grains with appropriate concentration of interstitial silver ions



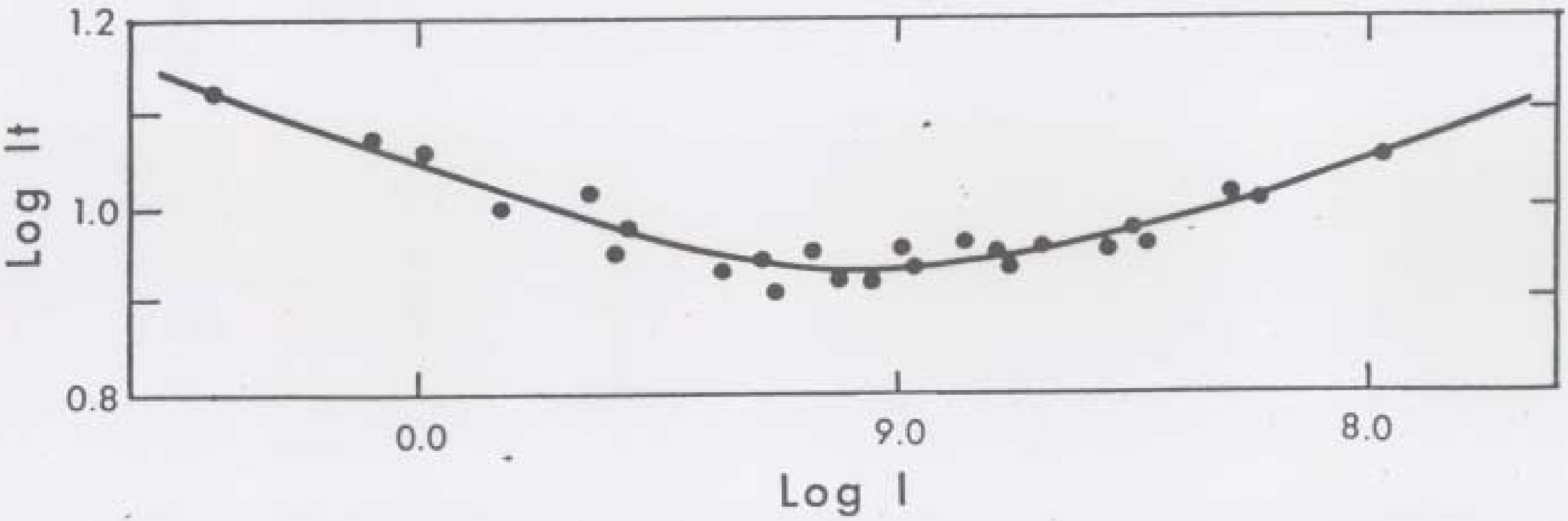


Fig. 7.1. *A reciprocity curve of an emulsion showing both high-intensity and low-intensity reciprocity failure.*

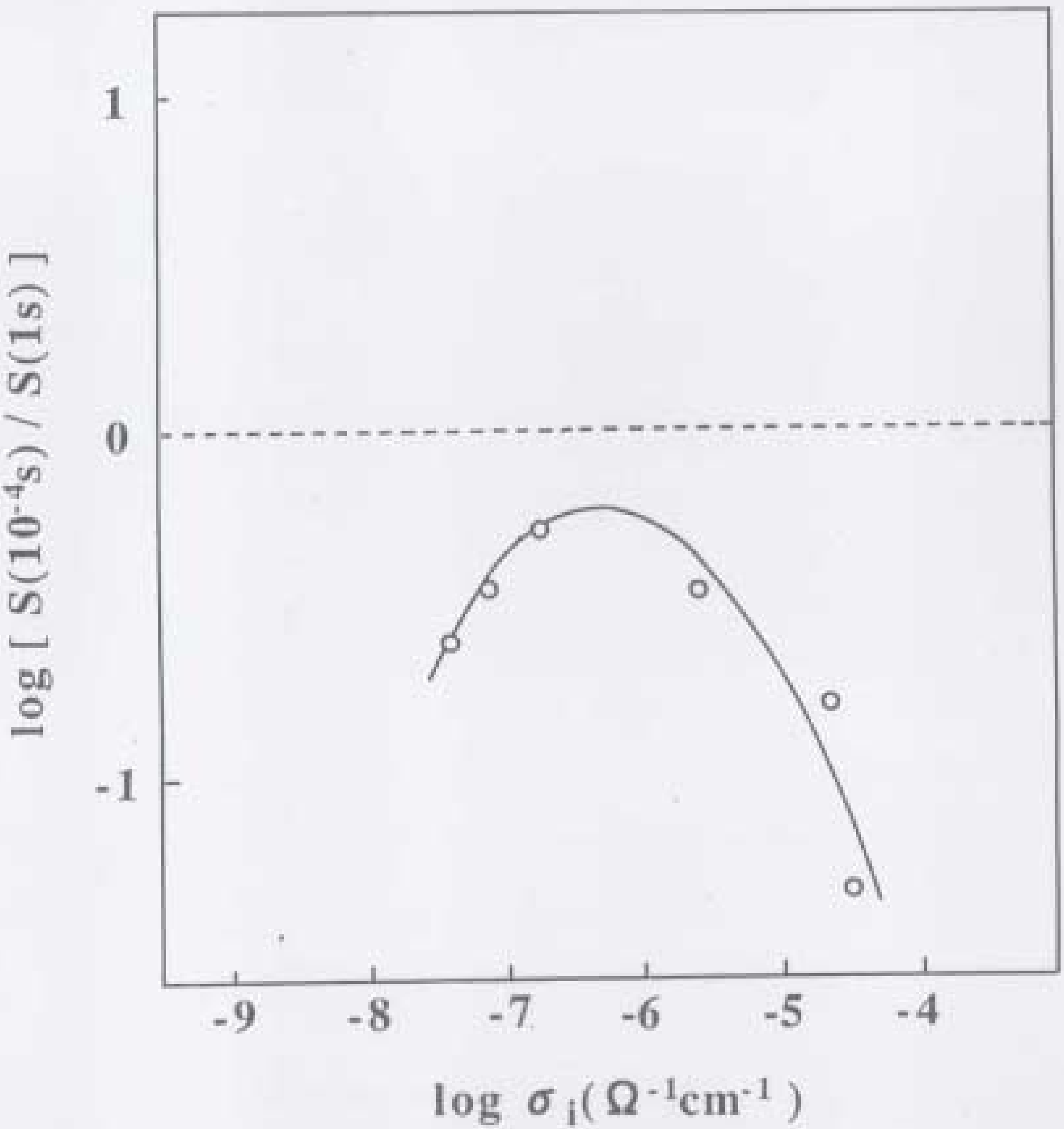


Figure 5

Silver Halide Emulsion as a Tool for High Energy and Nuclear Physics

Tadaaki Tani and Kenichi Kuwabara
Ashigara Research Laboratories, Fuji Photo Film Co., Ltd.
210 Minami-Ashigara, Kanagawa, 250-0193, Japan

1. Introduction for Nuclear Emulsion

2. Structure and Formation of Silver Halide Grains

3. Mechanisms and Sensitivity of Photographic Processes

4. Summary

2nd International Workshop on Nuclear Emulsion Technology
March 7-9, 2002, Nagoya University, Nagoya, Japan

To meet the requirements for a Nuclear Emulsion

1. Large frame area – Random arrangement and independent response of many fine AgX grains.
2. Three dimensions – Dispersion of transparent AgX grains in gelatin matrix
3. High sensitivity – Highly efficient formation and large degree of catalytic activity (amplification) of a latent image center
4. High stability on storage – Threshold for latent image formation
5. High resolution – Small and monodispersed AgX grains with high sensitivity
6. Ability to be reset – Discrimination of oxidation between Ag fog centers and Ag_2S sensitization centers by wet gelatin and oxygen