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RAL Report
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Metrology of Chrome on Quartz Photomasks using Low Voltage Scanning Electron Microscopy
I: Physical SEM Parameters

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METROLOGY OF CHROME ON QUARTZ PHOTOMASKS USING LOW VOLTAGE SCANNING ELECTRON MICROSCOPY

I: PHYSICAL SEM PARAMETERS

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ABSTRACT

This report is the first of two, describing work done under the JESSI T8 Project on SEM metrology of Cr/quartz photomasks. It outlines the T8 Project itself and describes in detail the determination of optimum physical parameters for low voltage SEM inspection. In addition, correlation with optical measurements is described.

A second report deals with further optimisation of SEM usage in photomask metrology.

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Joint European Submicron Silicon

1. THE JESSI T8 PROJECT

The work described here was done under JESSI (Joint European Submicron Silicon Initiative) Project T8, the main aim of which was to develop in Europe the essential reticle technology to give 0.35µm linewidths on silicon. The reticles are photomasks with features five times the size of the required dimensions, size reduction being achieved using ultraviolet light in a suitable wafer stepper system. A critical dimension (ie linewidth) precision of ± 0.05µm (3σ) was required on the reticle for linewidths down to 1.75µm.

The T8 Project was divided into five subprojects covering the various phases of photomask manufacturing, as follows:

1) Improved microimage generation (using electron beam lithography)

2) Advanced e-beam resist, substrate and processing development

3) Low voltage SEM metrology of uncoated reticles

4) Defect repair using lasers and focused ion beams

5) Microcleaning systems for reticle containers.

Seven partners collaborated in the various subprojects with Compugraphics International (Glenrothes UK) acting as Project Coordinators. The other partners were:

Mietec Alcatel (Oudenaarde, Belgium)
IMEC vzw (Leuven, Belgium)
Rofin Sinar Laser GmbH (Hamburg, Germany)
Laser Zentrum Hannover eV (Germany)
University of Dundee (UK)
RAL CMF Division (Chilton UK)

The Project was scheduled to run for three years starting in May 1991. Funding problems delayed German participation and eventually a 14 month extension (JESSI T8E) was agreed. This however, was not funded by the UK government.

2. METROLOGY SUBPROJECT

Two collaborators - RAL and IMEC - participated in this programme. Its main objectives were to determine the optimum conditions for low voltage SEM metrology of uncoated chrome-on-quartz reticles, both during and after processing - ie resist on Cr, etched Cr with resist, Cr on quartz. (SEM examination is easier at higher voltages if samples are coated with thin metallic layers : this is not possible when in-line metrology is needed to control processes).

Additional subproject requirements were the need to correlate SEM measurements with optical ones based on a recognised standard (eg from the National Physical Laboratory); a study of masks with antistatic layers, and possible replacements for chrome, ie molydenum silicide (MoSi) and silicon-germanium (SiGe).

3. SCOPE OF REPORT

The programme for Subproject 3 required two reports on low voltage SEM metrology of chrome/quartz. These are being published as RAL Reports, of which this is the first. As "Deliverable C1" it covers the main physical parameters for the SEM and correlation of SEM measurements with optical ones. It formed the bulk of the first year's report and was carried out almost entirely at RAL.

Further investigations such as optimised use of SEM measurement facilities, stability studies and correlation with other instruments were published as "Deliverable C2" at the end of the T8 Project, and also appear as a second RAL report, number RAL-95-012. This report includes comments on all the chrome-on-quartz metrology in the Subproject.

To distinguish between this introductory text and the JESSI report itself, pages in the latter are numbered C1-i, C1-ii etc. Tables are interspersed throughout the text but figures are collected together at the end.

4. ACKNOWLEDGEMENTS

Thanks are due to the JESSI organisation for approving the Project and the various member governments (UK, Belgium and Germany) for funding it.

Sub-Project Name : Mask and Reticle Technology Development
Project Number : T8
Programme: 3 - Low Voltage SEM inspection and metrology
Project Leader : R. Jonckheere, IMEC vzw
Participants : IMEC, RAL

DELIVERABLE C1 June 1992

SEM PARAMETERS FOR Cr/Quartz

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1. INTRODUCTION

The objectives of this subproject were revised in October 1991 to emphasise metrology rather than inspection. This report describes work done under Task 'C1':

> "To establish LV SEM parameters for Cr after resist stripping, including correlation to standards".

Much of this work was done at RAL where the necessary optical measuring apparatus is available, and where parameters in a Hitachi S4000 SEM can be varied more easily. At IMEC, by contrast, the S6100 SEM is devoted to production-line metrology, which restricts arbitrary changes, and there is no specialised optical measurement system. This report describes some features of the instruments used, the strategy behind the work and the results obtained. Preliminary work used antireflective chrome-on-quartz patterns made at RAL, with final measurements on a similar sample from IMEC.

2. OPTICAL METROLOGY

The main instrument for general use at RAL is an OSI Video Linewidth Measuring system. This is, basically, a precision microscope with a CCD camera driving a TV display. Microprocessor based software allows a variety of 'programs' for linewidth and pitch measurements.

The 'OSI' is calibrated for transmitted light (Fig 1) using an NPL Standard Photomask [1] and automatically converts 'observed' linewidths to 'calibrated' ones for both dark (Cr) and light (quartz) lines. Its internal conversion tables cover the range 1 - 10 μm, but to allow for slight non-linearity over this range [2], we found that a secondary calibration was needed for linewidths of 1 to 4 μm. For this minor correction our values of 'm' & 'c' in

$$\langle NPL \rangle = m * \langle OSI \rangle + c$$

are shown below, for two separate calibrations.

	m	c
Quartz run 1	0.995	-0.078
Quartz run 2	0.994	-0.083
Chrome run 1	1.004	0.088
Chrome run 2	1.004	0.094

Four linewidths on an IMEC sample - 1.0, 1.5, 2.0 and 2.5 µm - were measured and corrected as described above. In particular, for the 1.5 - 2.5 µm widths, adjacent Cr and quartz lines in an 'equally-spaced' pattern were chosen. The results are shown below in Table 1 for 2 separate runs.

µm	QUARTZ		CHROME	
1.0	0.880	0.873	0.973	0.974
1.5	1.429	1.427	1.571	1.567
2.0	1.970	1.959	2.053	2.050
2.5	2.443	2.441	2.554	2.562

Table 1. OSI linewidth measurements in µm
(RMS standard error is 0.007 µm)

To calibrate the SEM, an accurate pitch measurement of a periodic pattern is needed [3] and a set of 1.5 µm chrome/quartz lines was used. The OSI has an 'Engineering Profile' program for this purpose and preliminary calibration used the NPL 4 µm periodic pattern (Row D). Eight measurements of an IMEC sample gave a mean pitch of

2.992 + 0.007 µm

which agrees well with the value of 3.000 µm as expected in lithography from an EBMF10 microfabricator with a laser interferometer.

3. LVSEM metrology

3.1 HITACHI S4000 at RAL

3.1.1 System overview

The S4000 is a general purpose SEM for use by RAL's CMF Division. It has a Field Emission electron source, its accelerating voltage is variable between 0.5 and 30 kV, and there is a wide range of settings for sample tilt, rotation, translation and working distance. A scintillator in the specimen chamber is used for secondary electron imaging.

The beam current is controlled by

(a) the objective aperture : this has four possible values (100, 50, 30 and 20 µm) but only the last two are recommended for SE imaging.

(b) the condenser lens current ('Cond.lens' setting). This has 15 possible values of which only '7' - '15' (giving successively higher resolution) are recommended for SE imaging.

(c) the emission current, but the above adjustments allow us to standardise this at 10 µA.

For experimental work the samples are cleaved so that they can be loaded through a small 'secondary exchange chamber', giving much faster pump-down times than the main chamber. Moreover, the size of the main SEM chamber allows only limited movement (about 1") of full 5"-sized plates.

Finally, although the S4000 has an 'automatic focus' facility, we tend not to use this as manual adjustment of the coarse and fine focus is quicker and more effective. After these, the X and Y stigmators provide final focusing. For linewidth measurement, we use 'line scan' mode for fine focusing as more reliable than 'visual' mode.

3.1.2 CD Measurement Option

The S4000 offers two menus to control 'Measurement Conditions' and 'Calibration Settings'.

'Measurement Conditions' include the type of measurement - threshold or linear approximation - and four parameters to control how blocks of scan lines in a frame store should be processed to give measurable line profiles.

A section of the line to be measured is divided into blocks for averaging. For each block the machine reports the mean, maximum and minimum line width together with a '3σ' value, which is a function of both linewidth variations and random errors.

Five 'calibration settings' may be stored in the machine, as a table of kV, working distance, scan speed, magnification and X-Y calibration factors. The latter may be varied between 0.90 and 1.10 in steps of 0.01.

The S4000 has no conventional image-processing facilities, such as frame-averaging and filters, as found, for example, in the CRYSTAL framestore used in ESPRIT Project 1043 [4] at IMEC.

3.2 HITACHI S6100 at IMEC

3.2.1 System overview

The S6100 is a low voltage metrology SEM optimized for wafers used as a day-to-day standard metrology tool in IMEC's pilot wafer processing line for linewidth control of optical lithography and dry etching. It also has a field emission source and its accelerating voltage is actually fixed at 0.8kV, although it is changable in the range of 0.7kV to 1.1kV. It is basically possible to inspect up to 6" wafers and to use a dedicated chuck to inspect the full area of at least a 5" mask. Secondary electron detection is done with a conventional scintillator/multiplier combination. Direction effects of the S.E.'s and hence edge effects are avoided since the detector is placed above the lens. The beam current can only be changed by the emission current, which is normally put at 2 μA, unless the standard diaphragm of 50 μm would be replaced by another size.

3.2.2 CD-measurement Conditions

A basic difference to the S4000 at RAL is that the calibration / focusing / stigmation correction and the measurement itself are done on a flicker-free TV-image. The image can be summed or averaged over up to 128 images, making it quasi noise free. As measurement techniques, both threshold and linear approximation techniques are selectable. On the standard version, as available at IMEC, it is not possible to use multipoint measurement. It is only possible to select a measurement area and the number of equidistant measurements within this area. Another drawback is that it is not possible to output the spread of a measurement, but only the mean value. In order to make both possible the purchase of the multipoint measurement option needs to be considered.

4. FINDING OPTIMUM SEM CONDITIONS

The operational parameters of the LVSEM can be divided into two sets - "SEM/Column Conditions" and "Measurement Conditions", which will be discussed separately below.

4.1 SEM/Column Conditions

Parameters are

Magnification
Accelerating voltage
Sample tilt
Working distance
Cond.lens (beam size)
Objective aperture
Frame scan speed

It was evident that basic machine parameters, such as accelerating voltage and working distance, should be fixed first to minimise charging and maximise the signal/noise ratio. We could then change the 'measurement conditions' to improve the consistency of results, thus reducing our '3σ' values.

Tilting the sample was not envisaged, since in most SEM's it is impossible with substrates measuring 5" or more.

4.1.1 S4000 at RAL

Rotation was needed so that the lines to be measured point at the detector. Misalignment can cause different amounts of SE emission from the line edges, giving asymmetric line profiles. The 'scan rotation' feature of the S4000 does not cure this problem and is only used as a fine adjustment.

To avoid negative charging at the slowest scan speed (20 sec), it was necesary to reduce the accelerating voltage to 0.9 kV. (This was further reduced to 0.8 kV for IMEC samples as some charging was suspected).

Under these conditions the signal/noise ratio was very poor and to obtain reasonable images we reduced the working distance to its minimum value of about 4 mm. The S4000 emission current was kept at 10μA and the objective aperture set to 30 μm. This is the maximum recommended value for SE detection: a smaller value (20 μm) is available but is not used since the condenser lens provides adequate control over beam diameter.

The magnification is determined by the need to measure 1.5 um lines and also calibrate the SEM with a 3.0 μm pitch. A value of 20,000 gives a scanned area about 6 μm wide, with a 'least count' of about 12 nm in the 512 x 512 frame store used for measurement.

Thus, at a fairly early stage, we found a close correspondence between the main physical parameters in the S4000 and those used in IMEC's S6100 for routine metrology.

The remaining two SEM/column conditions - beam size and scan speed - were investigated by varying each in turn to build up a matrix of '3σ' values. The S4000 provides two TV and four slow scan rates (0.25, 2, 10, 20 secs/frame). Beam sizes from '11' down to '14' were investigated, useful imaging being impossible at the highest resolution, '15'. The resulting trends in '3σ' are shown in Fig. 2.

The most accurate measurements came from beam setting '14' with 10- or 20-second scan rates. The small increase in accuracy from the slower rate did not seem to justify the increased measuring time, contamination and possible charging. Hence 'SS3' (10 sec) and Beam Size '14' were chosen as the best combination as demonstrated by Table 2. Fig. 3 illustrates the effect of scan speed on line profile and noise while Fig. 4 shows that TV scan rates are not suitable for CD measurement on the S4000.

Beam Size	Scan Speed	Pitch (µm)	3*sd (µm)	Mean Pitch	RMS 3*sd
12	SS3	2.993	0.058		
		2.993	0.057		
		2.908	0.048	2.925	0.055
13	SS3	2.931	0.045		
		2.940	0.048		
		2.939	0.043	2.937	0.045
14	SS3	2.923	0.042		
		2.921	0.045		
		2.920	0.034	2.921	0.041

Table 2. Effects of decreasing beam size from '12' to '14' at scan speed SS3 (10 sec) and 0.9 kV.

Finally, after using the S4000's automatic brightness control (needed after any column parameter change) we always reduce the detector 'brightness' control. This gives a better image and has some physical basis, since image contrast depends mainly on the mean atomic numbers of chrome and quartz, and we need to detect the results of backscattered electron reactions from this. Increasing the detector contrast just gives noisier profiles so the automatic setting is retained.

The variation of profile with beam size is illustrated in Fig. 5. As the beam size increases, the characteristic SE emission 'ears' develop (from sloping chrome edges) and the profile becomes more curved in the darker quartz lines.

The final set of SEM/column settings for the S4000 were selected as follows:

Magnification	20000
Acc.volts (kV)	0.8
Emiss.current (µA)	10.0
Tilt (deg)	0
W.D. (mm)	5.0
Cond.lens	14
Aperture (µm)	30
Scan speed (secs)	10

Table 3a. S4000 SEM column settings for metrology of IMEC sample of uncoated Cr-oxide / Cr / quartz wafer.

4.1.2 SEM/Column conditions at IMEC

The standard settings as mentioned in section 3.2 were used as a start. An accelerating voltage and emission current of 0.8kV and 2µA respectively, as recommended by Hitachi for the metrology on Si wafers, were quite satisfactory. Only at high magnifications (starting from 100kX) slight "discoloration" is noticed, resulting in a contaminated area after zoom-out. This effect is at least much less pronounced than the effect when resist is still on top (not in discussion in the present report), where it starts at about 40kX, although even there it is still usable for structures down to 1.5um lines and spaces.

In conclusion it can be said that the standard column conditions for Si wafers could be implemented straightforwardly for metrology of Cr masks.

Typically a magnification up to 30kX is used, resulting in a resolution of 12nm for the measurement on the framestore.

4.2 Measurement Conditions

The two methods of linewidth measurement derive different line widths from a given SE profile:

(a) 'linear approximation': the base of the profile [5], and

(b) 'threshold': the width at an arbitrary height defined by the user.

4.2.1 S4000 at RAL

Accurate focusing is quite critical in keeping '3σ' values below the required 50 nm value, so the 50% threshold method was chosen as being best suited to the S4000 as this is the least affected by focusing errors [6]. This has been checked on the S6100 as described in section 4.2.2.

The remaining parameters to be optimized on the S4000 are :

MEAS point (number of blocks of scan lines)
MULT pitch (pitch of blocks)
Summing line (number of lines / block)
MEAS pitch (pitch within block)
X & Y calibration factors

The four S4000 measurement parameters 'MEAS.point', 'MULT.pitch', 'Summing.line' and 'MEAS.pitch' are described in a brief set of notes supplied by Hitachi. They specify how a section of scanned line is divided into blocks of scan lines for analysis as shown in Fig. 6 . The mean, 3σ, etc values of these measurements are output on the SEM screen.

However, the S4000 uses a 512 x 512 frame store for this data compared with some 2000 lines for normal imaging: this reduces the image quality, and defines the 'least count' of the SEM (12 nm at x20,000).

The effect of these parameters on 3σ values is not at all obvious, so a simulation program was written for RAL's VAX computer. In this, each scan line is represented by a randomly-varying linewidth, and blocks of these are repeatedly averaged for different block sizes, etc. For a fixed number of scan lines we found that reducing the number of blocks ('MEAS.point') and increasing the size of each one ('Summing.line') produced the most 'accurate' results. The model showed that σ is proportional to

$$1 / \sqrt{\text{Summing.line}}$$

Attempts to confirm the model experimentally showed that its trends in 3σ were essentially correct (Fig. 7) although results were not ideal and some scaling was needed. Nevertheless, the model suggested changes to the 'Summing.line' and 'MEAS.pitch' parameters, which gave smoother profiles and lower 3σ values.

Further investigations would be useful as a recent experiment showed that scan lines in different blocks can be interleaved. The 'σ' values would then reflect random measurement errors rather than edge acuity variations, and we could choose either of these two regimes.

The final set of optimum parameters is shown below in Table 3b.

Auto-method	Threshold
Threshold (%)	50
Diff size	4
MEAS.point	25
MULT.pitch	8
Summing.line	32
MEAS.pitch	1
X-Calib.factor	1.04

Table 3b. S4000 SEM measurement settings for metrology of IMEC sample of uncoated Cr-oxide / Cr / quartz wafer.

4.2.2 S6100 at IMEC

The theory that the 50% threshold outputs a linewidth measurement which is independent of variations in focus setting, was checked again. The threshold level was varied and linewidth was measured for "best" focus and a defocus (both over and under). A 1 µm Cr line was measured on a summed image of 16 TV scans, at magnification 20kX.

threshold	in focus	under-	over-
20	in noise	not meas.	not meas.
30	1.038	not meas.	not meas.
35	1.039	1.067	1.119
40	1.040	1.044	1.065
45	1.040	1.026	1.047
50	1.041	1.024	1.028
55	1.041	1.024	1.067
60	1.028	not meas.	not meas.
70	1.025	not meas.	not meas.
80	in noise	not meas.	not meas.

It was found that the threshold was near to 50%, but depending on the direction of defocus a threshold just below or just above 45% was found.

To get an idea of the deviation in measurement results when using the linear approximation method as routinely used on the S6100, we compared the results for the threshold method with threshold values of 10, 50 and 90%, as shown in Fig 8.

The effect of summing several TV images on the quality of the stored image used for the linewidth measurement algorithm was evaluated as shown in Fig. 9. Unfortunately we could not evaluate, as was done on the S4000 for scan speed, how the spread of the measurements was affected, due to the lack of a multipoint measurement option.

5. SEM MEASUREMENT RESULTS

Further work on comparisons with optical measurement and the linewidth standard has been done on the S4000 at RAL because it could output a value for the spread on the measurements, like the OSI, though the quality & contrast of the LVSEM imaging on the S6100 is superior.

Two sets of S4000 measurements were done on the IMEC sample, choosing the same lines as had been measured optically. This was a non-trivial exercise owing to image-reversal in the OSI and poor TV-rate imaging in the SEM.

Four to six measurements of isolated 1.0 um Cr and quartz lines were made, followed by similar numbers of 1.5, 2.0 and 2.5μm lines in 'equal-sized' Cr/quartz patterns. Ten 3 μm pitch measurements were used to calibrate the SEM for each run, the pitch being taken as 3.000 μm. Typical measurements are shown in Figs 10 and 11 .

A typical set of measurements for a 1.5 μm chrome line is shown below in Table 4.

Width	3σ	
1.548	0.041)	
1.548	0.037)	Mean width = 1.549 μm
1.550	0.040)	RMS 3σ = 0.038 μm
1.550	0.037)	σ of mean = 0.001 μm
1.547	0.033)	

Table 4. Example of 5 consecutive S4000 measurements (1.5 μm Cr line, IMEC sample)

The standard error in the 5 readings ('σ of mean') is rather less than typical values of 0.004 - 0.006 μm, which are similar to those given by optical metrology (OSI).

Thus the SHORT-TERM REPEATABILITY is less than 10 nm, as required.

A photograph of the second measurement above (Fig. 11) shows a linewidth variation of 1.523 to 1.572 μm, ie. a spread of 0.049 μm. This is rather high, with typical 'spread' values averaging 0.038 μm.

To assess the overall quality of the SEM results, we plotted 'OSI linewidth' against 'SEM linewidth' for corresponding measurements. Tables 5 and 6 below show the results of two separate 'runs': between them, the sample was removed from its SEM stub for optical measurement.

In the tables, 'm' and 'c' are the gradient and intercept in the formula

"OSI = SEM * m + c"

and can be used to correct the OBSERVED SEM linewidths ('x') to the NPL standard ('SEM corr').

'Delta' is the difference between 'corrected SEM' and OSI values. All measurements are in microns. The corresponding plots for IMEC chrome and quartz lines in 'Run 2' are shown in Figs 12 and 13 .

Apart from the 1-μm quartz line in Run 1, there is reasonably good agreement between SEM and OSI results. Differences between OSI and SEM measurements are all less than typical S4000 3σ values.

CHROME	SEM	OSI	SEM-corr	delta
1.0	0.968	0.973	0.977	-0.004
1.5	1.552	1.571	1.567	0.004
2.0	2.029	2.053	2.049	0.004
2.5	2.533	2.554	2.558	-0.004

Gradient m = 1.010; Intercept c = 0.001

QUARTZ	SEM	OSI	SEM-corr	delta
1.0	0.835	0.880	0.842	0.038
1.5	1.411	1.429	1.424	0.005
2.0	1.948	1.970	1.967	0.003
2.5	2.443	2.443	2.467	-0.024

Gradient m = 0.976; Intercept c = 0.062

Table 5. SEM-OSI comparison, IMEC sample, run 1

CHROME	SEM	OSI	SEM-corr	delta
1.0	0.993	0.974	0.989	-0.015
1.5	1.549	1.567	1.546	0.021
2.0	2.050	2.050	2.048	0.002
2.5	2.575	2.562	2.571	-0.009

Gradient m = 1.002; Intercept c = 0.007

QUARTZ	SEM	OSI	SEM-corr	delta
1.0	0.845	0.873	0.867	0.006
1.5	1.422	1.427	1.437	-0.010
2.0	1.948	1.959	1.957	0.002
2.5	2.435	2.441	2.439	0.002

Gradient m = 0.988; Intercept c = 0.032

Table 6. SEM-OSI comparison, IMEC sample, run 2

6. OSI-SEM CORRELATION

The IMEC wafer includes patterns of equally - sized chrome and quartz lines. Measuring adjacent lines of each material and comparing their sum with the nominal pitch is a good way of checking the viability of the results. We expect pitch measurements to be precise since the underlying lithography relies on a laser interferometer. Tables 7 and 8 show how closely the average measurements, when added, correspond to the expected pitch measurements, for OSI and S4000 results respectively. (Note that the OSI-measured 3.0 μm pitch was 2.997 with sigma 0.007 μm.)

Nom Pitch	Cr Width	QZ width	Cr + Qz Width	Delta Pitch
3.000	1.569	1.428	2.997	-0.003
4.000	2.051	1.964	4.015	0.015
5.000	2.558	2.442	5.000	0.000

Table 7. Adjacent linewidths (μm) in equally-spaced chrome & quartz patterns: OSI optical system

Nom Pitch	Cr Width	QZ width	Cr + Qz Width	Delta Pitch
3.000	1.556	1.430	2.986	-0.014
4.000	2.048	1.962	4.010	0.010
5.000	2.564	2.453	5.017	0.017

Table 8. Adjacent linewidths (μm) in equally-spaced chrome & quartz patterns: S4000 SEM

We have, therefore, found a preliminary set of Hitachi S4000 SEM measurement conditions for a chrome-on-quartz sample. The results need only minor corrections to correlate them with the NPL Photomask Standard and the EBMF10.5 laser interferometer.

7. REFERENCES

[1] "The NPL-Alvey Photomask Linewidth Standard", National Physical Laboratory: document supplied with NPL Standard mask.

[2] Swyt D A, SPIE Vol 129 (1977) 98

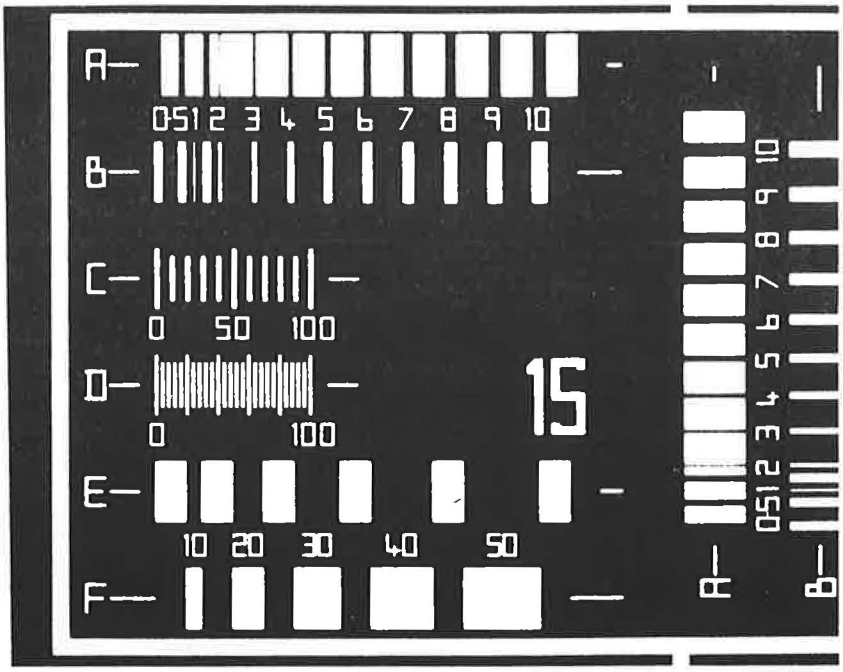
[3] Frosien J & Lischke B, Microcircuit Eng. Conf. Proceedings, (1984), 44

[4] Buysse P, Final Report on ESPRIT 1043 Mask Making Project, Task 7.1 (IMEC, 1989)

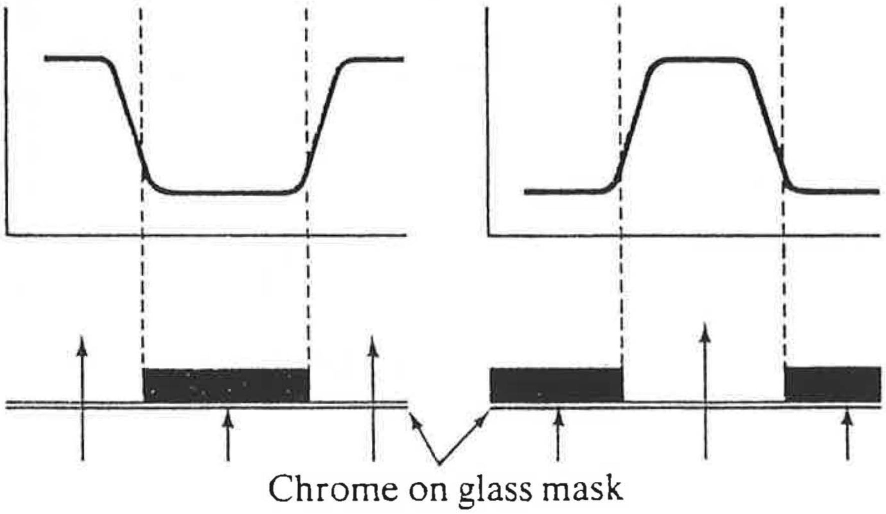
[5] Miyoshi M et al, J Vac Sci Technol, Vol B4(2) (1986) 493

[6] Nunn J W & Turner P, SPIE Vol 1464 (1991) 50

NPL STANDARD PHOTOMASK



Photograph of mask

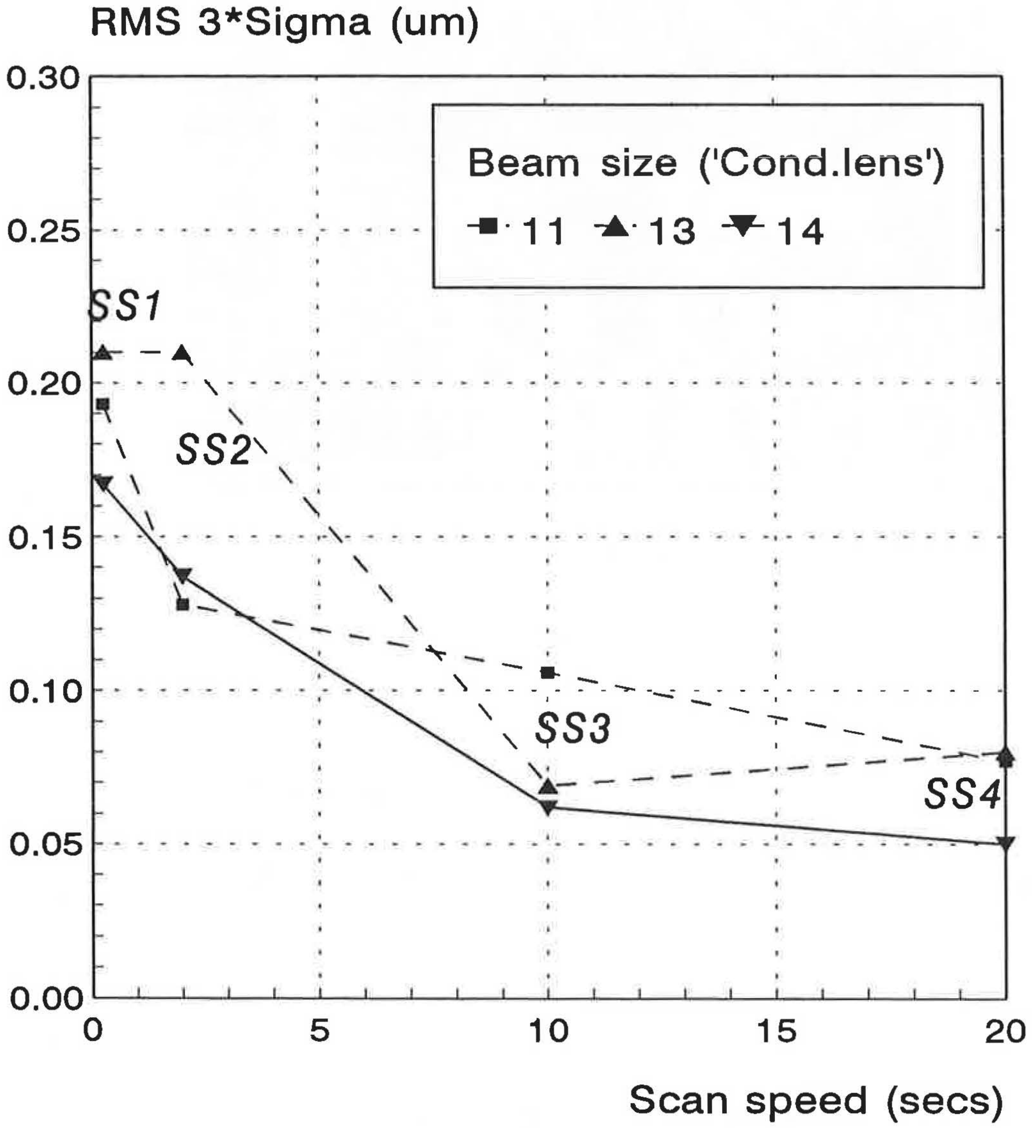


Use with transmitted light (25% threshold)

Fig. 1

S4000 3*SIGMA VALUES

Variation with Scan Speed and Beam Size



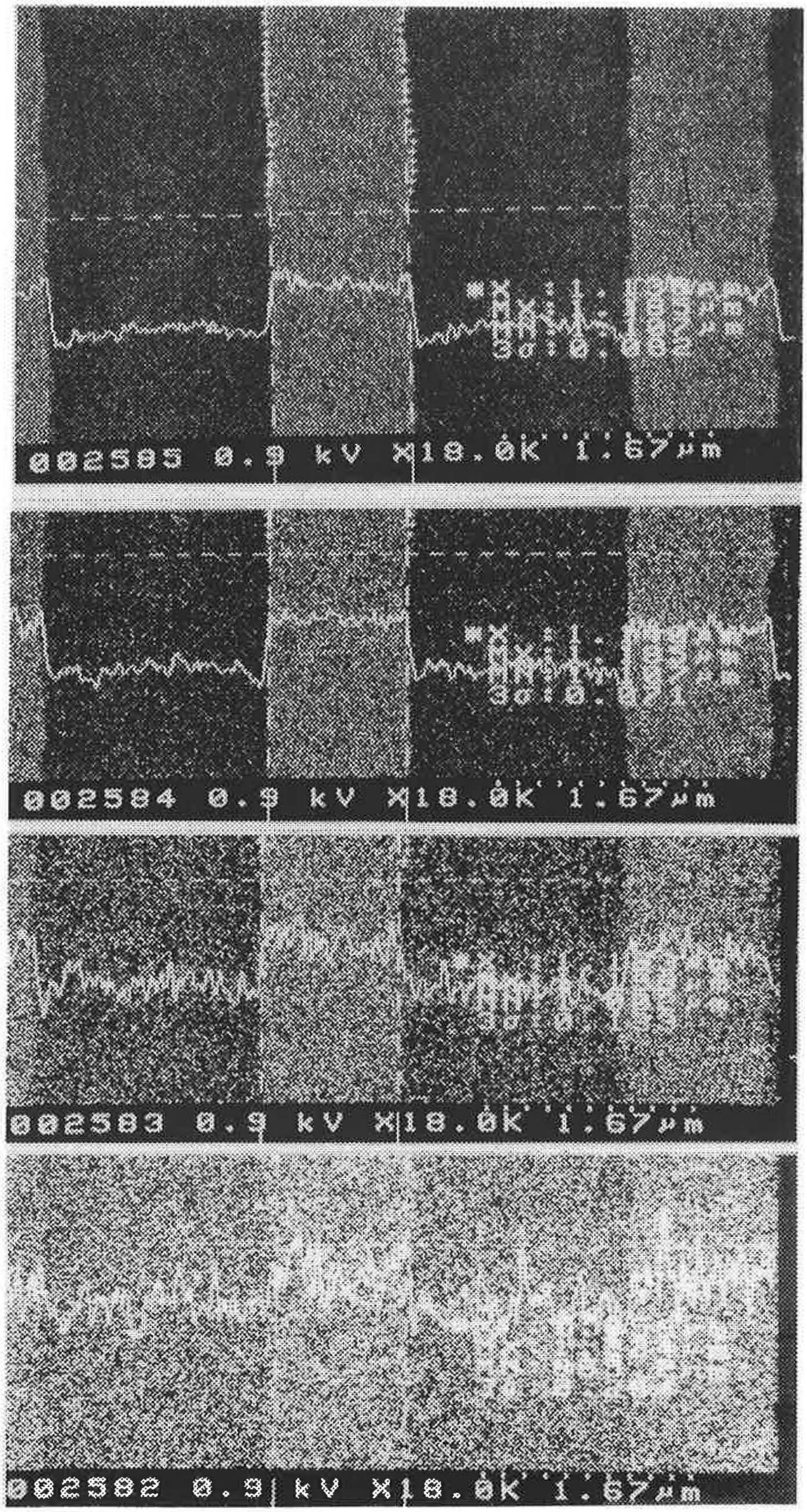
Frame times *SS1, SS2, SS3, SS4* = 0.25, 2.0, 10, 20 secs

Smallest beam size = '14'

Fig. 2

EFFECTS OF SCAN SPEED ON S4000 S.E. PROFILE

RAL (experimental) sample, beam size '14'



SS4 :
20 sec

SS3 :
10 sec

SS2 :
2 sec

SS1 :
0.25 sec

Fig. 3

EFFECTS OF SCAN SPEED ON S4000 S.E. PROFILE

RAL (experimental) sample, beam size '14'

Illustration showing how slow TV rate destroys contrast and is not suitable for CD measurement

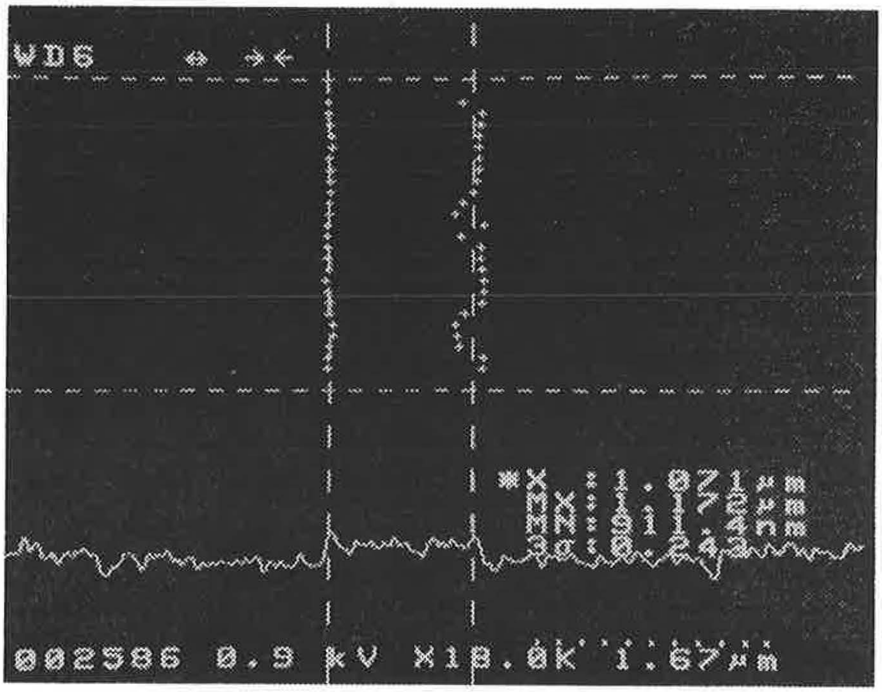


Fig. 4

EFFECTS OF BEAM SIZE ON S4000 S.E. PROFILE
RAL (experimental) sample
10 sec scan speed 'SS3'

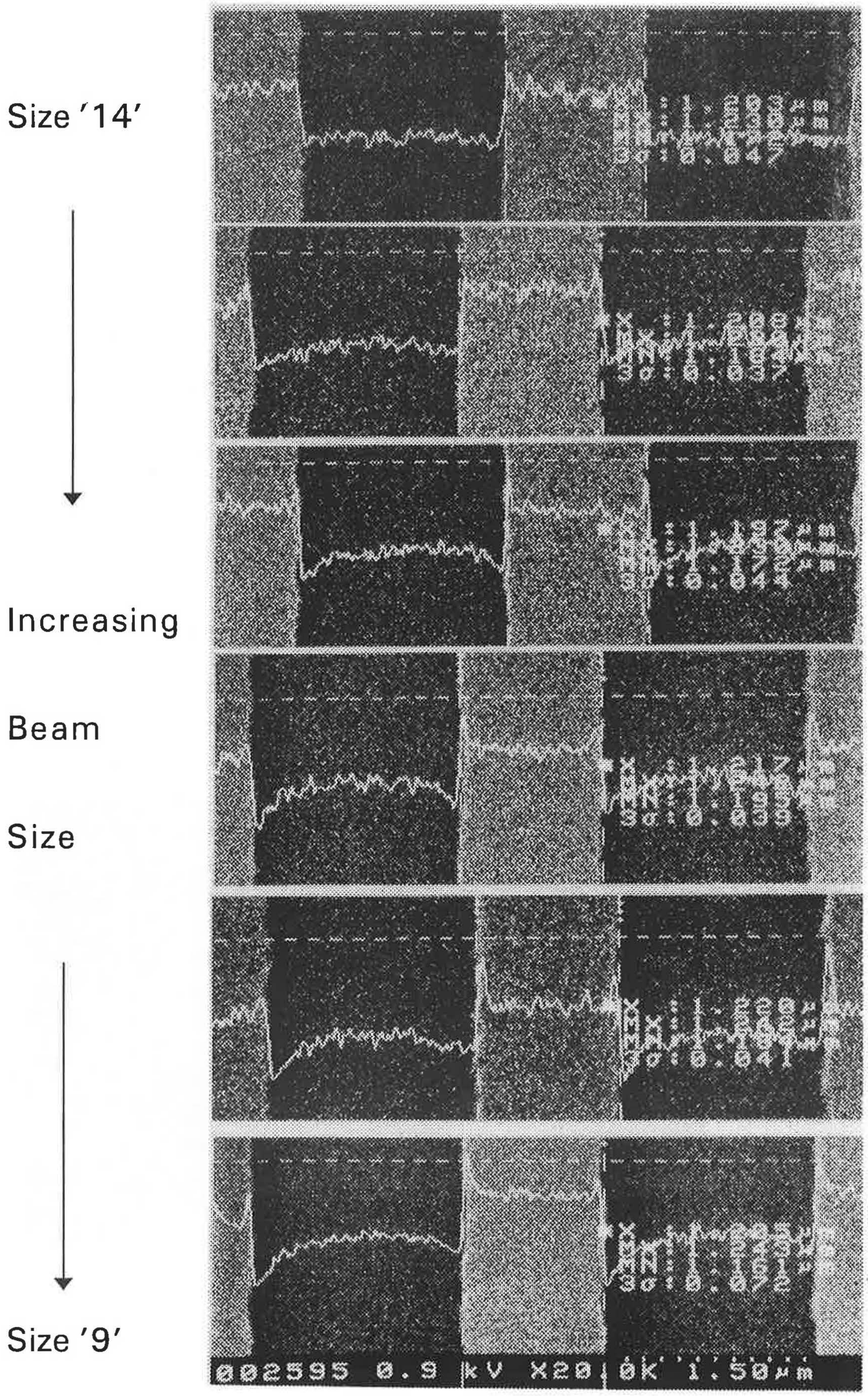
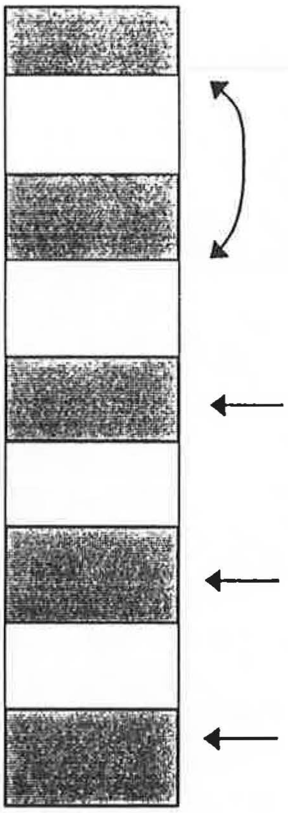


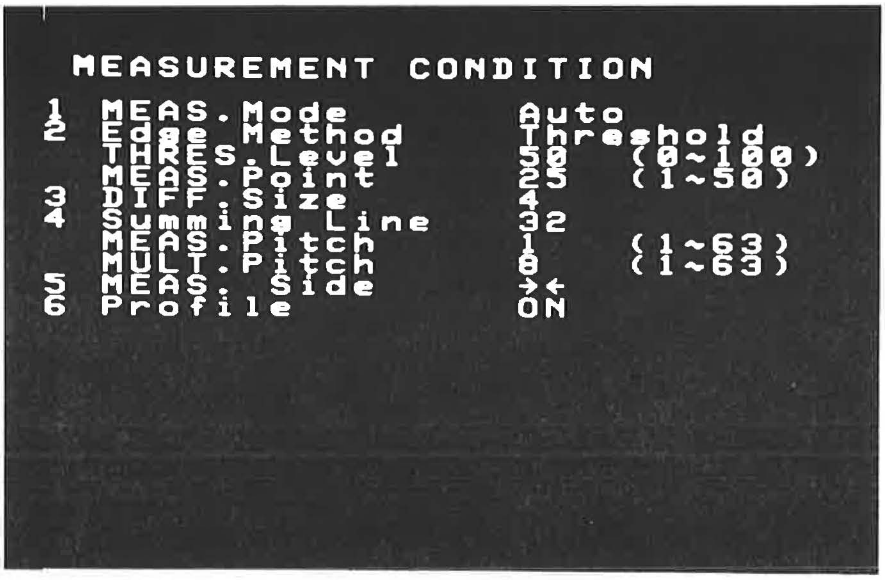
Fig. 5

HITACHI S4000 CD MEASUREMENT PARAMETERS



Takes average of
'*MEAS.POINT*' measurements,
at a pitch of
'*MULT.PITCH*' scan lines

Each measurement =
sum of '*SUMMING.LINE*'
scan lines ....
at a pitch of
'*MEAS.PITCH*' scan lines



```
 MEASUREMENT  CONDITION
1  MEAS.Mode           Auto
2  Edge Method         Threshold
   THRES.Level         50   (0~100)
   MEAS.Point          25   (1~50)
3  DIFF.Size           4
4  Summing Line        32
   MEAS.Pitch          1    (1~63)
   MULT.Pitch          8    (1~63)
5  MEAS. Side          →←
6  Profile             ON
```

SCREEN DISPLAY

Fig. 6

S4000 MEASUREMENT: COMPUTER SIMULATION
Variation of 3*sigma with scan-lines per block
320 scan lines (40*8, 20*16, 10*32, 5*64)

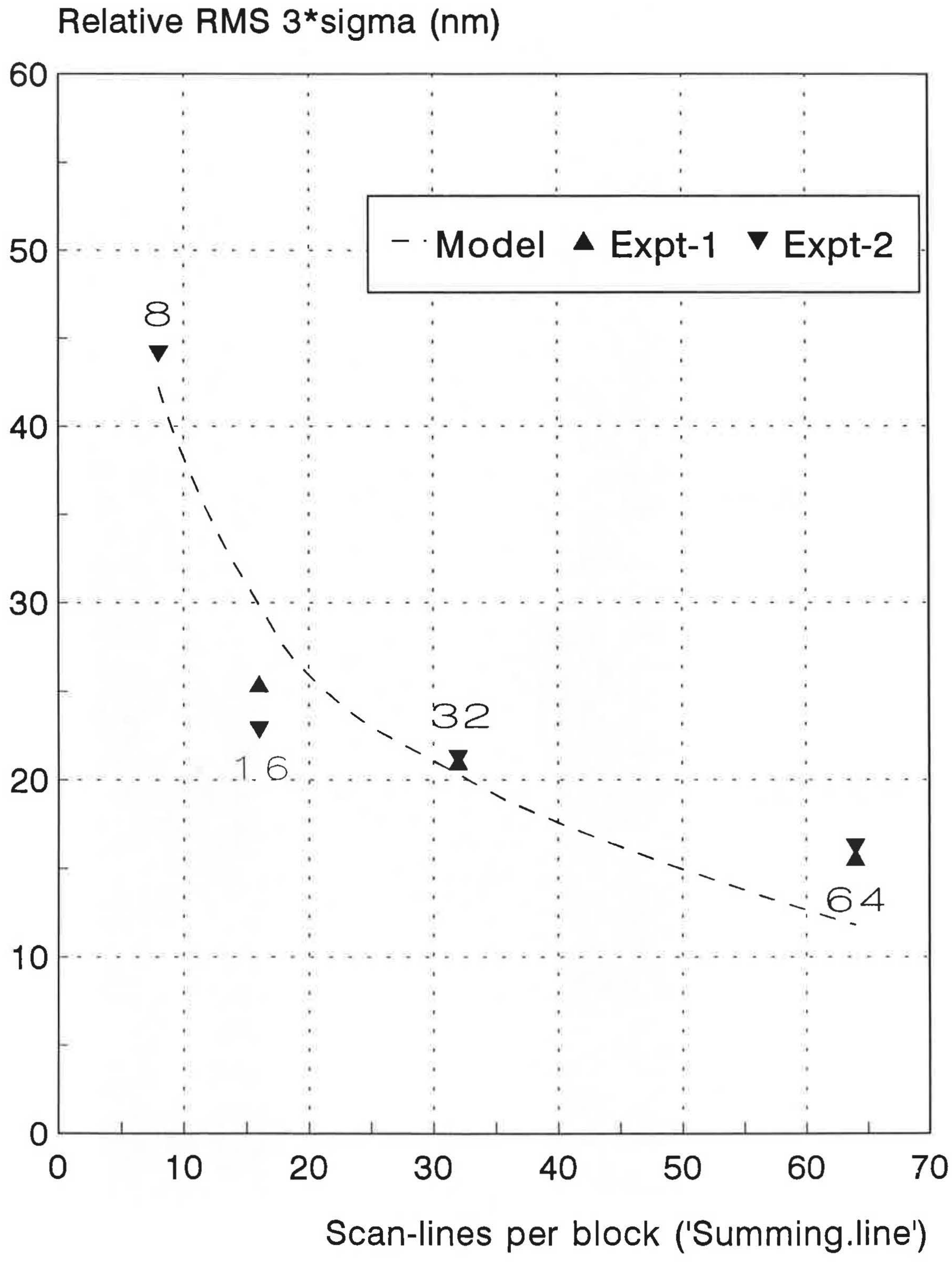


Fig. 7

S6100 : SENSITIVITY OF MEASUREMENT STRATEGY
(80kX, 4 summed images, 32 measured lines at pitch 2)

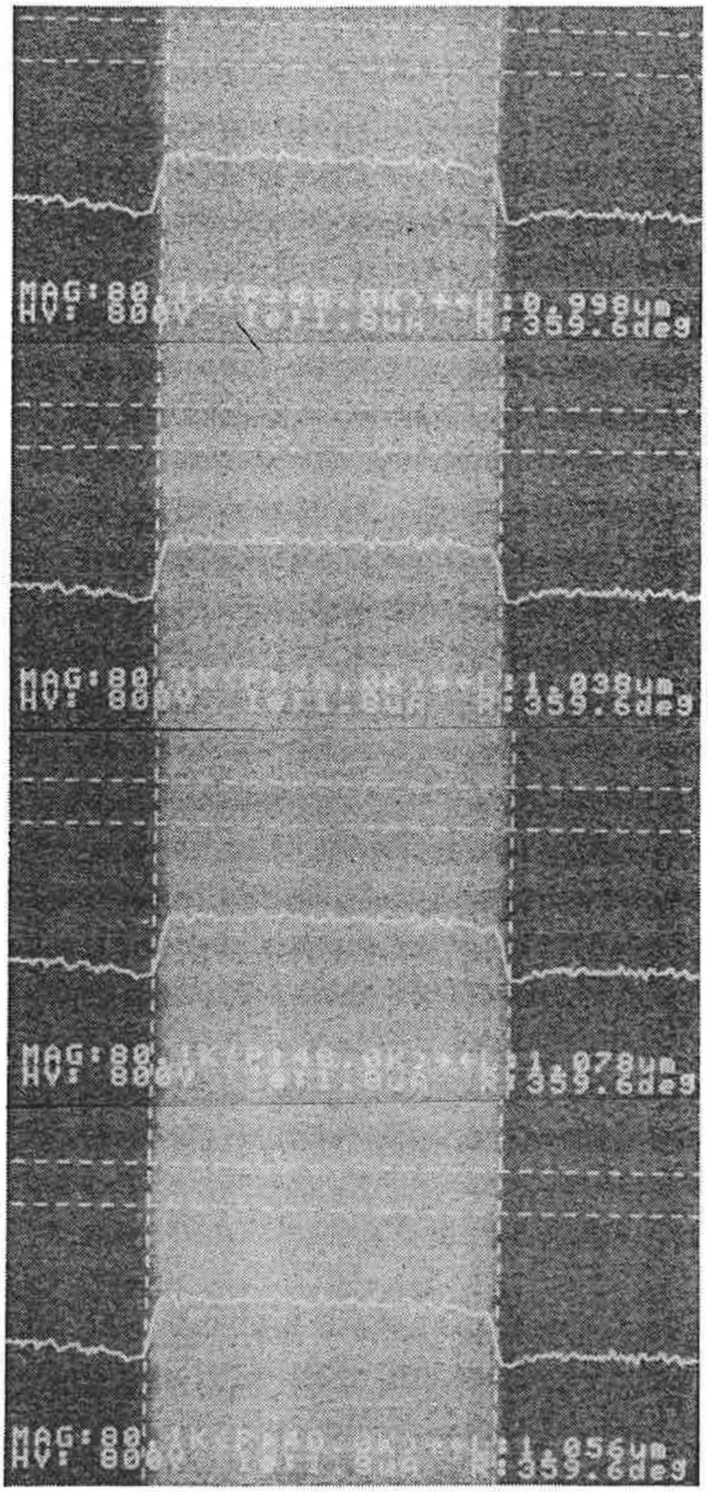
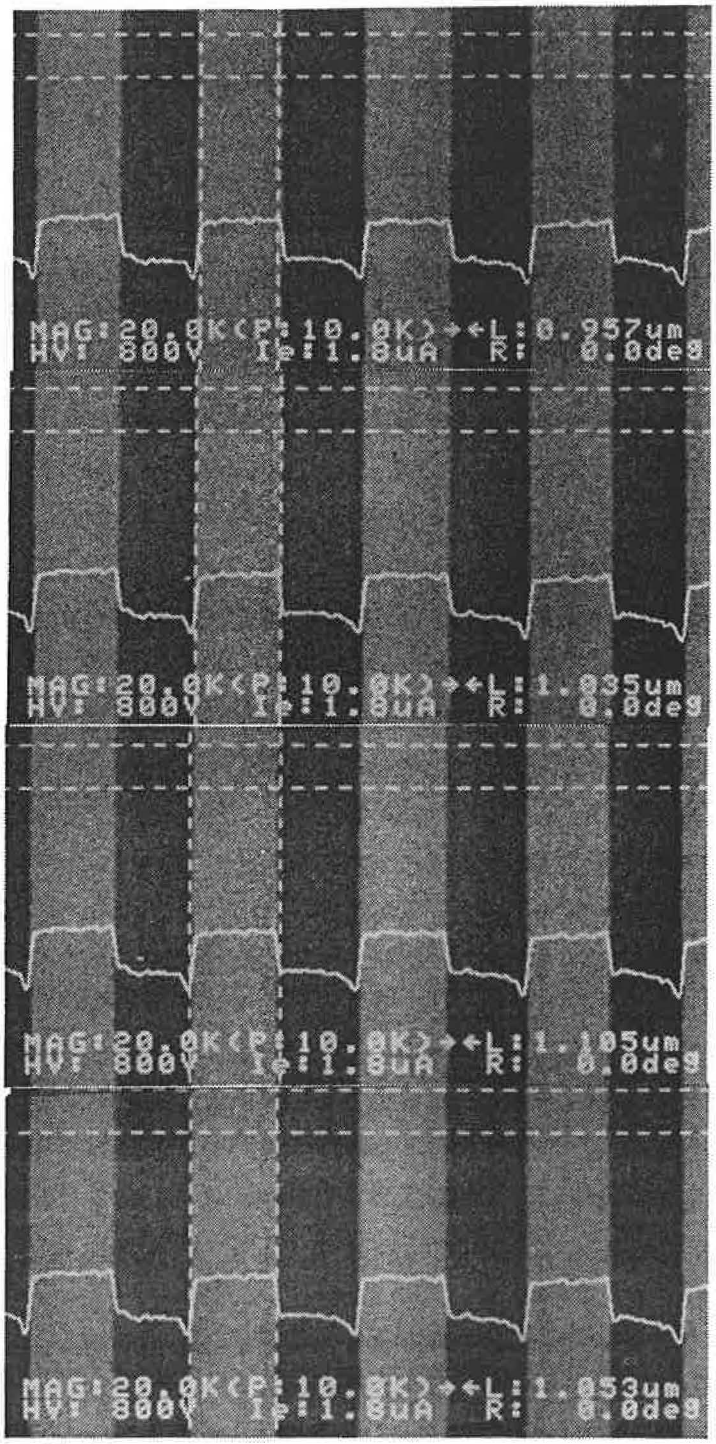


Fig. 8a

S6100 : SENSITIVITY OF MEASUREMENT STRATEGY
(20kX, 16 summed images, 32 measured lines at pitch 2)



THRESH 90

THRESH 50

THRESH 10

LIN. APPROX.

Fig. 8b

S6100 : EFFECT OF NUMBER OF SUMMED IMAGES ON S/N RATIO
(20kX, 32 measured lines at pitch 2)

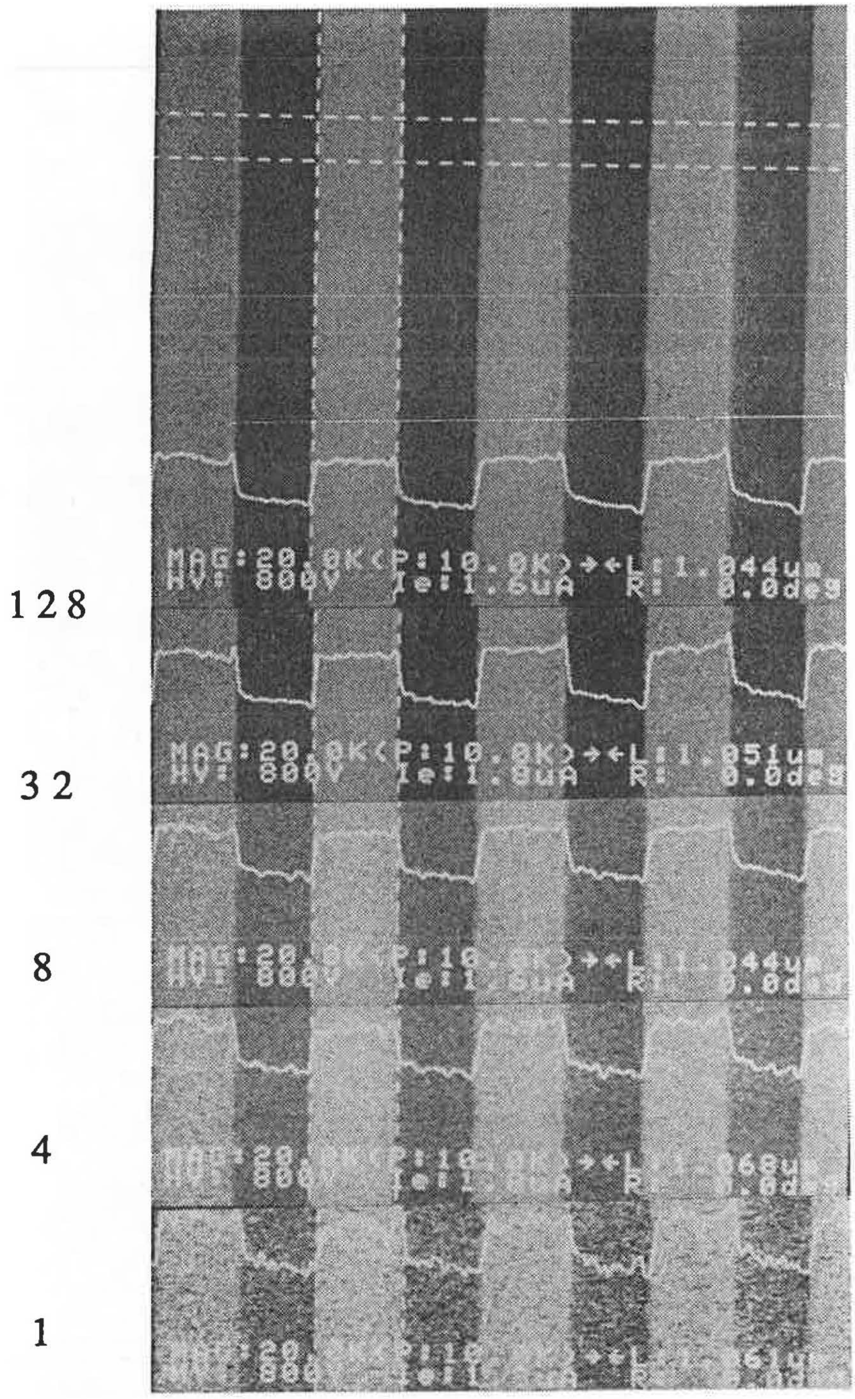
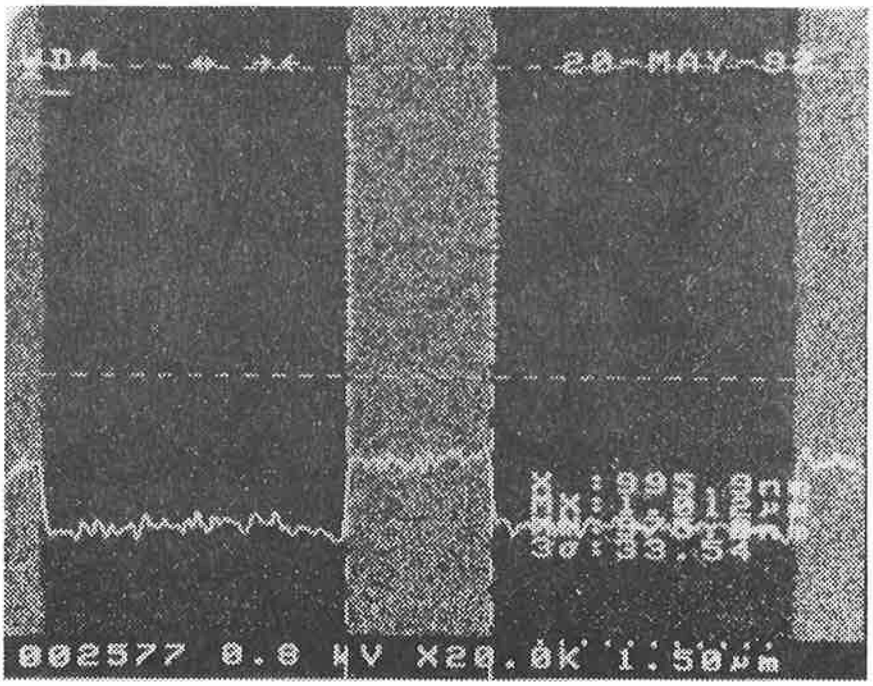
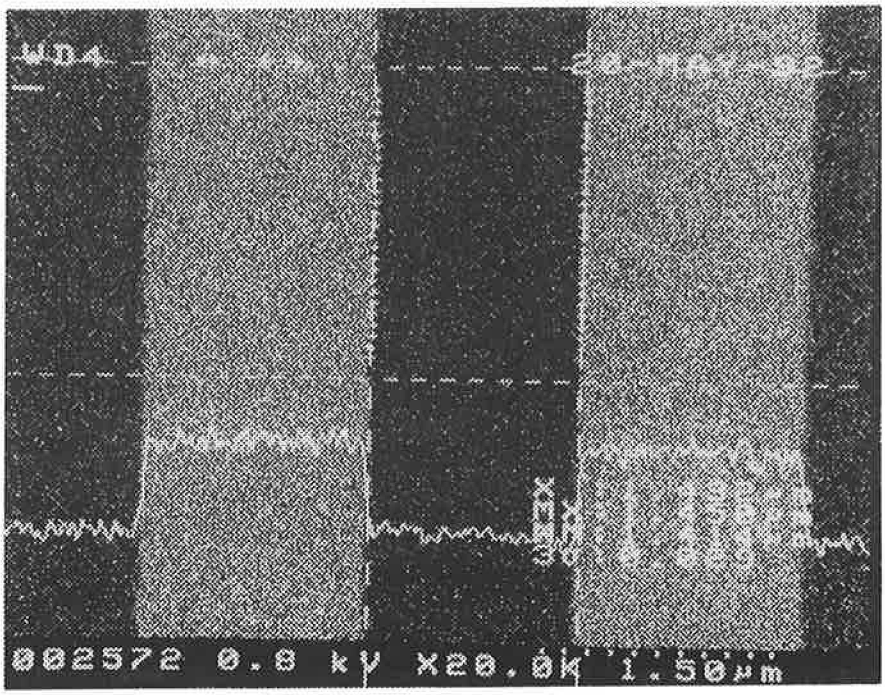


Fig. 9

S4000 MEASUREMENT EXAMPLES



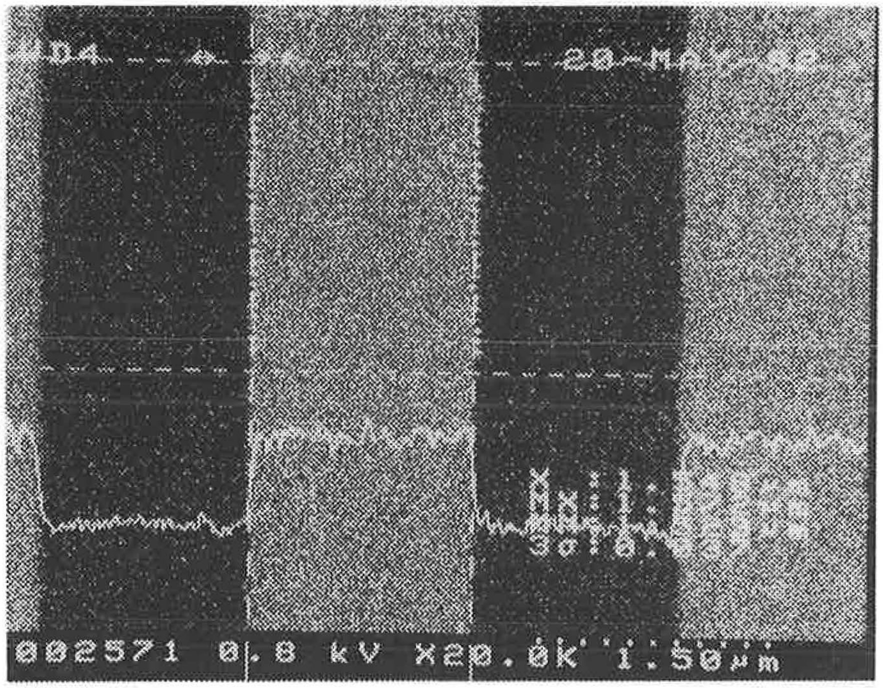
1.0 um Chrome



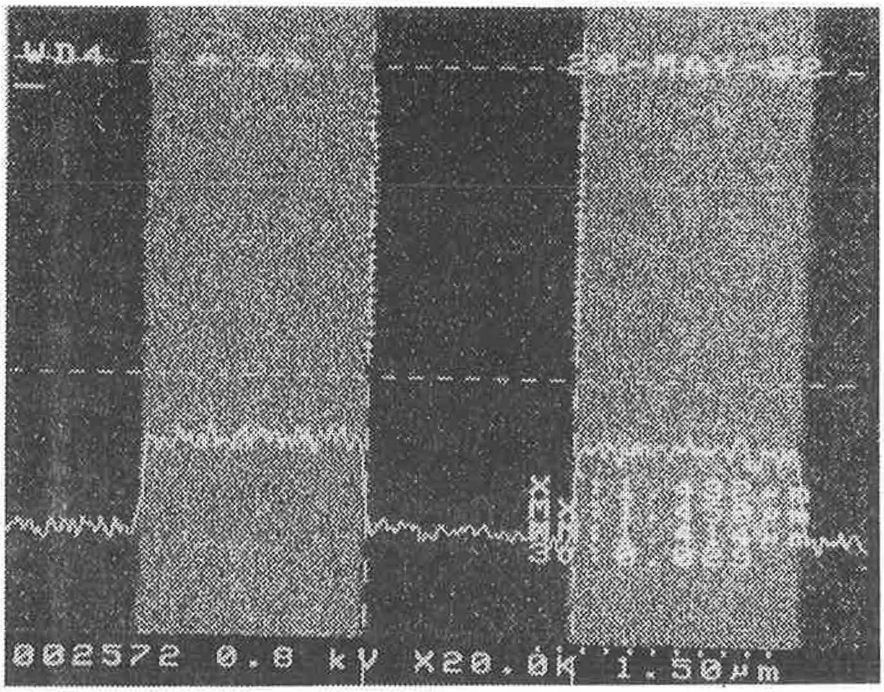
1.0 um Quartz

Fig. 10

S4000 MEASUREMENT EXAMPLES



1.5 um Chrome

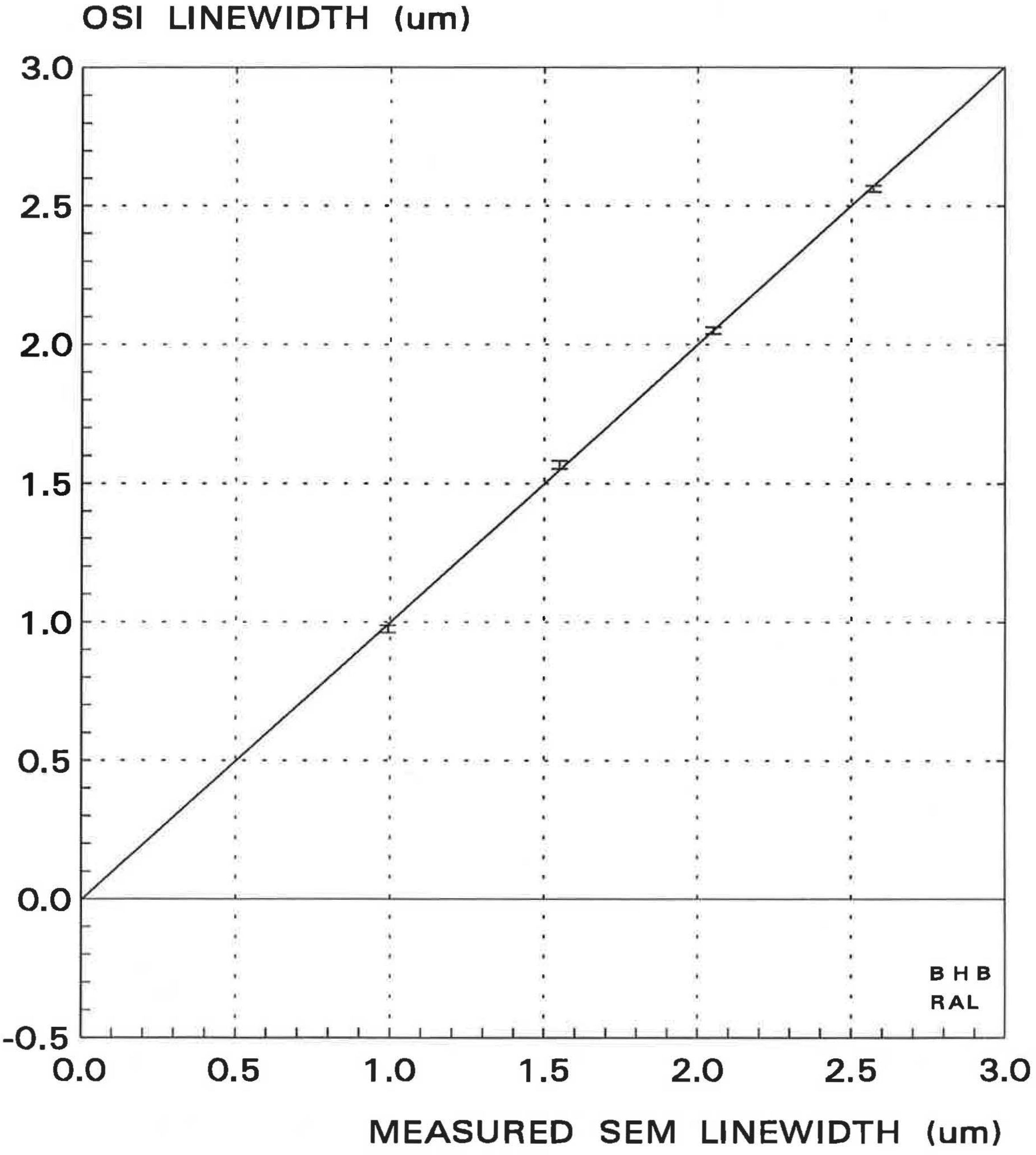


1.5 um Quartz

Fig. 11

S4000 LINEWIDTH CALIBRATION

Chrome lines, IMEC sample (run 2)

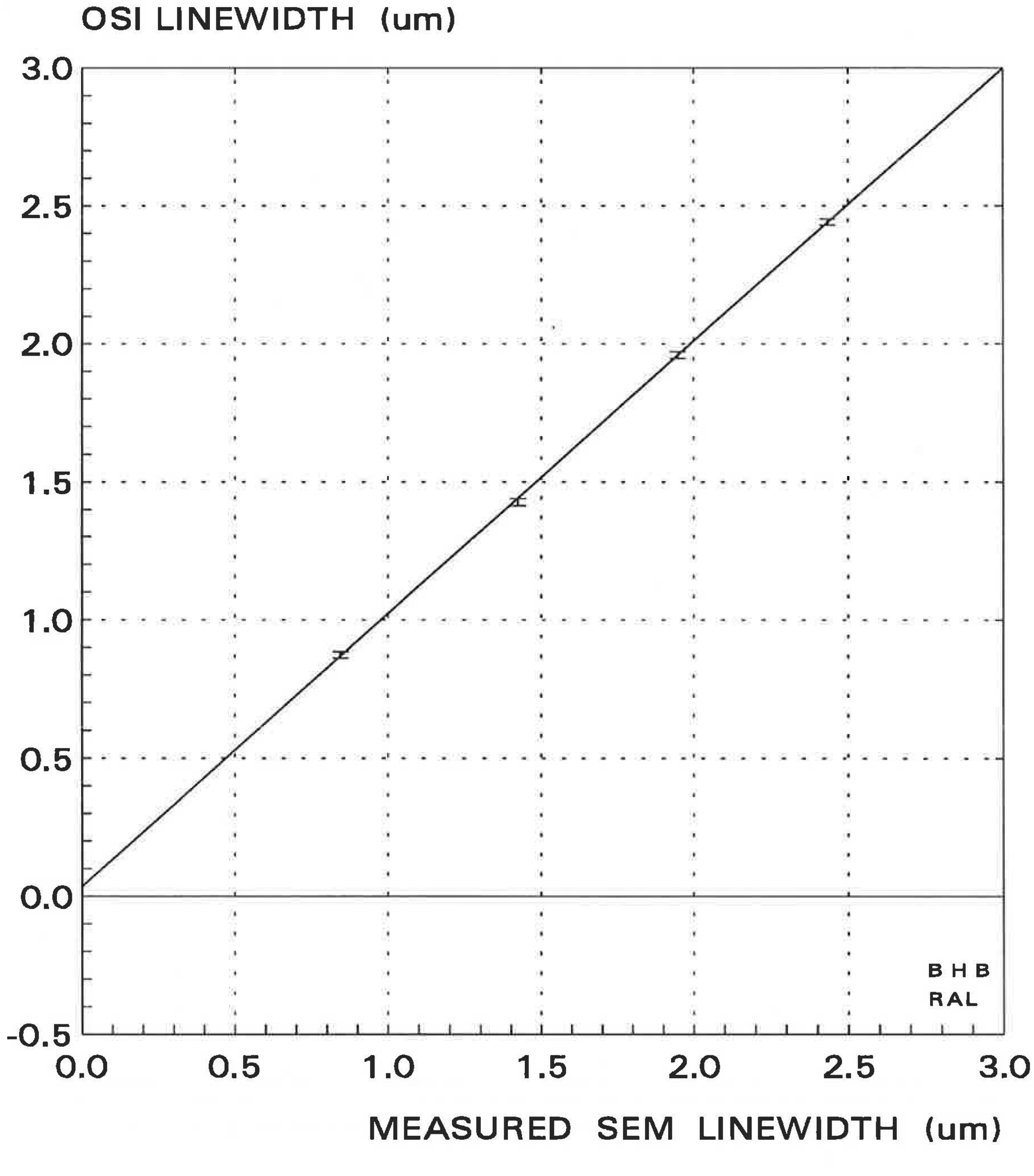


Correction to NPL standard :
<Corrected> = 1.002 * <Measured> - 0.007

Fig. 12

S4000 LINEWIDTH CALIBRATION

Quartz lines, IMEC sample (run 2)



Correction to NPL standard :
<Corrected> = 0.988 * <Measured> + 0.032

Fig. 13