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FINAL REPORT

to the UNIDO Project SF/ROK/91/002

"Research on Flat Display Development: Phase-II"

(Contract N° 92/149/VK)

AN ABSTRACT

Results of experiments and theoretical calculations related to the work made by the Centre "EPITAXY" according to the UNIDO Project SF/ROK/91/002 "Research on Flat Display Development - Phase II" (Contract N° 92/149/VK) are presented. The material includes (1) a review of the state-of-art in this field by the November, 1992; (2) new scientific results important for successful implementation of the Project; (3) information and description of a new working station which has been organized in scopes of preparation of pilot production of films for fabrication of thin film transistors for flat-panel displays; (4) data on some improvements of the working station; (5) results of experiments on crystallization of amorphous silicon films implemented on this station; (6) results of simulation of the crystallization process for excimer-laser technique; (7) some data on properties of the crystallized films as determined by the contractor-donor (the Goldstar Co., Ltd., Republic of Korea); (8) conclusions and recommendations.

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1. INTRODUCTION

Basing on results of the "Research on Flat Display Developments - Phase I", which was implemented in 1991 by the Centre "EPITAXY" under the Contract 91/227 (UNIDO Project SF/ROK/91/002), it was decided to concentrate on excimer-laser crystallization of amorphous silicon (a-Si) films prepared on low-melting-point glass substrates by plasma- enhanced chemical vapor deposition (PECVD) at low temperatures (about 250°C).

In addition, basing on the results and taking into account recent news on state-of-art in flat-display research, further efforts in this field were concentrated on extremely thin films (ca 40 nm= 400 Å or less) because such films ensure better reproducibility in microstructure and physical properties of prepared poly-Si films for active-matrix liquid-crystal displays (LCD's).

To contribute to the Korean electronics industry (in particular, the Goldstar Co., Ltd., as a donor of the Project), principal efforts in the research were concentrated on uniformity and reproducibility of the properties in scan-area, in pulse-to-pulse overlapping, and in line-to-line overlapping, where large-area LCD's were prepared.

The Centre "EPITAXY", following to the scheme accepted earlier (at the Phase-I of the research);

(a) carried out excimer-laser-crystallization experiments on a-Si films with the aim to prepare poly-Si films useful for fabrication thin-film transistors (TFT's);

(b) investigated microstructure of the prepared films;

(c) transfered samples of the prepared films to Goldstar Co., where the samples were estimated for fabrication of TFT's.

Considering this research as a step to pilot production of

LCD's, the Centre "EPITAXY", in accordance with the Technical Collaboration Agreement signed between the Centre and the Goldstar Co. acted since April 1st till November 30th, 1992, and served as a basis for the Project has organized in Moscow, at the Institute of Crystallography, Russian Academy of Sciences, a new working station with an excimer-laser system. This working station has operation parameters close to those acceptable for the pilot production of TFT-LCD devices.

Principal part of the experimental work has been performed on the working station. In addition, some part of the work was made on another excimer-laser set having other parameters and more suitable for research rather than for developments or production.

In parallel with the crystallization experiments at the station, some design work directed to improvements of parameters of the station (such as homogeneity of the excimer beam) has been made.

Finally, some computer simulation of the crystallization directed to optimization of the process was performed.

Description of the experimental procedure (including apparatus and processing), results obtained with different samples and parameters, discussion of the results, and conclusions are given below.

2. BACKGROUND: A REVIEW

In the Report on Phase-I of the research on flat panel displays, a general review of state-of-art in this field by 1991 with subdivisions for different techniques for preparation of poly-Si films on low-melting-point glass substrates has been done. In this work (Phase-II), we have concentrated on the chosen technique, namely, those based on using of excimer-laser crystallization of a-Si films. Accordingly, our attention was attracted mainly to the literature on excimer crystallization and some related topics.

Analysis of the 1992 literature /1-14/ devoted to the active-matrix LCD's shows the following.

a) In addition to Sony (Japan), Xerox (USA), and NEC (Japan), which were active in the excimer crystallization for this application, some other companies and laboratories became very active in this field (Giant Electronics Technology Co., SANYO Electric Co., Semiconductor Energy Laboratory Co., Tokyo Institute of Technology, all of them from Japan). This means that the approach to crystallization of amorphous films based on excimer-laser crystallization /1-9/ became principal one, in comparison, e.g., with Ar-laser crystallization, with thermal-annealing crystallization, with LPCVD-processing, etc.

b) A drastic (about one order of magnitude) increase of the field-effect mobility in the films crystallized by the excimer processing has been achieved during last year. The value of the mobility (200-300 $cm^2/V \cdot s$) is so high that such films can be, in principle, used not only in the active matrix LCD's but also in some other areas of modern microelectronics (such as three-dimensional integrated circuits).

c) This strong increase of the mobility was not occasional but a result of some principal improvements in the process as a whole,

namely: performing whole laser annealing processes sequentially in a vacuum container; using of preliminary dehydrogenated a-Si films; heating of the film during excimer crystallization up to about 400°C; utilizing high-purity as-deposited a-Si:H films; optimizing illumination conditions.

d) An activity in preparation of poly-Si films on glass substrates by laser-beam crystallization is continued /10/. Rather high mobility (390 $cm^2/V{\cdot}s$) has been obtained in such films; however, practically nothing is known about productivity of such a process and about smoothness of the films obtained.

e) Also, an activity in low-pressure chemical vapor deposition (LPCVD) for TFT-LCD is continued /11-13/. However, necessity for relatively high temperatures (550-630°C), time-consumity (several hours), and surface roughness inherent in such processes represent serious disadvantages of such an approach for fabrication of flat-panel displays on large glass substrates.

f) Recently, a new process for realization of poly-Si TFT's on glass substrates has been described based on crystallization of amorphous Si films deposited by LPCVD using rapid thermal annealing (RTA) with a halogen-lamp equipment /14/. The field-effect mobility achieved (20 $cm^2/V{\cdot}s$), although is today acceptable for some kinds of active-matrix LCD's, is not perspective in a future. A similar process has been described in /15/.

g) Another new process for preparation of active-matric LCD's has been proposed by a combined group of people from KOPIN Corp. (MA, USA) and David Sarnoff Research Center (NJ, USA) /16/. Such a device was fabricated in thin-film single-crystalline Si prepared by a Si-on-insulator technology (zone-melting recrystallization by a strip heater) with lateral seeding.

As a conclusion about active matric LCD's, there are expectations that continued improvements in the poly-Si processing will lead to a new paradigm for flat panel displays and electronic systems devices on large area substrates useful for different applications /17/.

3. EXPERIMENTAL PROCEDURE

3.1. Excimer-laser crystallization

A brief description of the crystallization procedure, including some general data on the processing, a scheme of the apparatus, and corresponding references, were given in our final report on the Phase-I of the research.

There, a crystallization apparatus based on an excimer laser LUMONICS-TE-861T with Kr:F gas mixture giving pulses of 248 nm radiation, durations at half-amplitude (FWHM) about 10 ns, pulse energy about 200 mJ in a rectangular frame 22x5 mm^2, has been described. In this research (Phase-II), the same apparatus, especially at the beginning of the research, was used, too.

In addition, and especially at later stage, a new crystallization apparatus ("working station") has been organized and established in the Centre EPITAXY (fig. 1). Principal features of the apparatus in comparison with the former one are the following.

- A new excimer laser, model LLA, developed and fabricated by Physics Instrumentation Center, General Physics Institute, Russian Academy of Sciences (Troitsk, Moscow region, Russia). This laser uses Xe:Cl gas mixture giving pulses of 308 nm radiation. Pulse duration in the laser was longer (several tens of ns), and total power was markedly higher.

- In the station, a vertical mechanical stage moving in X and Y directions was used allowing laser crystallization of films on such large substrates as 100x100 mm^2.

- Some other improvements in comparison with the former apparatus were made, too.

According to the Project, organization of the working station was one of the most important part of the research work. It was con-

sidered by the donor (the Goldstar Co.) that this station should serve as a prototype of the apparatus in the future system for pilot production of the films suitable for TFT-LCD devices. Generally, this station is based on the experimental set used at the Phase-I of the work (with Kr:F excimer laser). However, it has some omportant distinctions which make it fat more suitable for prosuction systems. First, contrary to the Kr:F gas mixture, the new station uses Xe:Cl one which is less hazard and more safe in exploitation. Second, such a mixture has far larger (about one order of magnitude) working resource that is important from both economical point of view and reproducibility of the results. Third, it is far easier with such a mixture to organize longer energy-pulse durations (e.g., 30 to 50 ns instead of 10 ns typical for Kr:F laser) which are, again, more suitable for reproducible crystallization of a-Si films.

3.2. Investigations of the film crystallized

At the Phase-II, relatively thin a-Si films, typically 40 to 100 nm in thickness, were underwent to crystallization. Such thin films deposited on glass substrates have very smooth surfaces (that is important for fabrication of TFT's). On the other hand, it is rather difficult to investigate microstructure of such films. In particular, practically no information can be obtained by scanning electron microscopy or by X-ray diffraction studies.

As it was in the Phase-I, principal information about microstructure of such films we obtained here from TEM studies of replicas prepared from the films. The studies allow both to determine their morphology (e.g., sizes and distribution of crystalline grains, or crystallites) and to estimate their crystallinity by microdiffraction technique. In addition, by cross-section TEM technique it was possible to obtain an information about kinetics of

the crystalline growth although such research was highly time-consuming (mainly due to necessity to etch rather thick glass substrates by ion milling) and less effective for such thin films.

In addition, Raman spectroscopy was used for estimation of relative amounts of crystalline and amorphous phases remained after the excimer treatments.

4. EXPERIMENTS ON PREPARATION OF POLYCRYSTALLINE SILICON FILMS ON GLASS SUBSTRATES. RESULTS AND DISCUSSIONS

Following to the scheme described above, in the INTRODUCTION, the Centre "EPITAXY" has crystallized by excimer laser several hundreds samples of a-Si films on glass substrates 50x50 mm^2 and 100x100 mm^2. Typically, the substrates were coated with a buffer Si_3N_4 layer (150 to 300 mm in thickness). Amorphous Si-films intended for crystallization most commonly had a thickness of 40 nm, although some of samples had a-Si films of 20, 30, 50, 60, 70, 80 and 100 nm in thickness. Some of samples were dehydrogenated (denoted as "DH"), while others, being prepared by a plasma-enhanced CVD process, contained up to 23-25% of hydrogen that complicated the crystallization process resulting in blistering of the films during excimer crystallization. Some samples were coated by a protecting silicon-nitride film.

These samples, grouped in several parties, had been transfered to the Goldstar Co. together with corresponding technical information.

Below, a summary of the results, including description of some typical and most characteristic samples, some processes and their simulation, is given.

4.1. Energy densities of the excimer laser

Basing on our former (Phase-I) experiments and on the literature data, energy density of the laser beam (in mJ/cm^2) was considered as a principal parameter influencing strongly on the microstructure. Unfortunately, an optimal range of the parameter is rather narrow: at relatively low densities, the a-Si film didn't con-

vert into crystalline state, while at relatively high densities, the films were damaged becoming unappropriate for fabrication of TFT's.

At this stage of the research (Phase-II), our main aim was to find more or less certain limits of the acceptable energy densities and pulse repetitions so that to obtain data which will allow to optimize crystallization conditions for the overlappings. At the same time, some experiments with the overlappings were made at this stage, too.

The mentioned high energy density above which the film are damaged and become unappropriate for fabrication of TFT's considered as threshold one (let's denote it as P_{max}). According to literature data (see, e.g., papers by Sameshima et al./18-20/), this threshold value for crystallization of a-Si films having thickness from 20 to 100 nm is typical about 200 mJ/cm^2. We have found a similar value, however, depending on prehistory of samples, the value varied, sometimes significantly, especially for PECVD-samples a-Si:H, i.e., hydrogenated amorphous films.

Experimenting with various density energies, we have found that films with at least two kinds of microstructures can be obtained:

a) at some densities, approximately 1.05 P_{max}, an amorphous phase having another, more dark colour than the initial a-Si film was observed. Investigations of the films in TEM have shown that they consist principally of amorphous areas in which separate, rather large (up to 1 m) crystalline grains are incorporated (indicated by an arrow in fig. 2). Electron diffractograms of such films consist of a bright central spot, inherent in amorphous Si, and separate, rather distinctive point reflexes originating from the grains;

b) at lower densities, the treated areas look far brighter in the transmitted (optical) light than the initial a-Si film. This is inherent in films prepared in a rather broad energy densities (0.75 to 0.95 P_{max}). This colour change is evidently caused by crystallization of the material. Indeed, TEM studies have revealed a tiny-crystalline material of the films with grain sizes about 10 nm (fig. 3). Decrease of the energy density leads to decrease of the sizes (cf.: fig. 3a to fig. 3b). Accordingly, electron diffractograms (see inserts in fig. 3), consisted mainly of point reflexes, are gradually transformed into rings, first rather sharp, then diffusing. Such a regularity evidences on decreasing of the grain sizes.

4.2. The role of dehydrogenization in crystallization of amorphous films

Numerous data in the literature (see, for example, the REVIEW above) evidence that prehistory of the samples of amorphous Si films influences strongly on both kinetics/mechanism of the crystallization and quality (microstructure, etc.) of the films crystallized.

In particular, when the initial amorphous films content large (up to 20-25%) amounts of hydrogen (i.e., we deal with a-Si:H films), that is typical for films prepared by PECVD, crystallization proceeds "stormily", with evolution of a lot of small bubbles in the film ("blistering"), and quality of the film is rather poor (see our Report on Phase-I of the Research Work).

To avoid such phenomena, the hydrogen must be removed from the film. This can be made by heating of the film, up to about 400°C in vacuum, in a gas flow, etc., or by preliminary treatment of the amorphous film with pulse laser, etc. Such treated films are named "dehydrogenated" (DH) in contrast to non-treated ("fresh").

Experimenting with DH-samples, we obtained films with grain sizes far (about one order of magnitude) larger than those in non-treated ones (fig. 4).

4.3. Cross-sectional TEM studies

Although studies of replicas from the crystallized films in TEM by in-plane technique were most common and principal (because they gave information about microstructure, namely, both morphology and crystallinity, of the films), some samples after crystallization were investigated in TEM by cross-sectional technique. This technique is highly time-consuming; at the same time, it gives a valuable information about mechanisms of nucleation and growth of the films.

In fig. 5, several cross-sectional TEM micrographs are given. They were obtained in films initially deposited by PECVD, i.e., contained rather large amounts of hydrogen (in a chemical bond with silicon). Accordingly, as was noted above (see Section 4.2.), these films are not so good for crystallization: in the film crystallized (see, e.g., areas between surface A and interface B), a lot of tiny crystallites are seen.

For comparison, an in-plane TEM image obtained from another area of the same film is shown in fig. 6. This morphology is typical for films initially prepared by PECVD process and not underwent to dehydrogenization: a lot of tiny crystallites, a marked part of the "crystallized" film remains amorphous.

In fig. 7, cross-sectional TEM image of excimer-laser crystallized film obtained from a dehydrogenated initial film is shown. Here, rather distinct crystallites are seen, they are cylindric-like in shape. Such a morphology seems to be characteristic of very thin films (in this case, thickness of the film is about 50 nm).

Quite another morphology is characteristic for thicker film (about 200 nm) shown in fig. 8. This film was crystallized by a Cu^{+} laser (see our Report in Phase-I of the Research Work). This laser

has much of common with the excimer one: short wavelength, short pulses, so, some common conclusions can be made. As is seen, here, crystallites have a conical rather than cylindrical shape, and the picture indicates to nucleation near the interface between the silicon film and the buffer layer. This means that inside the film a marked temperature gradient existed during the crystallization process.

4.4 Raman-spectroscopy

Raman-spectroscopy represents a non-destructive method suitable for investigation of crystallinity of grown films. This rather standard technique consists of analysis of reflected light in a certain spectral range where crystalline phase of the object under investigation (for example, of a silicon film) reflection peaks are exist. As a radiation tested we used a normal Ar-laser beam. Depending on presence or absence of the peak, its shape and shifting in respect to the peak corresponding to the crystalline phase a conclusion is made about phase composition and quality of the film prepared.

Results of our Raman-spectroscopy investigations are shown in figs 9 and 10. In particular, in fig.· aour curves are presented, of which upper one corresponds to an initial amorphous film, while other three ones relate to films treated at different laser energy densities successively increasing from the top to bottom. The upper curve has no peak inherent in crystalline phase; at the same time, its left part is slightly higher than the right one. These facts evidence that the film is amorphous. As the density increases, the asymmetry of the curve disappears; instead, a central peak inherent in crystalline material appears and becomes higher and higher.

The curves of fig. 9 correspond to initial film prepared by PECVD. Such films contain a lot of dissolved hydrogen (so-called a-Si:H films). The hydrogen plays a negative role in crystallization of the amorphous films. In fig. 10 are given curves for different points of a film from which the atomic hydrogen has been removed before the excimer-laser crystallization. As is seen (all the curves are symmetrical and have rather sharp peaks), the removal of hydrogen (dehydrogenation) favors to improvements of the films crystallized. In addition, high similarity of the curves evidences on high uniformity of the films along the substrate.

4.5. Improvements of the working station

4.5.1. Shaping of the laser beam

Laser beam at the output of the equipment has sizes about 10x25 mm^2. Energy density in the beam is determined by peculiarities of the gaseous discharge in the laser chamber and, typically, is not uniform. In addition, during operation of the laser, due to changes in the discharge chamber, the mode structure of the radiation is continuously changed.

It is clear that the output distribution of the laser energy is not optimal from the point of the crystallization processing. In addition, for production, it is important to ensure the spatial uniformity of the energy density during a long time period.

In this work, using an objective, we shaped the beam incident onto the sample in the form of an elongated, narrow stripe. In such a way, we were able, first, to treat as large area as possible by one passing of the beam. Second, it was possible to improve the uniformity along the laser-beam stripe. Next, the uniformity was achieved owing to extension of the beam and diaphragming of its peripherial areas where radiation intensity dropped.

4.5.2. Homogenizer

This point of the working station represents an optical system consisting of several components. It is intended for formation of a uniform (homogeneous) distribution of the energy in a given plane. One of the most serious drawbacks of the optical system is loss of energy that can be as large as up to 50% of an initial value. In the crystallization processes, large energy densities are necessary; accordingly, we aimed at homogenization of the energy distribution together with minimization of the losses.

In this working station, a known system of raster-type homogenizer. In a plane normal to the laser beam, an optical system of a lot (e.g., 64) of small spherical lenses of square aperture about 5x5 mm^2 were spaced. The lenses were tightly fitted each to other. This optical system transformed rectangular laser beam into a set of regularly-spaced point sources. This radiation propagated from each of the sources within a limited solid angle along the laser-beam axis. Homogeneity of the radiation was obtained owing to mixing of small beams from the point sources. In such a way, the homogeneity better than 90% has been achieved.

4.6. Additional processing in film crystallization

In the Review (see above, Section 2) it was noted that among factors which facilitated to the strong (about one order of magnitude) increase of the carrier mobility there is heating of the film during excimer crystallization up to about 400°C. This fact is not surprising if remember that thin films of typical semiconductors (silicon, germanium, gallium arsenide), being prepared in an amorphous state, are spontaneously transformed into crystalline films merely by heating to 300-500°C.

Taking this into account, we made some experiments on annealing of a-Si films delivered by the Goldstar Co. in an inert atmosphere (flowing, slightly purified nitrogen) in a furnace having rather uniform temperature zone at about 450°C during 1 to 3 hours.

TEM studies of such films have shown that this heat treatment, indeed, influence on their microstructure.

In figs 11 and 12 are shown the films before and after the treatment. As is seen, the heat-treated samples have a microstructure with markedly large crystalline grains.

In another series of experiments, the heat-treatments were combined with the excimer crystallization. Namely, before the heat-treatment in the furnace, samples were undergone to excimer irradiation. From literature data (see our Review in the Final Report on the Phase-I), it is known that the laser pulse having sufficient energy density melts the a-Si film. Further, the film remains in the molten state for 100 to 200 ns and, after that, is cooled with a sequence of processes including supercooling of the melt, nucleation of the crystallites, solid-state crystallization, etc. This means that, even after a single excimer-laser pulse, there is a probability for formation of crystalline nuclei. On the other hand,

it is well known that in crystallization phenomena, nucleation, being an activated process, is typically a critical, rate-determining stage. Accordingly, if "activate" the nucleation by the laser pulse, it is possible to facilitate further crystallization by simple heating of the samples.

Results of such a combination are shown in figs 13 and 14. As is seen in fig. 14, excimer-laser irradiated samples have far more large and distinctive crystallites than samples without the irradiation.

Accordingly, it would be instructuve to compare figs 12 and 14: it is clear that the laser irradiation contribute to the crystallization process.

4.7. Simulation of the crystallization process

One of the aim of this research work consisted of development of a PC-computer program which could simulate, with a sufficient approximation, the real crystallization process. Such a program is necessary for consideration of various situations (i.e., version of the process with different parameters) aiming, first, to determine values of the parameters which cannot be ontained by direct experiments; second, to find optimal parameters and versions of the process.

It was considered that processes of heating and cooling are described by nonsteady equations of heat transfer: to solve the equations, the method of finite differences was used. To this aim, the film system (substrate/buffer layer/silicon film) was presented as a one-dimensional network where each unit (knot) was responsible for a small volume corresponding to an area of the network. Values of temperature in the knots correspond to average temperatures of the volumes. Values of real times serve as values of second coordinate of the network. Heating of the film system has been simulated by a function of the heat source normalized in accordance with deviding on the time coordinate.

As a result of the calculation, two-dimensional massif of the temperature values in the knots of the elementary volumes of the film structure for a given moment of time.

In order to facilitate interpretation of the obtained decision, an additional program for PC has been developed which represents the result in figs 15 and 16.

In the figures, a cross-section of the layered structure is shown, the dotted horizontal lines separating 10 elementary volumes of the silicon films represent 10 equal-width stripes. Eleventh,

more wide elementary volume represents the first one belonging to the buffer layer. Other underneath ones are not shown in the figure because they are of no interest here. The vertical lines divide the time coordinate for 5-ns intervals that correspond to the half-width of the time coordinate (at the level of the half-height of the amplitude interval) of the heat source which is shown (in not-normalized amplitude interval) in the left upper corner of the figure.

The solid lines crossing the cross-section of the layered structure represent isotherms. The value of the maximal isotherm (shown by arrow) is given in the left upper corner. Underneath, the temperature difference of the neighbor isotherms is shown. The lower caption indicates to respective values (from left to right) of the parameters for which the table has been obtained: 5=5 ns of half-width of the heat source, 50= 50 nm of the film thickness, and 17= 170 mJ/cm^2 of the amplitude of the heat source.

In general, the figure gives time-changes of the temperature. As the structure is heated, the temperature gradient increases (the isotherms become close to each other). When the melting point of silicon is reached (i.e., the upper silicon layer melts), a plateau appears as stabilization of the temperature due to evolution of the latent heat of crystallization. This effect decreases the temperature gradient, and the intervals between isotherms decrease. After complete melting of the silicon film, the temperature increases again, however, with smaller speed because of the heat conductivity of the melt is higher than that of the amorphous phase. Cooling of the structure goes in a reverse order, however, it is slower.

The figures given differ in power of the heat source. Thus, in fig. 15 (170 mJ/cm^2), the silicon film melts only for 0.7 of its thickness. In fig. 16 (200 mJ/cm^2), the film melts completely.

4.8. Carrier mobility in the films

Carrier mobility in the films represents a principal parameter of the material that determines characteristics of TFT's fabricated from such films. It is the relatively high mobility of poly-silicon films that motivated the research directed to use them instead of a-Si films in LCD's.

From data published in the literature (see the REVIEW above) it is known that, although poly-Si films with mobilities as high as 200-300 $cm^2/V\cdot s$ can be currently prepared by excimer crystallization, for practice, where uniformity of properties (as a sequence of uniformity of microstructure) plays a crucial role, smaller mobilities (e.g., at the level of 20 $cm^2/V\cdot s$) are satisfactory, at least currently.

Here, we consider so-called field-effect mobility which is determined from measurements of TFT's fabricated in the films.

Poly-Si films prepared by excimer-laser crystallization in scopes of this Project were used by Goldstar Co., Ltd., for fabrication of testing TFT's. In these devices, values of the mobility determined were found to be 50 to 70 $cm^2/V\cdot s$.

CONCLUSIONS AND RECOMMENDATIONS

From the work implemented some conclusions and recommendations concerning further research and developments in LCD's can be made.

(1) Excimer-laser crystallization represents an effective technique for crystallization of very thin (20-100 nm) silicon amorphous films acceptable for production of TFT's not only for LCD's but for other devices and circuits.

(2) Further improvements in the processing for production of such films should be concentrated on optical elements of working stations.

(3) Preparations of initial films without dissolved hydrogen or at least with minimal its content is of high importance.

(4) Combinations of the excimer-laser processes with others (such as furnace annealing, ion implantation, etc.) are highly desirable.

Literature

1. H. Kuriyama, S. Kiyama, S. Noguchi, T. Kuwahara, S. Ishida, T. Nohda, K. Sato, H. Iwata, H. Kuwata, M. Osumi, S. Tsuda, S. Nakano, Y. Kuwano, Japan. J. Appl. Phys. 30, N 12B, 3700-3703 (1991).
2. K. Shimizu, H. Hosoya, O. Sugiura, M. Matsumura, Japan. J. Appl. Phys. 30, N 12B, 3704-3709 (1991).
3. D.H. Choi, K. Shimizu, O. Sugiura, M. Matsumura, Abstracts of the 39th Spring Meeting 1992 of the Japan Society of Applied Physics and Related Societies. Paper 29a-ZM-1.
4. H. Tanabe, K. Sera, K. Nakamura, K. Hirata, F. Okumura, ibid., Paper 29a-ZM-2.
5. H. Zhang, T. Inushima, N. Kusumoto, S. Yamazaki, ibid., Paper 29a-ZM-3.
6. T. Inushima, N. Kusumoto, H. Zhang, T. Horiuchi, S. Yamazaki, ibid., Paper 29a-ZM-4.
7. H. Zhang, N. Kusumoto, T. Inushima, S. Yamazaki, IEEE Electron Device Lett. 13, N 5; 297-299 (1992).
8. S. Yamamoto, Y. Nishihara, T. Nicuchi, Y. Uno, I. Asai, M. Fuse, T. Hamano, Paper S14-3 at 12th Intern. Display Res. Conf., October 1992, Hiroshima, Japan.
9. Noguchi, Paper at Semicon-Korea, Seoul, November 1992.
10. S. Shirai, T. Serikawa, IEEE Trans. on Electron Dev. ED-39, 450-452 (1992).
11. C.A. Dimitriadis, P.A. Coxon, L. Dozsa, L. Papadimitriou, N. Economou, IEEE Trans. Electron Dev. ED-39, N 3, 598-606 (1992).
12. T.-J. King, K.C. Saraswat, IEEE Electron Dev. Lett. EDL-13, N 6, 309-311 (1992).

13. C.H. Hong, C.Y. Park, H.-J. Kim, J. Appl. Phys. 71, N 11, 5427-5432 (1992).

14. M. Bonnel, N. Duhamel, M. Guendoux, L. Haji, B. Loisel, P. Ruault, Japan. J. Appl. Phys. 30, N 11B, L1924-L1926 (1991).

15. G.Liu, S.J.Fonash, Japanese J. Apllied Physics, 30, N° 2B L269-L271 (1991).

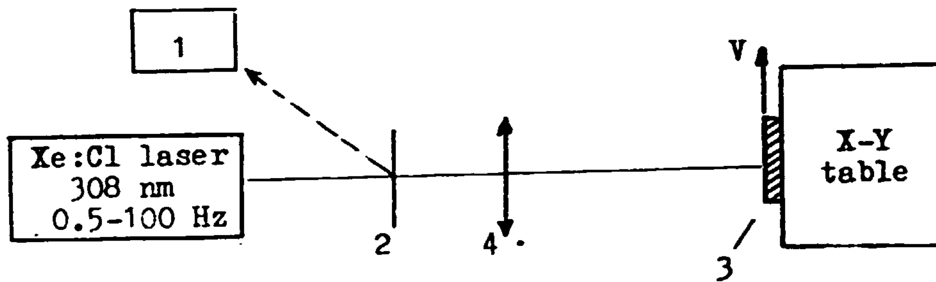
16. J.P. Salerno, D.P. Vu, B.D. Dingle, M.W. Batty, A.C. Ipri, R.G. Stewart, D.L. Jose, M.L. Tilton, Paper 5.7 in SID-92 Digest, pp. 63-66.

17. A.H. Firester, W.R. Roach, R. Stewart, Paper S14-1 at 12th Intern. Display Res. Conf., October 1992, Hiroshima, Japan.

18. T.Sameshima, M.Hara, S.Usui, Japan. J. Appl. Phys. 29, L548 (1990).

19. T.Sameshima, M.Hara, N.Sano, S.Usui, Japan. J. Appl. Phys. 29, L1363 (1990).

20. T.Sameshima, S.Usui, J. Appl. Phys. 70, 1281 (1991).



1 - power controller
2 - splitter
3 - sample
4 - objective

Fig. 1. A scheme of the working station for excimer-laser crystallization. The station has been organized and used for the research work in the Centre "EPITAXY".

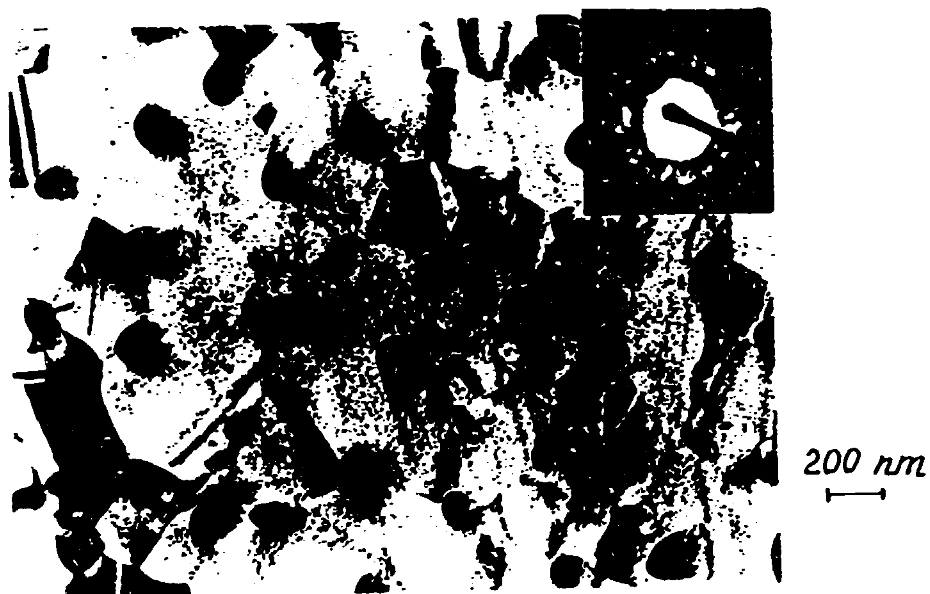


Fig. 2. An example of the mainly-amorphized, partly-crystallized Si film prepared at relatively high (1.05 P_{max}) energy densities.

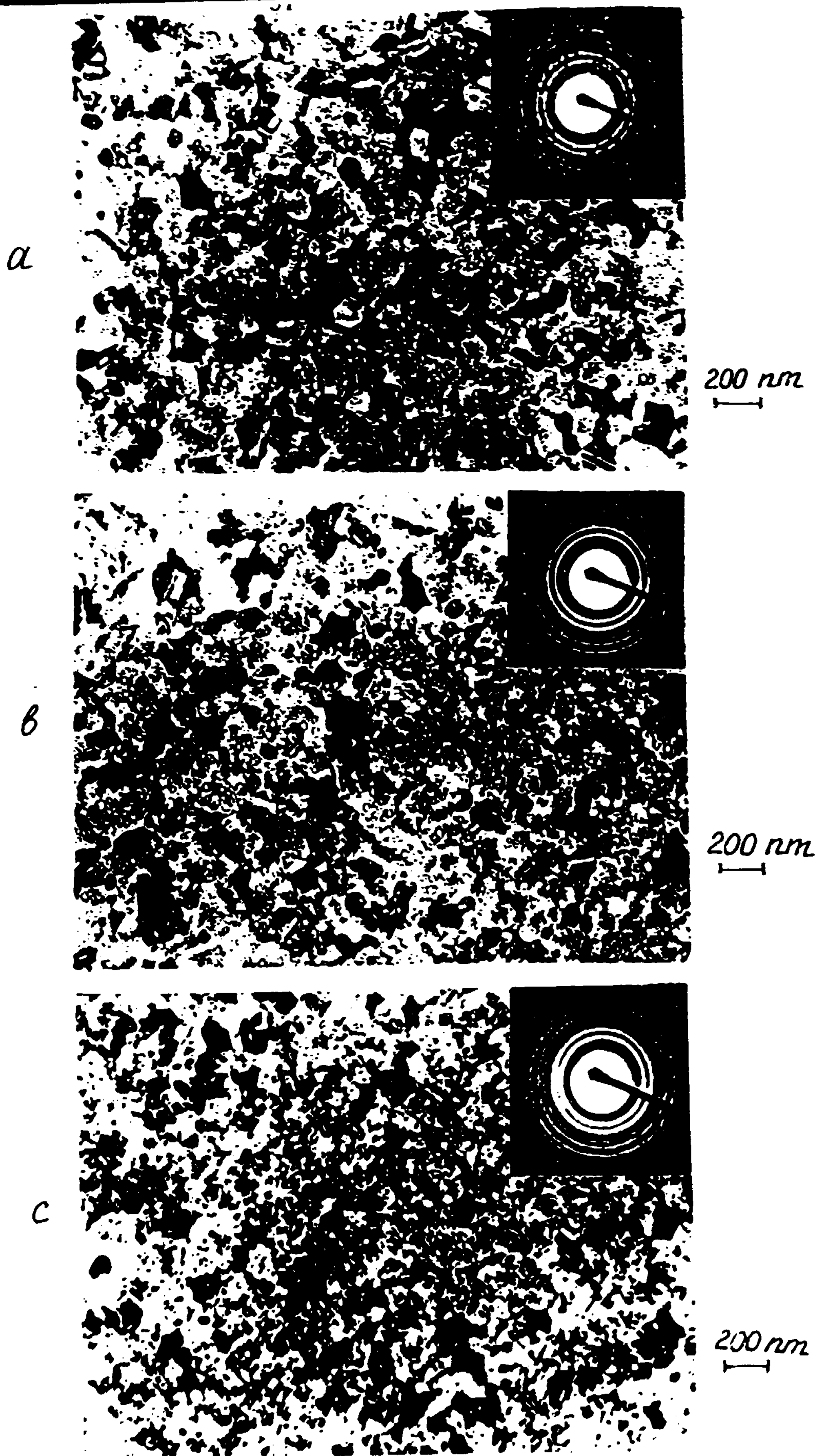


Fig. 3. Poly-Si films prepared at relatively low energy densities: a - at 0.95 P_{max}; b - 0.85 P_{max}; c - 0.75 P_{max}.

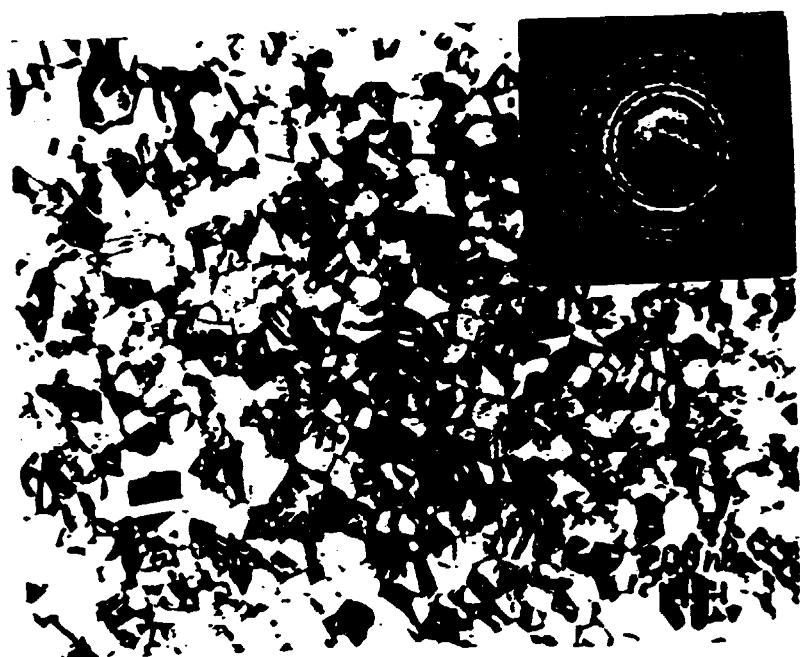


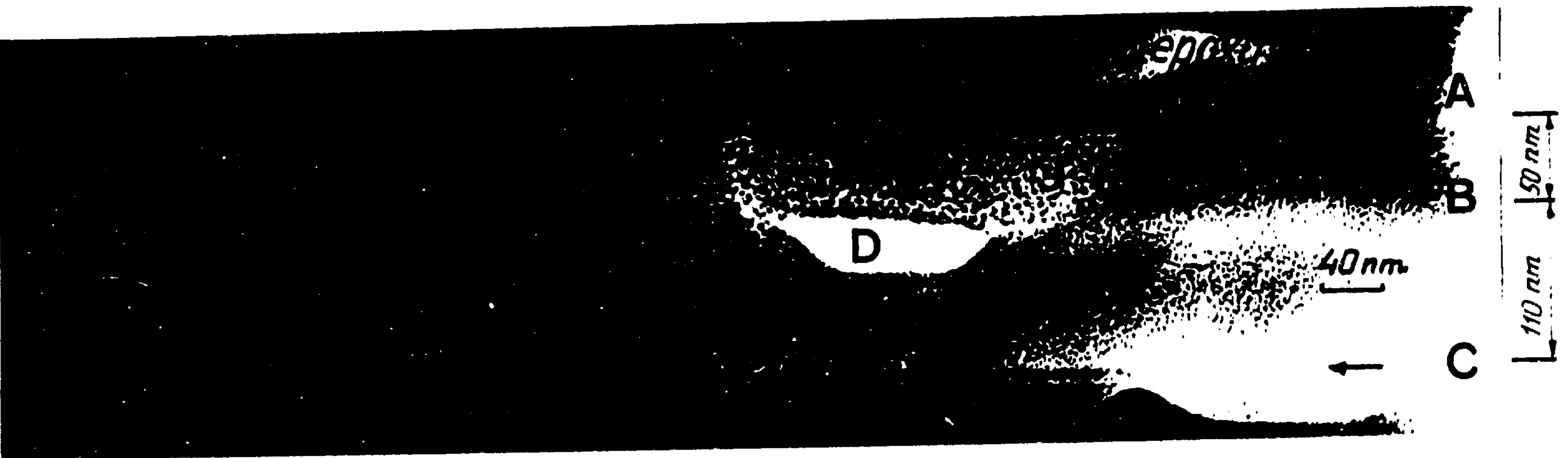
Fig. 4. Excimer-laser-recrystallized poly-Si film prepared from a dehydrogenated initial a-Si film.

Fig. 5a. Cross-sectional TEM image of a poly-Si film prepared by excimer-laser crystallization from a PECVD-deposited amorphous film.

A - surface of the Si film;

B - interface between the Si film and SiN buffer layer;

C - interface between the buffer layer and glass substrate.



Fi[illegible]. [illegible]. D - a hole formed during preparation of the sample for TEM studies (by ion-beam etching).

epoxy
A

Fig. 5c. [illegible] - a material re-evaporated during ion-beam etching.

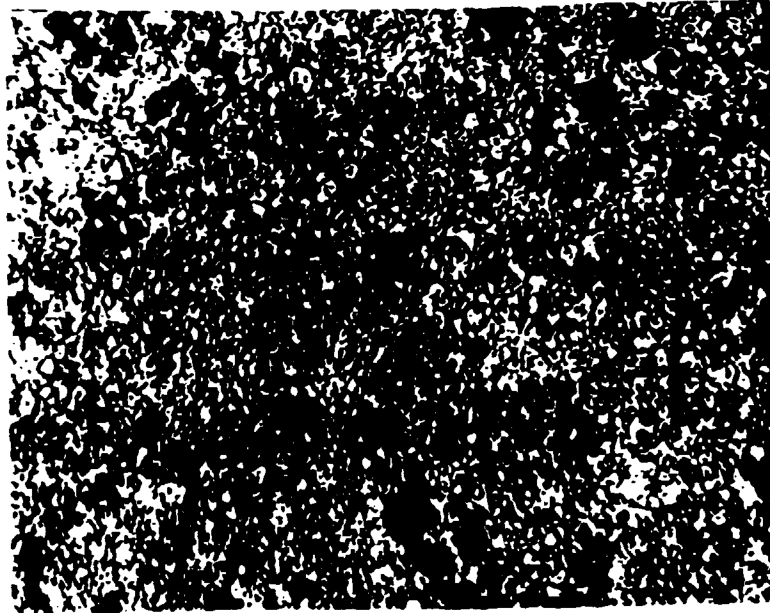


Fig. 6. TEM image of poly-Si film prepared by excimer-laser crystallization from a PECVD-deposited amorphous film. Thickness of the film 50 nm.

Fig. 7. Cross-sectional TEM image of a poly-Si film prepared by excimer-laser crystallization from a relatively thin dehydrogenated amorphous film.

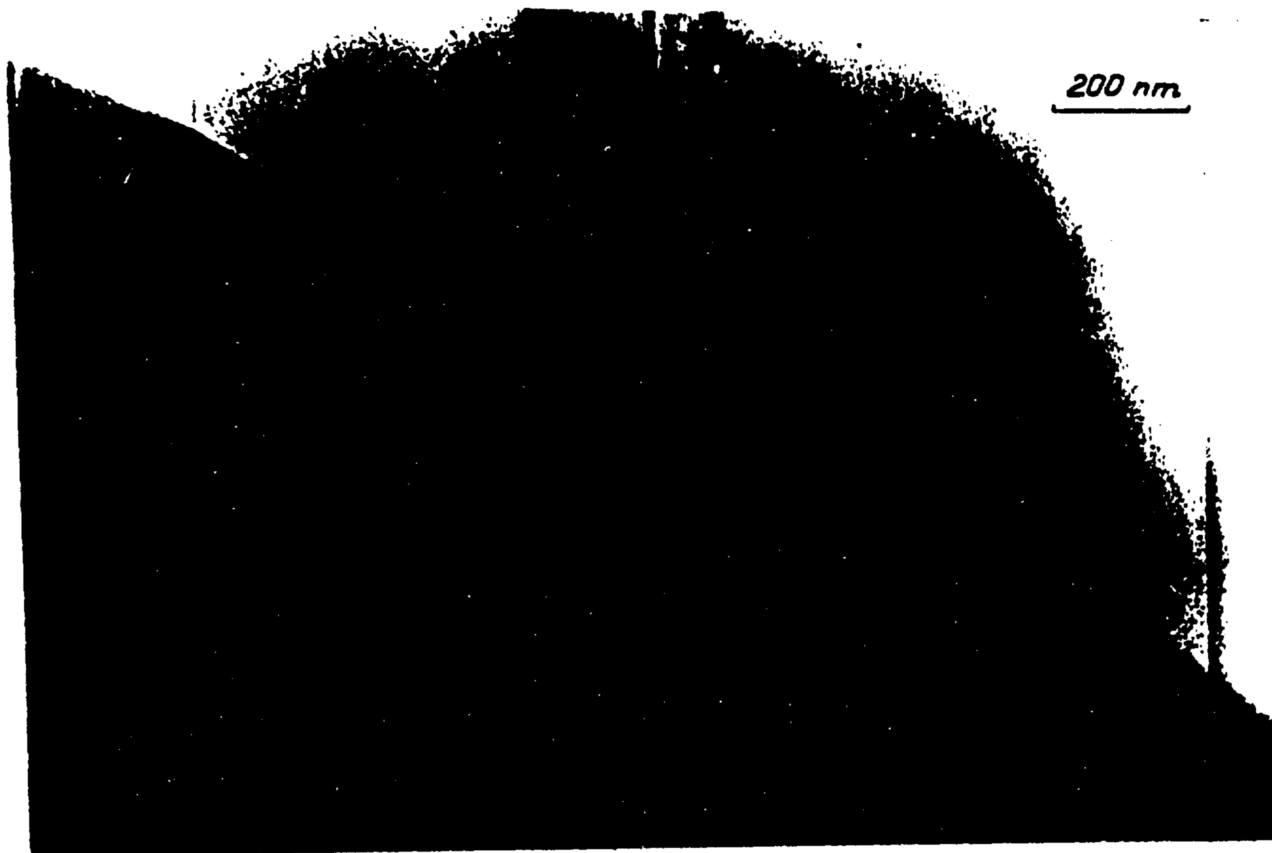


Fig. 8. Cross-sectional TEM image of a poly-Si film (A) prepared by Cu^+ laser crystallization from a relatively thick amorphous film deposited by LPCVD process (B - SiO_2; C - glass).

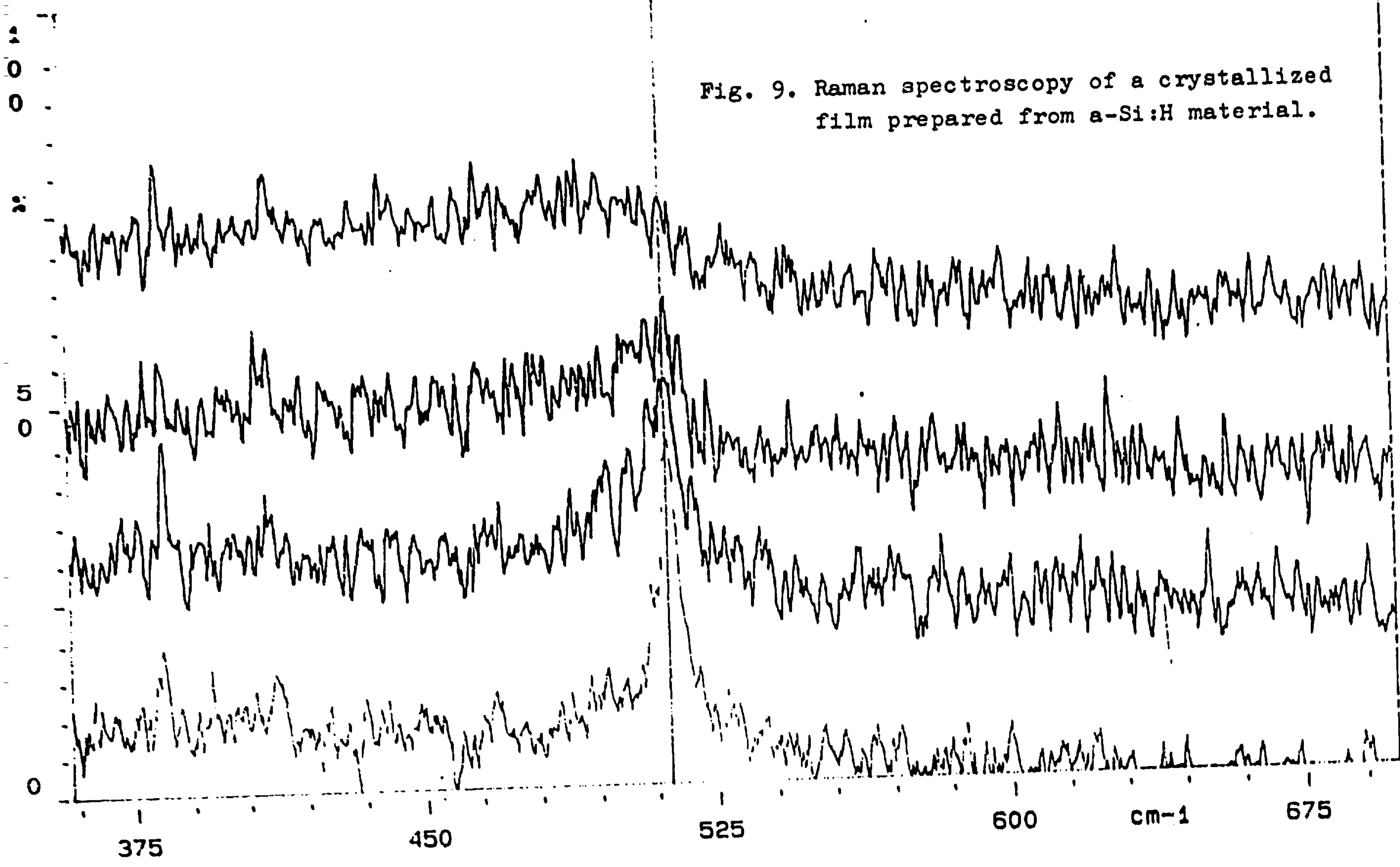


Fig. 9. Raman spectroscopy of a crystallized film prepared from a-Si:H material.

(5-21)

D5.50

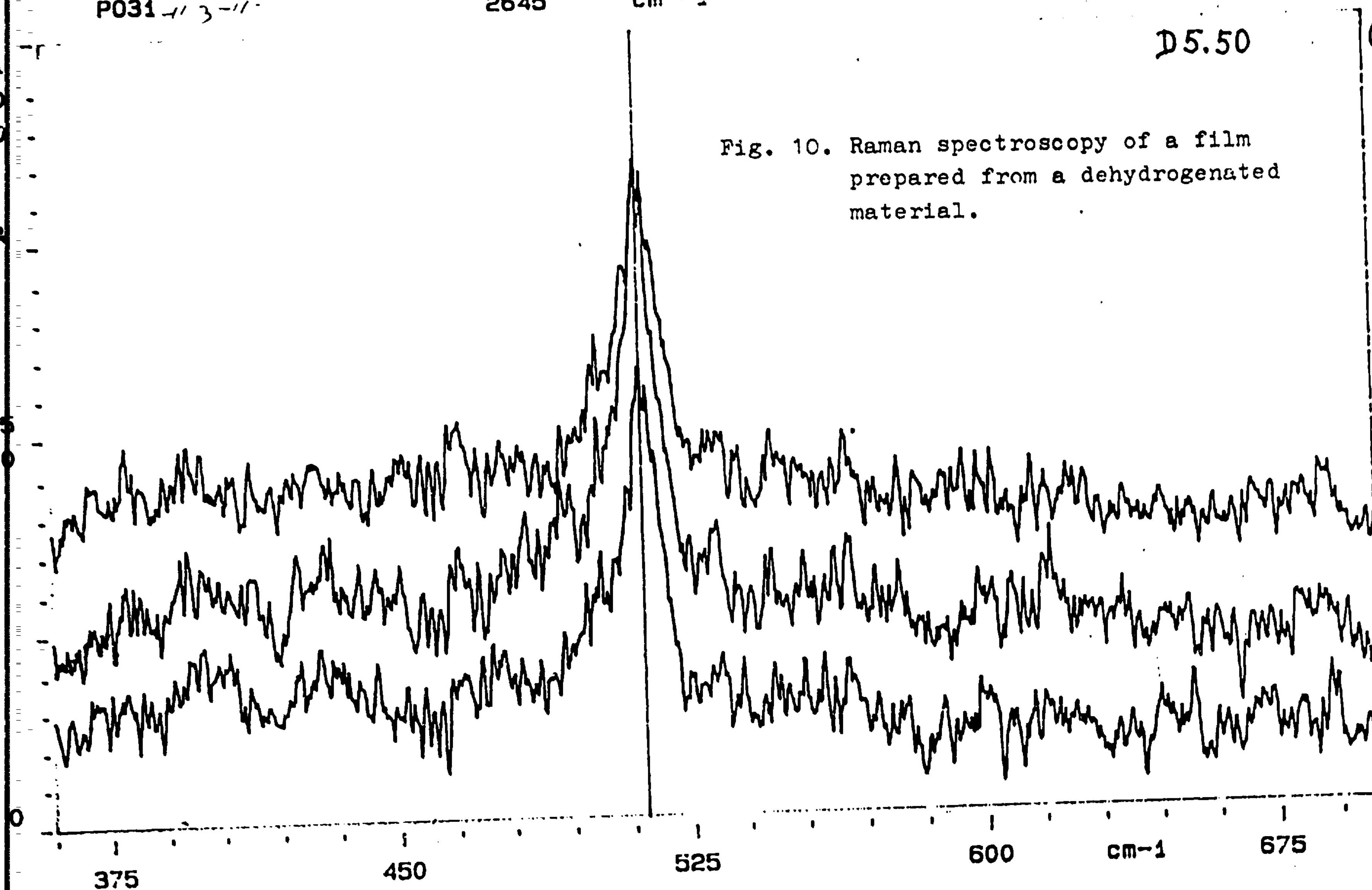


Fig. 10. Raman spectroscopy of a film prepared from a dehydrogenated material.

Fig. 11. TEM image of a-Si film.

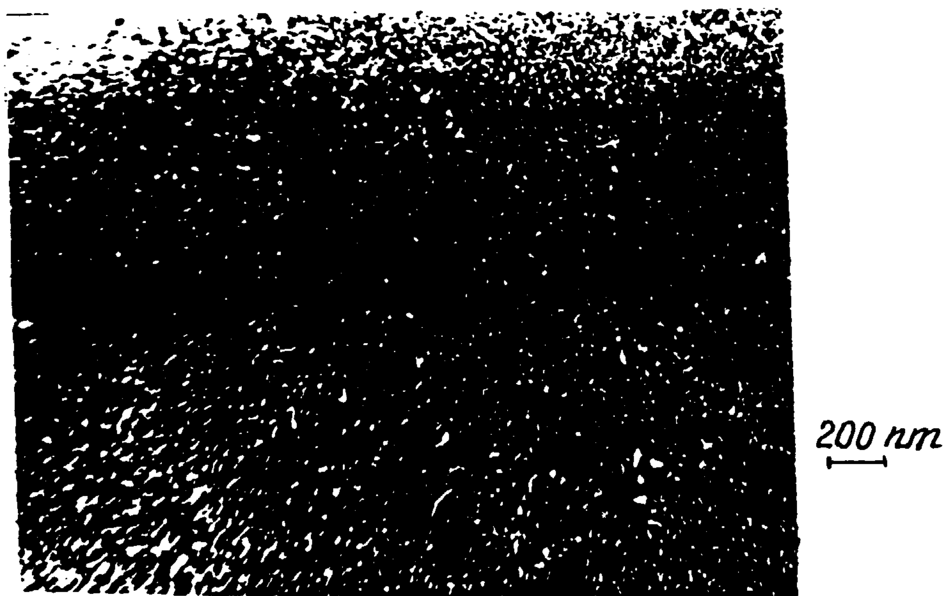


Fig. 12. TEM image of Si film prepared from a-Si film by heating in a gas flow (N_2) at 450°C during 3 hours.

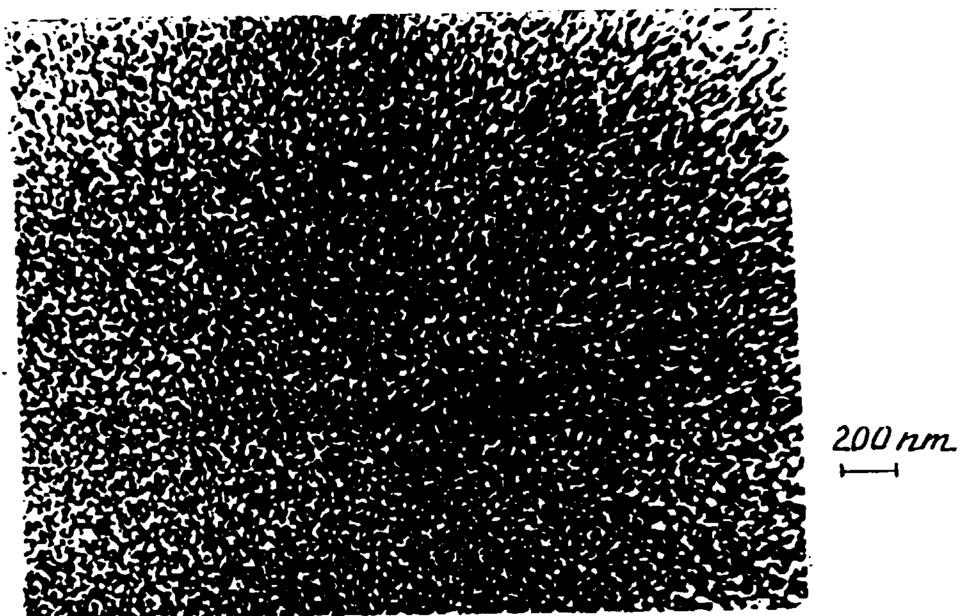


Fig. 13. TEM image of Si film prepared from a-Si film by heating in a gas flow (N_2) at 500°C during 2 hours.

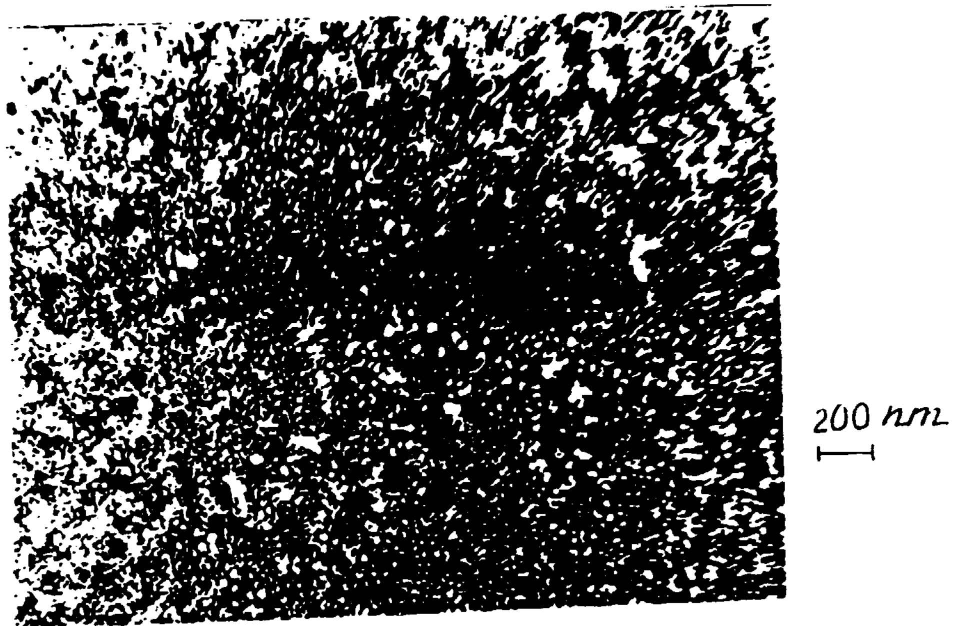


Fig. 14. TEM image of Si film prepared from preliminary "nucleated" (by excimer irradiation) film by heating in a gas flow (H_2) at 500°C during 2 hours.

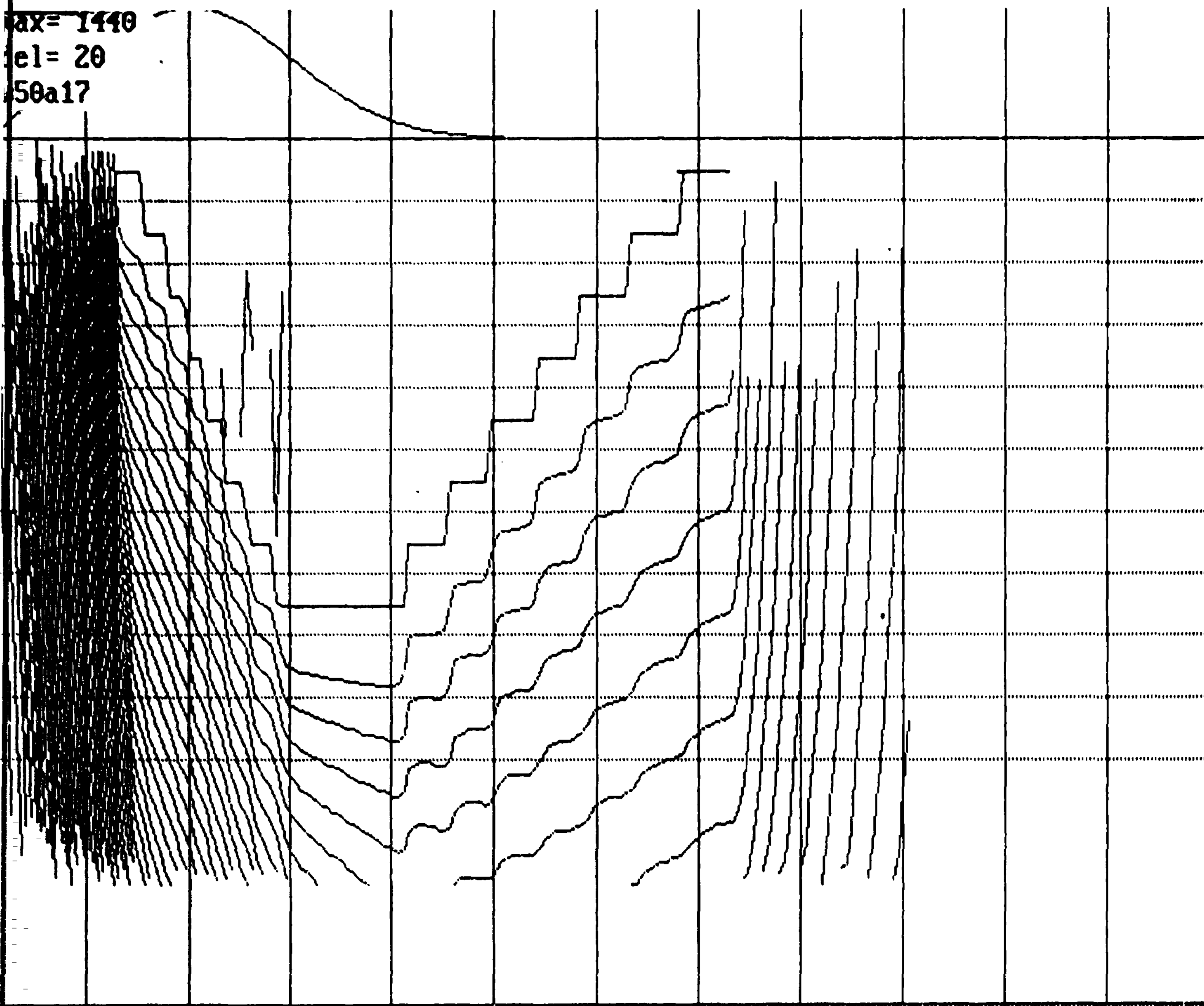


Fig. 15. Results of simulation of the temperature distribution during excimer-laser crystallization . Energy density 170 mJ/cm^2.

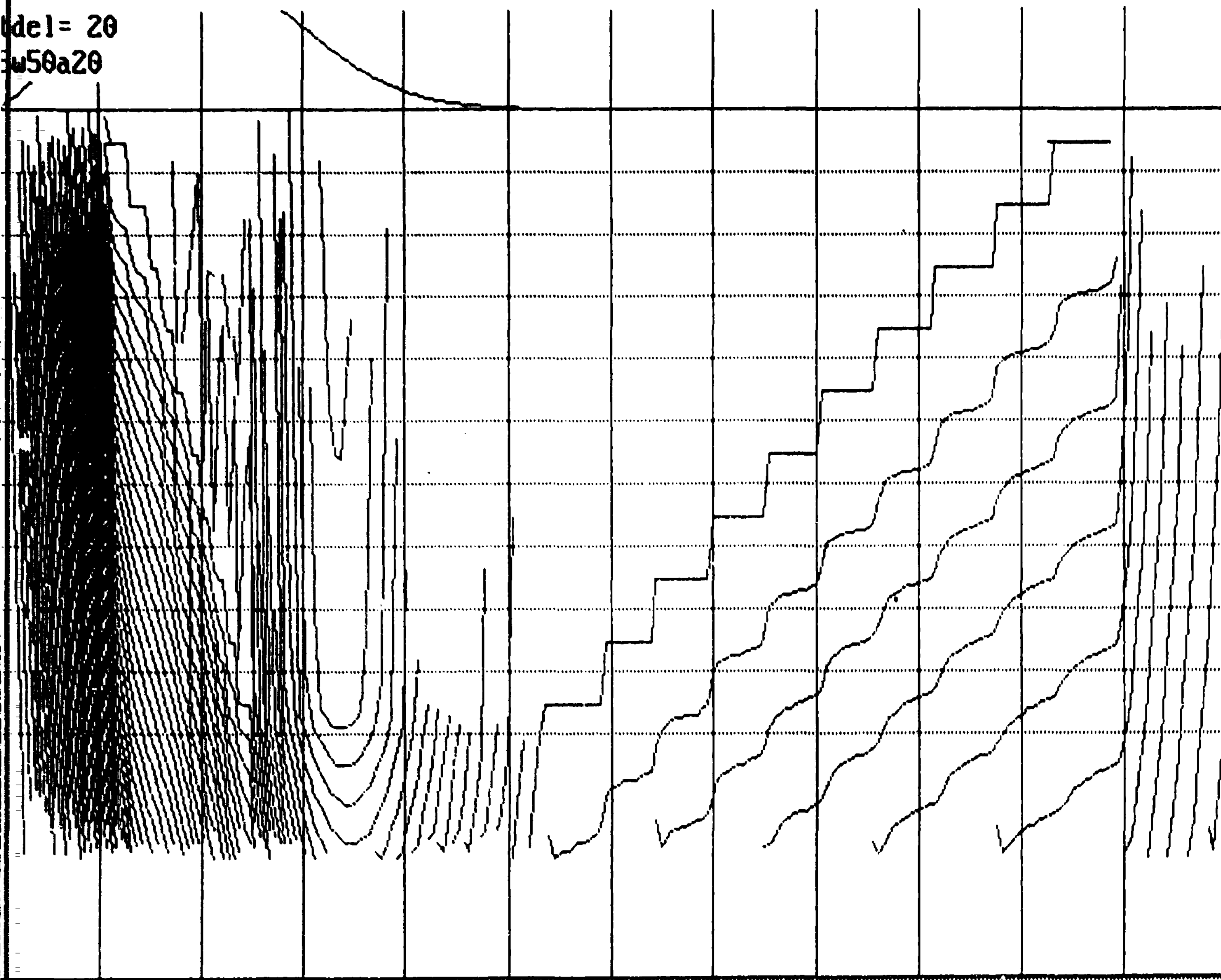


Fig. 16. Results of simulation at energy density 200 mJ/cm^2.