Fundamentals of General Metallography

Table of Contents

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The micrographs included in this series of projection films on fundamentals of general metallography were made available by Laboratory of Metallography, Materials Engineering Department, Hennigsdorf Institute of Technology.

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1. General

This series of projection films on fundamentals of general metallography can be used for the theoretical education and practical training in metal fabrication. It can also be used for further and refresher training in the metal–fabricating field. It covers the following subjects:

	Film no.
(1) Crystalline structure of metals	1, 2, 3
(2) Structure and real lattice	3, 4, 5, 6
(3) Methods of examination	7 thru 13
(4) Eutectic diagram	14
(5) Solid solution diagram	8, 9, 15
(6) Precipitations from solid solutions	16

(7) Deformation of metals	17, 18, 19
(8) Recrystallization	19, 20
(9) Iron−carbon diagram	21 thru 26

To aid instructors in making preparations for lessons and avoid misinterpretations of the contents of projection films, all of the films have detailed explanations attached to them. Ease of comprehensibility called for the liberal use of colors in the design of projection films on methodological principles.

All crystallographic relationships (e.g., lattices and unit cells) were marked in blue, whereas transitions to higher temperatures accompanied by state changes were marked in red.

Cooling curves of thermal analysis and heating curves of thermal treatment were plotted against a blue background, whereas constitutional diagrams and those relating to strength properties were plotted against yellow and green backgrounds, respectively.

Micrographs of metals were unilaterally fixed to base films, thus providing for various forms of representation during classes. To enable instructors to plot their own diagrams, blank films nos. 27 and 28 were provided with centimeter grids. A4 size films are used together with frames to take up base films.

The films in this series are contained in suitable bags which together with the booklet and frame are accommodated in a plastic folder, thus providing for ease of storage together with other types of information carriers.

2. List of projection films

Film no.	Film title
1	Crystal lattice
2	Grain and grain boundary
3	Unit cells
4	Crystal growth
5	Real lattice structure
6	Dislocation
7	Etching possibilities
8	Macro− and micro−etching
9	Coarse and fine grains
10	Segregations in rimmed steel
11	Metallurgical microscope
12	Thermal analysis
13	Curve of solidification
14	Eutectic
15	Solid solutions
16	Precipitations from solid solutions
17	Stress−strain diagram
18	Process of deformation

19	Work hardening of copper
20	Recrystallization of copper
21	Iron−carbon diagram no. 1
22	Iron−carbon diagram no. 2
23	Steel corner of the iron−carbon diagram
24	Ferrite−Austenite
25	Primary and secondary cementite
26	Pearlite−Ledeburite
27	Blank film with centimeter grid
28	Blank film with centimeter grid

3. Explanations of films

Film no. 1
Crystal lattice

It is essential to point out that the crystalline structure of metals can be explained only with the use of a model theory. To convey such model concepts, film no. 1 should be presented together with films nos. 2 and 3 which are concerned with grains and grain boundaries and with unit cells, respectively. By representing rows, lattice planes, space lattices, and unit cells and indicating the order of magnitude of the lattice constant, it is possible to explain the abstraction from the solid sphere model to the point lattice. Geometric laws can thus− be understood more easily.

If required, portions of the film presented can be covered during instruction (e.g., representation of the lattice plane and unit cell). This allows the students' attention to be concentrated on what is being discussed.

Film no. 2
Grain and grain boundary

This film compares a model concept that is used to explain the polycrystalline structure of metals with real structural conditions. When viewing this film it is necessary to take into account the different scales. This film can be used to explain the term anisotropy which indicates variation in properties in different directions, e.g., in a steel sheet. When discussing the contents of the film, halves thereof can be covered and compared with micrographs, and more particularly film no. 7 (etching possibilities), film no. 8 (macro− and micro−etching), and film no. 9 (coarse and fine grains).

Film no. 3
Unit cells

This film shows a "body−centered cubic unit cell and a face−centered cubic unit cell as the most important representatives of the crystal systems. It should be noted that multifarious cubic unit cells occur in nature and that not only the form and size but also the configuration or arrangement of the atoms are of importance (properties of metals).

It is appropriate for a table of lattice constants and other values to be set up during discussion of the subject matter.

The imaginative faculty of students can be substantially supported through using a combination of sphere model and film representation.

Film no. 4
Crystal growth

This film shows, in a series of single images, the process of crystallization during transition from the liquid to the solid phase (anisotropy of crystal growth). It should be pointed out that crystals will not assume a stable position in the melt but will move within the melt up to a certain degree of solidification. Since impurities often tend to accumulate in the residual melt during solidification, segregations in the structure will occur. It is in this particular context that film no. 10 (segregations in rimmed steel) can be referred to. The objective should be to reduce model concepts to reality. Such terms as real structure and' structural faults can be introduced to explain the actual behavior of materials. This confirms the possibility of affecting the properties of materials.

Also, film no. 4 can be used to discuss the dependence of the grain boundary upon the number of nuclei present. The individual images of this film can be presented one after the other, with those that are not be shown being covered.

Film no. 5
Real lattice structure

This film, which is a continuation of film no. 4 (crystal growth), is concerned with the structural faults of crystal lattices. The extent to which these forms of real lattice are discussed in classes is left to the discretion of the instructor. However, it is essential that he should discuss at least vacant lattice sites, exchange atoms, and interstitial impurities. It should be pointed out that the exchangeability of atoms (the atomic volume must be no greater than fifteen percent of the atoms of the basic lattice) and incorporability of atoms at vacant sites (comparison with the sphere model in film no. 1) are limited. It was only in recent years that concepts of the real lattice structure could be developed as a result of researches conducted by solid state physicists. They form the basis for the theory of dislocations and, hence, for the workability of metals. Individual types of fault should be presented and discussed separately by covering the film. Film no. 5 provides the basis for discussing the contents of film no. 18 (process of deformation).

Film no. 6
Dislocation

To be able to explain the process of translation (deformation by shear – film no. 18) it is necessary to introduce the term dislocation. Only edge dislocations will be discussed here notwithstanding the fact that, in reality, there' are numerous forms of dislocations such as screw dislocations, mixed–type dislocations, and so on. This representation of dislocation requires that we confine ourselves, for epistomological reasons, to few atoms and lattice planes although, in actuality, thousands of atoms are involved in it. A dislocation is a higher energy (lower equilibrium) site surrounded by stress concentrations. Be sure to point out the possibility of such stresses joining so as to increase the overall stress level (cf. film no. 19 that is concerned with the work hardening of copper).

Film no. 7
Etching possibilities

Microscopic and metallographic examinations of metals and alloys are not usually performed in all areas of vocational education and training. However, it is necessary to discuss problems associated with structural examinations. This film can be used to compare theoretical knowledge with practical results of structural examinations. Students should realize that results of structural examinations obtained with the use of micrographs form the basis for obtaining new knowledge (e.g., in constitutional diagrams). Shown in this film are, at a scale of 100: 1, two micrographs of pure copper etched using hydrochloric acid and iron chloride, respectively.

It can be seen that etching results in the grain boundaries and, later, the grain surfaces being attacked, with the structural pattern thus being essentially dependent upon the time of etching.

Contrast etching is also possible by using other and more aggressive etchants. The action of etching agents can be discussed by reference to film no. 2 (grain and grain boundary).

Film no. 8
Macro– and micro–etching

This film can be used to demonstrate different methods of examination. In metallography, a distinction is made between macroexamination and microexamination depending upon whether a particular structure can be observed or identified with the naked eye or by means of a microscope. Shown in film no. 8 are the images of an etched pure aluminum ingot (at a scale of 1: 1) and of a structural steel microsection (at a scale of

100:1).

In the case of the pure aluminum ingot, there can be seen grain growth taking place as a result of cooling of the small cast ingot from the outside in. Indentation results from the decrease of volume. Whereas the structural pattern of pure aluminum allows only the kind of crystal formation to be seen, that of structural steel provides qualitative information about individual structural components. Because of the larger number of nuclei of crystallization, the structural constitution of mild steel is nearly uniform in all regions.

Film. no. 8 can be discussed in connection with films nos. 2 and 4 that are respectively concerned with grains and grain boundaries and with crystal or grain growth.

Film no. 9
Coarse and fine grains

This film, which can be discussed in connection with film no. 4 (crystal growth) and film no. 13 (curve of solidification), enables instructors to explain the development of different grain sizes. It includes two micrographs of different grain size low−carbon steel etched using 3% alcoholic nitric acid, the scale being 100:1.

It is essential to discuss the effect of grain size upon material properties (structure, behavior) with particular reference to the causes of formation of coarse grains.

Film no. 10
Segregations in rimmed steel

The macrostructure of steel is greatly influenced by processes of segregation taking place during solidification thereof. Such elements as phosphorus and sulfur show a marked tendency toward segregating. Segregations present in the original steel ingot are correspondingly modified during metal working operations.

This film shows the images of two macroetches and of one Baumann sulfur print of rimmed steel. The segregations shown here are generally referred to as macro− and micro−segregations, respectively. Be sure to give instructions for use and fabrication (welding, drilling, corrosion, etc.) of rimmed steels.

Film no. 11
Metallurgical microscope

A metallurgical microscope can be used to examine the kind, proportion, size, form, and distribution of structural constituents.

Unlike transmitted−light microscopy of biological objects, the metallurgical microscope is a reflected light microscope.

Film no. 11 shows the "Epityp" 2 metallurgical microscope made by VEB Carl Zeiss of Jena, G.D.R., and it is supplemented by a schematic representation of the optical path in the microscope.

It is recommended that the applications of a metallurgical microscope be explained during a visit to a metals testing laboratory. The specimens examined using the microscope should be ground, polished, and etched metal surfaces. The contents of film no. 11 can be discussed in connection with those of film no. 7 (etching possibilities), film no. 8 (macro− and micro−etching), and film no. 9 (coarse and fine grains).

In so far as examinations performed using metallurgical microscopes are concerned, it should be pointed out that what counts is the results obtained rather than details of methods of examination.

Film no. 12
Thermal analysis

This film can be used to explain metallographic analyses of metals and alloys made with a view to determining melting points and intervals. It should be pointed out that for a determination of solid state transformation points use should preferably be made of a dilatometer which allows changes in length to be measured, since the heat of transformation is too low for a thermal analysis to be done. Film no. 12 shows the arrangement of an electrically heated furnace with the sample connected to the reference junction which, in turn, is connected with the measuring instrument. Also shown is a schematic diagram of a thermocouple with measuring and reference junctions. Be sure to again explain the operating principle of the thermocouple, if necessary. It is in connection with the discussion of thermal analysis that film no. 4 (crystal growth) and film no. 13 (curve of solidification) can be touched upon and discussed, respectively.

Film no. 13
Curve of solidification

This film can be used to again explain the process of crystallization and, at the same time, learn and practice the reading of diagrams. Also, this film can be used together with film no. 4 (crystal growth) to explain the thermodynamic theory of fusion and solidification. The film also shows individual phases of the process of crystallization in a didactically simplified and graphic form as well as the curve of solidification of lead of which the solidification temperature is 327°C It should be pointed out that such an 'ideal curve' can be obtained under laboratory conditions only.

Film no. 14
Eutectic

This film shows, in a concentrated form, the solidification curves of five alloys, the constitutional diagram, and the schematic representations of structural patterns. Using this film, it is possible to explain the plotting of a constitutional diagram from cooling curves as well as the constitutional or state changes taking place during the cooling of individual alloys. Be sure to point out that structures constitute what is known as a crystal aggregate.

It is essential that students should realize that constitutional diagrams are stores of information on the states of alloys in dependence upon both temperature and concentration and that they are required for making and heat–treating alloys (concentration and temperature, respectively).

It is recommended to present the individual images in their proper order by covering portions of the film.

Film no. 15
Solid solutions

This film can be used to explain the constitutional diagram of complete miscibility of alloy components in the liquid and solid states, which is derived from the curves of solidification of four alloys. From the diagram there can be read changes taking place during the cooling and heating of alloys in dependence upon both temperature and concentration.

The micrographs show equal–appearance solid solutions of which the composition can be determined by chemical analysis only. By using the schematic representations for substitutional and interstitial solid solutions, it is possible for this subject matter to be discussed and repeated graphically.

Depending upon the procedure used by the instructor, portions of the film can be covered one after the other.

Film no. 16
Precipitations from solid solutions

This constitutional diagram with solid state miscibility gaps and the cooling curve of an alloy with the corresponding micrographs (in dependence upon temperature) can be used to explain the process of hardening by precipitation and the changes in the properties of alloys which are due to dispersion. The schematic micrographs enable students to arrive at a better understanding of the process of precipitation and the change in solubility of an alloy with decreasing temperature. Students should realize that properties of materials are temperature–dependent". The contents of this film should be discussed in steps corresponding to individual stages of instruction.

Film no. 17
Stress–strain diagram

The objective of conveying knowledge of the workability of materials is to enable students to interpret processes proceeding within materials during working, for example. To prepare students for a discussion of processes of deformation, this stress–strain diagram of a soft type of steel which includes the most important parameters as well as the elastic and plastic strain, respectively, can be used to explain such characteristics as strength and strain. This film can also be used for a discussion of materials testing. It is essential that special importance be attached to the distinction between elastic and plastic strain and elastic and plastic deformation.

The contents of film no. 17 should be discussed in connection with those of film no. 18 (process of deformation) and film no. 19 (work hardening of copper).

Film no. 18
Process of deformation

Film no. 18 shows the stages of deformation of a lattice portion in six individual images. Preferably, part of a lattice model should be used to explain the terms elastic and plastic deformation. Sliding in plastic deformation occurs along a slip plane and is made possible by dislocation. It is appropriate for the contents of film no. 6 (dislocation) to be discussed again in this context. It is essential that knowledge of the polycrystalline material involved in the elementary process of sliding, which was here acquired on a portion of the lattice only, should be extended to cover the entire material. The contents of this film should be discussed in steps.

Film no. 19
Work hardening of copper

Work hardening of metals can be regarded as being due to an increase in dislocation density, the accumulation of dislocations at obstacles, and the addition of concentrations of stresses around individual dislocations. This film can be used to discuss cold working results. It shows the changes in tensile strength, elongation, and reduction in area of pure copper during wire drawing and enables several curves to be compared. Intentional and unintentional changes in properties due to cold working should be discussed in detail.

This film enables students to read and interpret the diagram and compare the structures of soft and work−hardened copper wire.

Film no. 20
Recrystallization of copper

After having clarified the term work hardening, it is essential to explain the terms recrystallization, cold working, hot working, and critical amount of deformation. Students should realize that properties of materials have to be influenced by increasing the temperature and causing the structure to re−form in the solid state far below the melting temperature.

This film shows the variation in tensile strength and elongation as a function of the temperature of annealing. The recrystallization range is supplemented by schematic micrographs. The film allows to explain processes proceeding during recrystallization, desirable heating (e.g., annealing as an intermediate stage of wire drawing in order to make possible additional drafts), and undesirable heating (e.g., in the soldering of contact springs which may involve a loss of elasticity). Be sure to distinguish between cold and hot working in dependence upon the recrystallization temperature of a metal (T_R ? 0.4 T_S in °K). Also, point out the relationship between time of annealing and structure.

Film no. 21
Iron−carbon diagram no. 1

The contents of films 21 through 26 have to be discussed on the basis of the iron−carbon diagram described in the literature. The forms of constitutional diagrams can be assumed to be known. Since structures of alloys are to be considered crystal aggregates, the modification of iron can also be dealt with here.

This film shows, in the left and right halves thereof, the cooling curve of pure iron and the iron−carbon diagram up to 2% of C (steel corner), respectively, as well as schematic micrographs of steels having 0, P.4, 0.8, and 1.2% of C at temperatures below 723°C. Explain that the different solubility of iron modifications for carbon and the consequent change in the temperature of transformation lead to the iron−carbon diagram. It is essential that film no. 21 be discussed, step by step, in connection with the contents of film no. 24 (ferrite−austenite), film no. 25 (primary and secondary cementite), and film no. 26 (pearlite−ledeburite).

Film no. 22
Iron−carbon diagram no. 2

This film can be used in vocational education and training. It shows the complete iron−carbon diagram and a graphic representation of the structural rectangle, which provides information about the proportional percentages of structures present under equilibrium conditions. It. is essential to point out that this diagram corresponds to a state of equilibrium (extremely slow heating and cooling), whereas this equilibrium is often disturbed in engineering and technical processes.

After having discussed the contents of films 24 through 26, it is appropriate to replace the phase designations in state fields with the names of the respective structures. For this, film no. 22 has to be covered with a blank film on which the diagram is supplemented "by dashed vertical lines at 0.8, 2.06, and 4.3% of C as well as by the names of structures.

Film no. 23
<u>Steel corner of the iron−carbon diagram</u>

This representation forms the basis for all heat treat methods. It is for this reason that knowledge of the iron−carbon diagram with steel corner is of particular importance. To be able to correctly interpret all temperature−dependent processes proceeding within a particular material, it is recommended to discuss variations in the structure of steels with 0.4, 0.8, and 1.6% of C. By partly covering the film, it is possible to draw the student's attention to the steel whose structure is being discussed.

Film no. 24
<u>Ferrite−Austenite</u>

The original micrographs (200: 1) in this film show the ferritic and austenitic structures of iron. Since austenite cannot generally be observed at room temperature, a high−alloy austenitic chromium−nickel steel had to be used for examinations.

Film no. 25
<u>Primary and secondary cementite</u>

This film shows the structure of primary cementite in ledeburite (at a scale of 100: 1) and the structure of secondary cementite in pearlite (at a scale of 500: 1). Primary cementite is the bar− or needle−shaped structural constituent of hypereutectic iron−carbon alloys. It is precipitated from the melt in the form of platelike crystals along the C − D line (iron−carbon diagram).

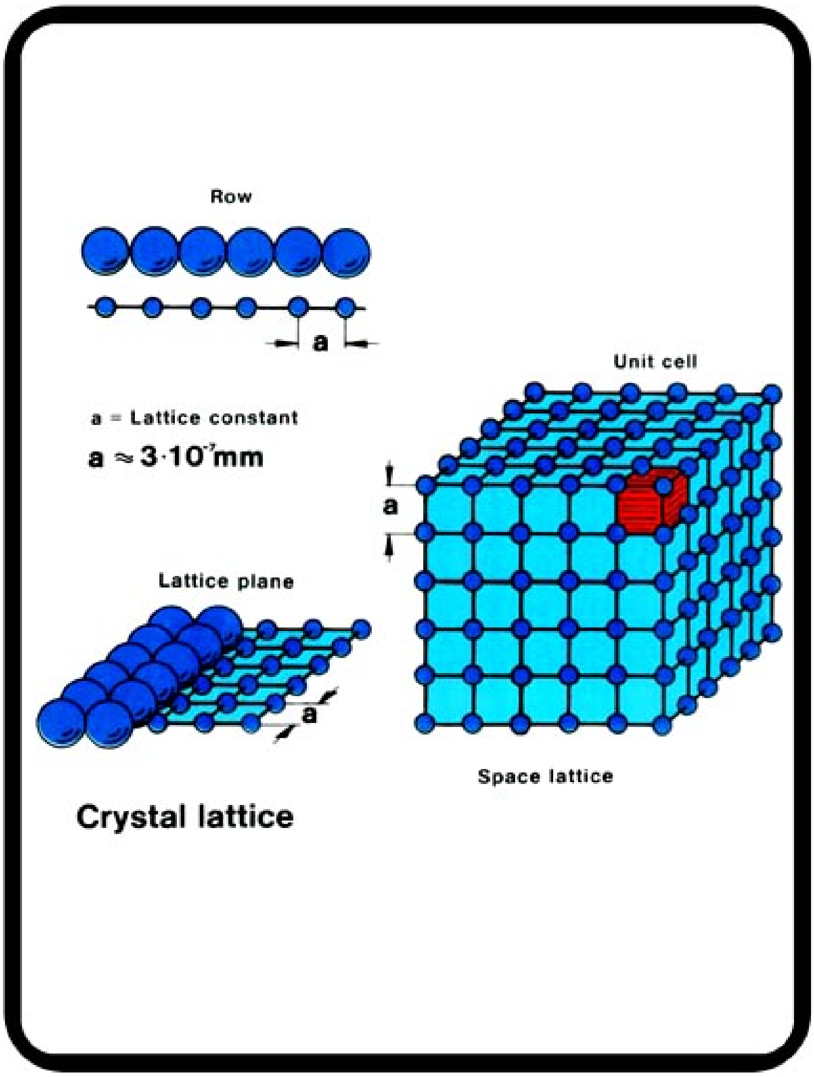
Secondary cementite is a structural constituent of hypereutectic iron−carbon alloys appearing as grain−boundary cementite or, in the case of higher carbon contents, as needles in pearlite. It is precipitated, along line E − S, from gamma−iron solid solutions because of diminishing solubility.

Film no. 26
<u>Pearlite−Ledeburite</u>

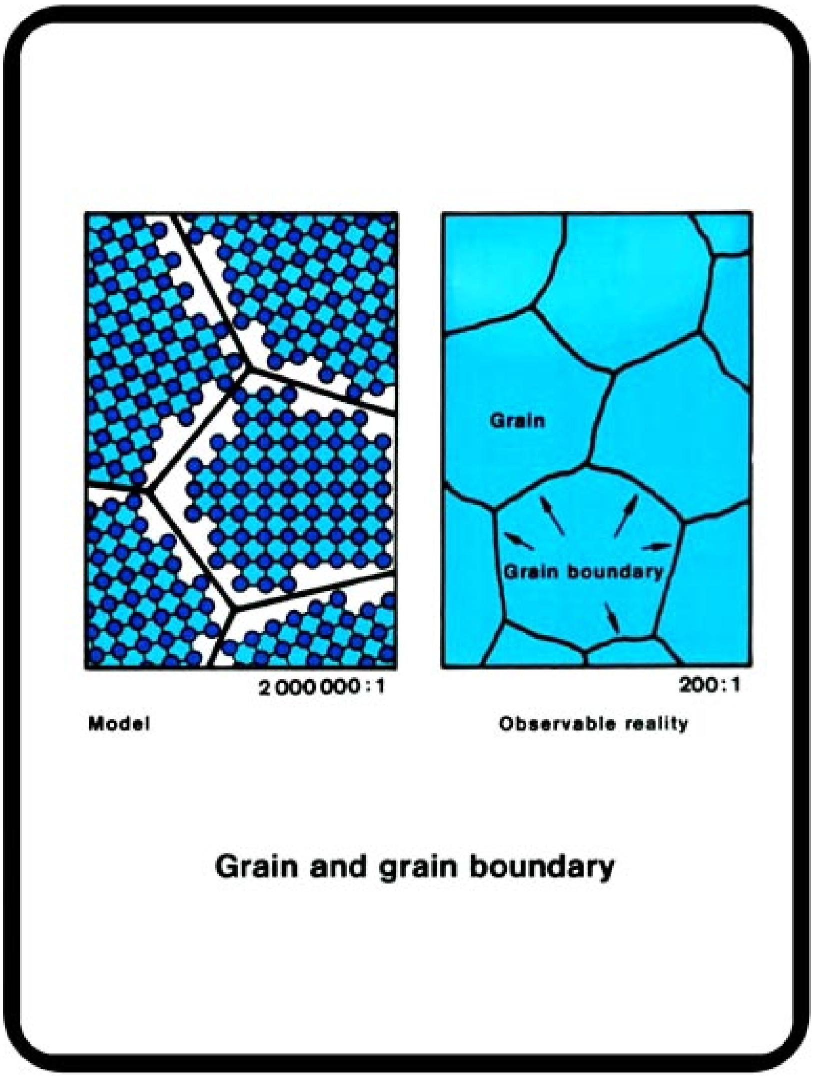
This film shows the structures of both pearlite and ledeburite (the scales being 500: 1 and 100: 1 for pearlite and ledeburite, respectively). When showing the structures of pearlite and ledeburite it is necessary to consider that ledeburite (liquid−solid transition) is, in general, much coarser in grain than pearlite (solid−solid transition).

The metallographic specimens were etched using 3% alcoholic nitric acid.

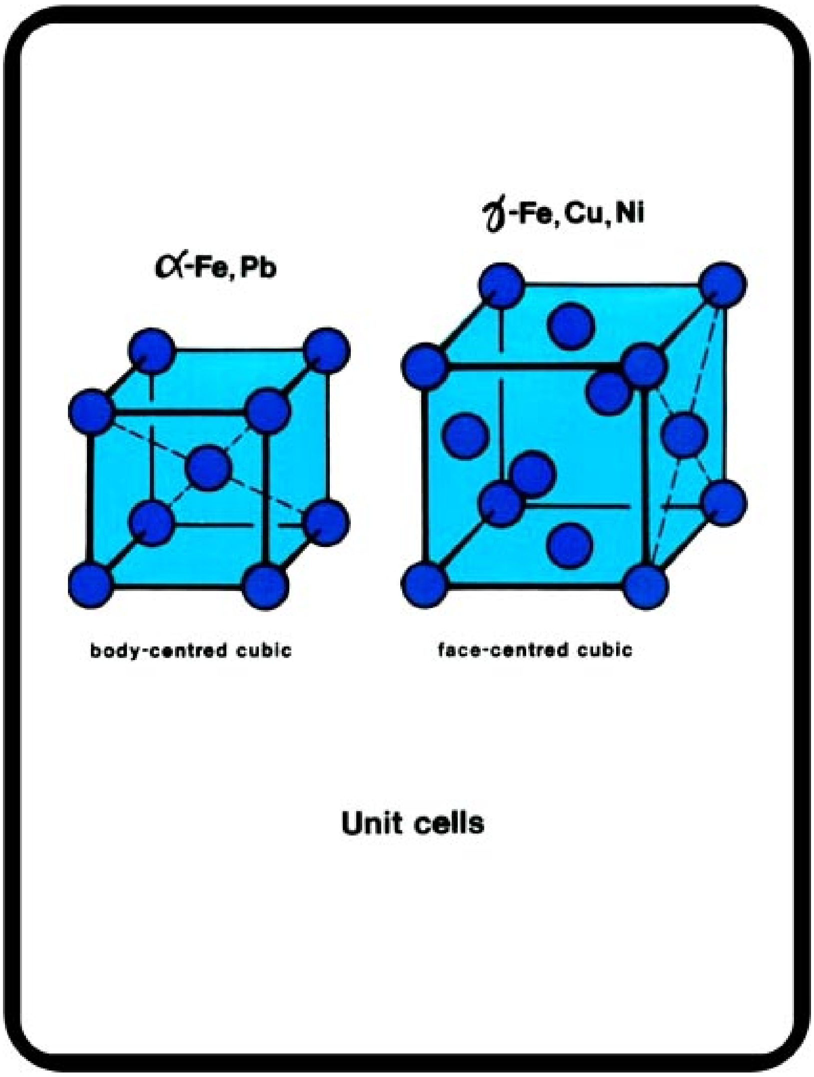
Ledeburite is a eutectic that is composed of austenite and cementite. Pearlite is a lamellar conglomerate of ferrite and cementite.



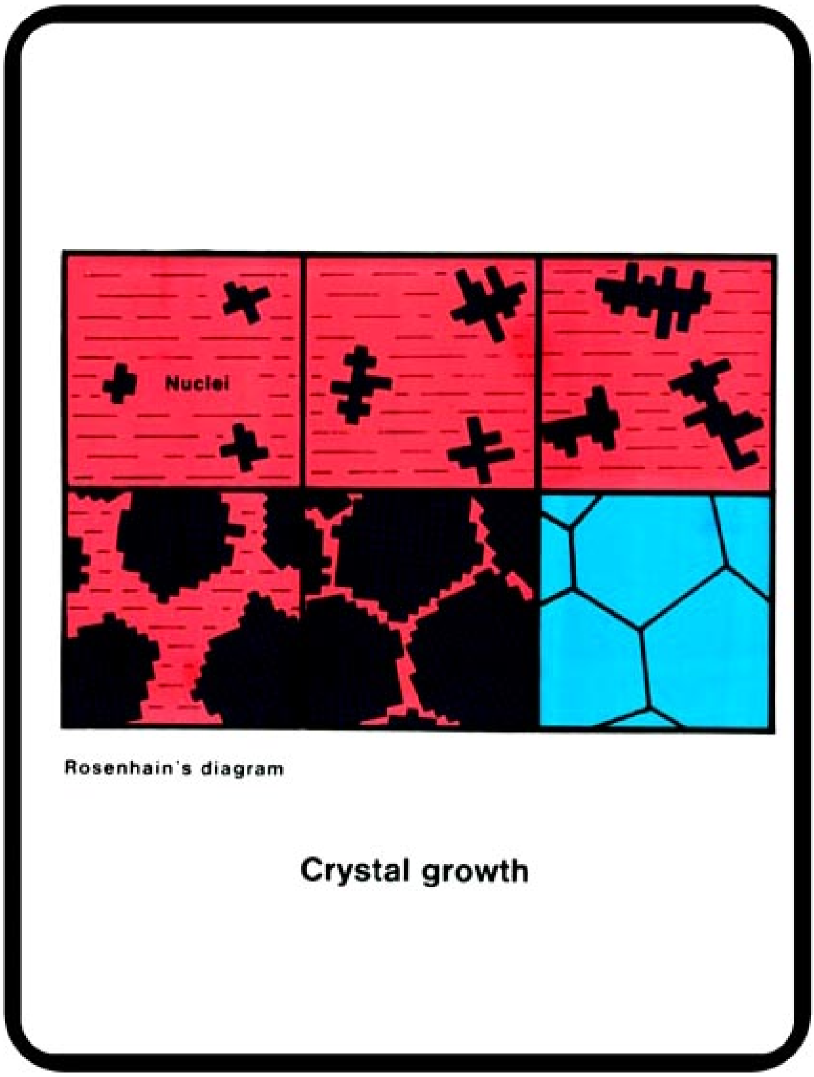
Film no. 1. Crystal lattice



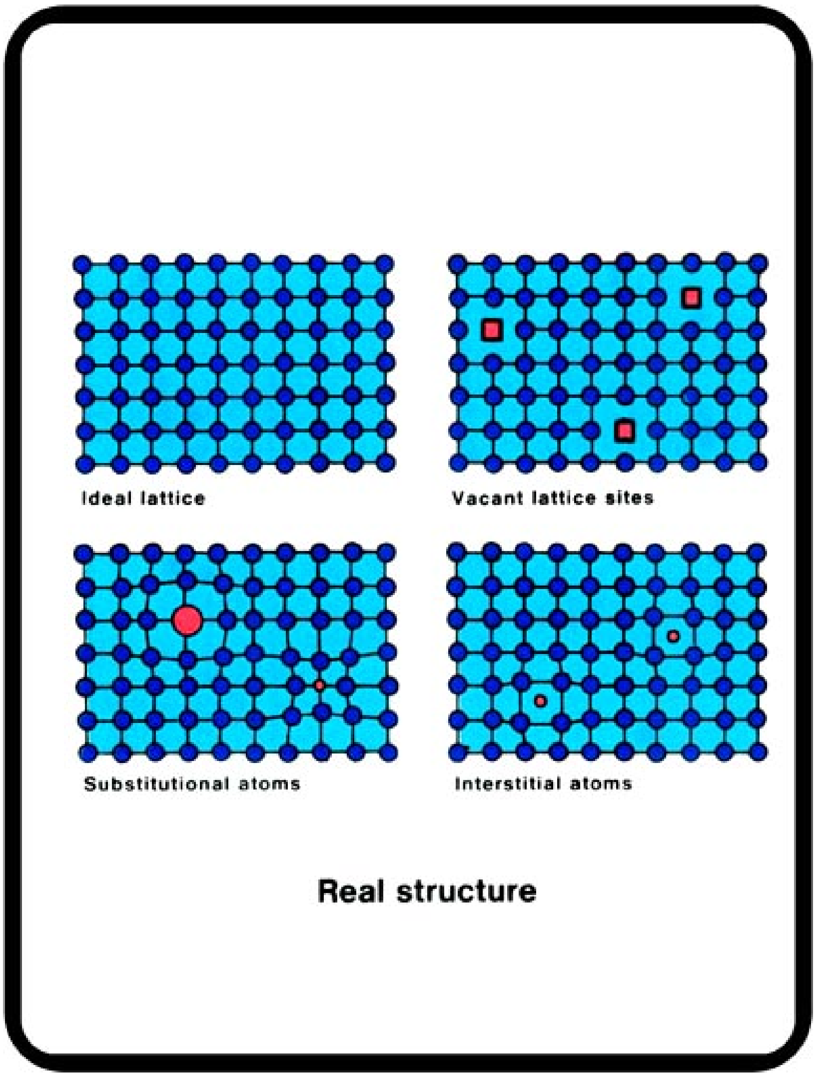
Film no. 2. Grain and grain boundary



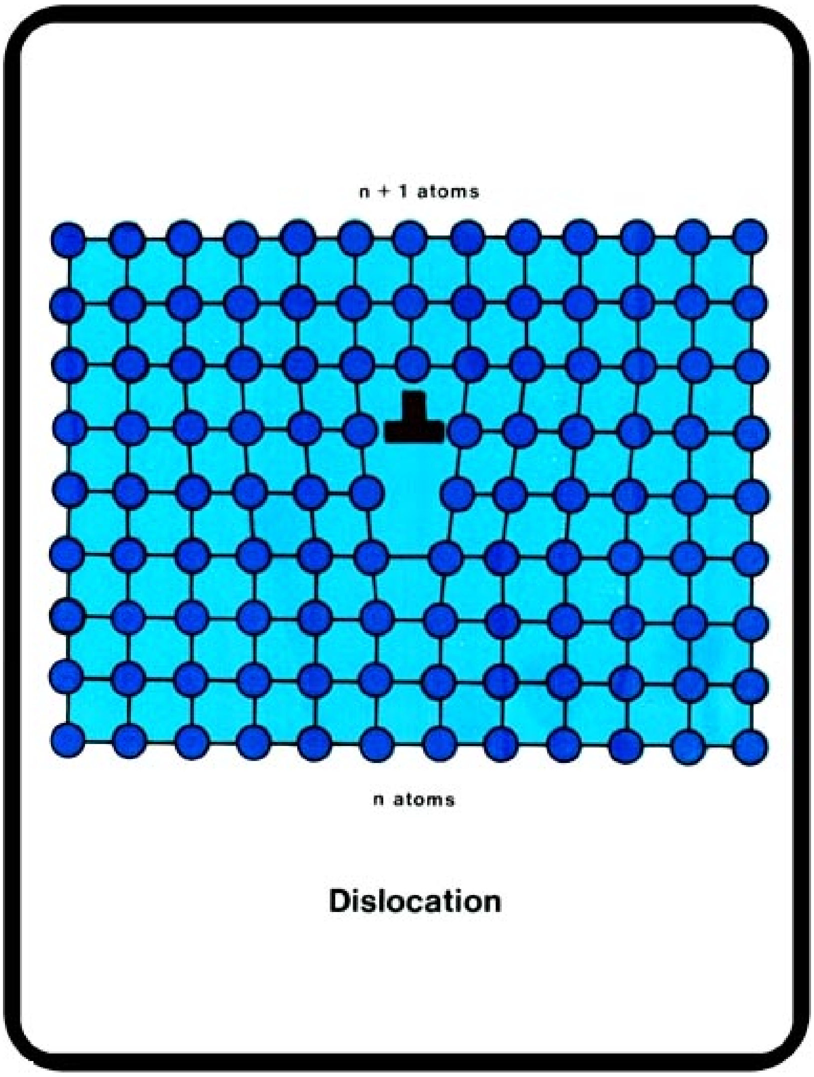
Film no. 3. Unit cells



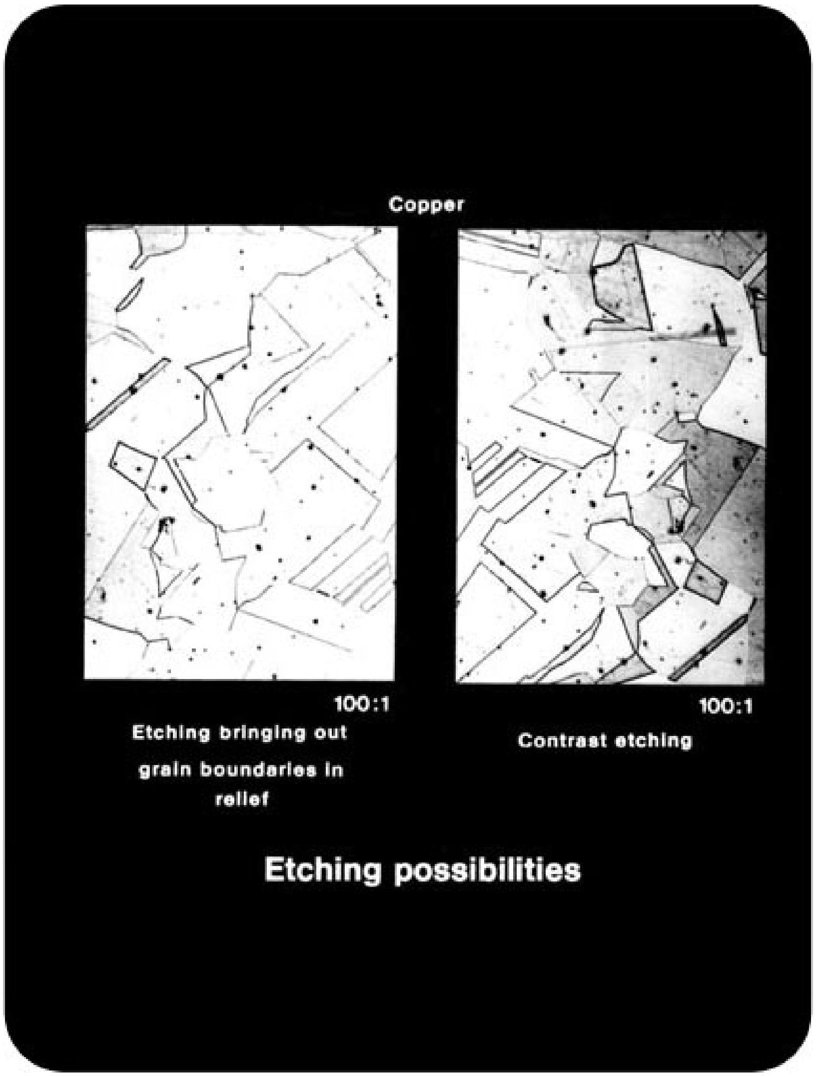
Film no. 4. Crystal growth



Film no. 5. Real lattice structure

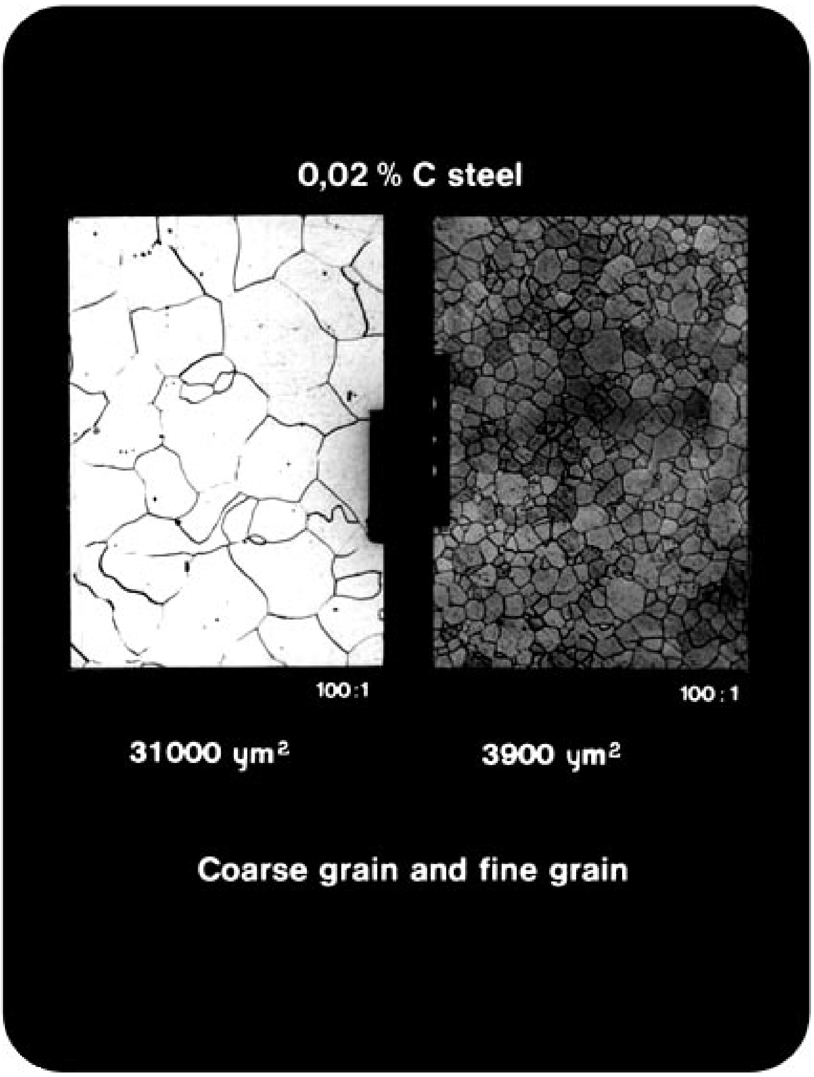


Film no. 6. Dislocation

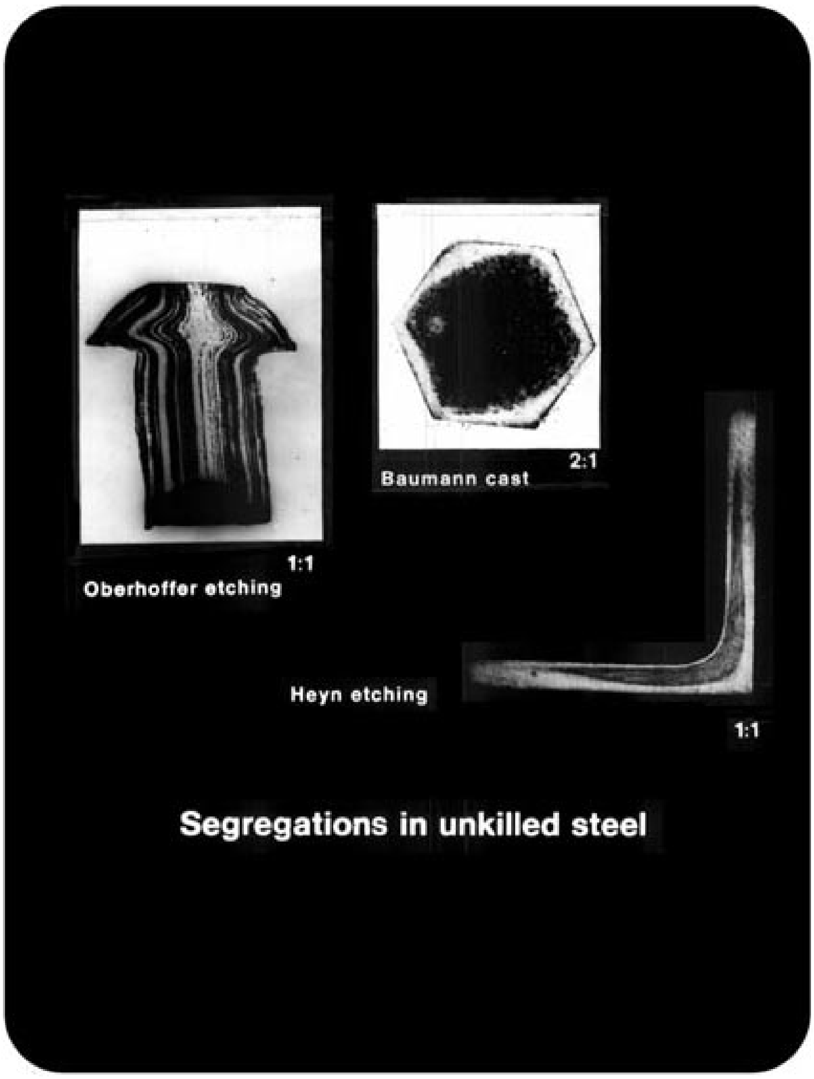


Film no. 7. Etching possibilities

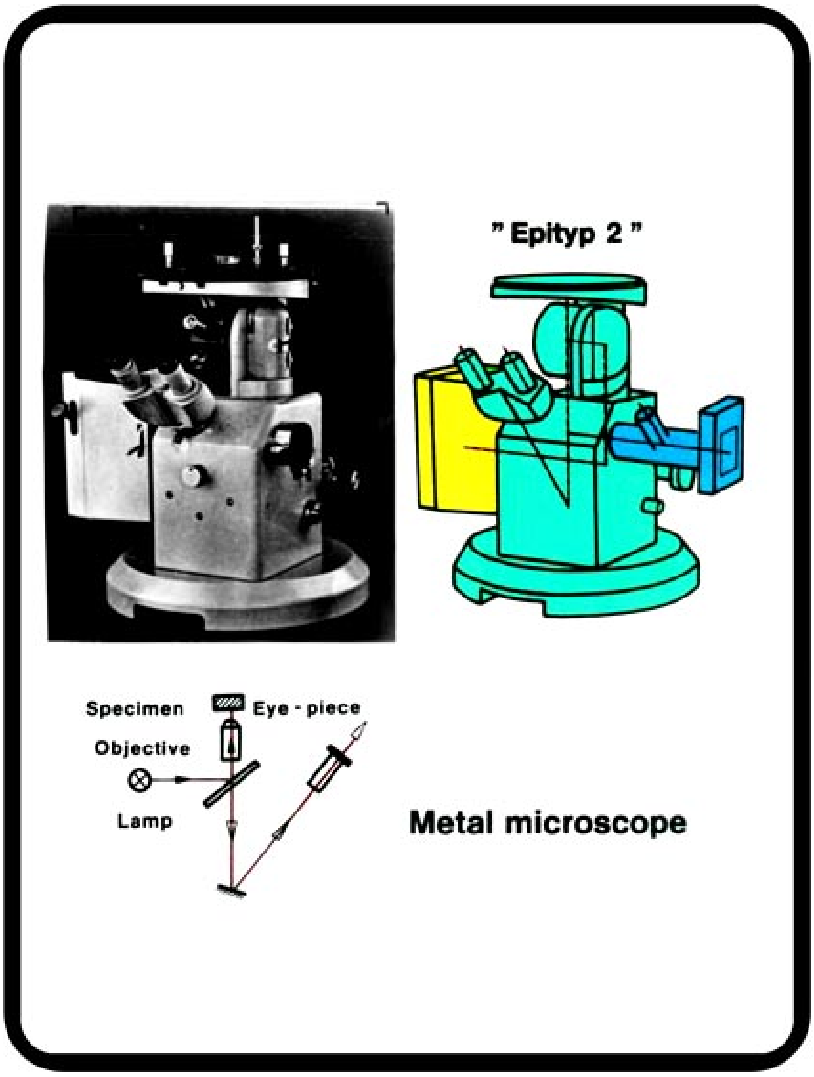
Film no. 8. Macro− and micro−etching



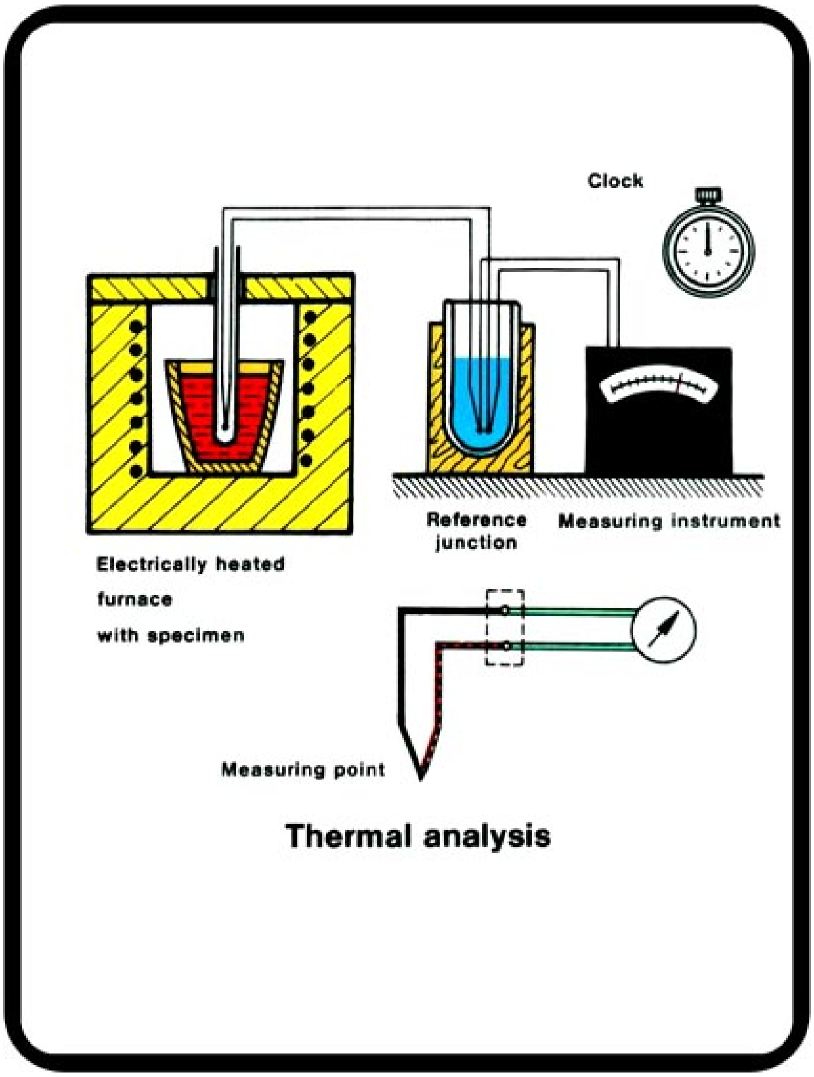
Film no. 9. Coarse and fine grains



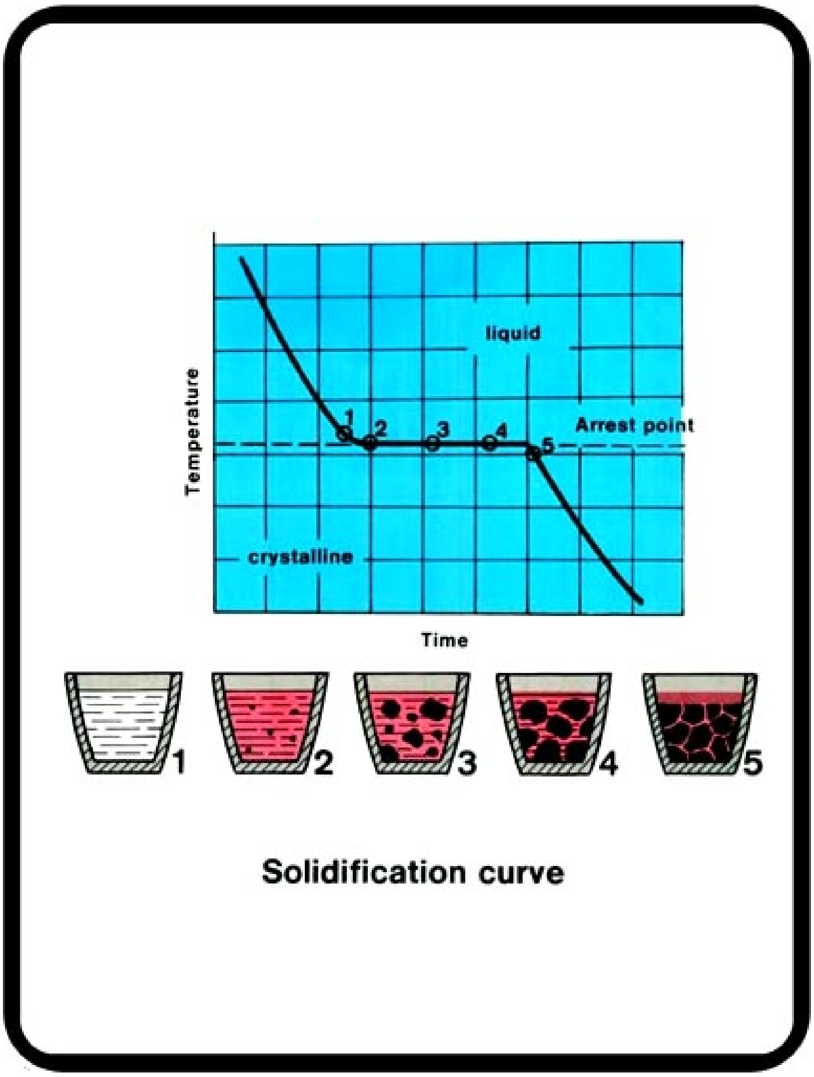
Film no. 10. Segregations in rimmed steel



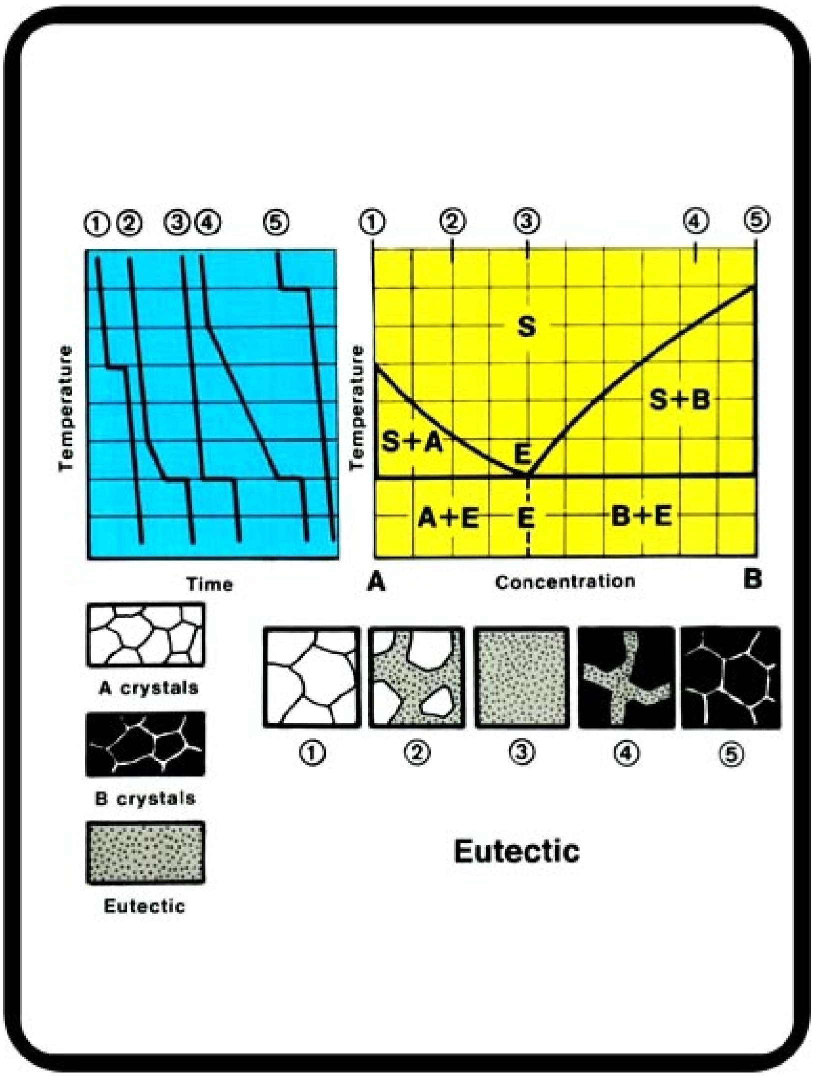
Film no. 11. Metallurgical microscope



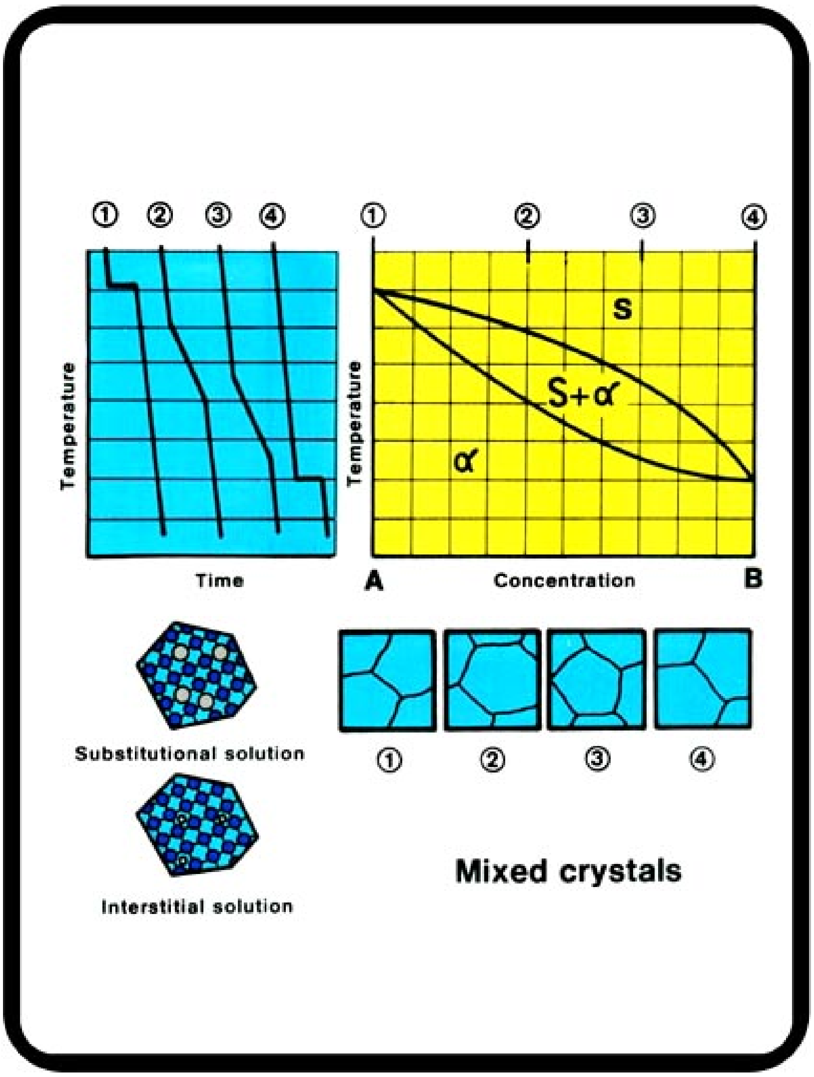
Film no. 12. Thermal analysis



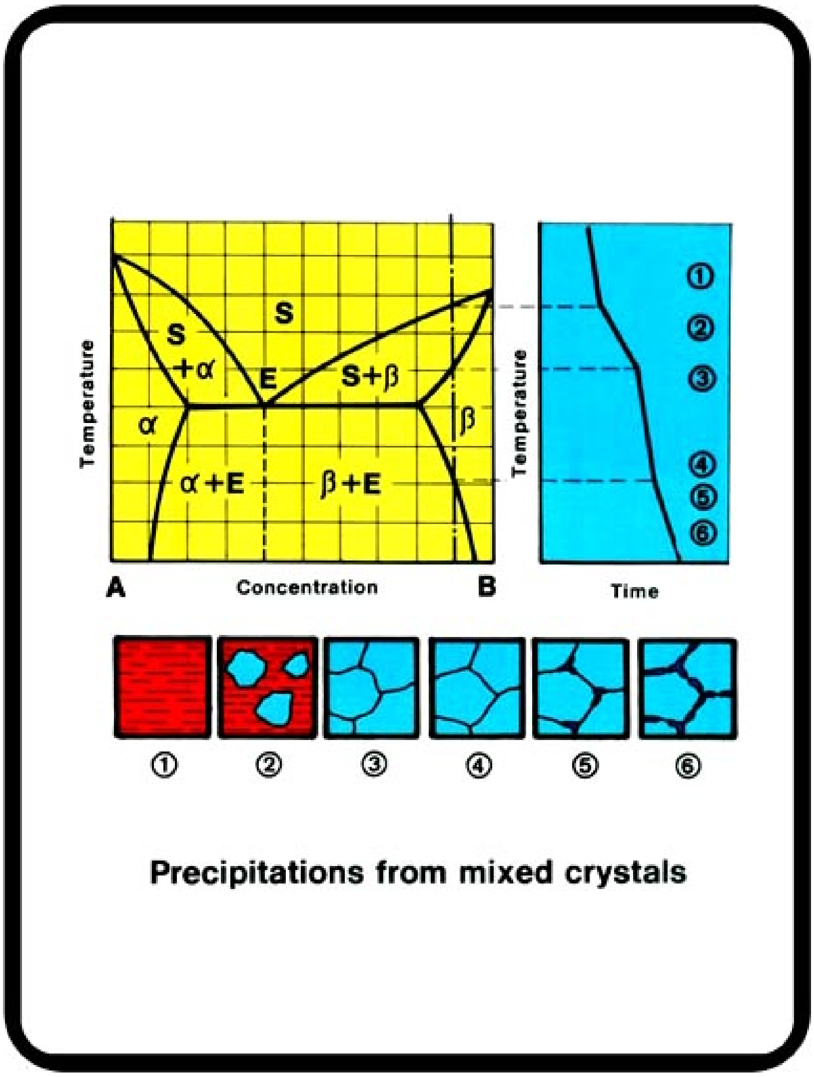
Film no. 13. Curve of solidification



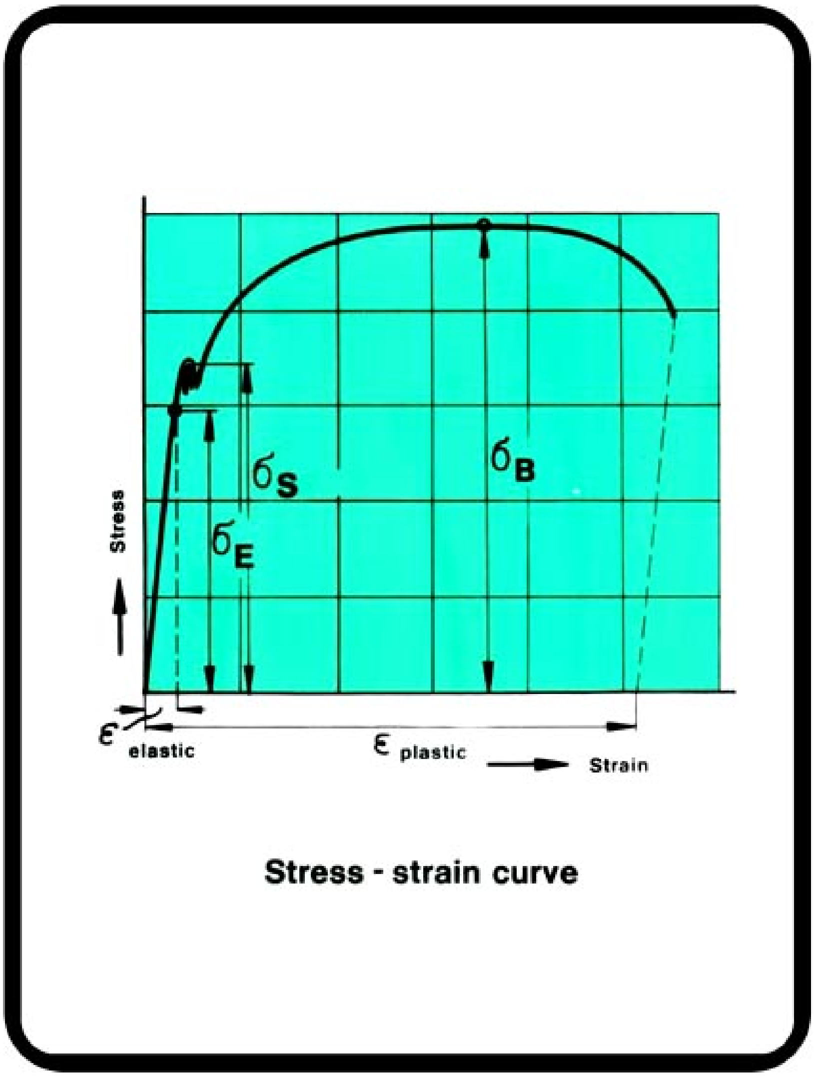
Film no. 14. Eutectic



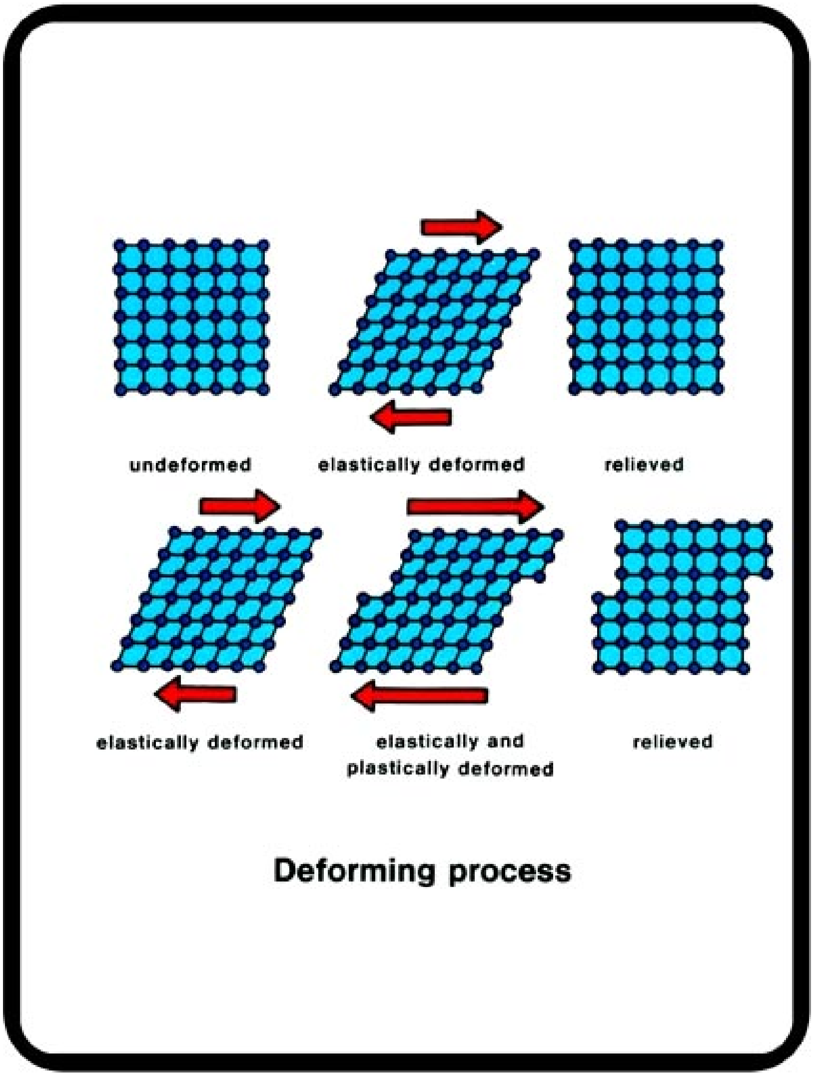
Film no. 15. Solid solutions



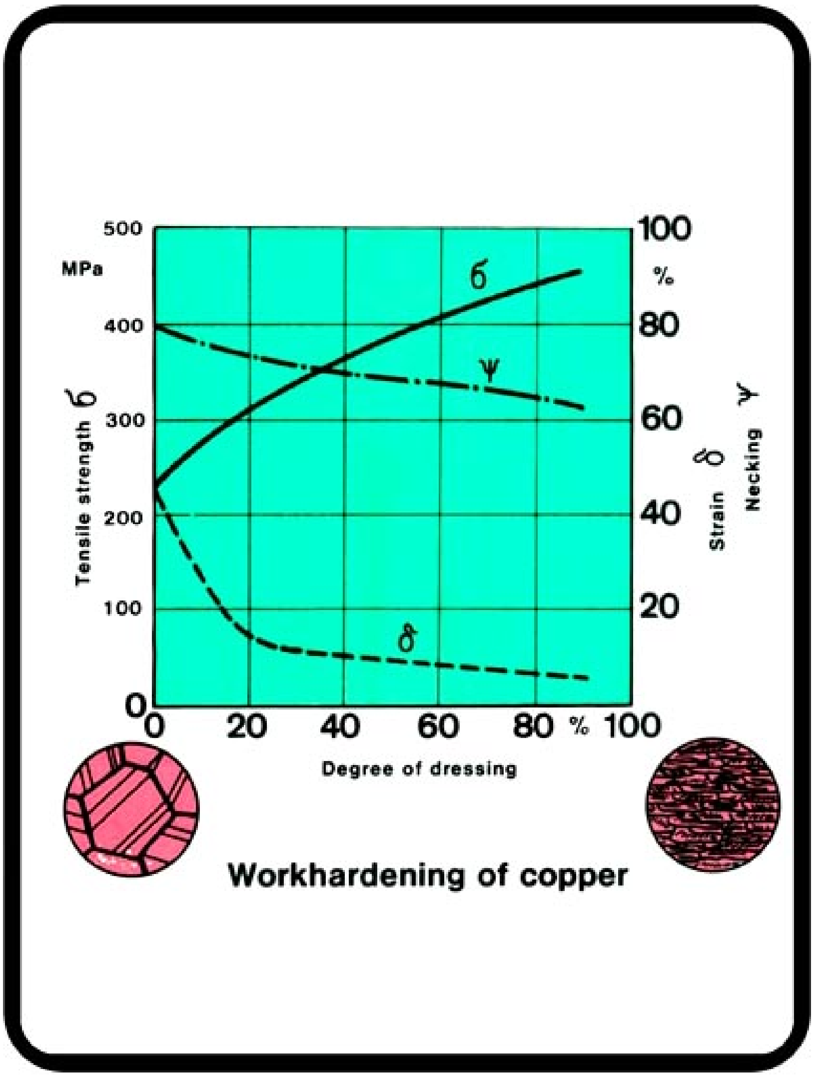
Film no. 16. Precipitations from solid solutions



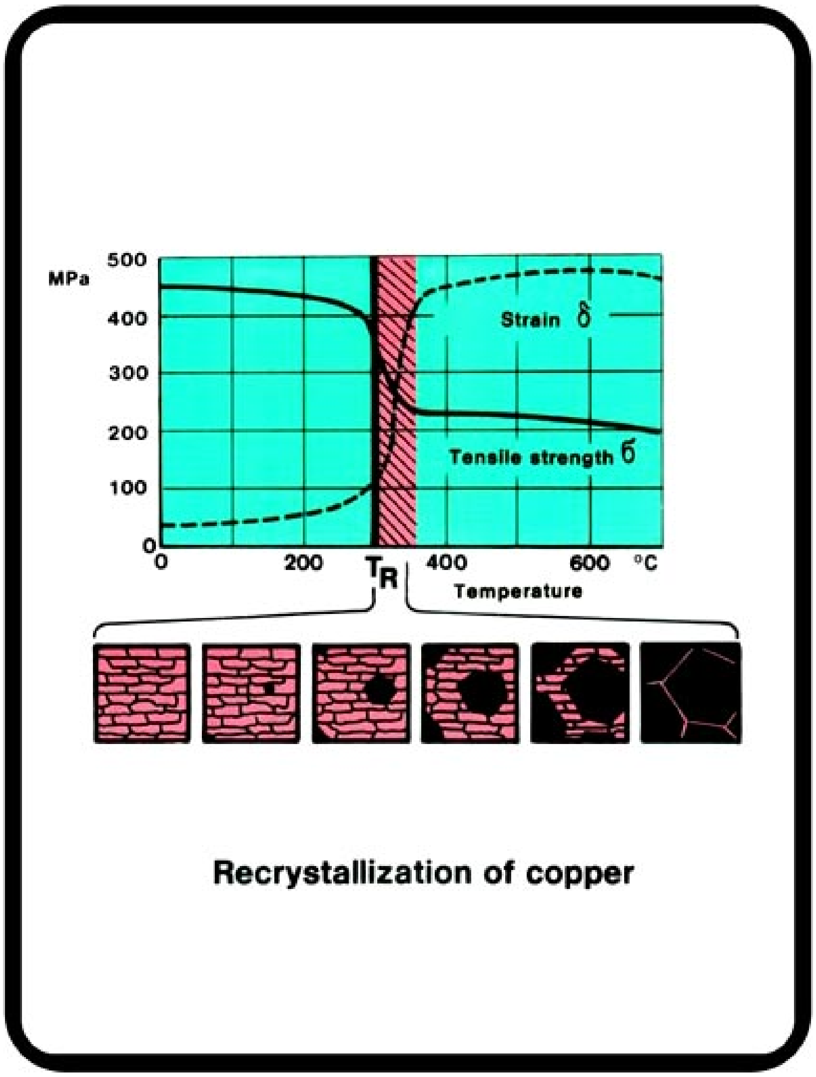
Film no. 17. Stress−strain diagram



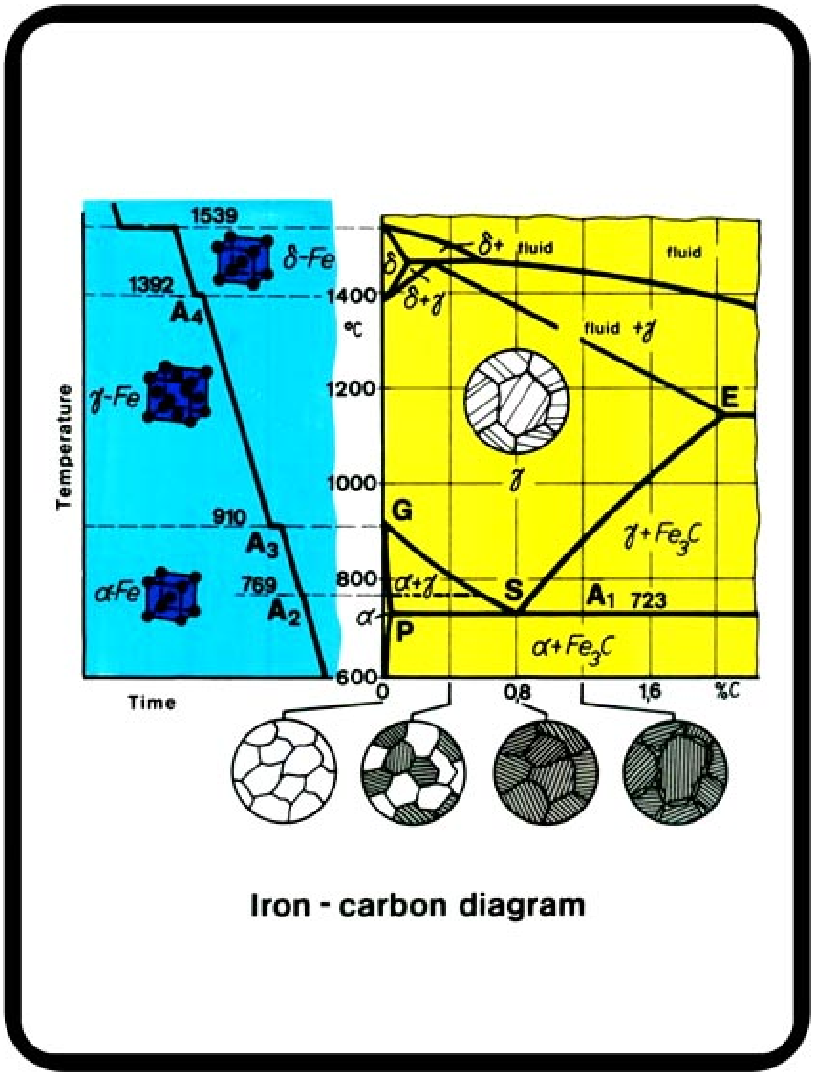
Film no. 18. Process of deformation



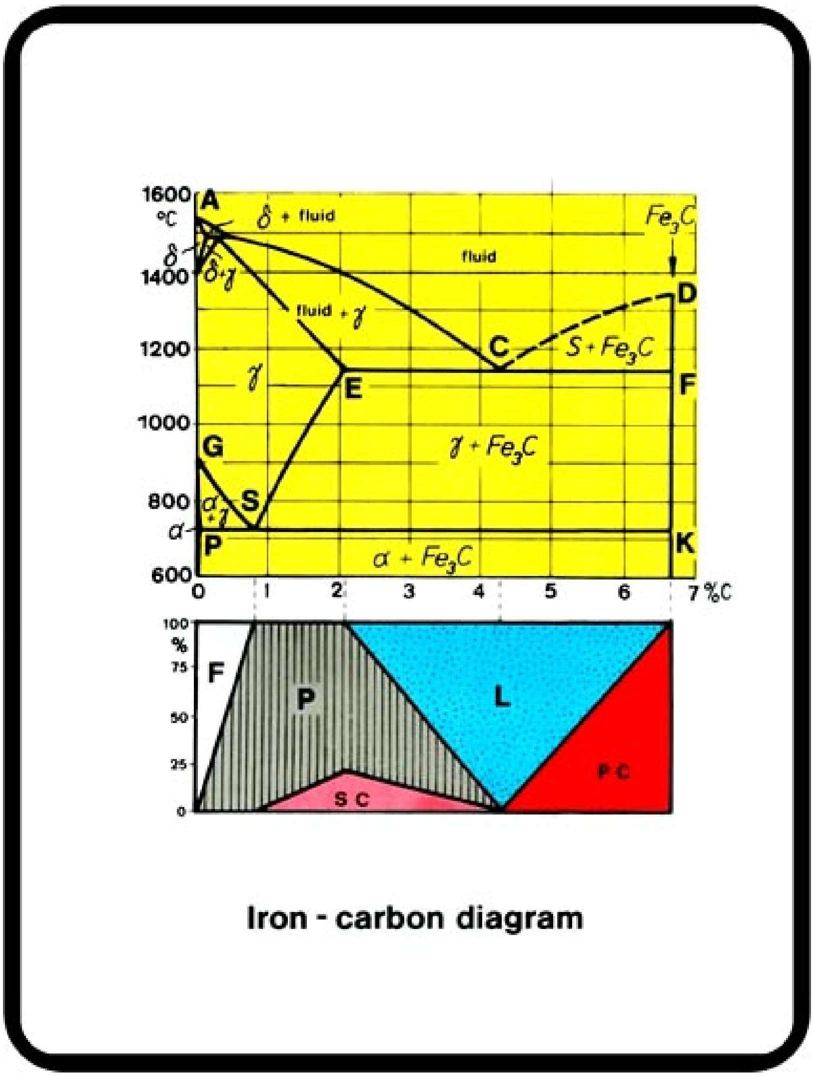
Film no. 19. Work hardening of copper



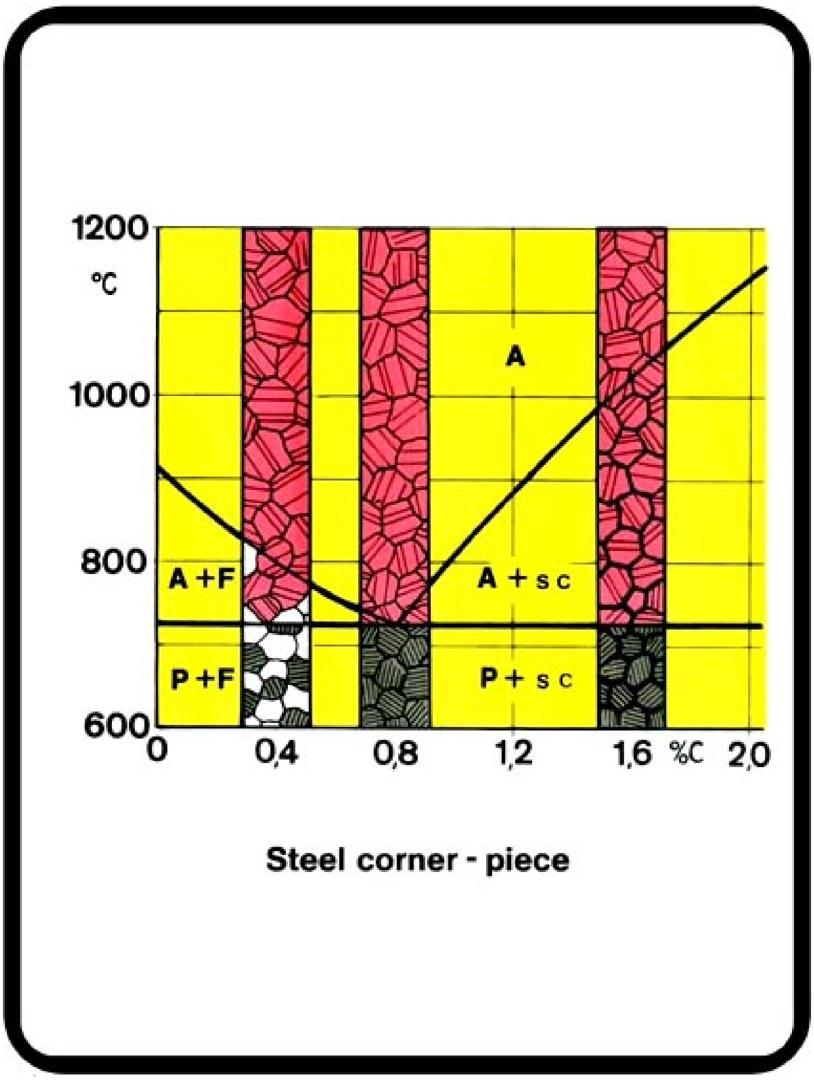
Film no. 20. Recrystallization of copper



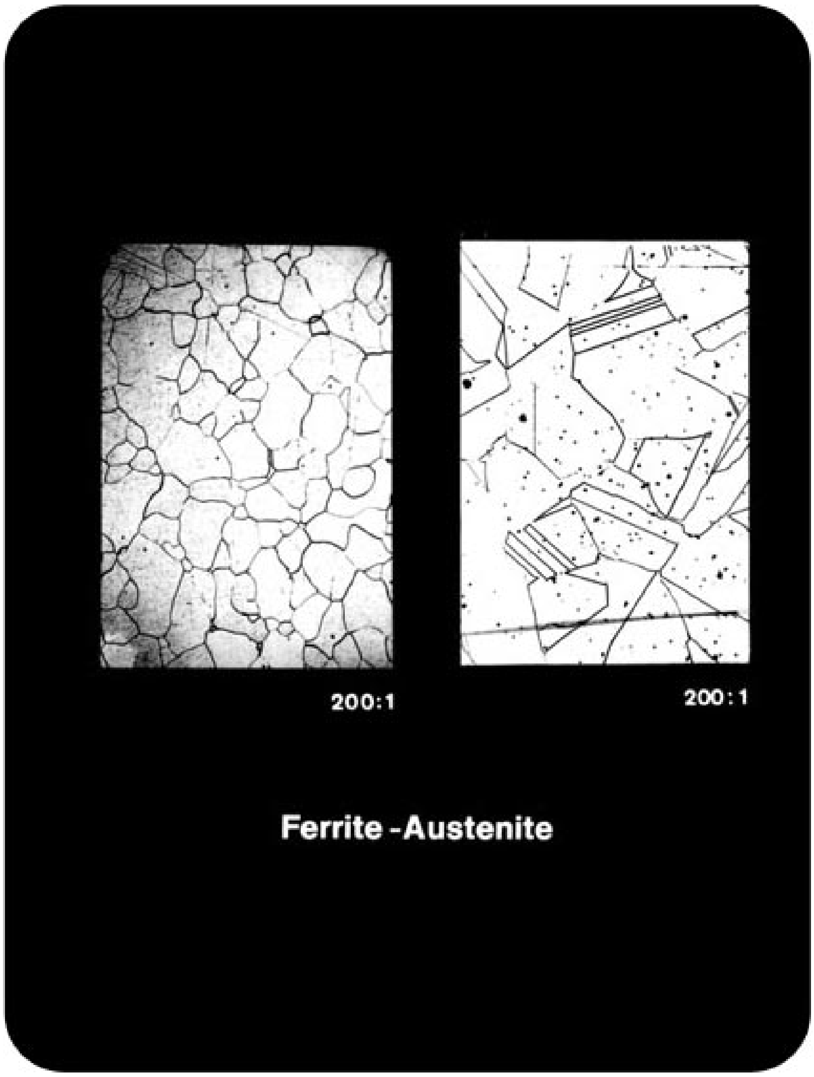
Film no. 21. Iron−carbon diagram no. 1



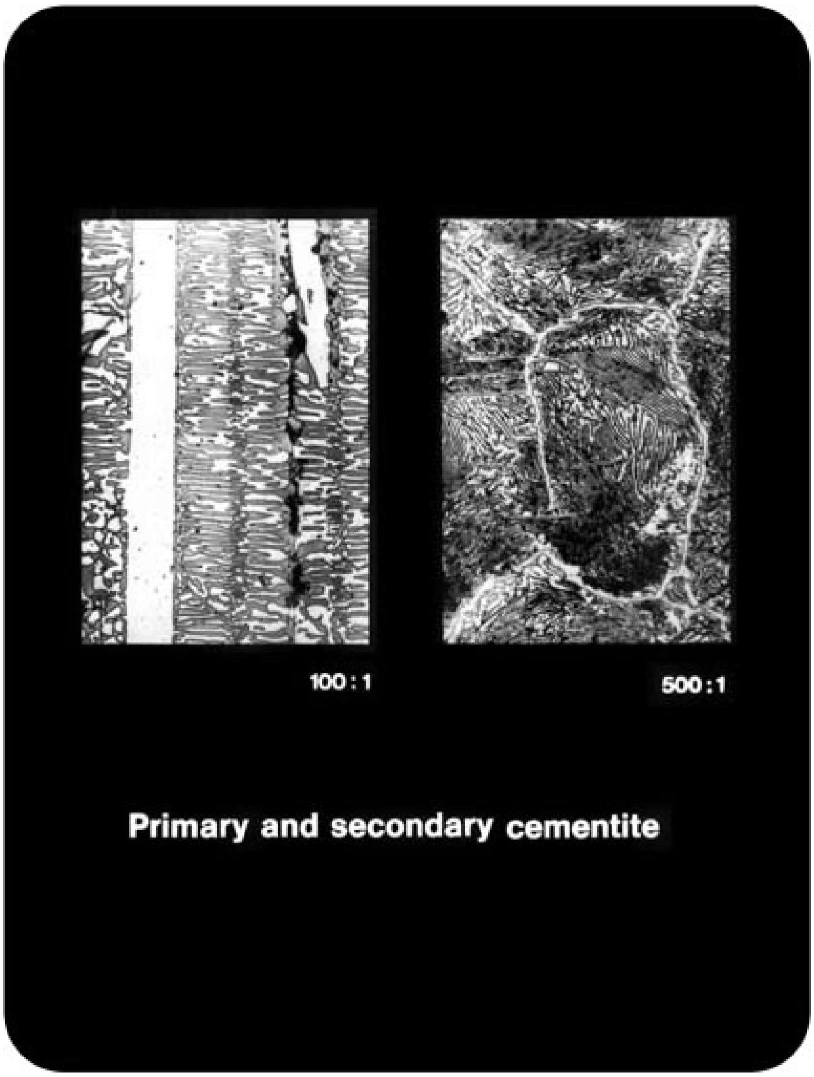
Film no. 22. Iron−carbon diagram no. 2



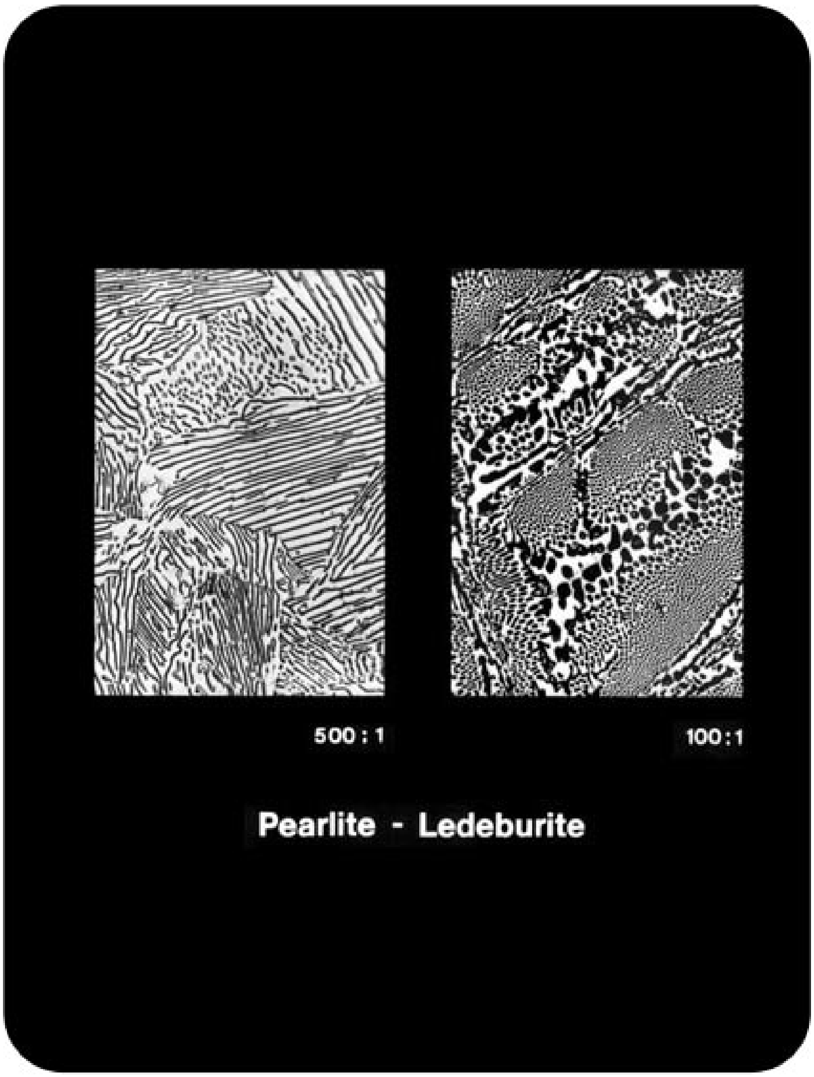
Film no. 23. Steel corner of the iron−carbon diagram



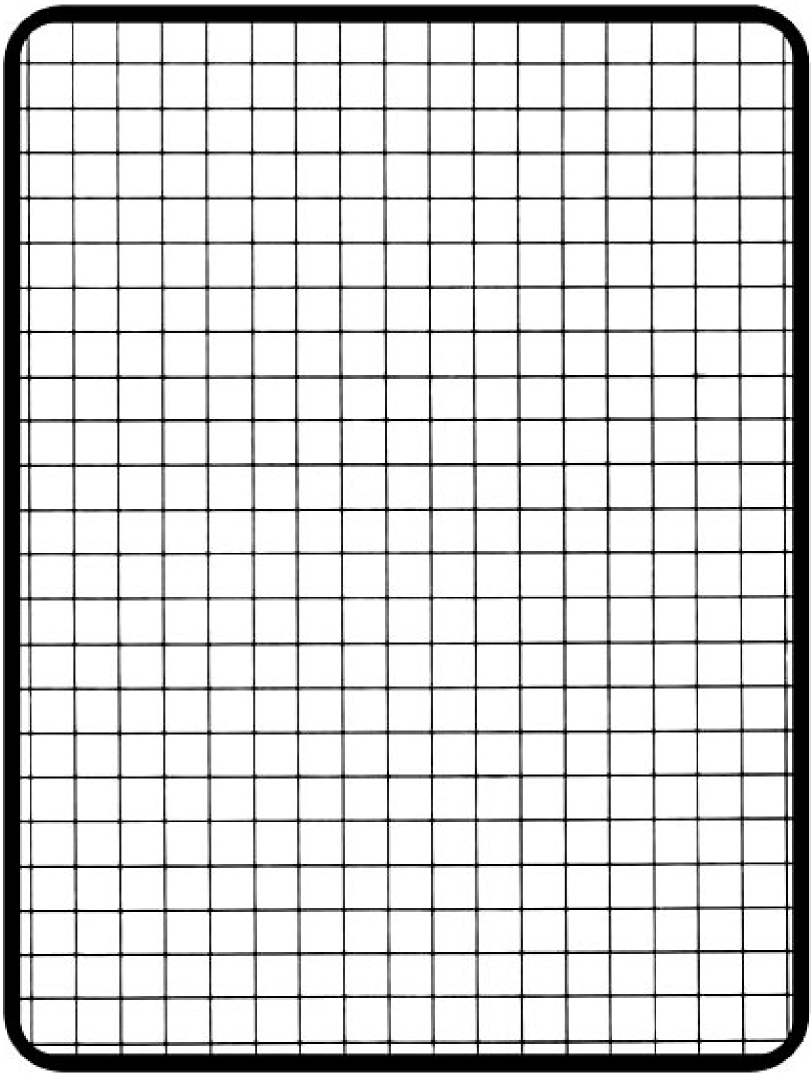
Film no. 24. Ferrite−Austenite



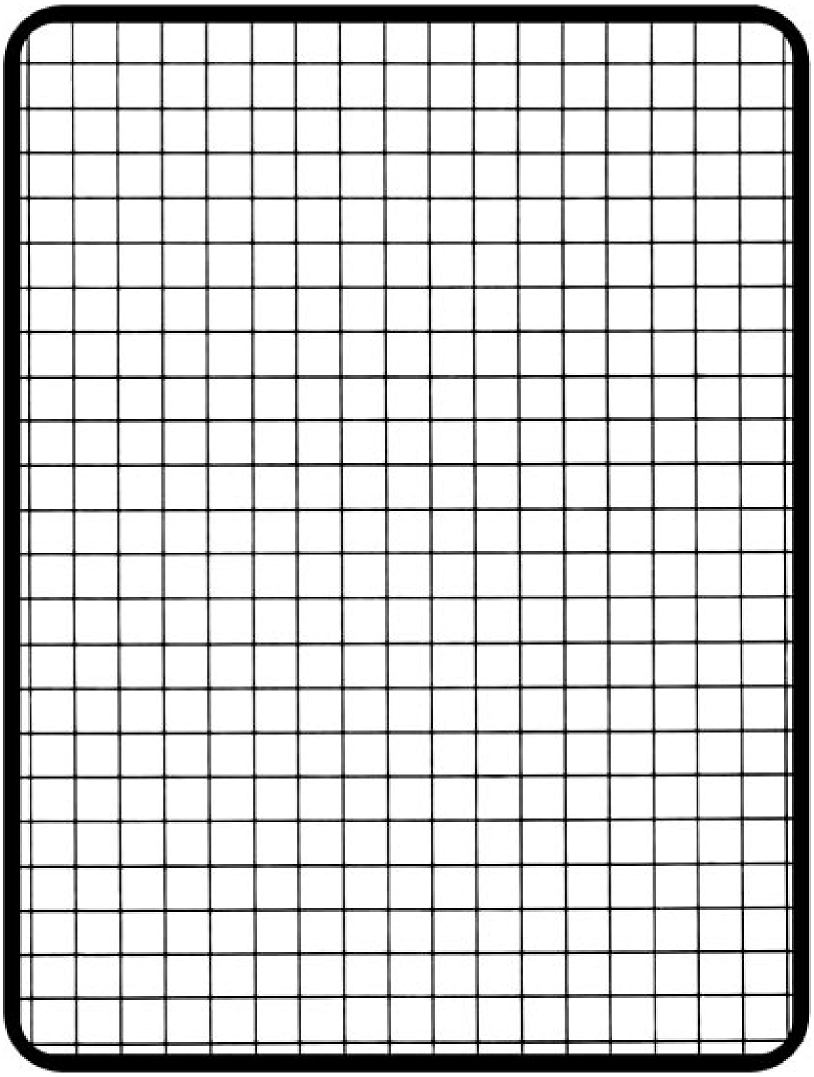
Film no. 25. Primary and secondary cementite



Film no. 26. Pearlite−Ledeburite



Film no. 27. Blank film with centimeter grid



Film no. 28. Blank film with centimeter grid