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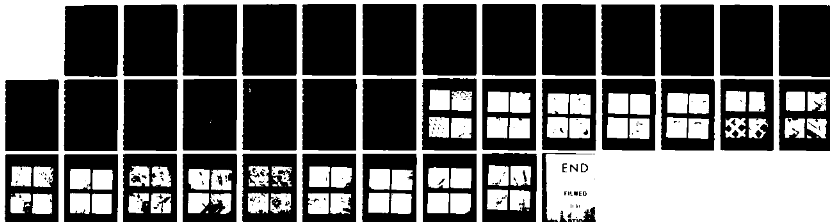

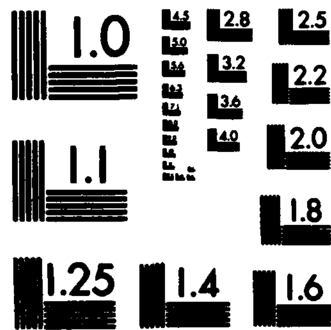

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Field	Entry
1. REPORT NUMBER	AFOSR-TR- 83-0765
2. GOVT ACCESSION NO.	
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	STUDY ION-SOLID INTERACTIONS AND MATERIAL CHARACTERIZATION WITH A NEW HIGH-RESOLUTION SCANNING ION PROBE
5. TYPE OF REPORT & PERIOD COVERED	FINAL REPORT 01 JUN 82 to 31 MAY 83
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	Riccardo Levi-Setti
8. CONTRACT OR GRANT NUMBER(s)	F49620-80-C-0074
9. PERFORMING ORGANIZATION NAME AND ADDRESS	University of Chicago, Chicago, IL
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	61102F 2305/A9
11. CONTROLLING OFFICE NAME AND ADDRESS	Air Force Office of Scientific Research, Building #410, Bolling AFB, Washington, DC 20332
12. REPORT DATE	15 June 1983
13. NUMBER OF PAGES	35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)	Public release approved; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)	
18. SUPPLEMENTARY NOTES	
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)	Ion microprobe

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The program is a collaboration between the University of Chicago and Hughes Research Labs. The major goal is to produce two 60 KeV high resolution (10-100 A), high current density (1 A/cm^2) ion microscopes microprobes. The project is partly funded by the NSF.
During the first year of the program, the basic optical and overall engineering design of the two ion microprobes was consolidated, with the procurement and constraction phase being completed near the end of the second year. - OVER -

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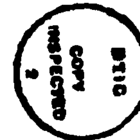

FINAL TECHNICAL REPORT

AFOSR Contract No. F49620-80-C-0074
Principal Investigator: Riccardo Levi-Setti
Contract Period: June 01, 1982 through May 31, 1983.

Research Objectives for the Second Year

The University of Chicago (UC) and Hughes Research Laboratories (HRL) collaborative program aims at the development and construction of two 60 keV high resolution (10-100 Å), high current density (1A/cm^2) ion microscopes/microprobes over a three year period. A pictorial summary of the organization of the project and its funding is contained in Fig. 1. Two sets of coordinated technical and scientific tasks form an integral part of the UC-HRL program. A phasing diagram for these tasks is given in Fig. 2, also showing the repartitioning of DOD (through AFOSR) and NSF support among the various tasks.

The research objectives for the second year of the program, comprehensive of both the UC and HRL effort, are incorporated in the following main tasks:

1. New Ion Microscope Development

After having consolidated the basic optical and overall engineering design of the two ion microscopes during the first year of the program, the procurement and construction phase was to be carried out to completion during the second year.

2. Study of Physical Processes Yielding Image Contrast in Ion Microscopy

This continuing task was to be pursued using the existing UC-SIM, modified during the first year to operate with a Ga$^+$ liquid metal source. Objectives were the study of secondary electron and secondary ion emission under gallium ion bombardment of solid targets. This exploratory program was meant to provide a better understanding of the phenomena to be exploited with the new ion microscopes in various research applications. Furthermore this part of the program fullfills the very important role of training graduate physics students in research, while providing suitable topics for their Ph.D. theses.

Status of the Research Effort

Since last year's report (July 1981) the program has progressed most satisfactorily. The accomplishments to date within the scope of each of the above tasks are described in the following summaries.

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1. Progress on New Ion Microscope Development

a) Ion Microscope Design. Since last year's report, the design of the entire microscope system has undergone close scrutiny,and several modifications and improvements have been introduced. Updated layouts, corresponding to those contained in last year's report, are shown in Fig. 3 and 4. Details of the microprobe specimen chamber are shown in Fig. 5. Further aspects of the design have been consolidated. These include:

--specimen inserter and stage motions

--SIMS system

--control and data acquisition electronics

--data processing techniques.

A versatile specimen inserter system has been added to the microprobe design. It will allow the exchange of 12 specimens in one loading (pump-down of the air-lock chamber), eliminating the need to wait while new specimens are pumped down. In addition, the specimen motions (Perkin-Elmer x-y-z + 12 positions) will be modified to provide x-y motions plus tilts about two axes and 12 specimen positions. The specimen height will have a range from 1.6 cm (only secondary electrons) down to 3.1 cm (SIMS and secondary electrons).

Between the final (einzel) lens and the specimen will be located the SIMS energy analyzer and 90° deflector which will collect ions emitted upwards from the specime and direct them into the quadrupole mass spectrometer (Fig. 6). The geometrical collection efficiency of the energy analyzer determines the minimum detectable amount of material ionized from the specimen. Therefore we are still attempting to optimize the analyzer design, aiming for overall efficiencies of at least 50%, comparable to commercial microprobes.

The most important element in achieving an easily usable analytical instrument is making the controls "friendly". This means that the various adjustments to the optics and data acquisition must be straightforward and reliable. To accomplish this, the control and data acquisition electronics have been designed using state-of-the-art microprocessor-based digital and analog circuits. All control and data variables will be displayed on the computer monitor screen and most adjustments wil be set by an x-y joystick. In addition, various data processing techniques will be available through the microprocessor (a Z-80 connected to an S-100 bus) such as Fourier transforms, spatial frequency analysis and filtering, differentiation and

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Chief, Technical Information Division

integration and contrast enhancement. The microprocessors will control the specimen position (d.c. raster deflection), stigmators, alignment position, channeltron voltages, raster size, raster elements (16 x 16 up to 1024 x 1024), scan speed (0.5 μsec/pixel up to 16 μsec/pixel), type of scan mode, the parameters involved in image processing (bias, gain, bandwidth, differentiation), the SIMS energy analyzer and SIMS mass selection.

b) Parts Fabrication and Procurement. A substantial amount of the total parts fabrication and procurement has been completed as of May 31 1982 as shown in "Program Schedule of 30 June 1982" (Fig. 7). The high voltage rack is awaiting only the installation of two 500 l/s ion pump controllers. Tests have been completed for the high voltage connectors between the Bertan supplies and the optical column. The vacuum system, comprising the vacuum chamber, support table, 500 l/s ion pumps, specimen inserter and foreline with three sorption pumps, is now being built by Torr Vacuum Products and will be delivered to HRL by the end of July. The various vacuum flanges have been manufactured by MDC Manufacturing, Inc. and delivered.

The optical columns have been machined by the HRL shop and were completed as of 31 May 1982. After this, a period of about eight weeks has been allotted for cleaning, assembly and alignment at which time the two optical columns will be ready for insertion into the vacuum system.

The ground-based electronics is being fabricated largely by MT Systems, Inc., after close consultations with HRL and UC. Purchases have been divided into those which are off-the-shelf commercially available digital electronics and the custom digital and analog circuitry for controlling the optical column and data acquisition electronics. The first subsystem (the commercially available components) is now running and was delivered to HRL in early April. The control program (written in BASIC for easy modification and expansion) has already been written and is operational. The remaining electronics will arrive after extensive testing at MT Systems and should be ready about the time the optical column is together by the end of July.

The schedule shows system integration to be complete by mid-September, with a 10-100 Å probe demonstrated by mid-October. The final design of the SIMS energy analyzer is still being discussed, to take advantage of the latest advances in the field, of which we became recently aware. The quadrupole mass filter and

the SIMS control electronics have been purchased. After preliminary vacuum, high-voltage and control electronic tests at HRL, one microprobe will be delivered to UC in November.

c) UC-HRL Contacts. Beyond last-year's report, the UC and HRL teams have met on several occasions, in April 1981, July 1981, and in April 1982. Furthermore, Mr. N. W. Parker, a graduate student of Prof. A. V. Crewe at Chicago, joined HRL in the Fall of 1981 and splits his time between UC and HRL. This has provided a most effective liaison between the two collaborating groups.

2. Progress in the Study of Physical Processes Yielding Image Contrast in Ion Microscopy

This aspect of the UC program is yielding important and exciting results. We have investigated various contrast mechanisms based on secondary electron and secondary ion emission and performed sputtering tests with the prototype 60 keV Ga^+ UC-SIM. In addition to contrast due to the surface topography, the SIM was found to yield strong elemental contrast (Z-contrast) and dramatic crystallographic contrast due to ion-channelling effects.

a) Topographic Contrast. We have established that the SIM can give remarkably good contrast due to the surface topography of any kind of material, by collecting the secondary electron signal. We have extended the exploration reported in last year's report to include also biological objects and integrated circuits. We observe that the gallium implant often makes insulators conducting enough to eliminate charging effects. Thus it is generally not necessary to coat insulating specimens with heavy metals, like is done in the SEM, to avoid the detrimental effects of local fields. As examples, Fig. 8 shows details of an uncoated specimen of fruit fly (Drosophila melanogaster); Fig. 9 shows the progressive disappearance of charging effects in the observation of uncoated human red blood cells; Fig. 10 shows that, after SIM scans, red blood cells became conducting enough to be observable also in the SEM. Furthermore, Fig. 11 shows details of an integrated circuit, covered by passivation layers, which can be imaged without any difficulty in the SIM. Fig. 12 shows that in the SEM, similar focusing cannot be achieved due to charging effects. However, after gallium implant in the SIM, SEM focusing becomes possible.

b) Z-Contrast. We have determined that the contrast due to the Z-dependence of the secondary electron emission yields is very pronounced in our Ga^+ SIM and differs from that provided by the SEM. An example is shown in Fig. 13. This investigation

will be extended to survey systematically a much greater spectrum of elements. The results obtained thus far confirm our expectation that Z-contrast in ion microscopy may become a very useful tool for the visual discrimination of surface microstructures due to elemental segregation.

c) Crystallographic Contrast. SIM imaging of polished samples of metals and alloys was found to be dominated by ion-channelling effects, yielding very pronounced crystallographic contrast in both secondary electron and secondary ion images. We have concentrated on this novel aspect of scanning ion microscopy which opens up a vast horizon of immediate practical applications in material science, metallurgy and semiconductor technology. A summary of relevant results is as follows:

i) The ion beam scan cleans the specimen surface of contaminants, absorbed layers and oxides, while imaging. The image contrast is observed to evolve until a stable configuration is reached in a few minutes. This is particularly noticeable on polished surfaces of non-noble metals (see Fig. 14).

ii) Secondary electron images of crystalline but chemically uniform samples (such as, e.g., recrystallized, polished, etched α-brass and Cu) show dramatic evidence of crystallographic contrast, when only surface topography is the source of contrast in SEM images (see Fig. 15, 16). Upon rotating a sample by, e.g., 10°, the contrast between crystallite pairs may completely reverse (see Fig. 17, 18). These effects have been understood in terms of the dependence of the secondary electron yields on lattice orientation with respect to the incident beam due to primary ion channelling. The contrast effects observed are large, the signal level changing up to a factor of three when comparing channelling with non-channelling conditions. Similar observations have been performed on a sample of recrystallized, polished die steel (Fig. 19) and are in progress on Si samples.

iii) We have shown that ion-channelling contrast can be applied to the detection of shock-induced defects in single crystals of meteoric iron (structures known as Neumann bands, see Fig. 20).

iv) Crystallographic contrast is present also in secondary ion images in definite relationships to that observed in secondary electron images.

Comparisons of this kind are valuable for a better understanding of the mechanism of secondary ion emission (see Fig. 21, 22) to be exploited for SIMS analysis.

v) Ion-channelling effects on the sputtering rates have been probed by ion beam writing across crystallite boundaries (see Fig. 23). Quantitative results have been obtained on the crystal orientation dependence of writing speeds.

From the above it appears that the SIM may be a very valuable tool in material sciences and metallurgy, providing bulk sample information even through the immediate secondary electron imaging. The addition of analytical capabilities, such as being implemented in the new instruments under construction, will clearly open up a much broader range of applications. The above results have been presented at several international meetings (see list of publications) and have attracted the attention of the news media. Reports have appeared in Science News, Vol. 121. NO. 8, February 20, 1982, p. 118, Science 82, May 1982, p. 10, Industrial Research and Development, March 1982, p. 91. A cover story in Physics Today is scheduled for the July 1982 issue.

Research Plans for the Coming Year

We plan to follow our schedule of tasks described in our original proposal and outlined in Fig. 2. Clearly the first priority will be that of bringing to completion the construction of the two new ion microscopes/microprobes and to demonstrate and evaluate their performance. This task will be pursued in parallel at UC and HRL. In essence this will consist in:

a) establishing the resolution limits of the instruments;
b) measuring the probe current vs. probe size for both modes of ion source operation (field ionization and liquid metal):
c) bringing into operation the SIMS systems and
d) at UC, bringing into operation also the magnetic sector spectrometer for transmission measurements, to be transferred to the new instrument from the existing UC prototype.

This phase will merge with the task of initiating research applications of the new microprobes. The activity which is presently being carried out will greatly facilitate the choice of immediate fruitful applications. At UC, we want to pursue

and reexamine, at improved spatial resolution, much of the exploratory work presently in progress. The most promising areas of applications of the image contrast features of the SIM are in the study of metals and semiconductors, aimed at the detection of lattice defects, dislocations, impurities and microstructures which might be detectable due to ion-channelling effects. We also wish to complement this study with elemental microanalysis by SIMS. We have made definite collaborative plans with Prof. Hellmut Fritsche toward a joint study of the characterization of microstructures in amorphous semiconductors, using our new SIM/SIMS. We are involved in a preliminary survey of applications to the study of meteorites in collaboration with Drs. Edward J. Olsen and Lawrence Grossman of our Department of Geophysical Sciences. Arrangements for the study of biological specimens have been made with a number of scientists at UC. Jointly with HRL we will also pursue studies of channelling effects relevant to problems in semiconductor microfabrication.

Substantial progress has also been made at HRL toward the choice of research applications to be implemented with the new instrument. A specific topic involves the problems in the manufacture of Ga-As FET devices. This will be the initial test of the usefulness of the microprobe to an actual problem of great current interest. The SIMS capability of the microprobe will be used to search for the causes of the substantial non-uniformity of Fa-As FET characteristics, unexplainable by other techniques.

Within the scope of the current program, only an initial exploration along the above lines of research will be permitted. These topics and other ones will be taken up again in more detail in a new proposal for continuation of our work with the new high-resolution microprobes, presently being prepared.

Personnel

1. Research Associates

Dr. Timothy R. Fox, who obtained his Ph.D. in 1980 and has participated in our program until March 1982, has joined an industrial concern. He was replaced by Dr. Paul H. LaMarche, a graduate of Yale University, who joined our group on May 1, 1982. Dr. LaMarche has excellent credentials in our field of specialization.

2. Graduate Students

Mr. Kin Lam is making excellent progress toward his Ph.D. degree. His thesis topic relates significant results obtained with the STIM on the observation of anomalous energy losses in the traversal of thin carbon foils by molecular hydrogen ions. His results, presented by R. Levi-Setti in an invited paper at the US-Japan seminar on Ion Penetration Phenomena in Solids, Honolulu, Hawaii, January 1982, have attracted much interest.

A new graduate student, Mr. Thomas H. Shields, joined our group in October 1981.

3. Undergraduate Students

During the summer of 1981, Mr. David Cousins worked in our group as an NSF Undergraduate Research Participant.

Mr. Daniel J. Welsh and Mr. Larry Whitlow are employed as undergraduate student technicians.

Cumulative Chronological List of Written Publications in the Technical Journals

(a) Published and in press

1. H_2^+ Traversing Ultra-Thin Carbon Foils: Measurements of Recombination Yields at 12.5 and 25 keV/amu.
   T. R. Fox; Nuclear Instruments and Methods 179 (1981) 407-10.
2. Molecular States from 25 keV/amu H_2^+ Traversing Ultra-Thin Carbon Foils.
   R. Levi-Setti, T. R. Fox and K. Lam; Annals of the Israel Physical Society, 4 (1981) 127-129.
3. H_2^+ Traversing Ultra-Thin Carbon Foils: Exiting Molecular States at 12.5 and 25 keV/amu.
   T. R. Fox, K. Lam and R. Levi-Setti; Nuclear Instruments and Methods, 194 (1982) pp. 285-289.
4. H_2^+ Traversing Ultra-Thin Carbon Foils: Cluster Effects in the Energy Loss at 12.5 and 25 keV/amu.
   R. Levi-Setti, K. Lam and T. R. Fox; Nuclear Instruments and Methods, 194 (1982) pp. 281-284.
5. Scanning Microscopy with Gallium Ions from a Liquid Metal Source.
   K. Lam, T. R. Fox and R. Levi-Setti, Proc. 28th Int'l Field Emission Symposium, eds., L. Swanson and A. Bell (The Oregon Graduate Center, Beaverton, Oregon, 1981) pp. 59-61.
6. Magnetic Prism Analysis of a Practical Gallium Ion Probe from a Liquid Metal Source.
   K. Lam, T. R. Fox and R. Levi-Setti, Proc. 28th Int'l Field Emission Symposium, eds. L. Swanson and A. Bell (The Oregon Graduate Center, Beaverton, Oregon, 1981) pp. 92-94.
7. Ion-Channelling Effects in Scanning Ion Microscopy with a Ga^+ Probe.
   R. Levi-Setti; Symposium paper, Proc. of the United States-Japan Seminar on Charged Particle Penetration Phenomena: "Charge States and Dynamic Screening of Swift Ions in Solids," Honolulu, Hawaii, Jan. 1982, ORNL Report, in press.
8. Ion-Channelling Effects in Scanning Ion Microscopy and Ion Beam Writing with a 60 keV Ga^+ Probe.
   R. Levi-Setti, T. R. Fox and K. Lam; Proc. SPIE Conference on Submicron Lithography at Santa Clara, Calif., March 1982, Vol. 333, 5 pages, in press.

9. Secondary Electron and Ion Imaging of Crystalline Materials with a 60 keV Ga^+ Scanning Ion Microscope.
R. Levi-Setti, T. R. Fox and K. Lam; Proc. Tenth Int'l Conf. on Electron and Ion Beam Technology, The Electrochemical Society, Inc., Montreal, Canada, May 1982, Extended Abstracts, Vol.82-1. pp.462-463.

10. Ion-Channelling Effects in Scanning Ion Microscopy with a 60 keV Ga^+ Probe.
R. Levi-Setti, T. R. Fox and K. Lam; to be published in Nuclear Instruments and Methods.

(b) In course of preparation

11. H_2^+ Traversing Ultra-Thin Carbon Foils: The Energy Loss of Two Correlated Protons Below the Fermi Velocity.
K. Lam; to be published in Nuclear Instruments and Methods.

(c) Theses

1. Hydrogen Ion-Solid Interactions Near the Bohr Velocity.
Timothy R. Fox, Ph.D. Thesis, The University of Chicago, December 1980.

Interactions (Coupling Activities)

(a) Spoken papers presented at meetings, conferences, seminars.

1. Progress in the Development of a Field Ionization Scanning Transmission Ion Microscope.
R. Levi-Setti, T. R. Fox and K. Lam.
Paper presented at the 38th Annual EMSA Meeting, Reno, Nevada, August 1980.
Abstract in Proc. 38th Ann. Meet. EMSA, pp. 66-7, ed. G. W. Bailey, Claitor's Publ. Div., Baton Rouge, 1980.

2. Information and Dose in the Scanning Transmission Ion Microscope.
T. R. Fox and R. Levi-Setti.
Paper presented at the 38th Annual EMSA Meeting, Reno, Nevada, August 1980.
Abstract in Proc. 38th Ann. Meet. EMSA, pp. 232-3, ed. G. W. Bailey, Claitor's Publ. Div., Baton Rouge, 1980.

3. Same title as Publications (a) 2. Paper presented by R. Levi-Setti at the Bat-Sheva Seminar on Molecular Ions, Molecular Structure and

Interaction with Matter; Israel, January 1981.

4,5. Same title as Publications (a) 3, (a) 4. Papers presented by R. Levi-Setti at the Ninth Int'l Conf. on Atomic Collisions in Solids, Lyons, France, July 1981.

6. Same title as Publication (a) 5. Paper presented by R. Levi-Setti at the 28th Int'l Field Emission Symposium, The Oregon Graduate Center, July 1981.

7. Same title as Publication (a) 6. Paper presented by T. R. Fox at the 28th Int'l Field Emission Symposium, the Oregon Graduate Center, July 1981.

8. Same title as Publication (a)7. Invited paper presented by R. Levi-Setti at the United States-Japan Seminar, Honolulu, Hawaii, Jan. 1982.

9. Phenomenology of Low Energy Hydrogen-Ion Transmission through Thin Solid Foils.
   Invited paper presented by R. Levi-Setti at the United States-Japan Seminar, Honolulu, Hawaii, Jan. 1982. R. Levi-Setti also chaired one session at the Seminar.

10. Same title as Publication (a) 8. Paper presented by R. Levi-Setti at the SPIE Conf. on Submicron Lithography, Santa Clara, Calif., March 29-30, 1982.

11. Same title as Publication (a)9. Paper presented by R. Levi-Setti at the Tenth Int'l Conf. on Electron and Ion Beam Technology, The Electrochemical Society, Montreal, Canada, May 9-14, 1982.

12. Imaging and Crystallographic Contrast with a 60 keV Ga^+ Scanning Ion Microscope.
    R. Levi-Setti, K. Lam and T. R. Fox. Paper to be presented by R. Levi-Setti at the 10th Int'l. Congress on Electron Microscopy, Hamburg, August 17-24, 1982. Abstract to be published in the Proceedings.

14. Crystallographic Contrast with a 60 keV Ga^+ Scanning Ion Microscope.
    R. Levi-Setti, K. Lam. Paper to be presented by R. Levi-Setti at the 29th Int'l Field Emission Symposium, Göteborg, Sweden, August 9-13, 1982.

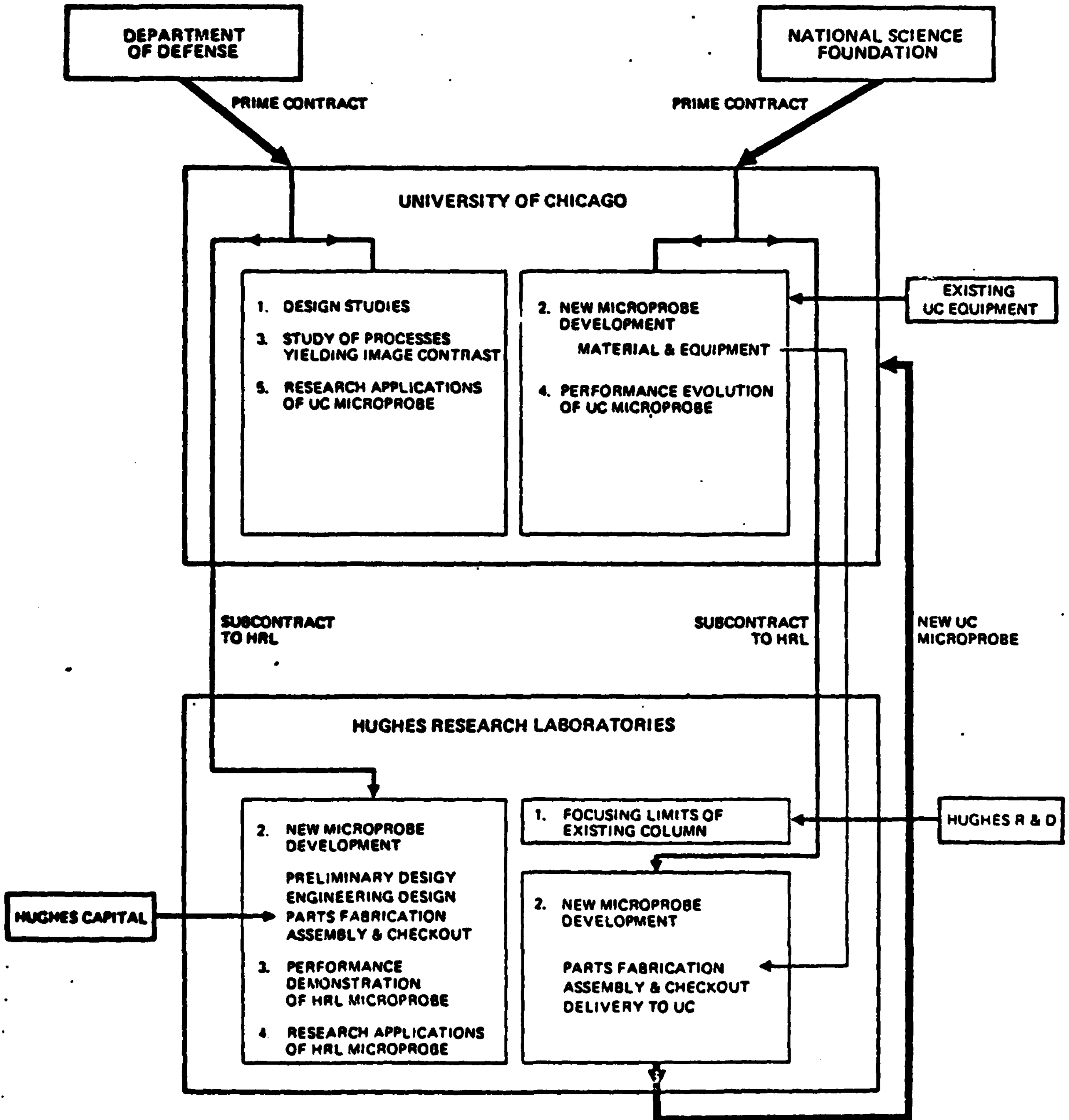
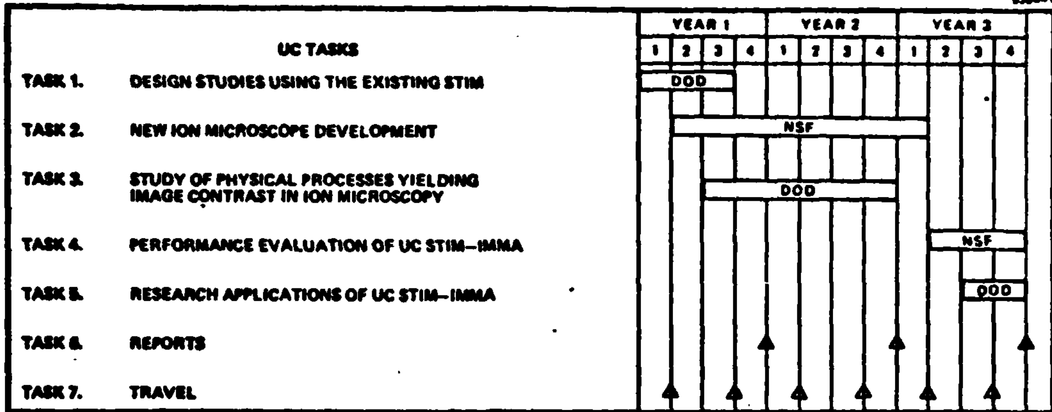


Fig. 1



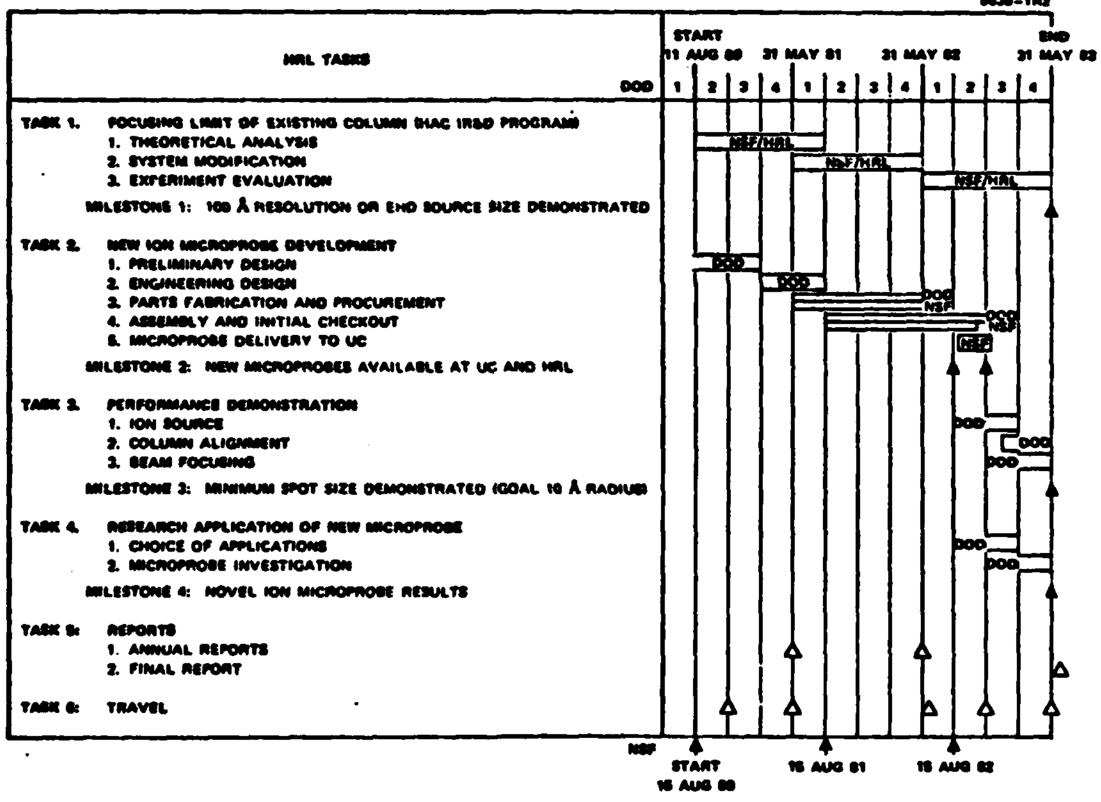


Fig. 2

Fig.3 Ion Microprobe Layout

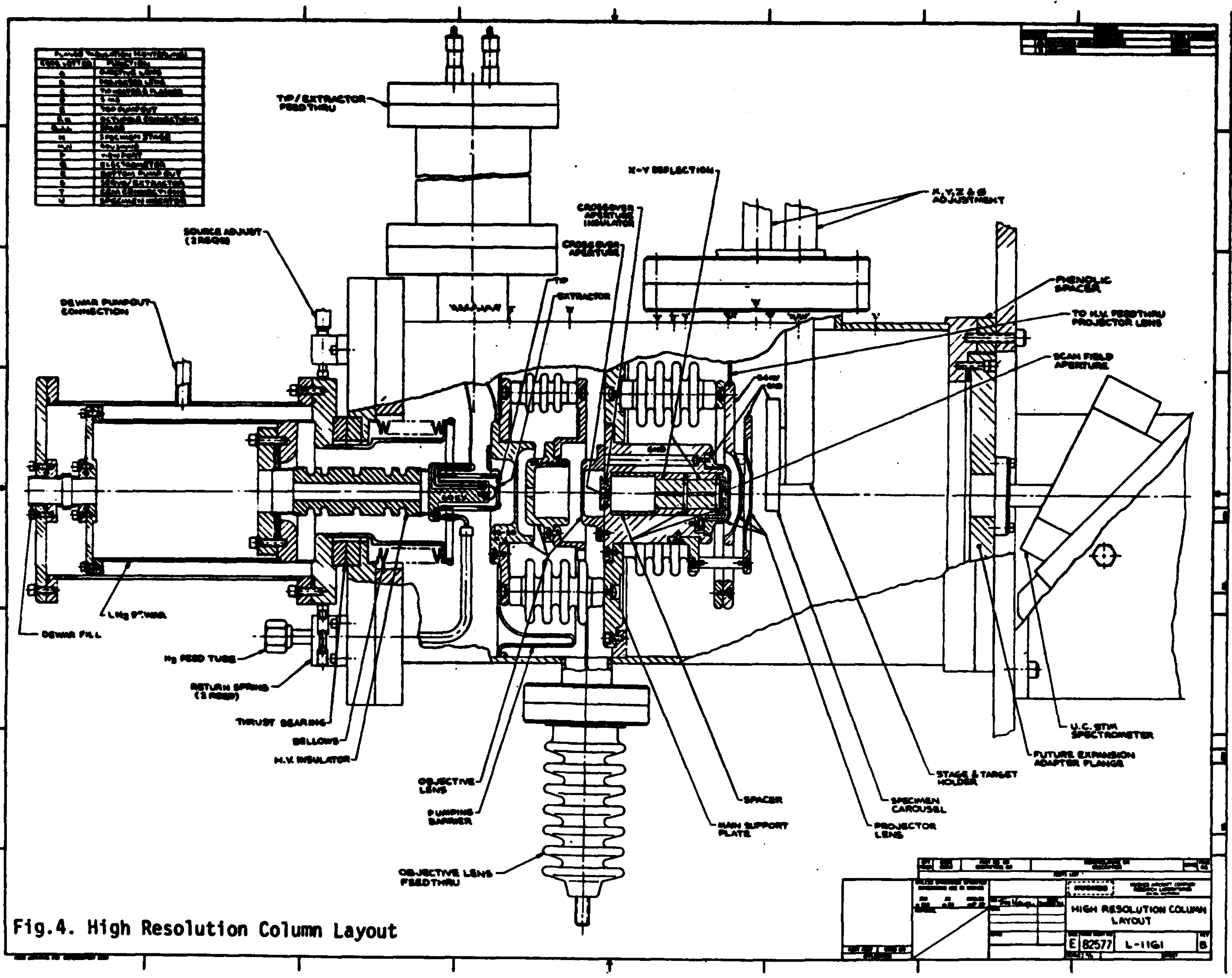


Fig.4. High Resolution Column Layout

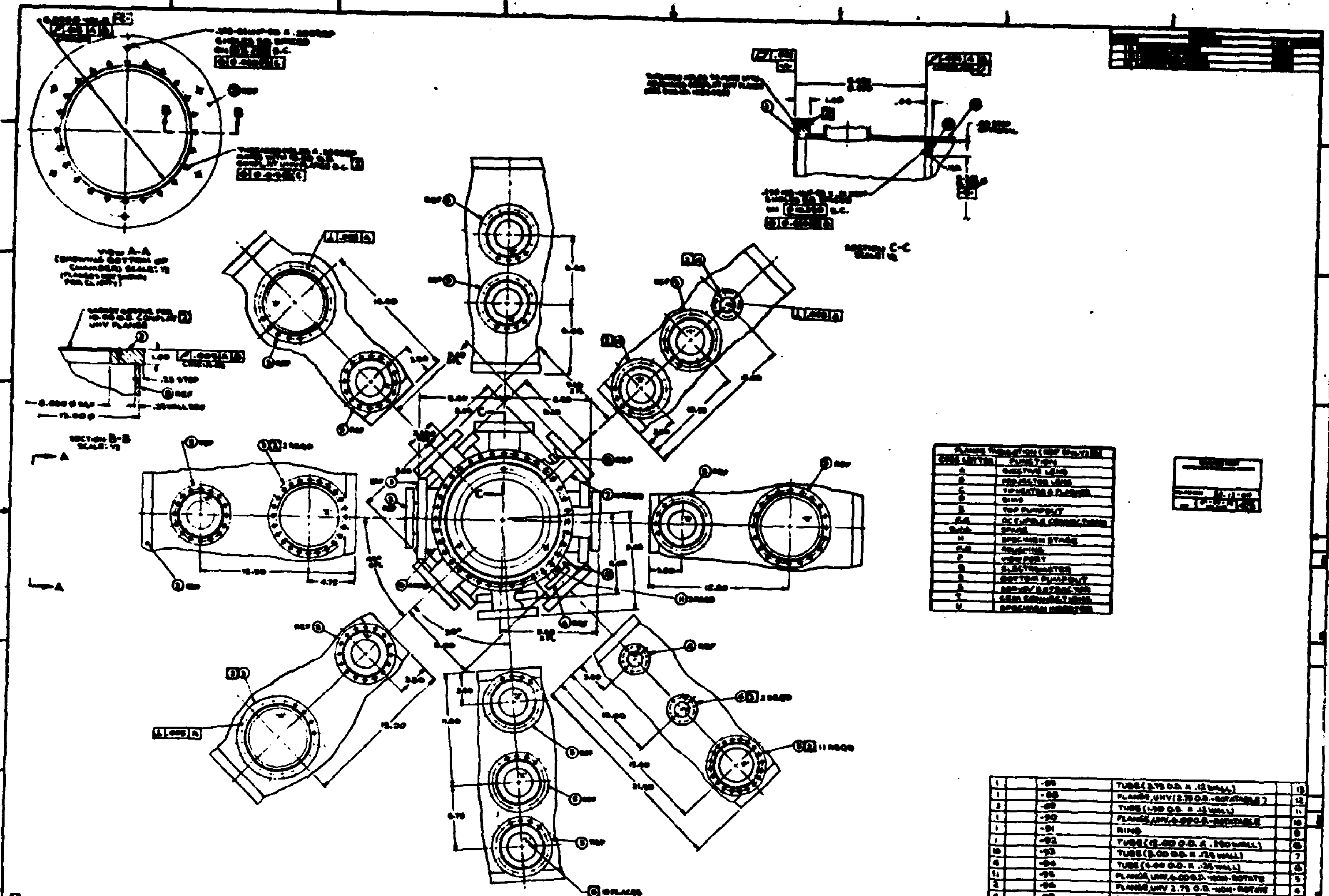


Fig. 5. Microprobe Chamber Layout

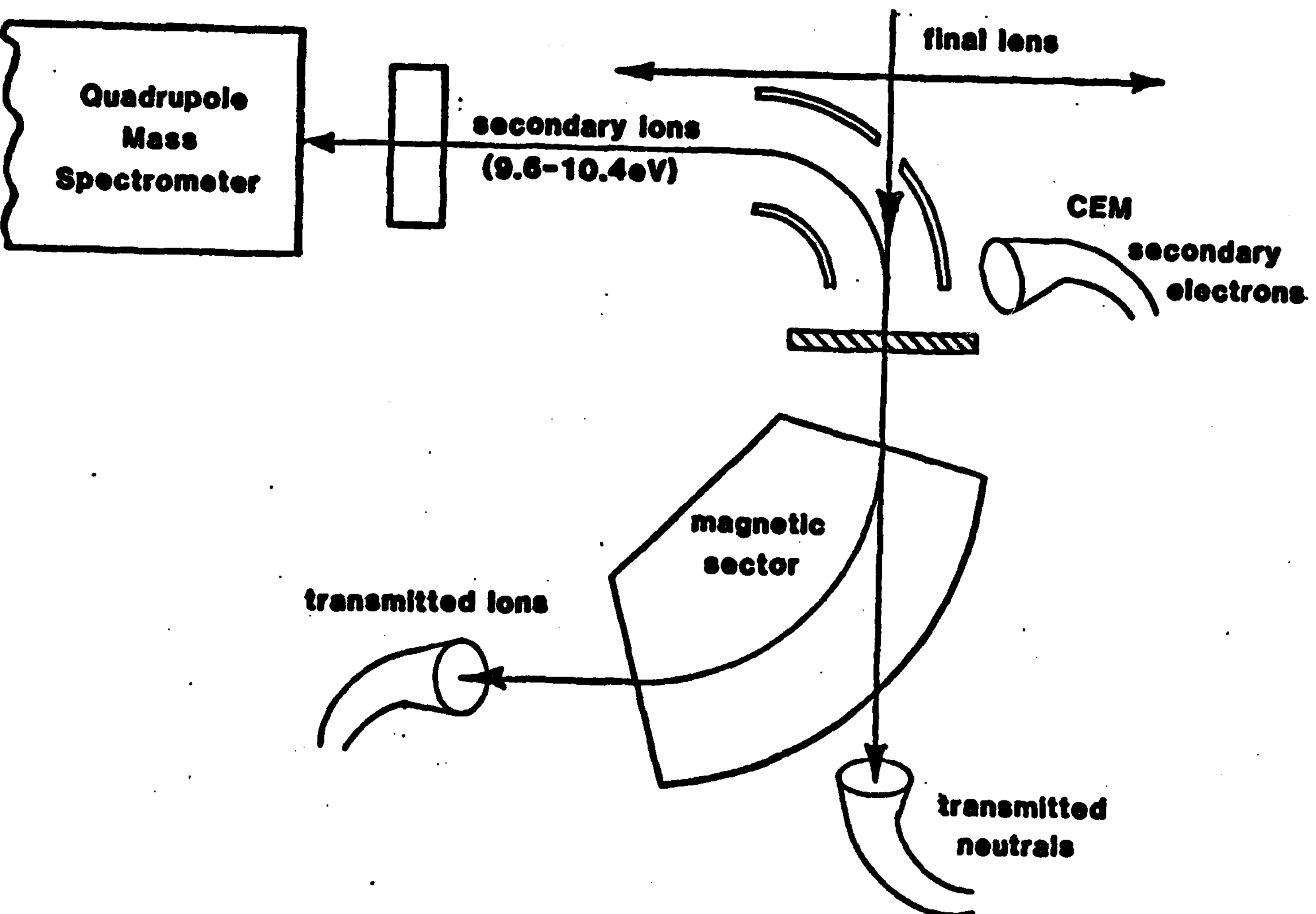


Fig.6. Schematics of the detection and analysis system

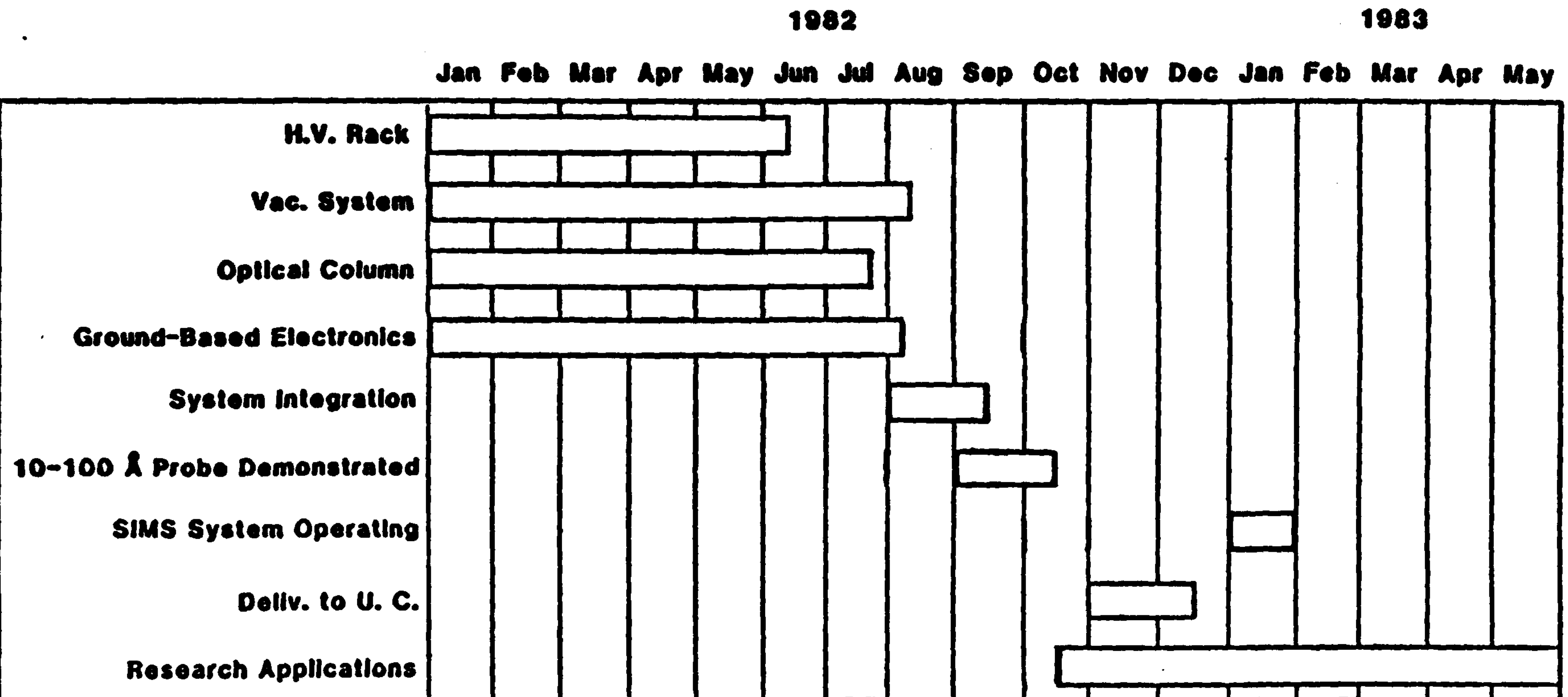
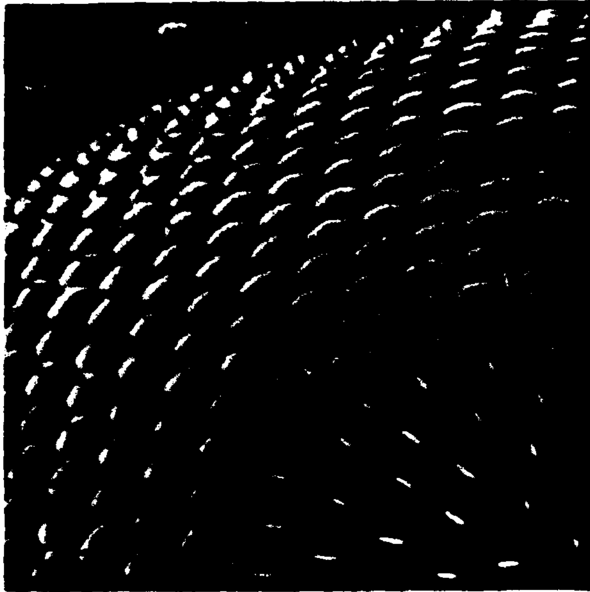


Fig. 7 Schedule for the completion of the two high-resolution ion microprobes

Ga^+ FOCUSED-ION-BEAM IMAGES

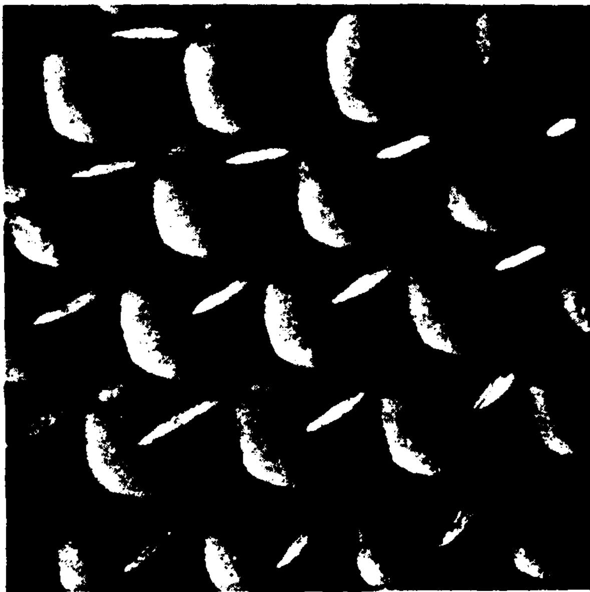
DROSOPHILA MELANOGASTER, UNCOATED

SECONDARY ELECTRON SIGNAL, 60 keV UC-SIM

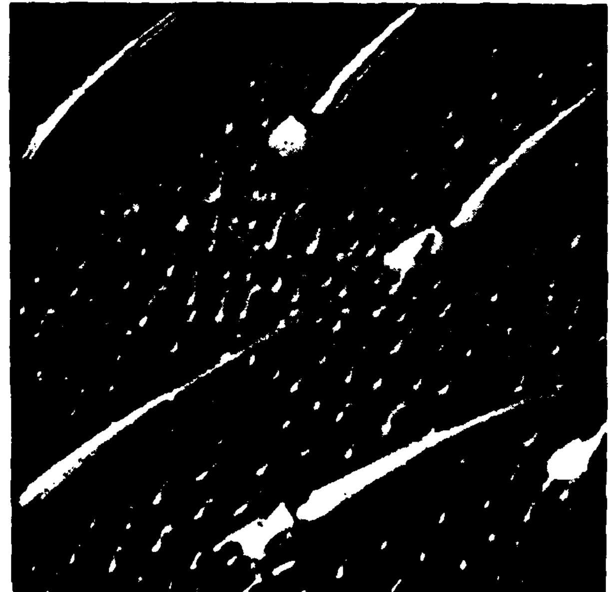


EYE, 180 µm FULL SCALE

EYE, 72 µm F.S.



EYE, 72 µm F.S.



LEG, 72 µm F.S.

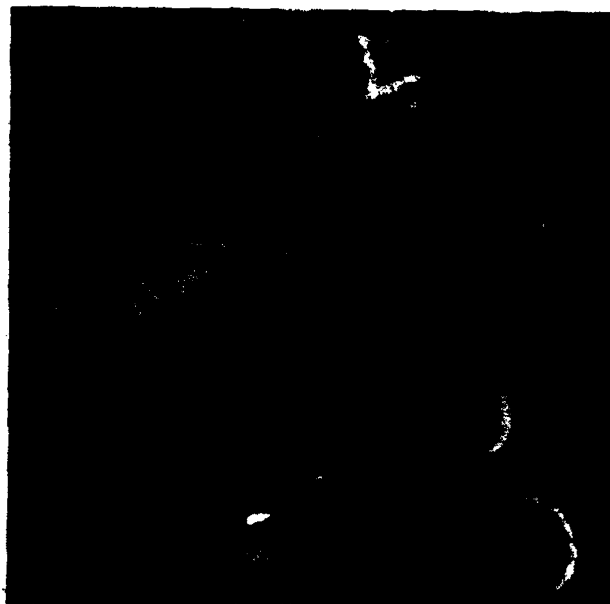
Fig. 8

GA^+ FOCUSED-ION-BEAM IMAGES

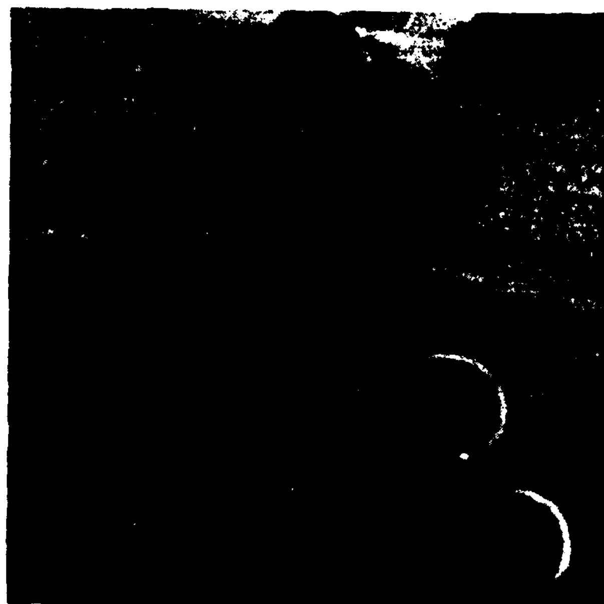
UNCOATED HUMAN ERYTHROCYTES, CRITICAL POINT DRIED

DISAPPEARANCE OF CHARGING EFFECTS UNDER GA^+ IMPLANT

55 kV UC-SIM



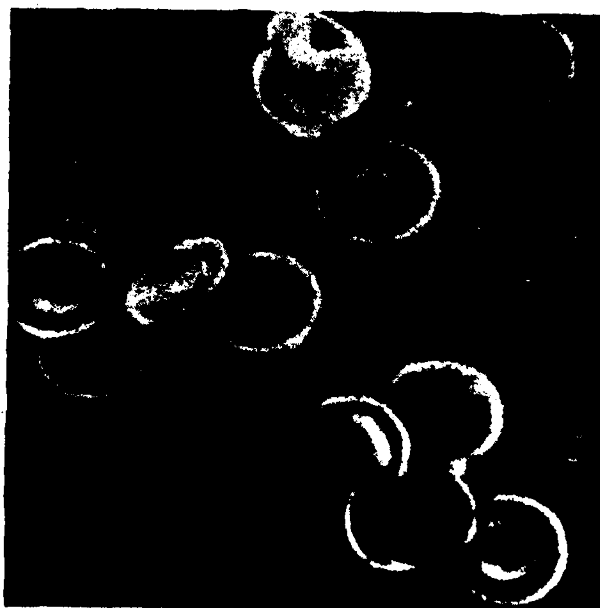
INITIAL IMAGE



AFTER 7.3×10^{15} IONS/CM^2

36 μm FULL SCALE

AFTER 1.7×10^{16} IONS/CM^2



AFTER 2.9×10^{16} IONS/CM^2

Fig. 9

Ga^+ FOCUSED-ION-BEAM IMAGES
UNCOATED HUMAN ERYTHROCYTES, CRITICAL POINT DRIED
SIM vs SEM IMAGING (AFTER Ga^+ IMPLANT)

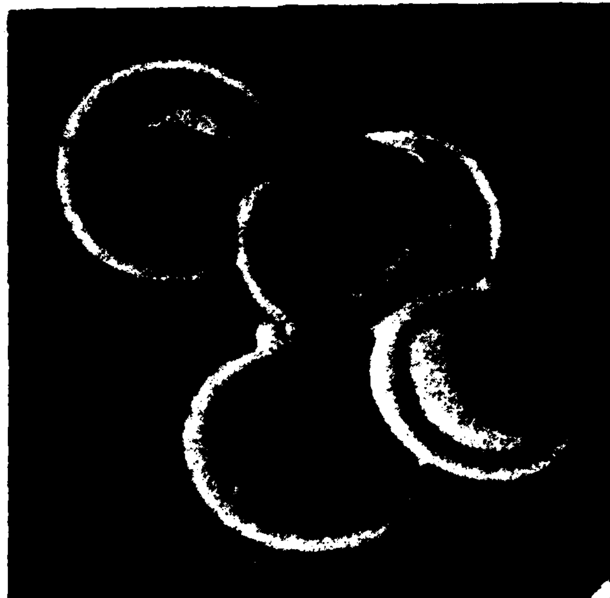
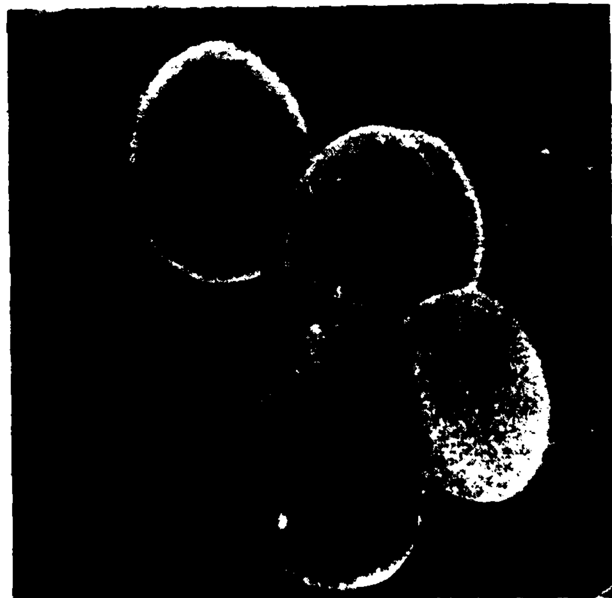
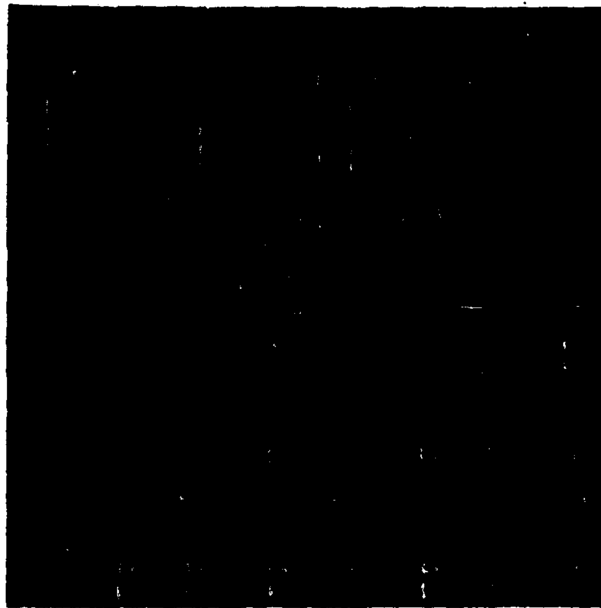
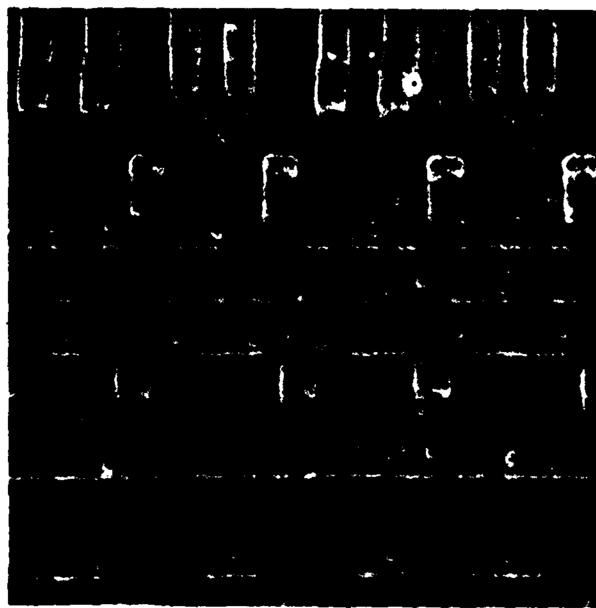
55 kV UC-SIM	10 kV HITACHI HFS-2 SEM
36 µM FULL SCALE	36 µM F.S.
	
18 µM F.S.	18 µM F.S.

Fig. 10

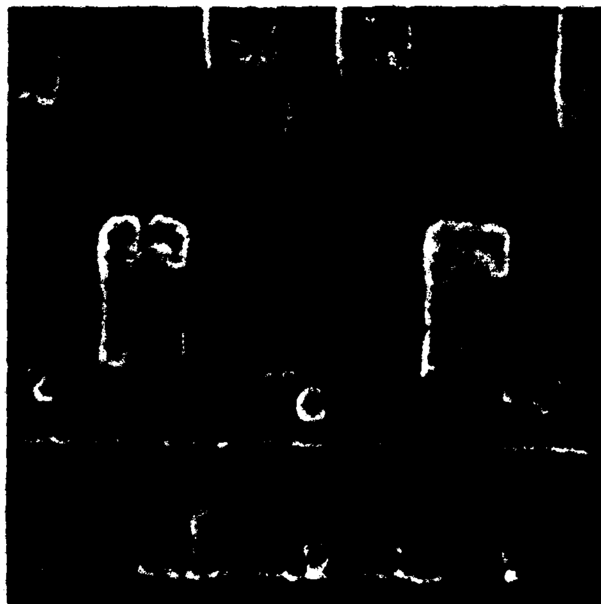
Ga^+ FOCUSED-ION-BEAM IMAGES
UNCOATED EPROM CHIP (INTEL D 2758)
SIM IMAGING (UNAFFECTED BY SURFACE CHARGING OF PASSIVATION LAYER)
60 kV UC-SIM



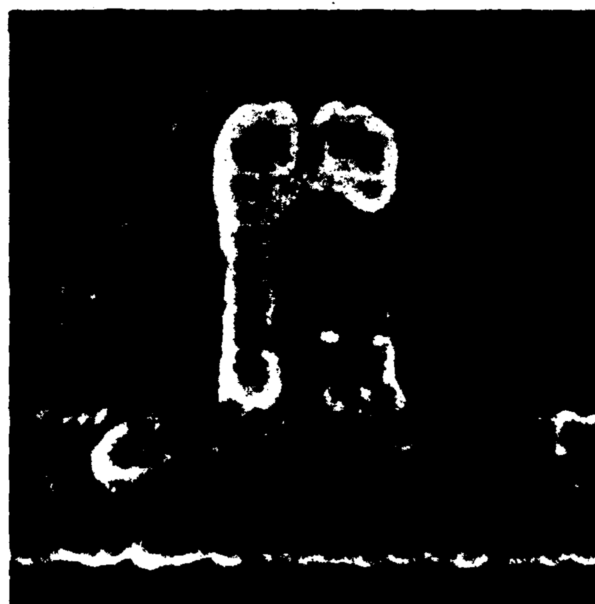
360 µm FULL SCALE



180 µm F.S.



72 µm F.S.



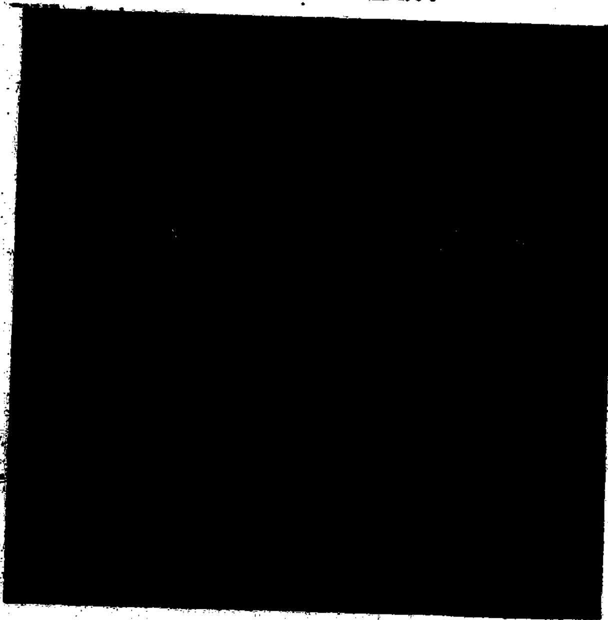
36 µm F.S.

Fig. 11

UNCOATED EPROM CHIP (INTEL D 2758)
SEM IMAGING (AFFECTED BY SURFACE CHARGING OF PASSIVATION LAYER)
VS. SEM IMAGING OF AREAS GA^+-IMPLANTED DURING SIM IMAGING
25 kV HITACHI HFS-2 SEM

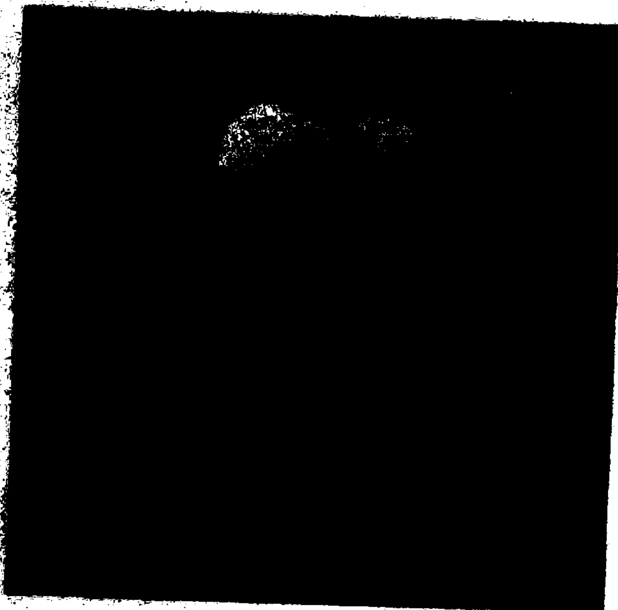
No GA^+ IMPLANT

AFTER SIM SCAN



72 μm FULL SCALE

72 μm F.S.



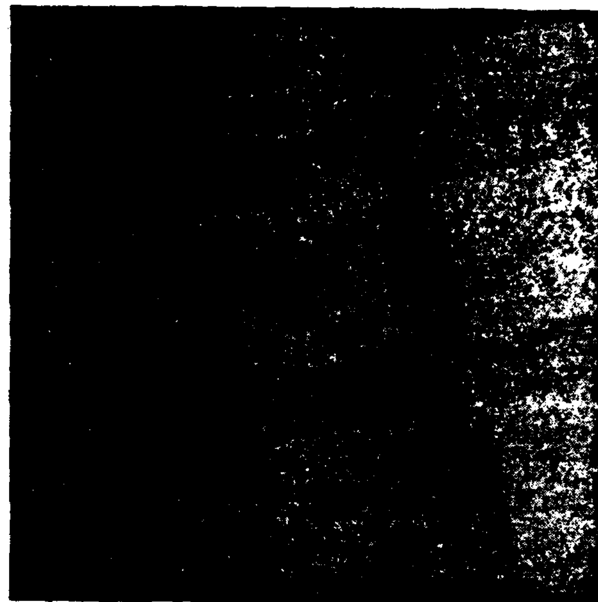
36 μm F.S.

36 μm F.S.

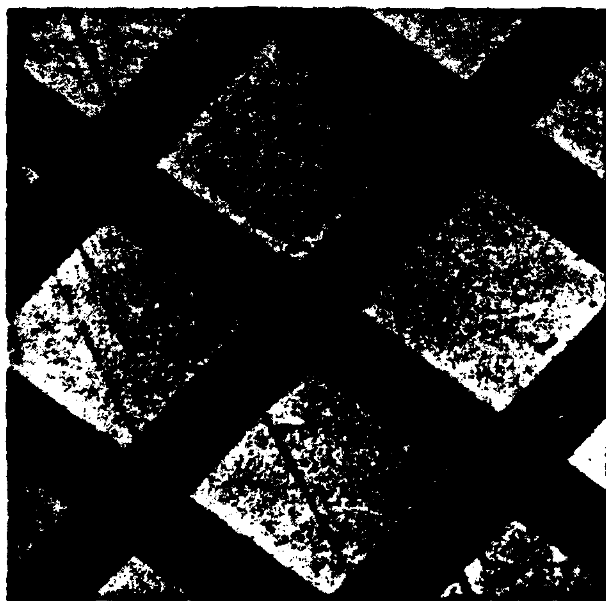
Fig. 12

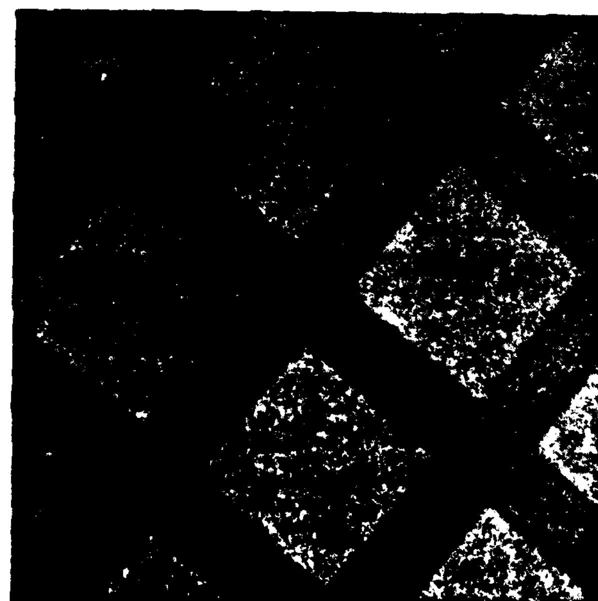
GA^{+} FOCUSED-ION-BEAM IMAGES

ELEMENTAL CONTRAST IN SECONDARY ELECTRON IMAGES FROM ION VS. ELECTRON BEAM SCANS



320 μM FULL SCALE   AU ON FE   320 μM F.S.





320 μM F.S.   AG ON FE   320 μM F.S.

60 KEV UC -SIM   10 KEV COATES & WELTER SEM

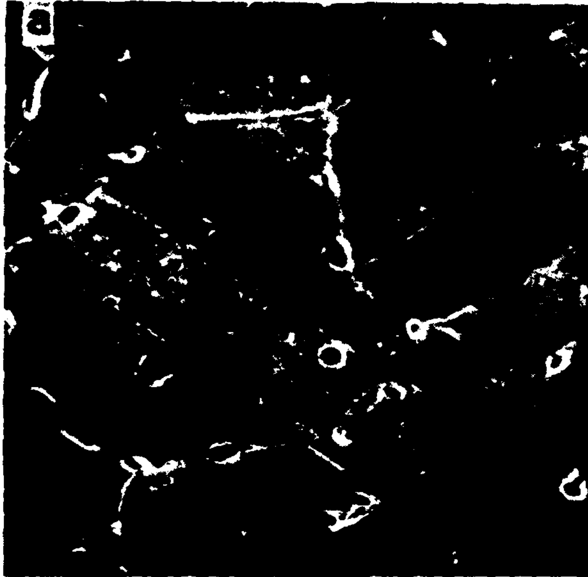
Fig. 13

GA^{+} FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED BRASS

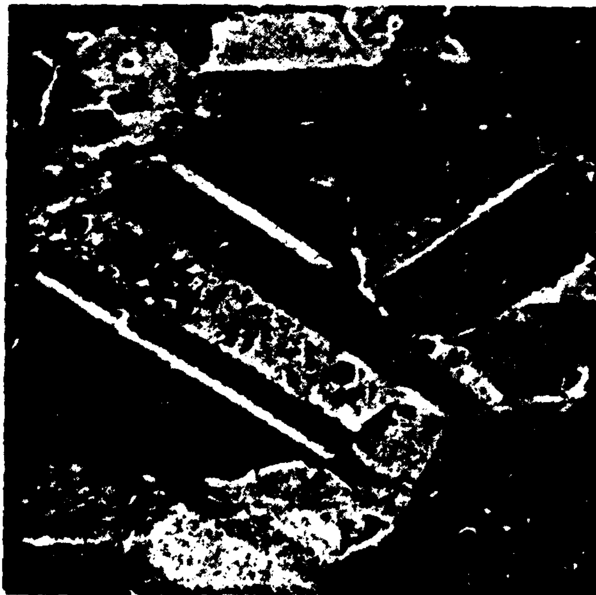
EVOLUTION OF SECONDARY ELECTRON IMAGE

UNDER CONTINUOUS RASTER ION BOMBARDMENT



160 µM FULL SCALE
ELAPSED TIME: 0

160 µM F.S.
ELAPSED TIME: 10 MIN.



160 µM FULL SCALE
ELAPSED TIME: 15 MIN.

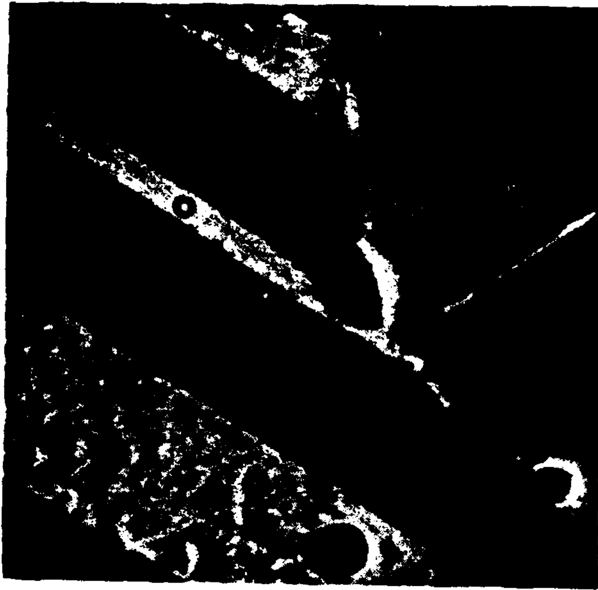
64 µM F.S.
AFTER 200 MIN. AT 160 UM F.S.

Fig. 14

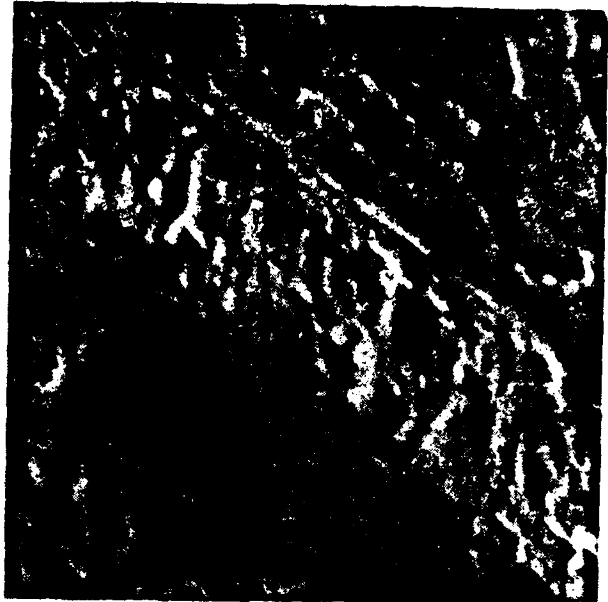
Ga^+ FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED BRASS

CRYSTALLOGRAPHIC CONTRAST IN SECONDARY ELECTRON SIM IMAGES VS. SURFACE TOPOGRAPHY IN SEM IMAGES



64 µm FULL SCALE



13 µm F.S.

64 µm F.S.
60 keV UC-SIM

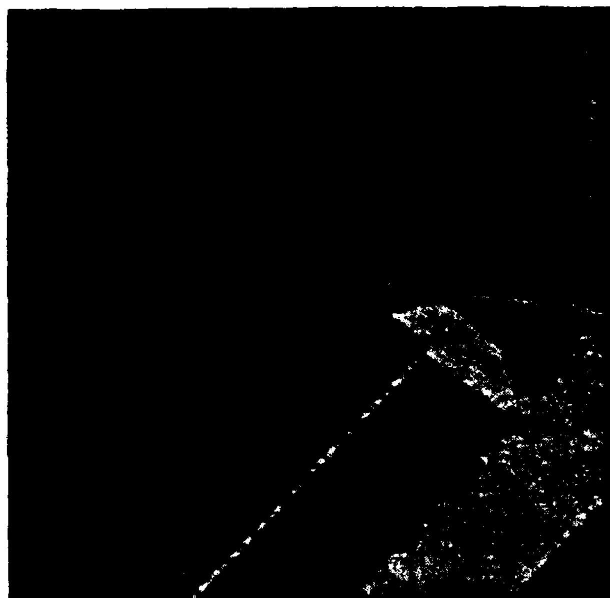
15 µm F.S.
10 keV COATES & WELTER SEM

Fig. 15

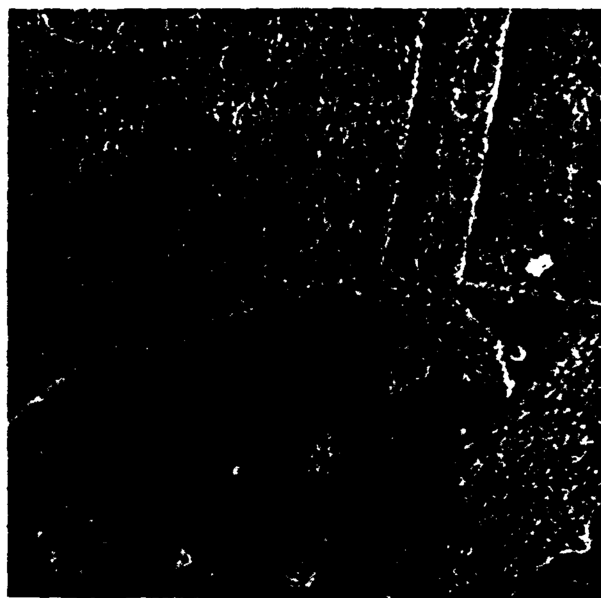
Ga^+ FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED COPPER

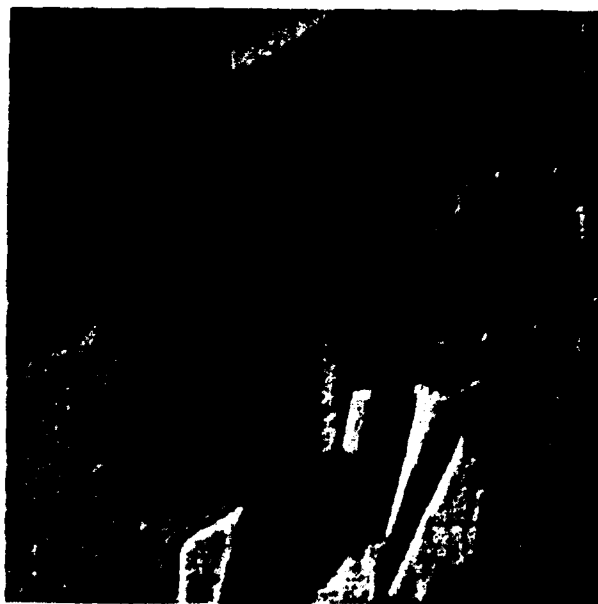
SECONDARY ELECTRON IMAGES FROM ION VS. ELECTRON BEAM SCANS



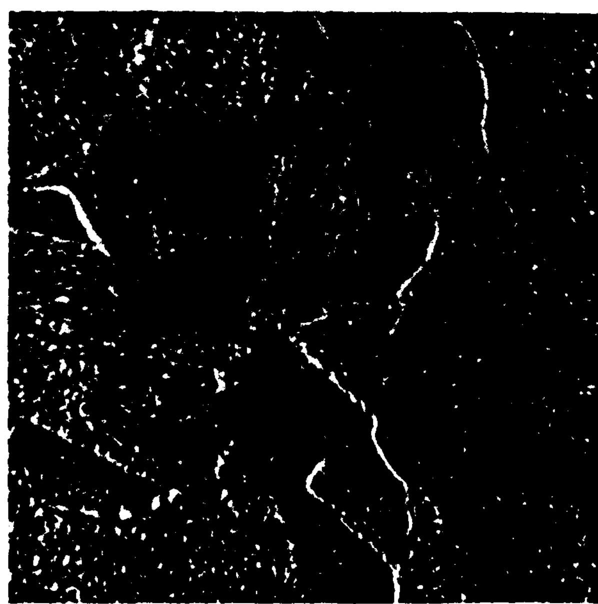
180 μm FULL SCALE



180 μm F.S.



180 μm F.S.
60 keV UC-SIM



180 μm F.S.
25 keV HITACHI HFS-2 SEM

Fig. 16

Ga$^+$ FOCUSED-ION-BEAM-IMAGES

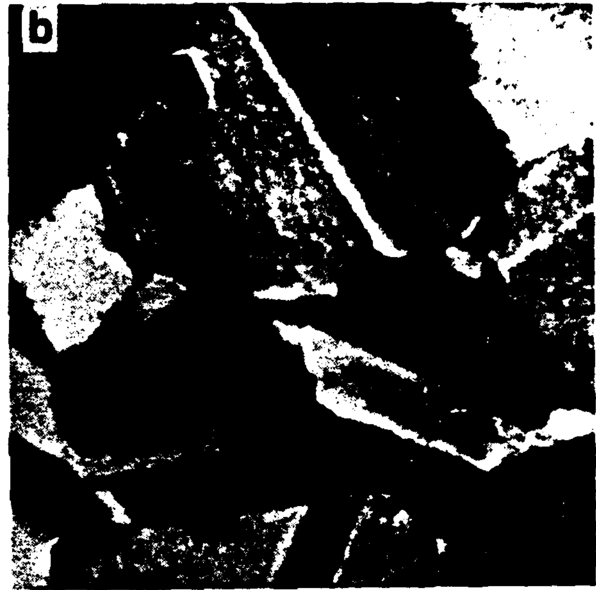
RECRYSTALLIZED, POLISHED, HNO_3-ETCHED BRASS

CONTRAST REVERSALS DUE TO PRIMARY ION-CHANNELLING

SECONDARY ELECTRON IMAGES, 60 KeV UC-SIM

NORMAL INCIDENCE | 10^0 NORTH-SOUTH TILT

64 µM FULL SCALE



64 µM F.S.

64 µM F.S.

64 µM F.S.

Fig. 17

Ga^+ FOCUSED-ION-BEAM IMAGES

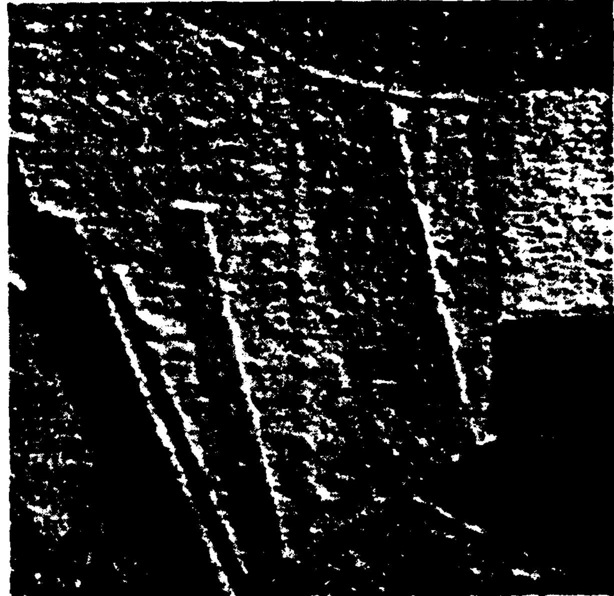
RECRYSTALLIZED, POLISHED, HNO_3-ETCHED COPPER

CONTRAST REVERSALS DUE TO PRIMARY ION-CHANNELLING

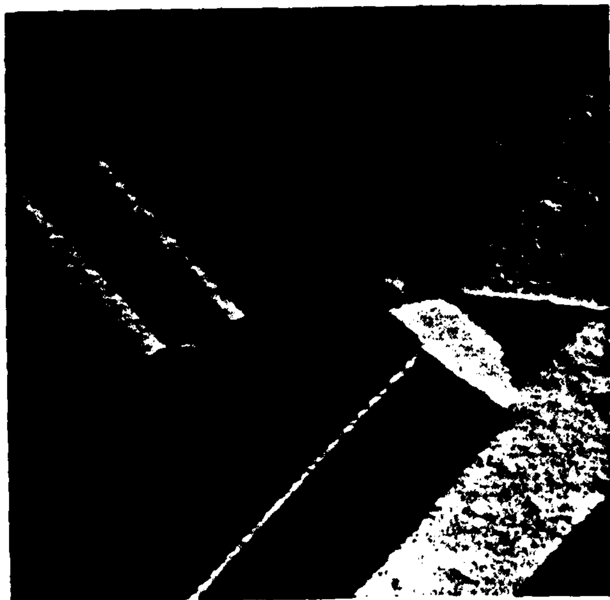
SECONDARY ELECTRON IMAGES, 60 keV UC-SIM

NORMAL INCIDENCE | 10° NORTH-SOUTH TILT

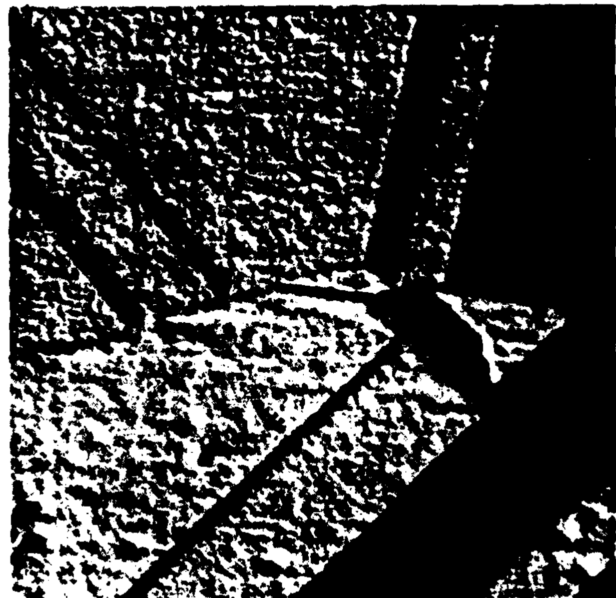
180 μm FULL SCALE



180 μm F.S.



180 μm F.S.



180 μm F.S.

Fig. 18

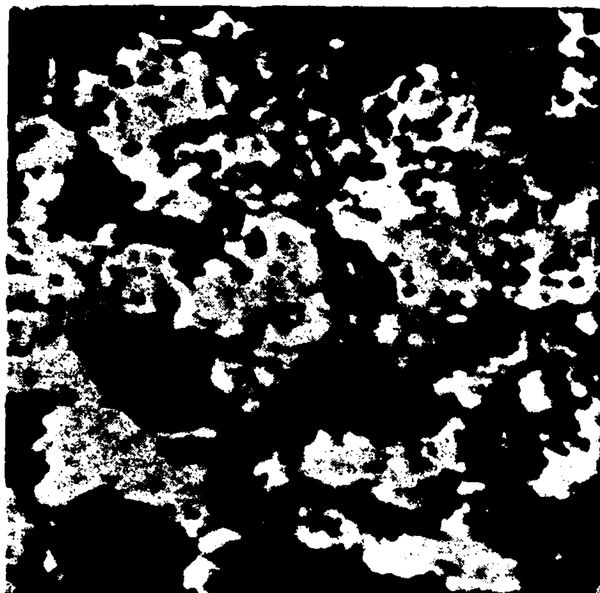
Ga^+ FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED DIE STEEL

CONTRAST REVERSALS DUE TO PRIMARY ION-CHANNELLING

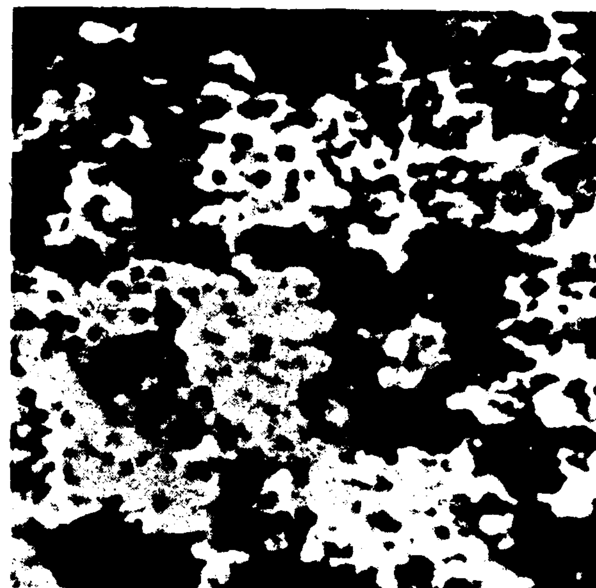
SECONDARY ELECTRON IMAGES, 60 keV UC-SIM

NORMAL INCIDENCE

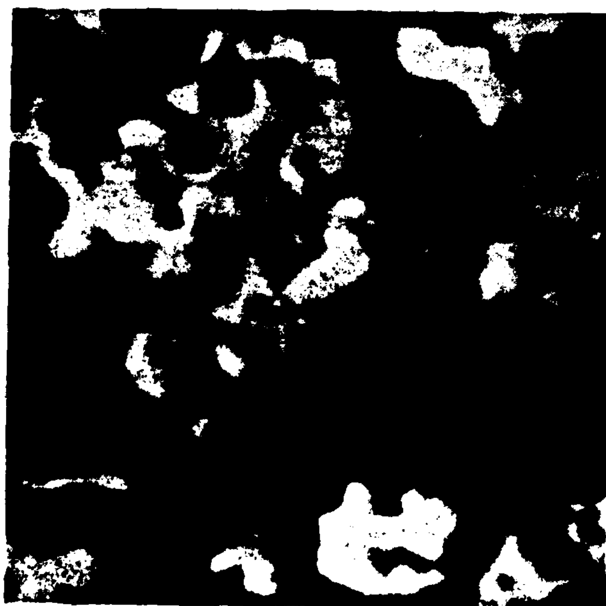


64 μM FULL SCALE

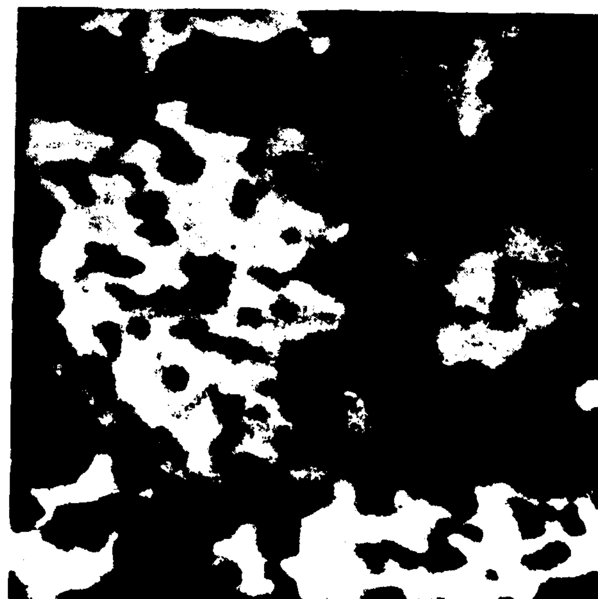
10^0 NORTH-SOUTH TILT



64 μM F.S.



32 μM F.S.



32 μM F.S.

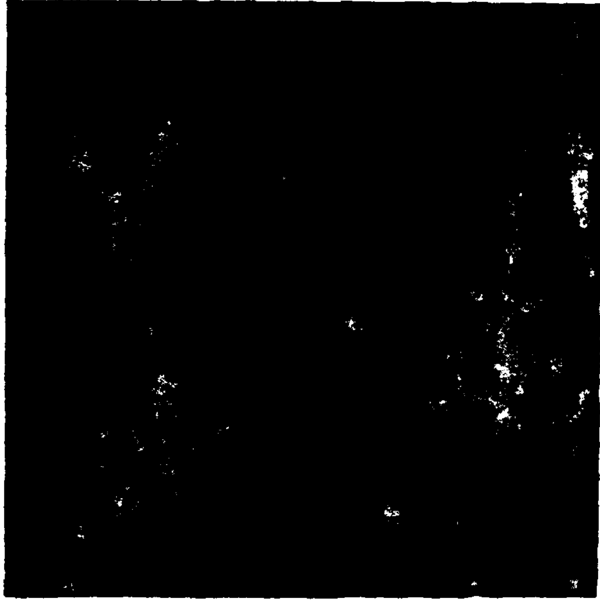
Fig. 19

Ga^+ FOCUSED-ION-BEAM IMAGES

DETECTION OF SHOCK -INDUCED DAMAGE IN POLISHED METEORITIC IRON CRYSTAL BY ION-CHANNELLING CONTRAST IN SECONDARY ELECTRON IMAGES

60 keV UC-SIM

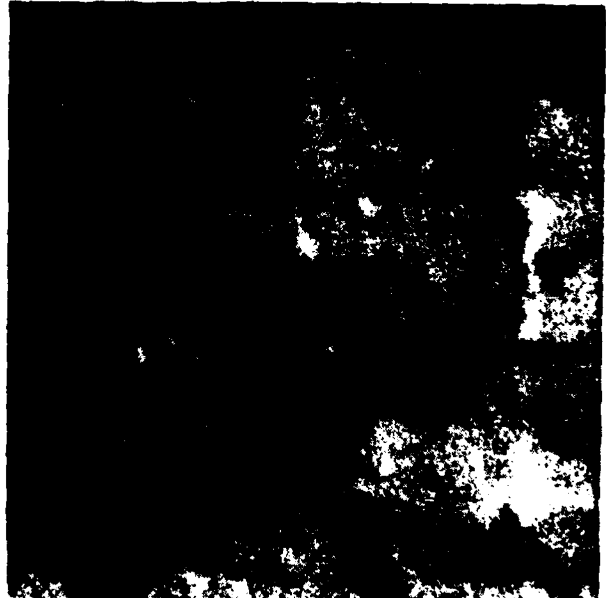
NORMAL INCIDENCE | 10° TILT



18 µm FULL SCALE

18 µm F.S.

18 µm F.S.



18 µm F.S.

Fig. 20

GA^+ FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED COPPER

CONTRAST REVERSALS DUE TO PRIMARY ION-CHANNELLING

COMPARISON OF SE VS SI IMAGES, 60 kV UC-SIM

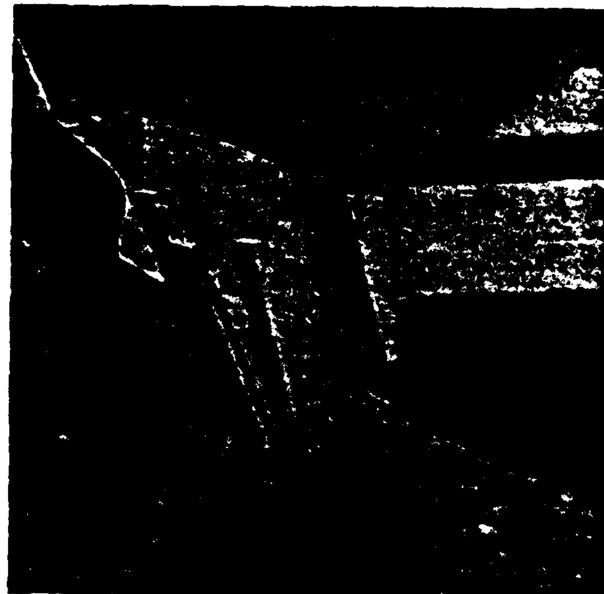
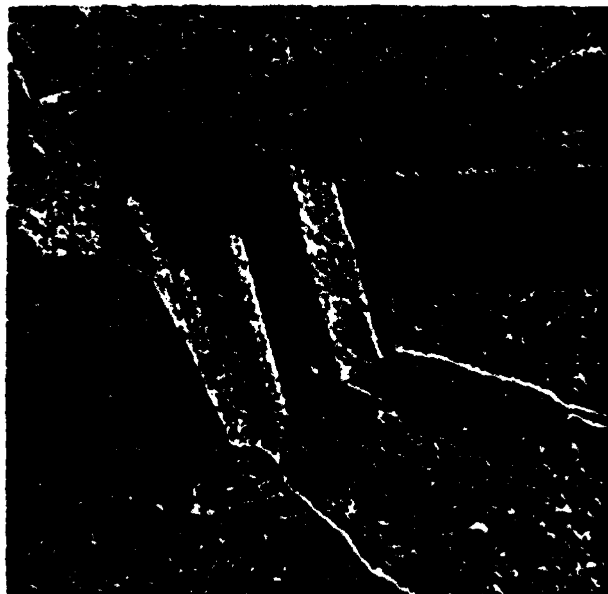
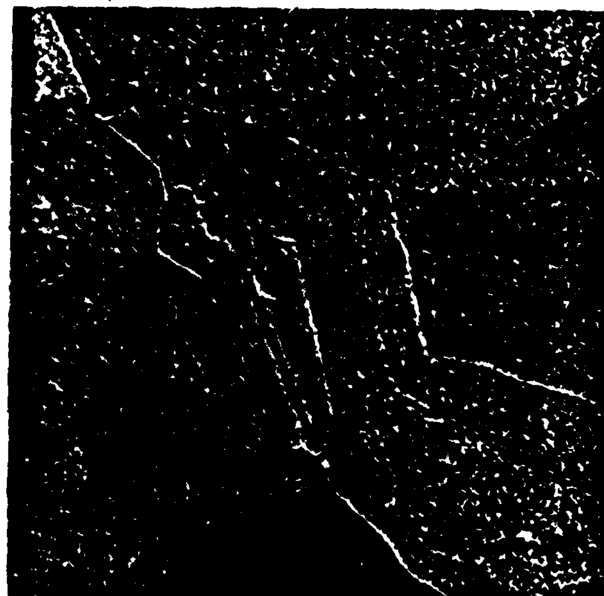
	NORMAL INCIDENCE	10° NORTH-SOUTH TILT
SE	 360 μM FULL SCALE	 360 μM F.S.
SI	 360 μM F.S.	 360 μM F.S.

Fig. 21

Ga^+ FOCUSED-ION-BEAM IMAGES

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED COPPER

CONTRAST REVERSALS DUE TO PRIMARY ION-CHANNELLING

COMPARISON OF SE VS SI IMAGES, 60 kV UC-SIM

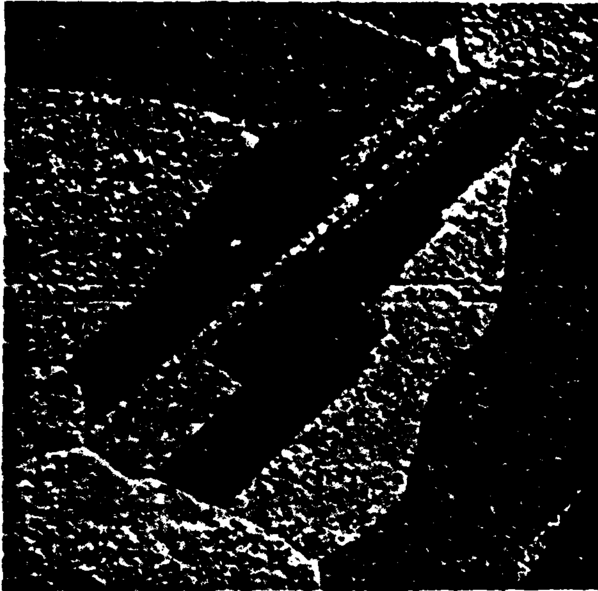
	NORMAL INCIDENCE	10° NORTH-SOUTH TILT
SE	 360 μm FULL SCALE	 360 μm F.S.
SI	 360 μm F.S.	 360 μm F.S.

Fig. 22

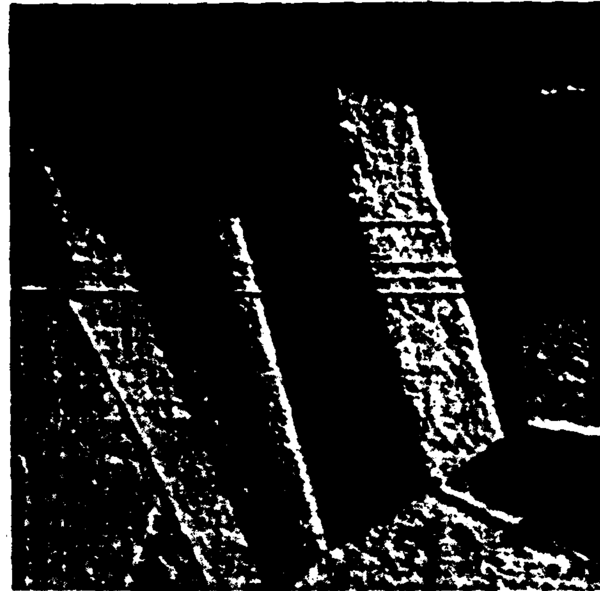
Ga^+ FOCUSED-ION-BEAM IMAGING AND ETCHING

RECRYSTALLIZED, POLISHED, HNO_3-ETCHED COPPER
CORRELATION OF ION-CHANNELING EFFECTS
IN SE, SI EMISSION AND SPUTTERING

Ga^+ SIM

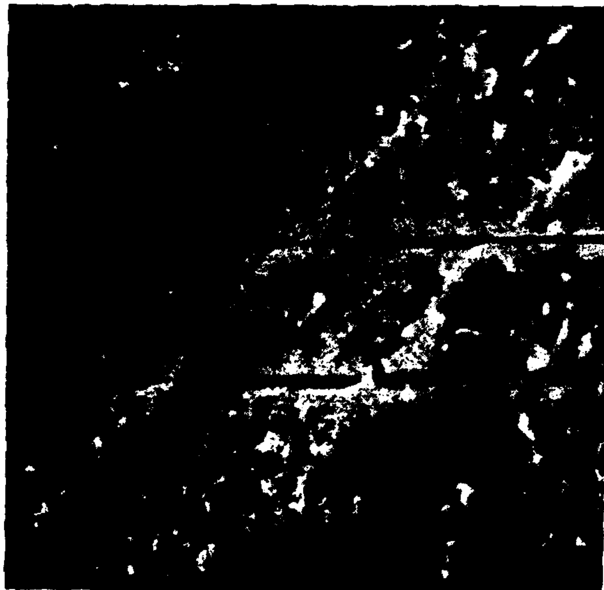


180 μM FULL SCALE, SI IMAGE



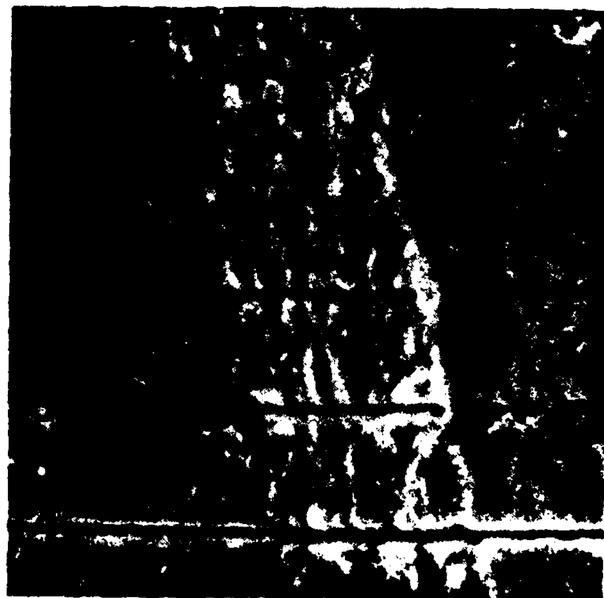
180 μM FULL SCALE, SE IMAGE

SEM



17 μM F.S.

TOTAL ION-BEAM WRITING DOSE OF 2.9×10^{18} IONS/CM^2, IN:
TOP LINE: SINGLE SCAN
BOTTOM LINE: 100 SCANS



17 μM F.S.

ION-BEAM WRITING DOSES ARE:
LINE 1: 3.1×10^{17} IONS/CM^2
LINE 2: 7.8×10^{17} IONS/CM^2
LINE 3: 1.2×10^{18} IONS/CM^2
LINE 4: 3.1×10^{18} IONS/CM^2

Fig. 23

Fig. 10

END

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