LEBES OPERATION GUIDE

by

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LEBES OPERATION GUIDE

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This write up covers an introduction to the Lebes Instruments. Section 1.0 describes its various modules and peripherals. Section 2.0 discusses a typical electron beam lithography flowchart. In section 3.0 the Pattern Writing strategy is discussed. Section 4.0 describes various Pattern development tools and their necessities in specialised cases. Section 5.0 gives the procedures of operation of the LEBES machine.

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Section 1.0

LEBES is an electron beam direct writing instrument useful for writing patterns on electron sensitive materials like PMMA. It is built around the AUTOSCAN SEM from the ETEC corporation.

1.1 The Electron Optical Bench

The electron optical column differs from the AUTOSCAN SEM (refer to AUTOSCAN manual) in the following aspects:

a It has a set of blanking plates which are used to blank the electron beam in the column.(Unlike the case in a typical SEM where is beam is unblanked)

b It has a larger specimen holder which holds 2" wafers and is movable in two mutually orthogonal directions with the help of two stepper motor drives. Electron beam writing is done normally at 20 KeV accelerating Voltage. The exposure and development data discussed anywhere in this write up is applicable to this electron energy unless specified otherwise.

1.11 The Electron Optics

This sub section describes the actions of electron beam generation, blanking, focussing, deflection and aberration correction as applied to the LEBES machine.

1.111 The Electron Gun

The electron source is a directly heated, precentered, tungsten filament which emits thermal electrons. These electrons are accelerated towards the anode cap while passing through a wehnelt cup. The wehnelt cup is maintained at -20 KV (or any other voltage selected on the electron source module). The anode cap is at the ground potential. This electrostatic field causes the thermally emitted electrons to accelerate and converge into a crossover point. This is termed also as the gun crossover. The position of this crossover and its size is determined by the field distribution in the region between the whenelt cup and the emission tip. In the LEBES electron gun the "self biasing" method is used by introducing a fixed resistance between the cathode(filament) and the wehnelt. The structure of the electron gun is similar to that of a self biased triode, where the grid is analogous to the wehnelt and maintained at the most negative potential.

1.112The Blanking Plates

The blanking plates are placed such that the crossover is formed between them. When an electric field is applied across these plates, it causes the in coming beam to deflect transverse to its direction of movement. There is an aperture at the end of the blanking plate assembly which blocks the beam when it is deflected more than a particular angle and thus blanking off the beam from entering the successive stages.

1.113The Condenser Lens

The electron beam if unblanked passes through the aligner pipe which is surrounded by the pole pieces of the "condenser lens"(an electromagnetic lens with coils wound around a core). This lens focusses the beam onto the aperture which is in the center of the aligner pipe. The action of the condenser lens and the aperture combination is to control the electron current (number of electrons passing per unit time through the aperture). It also demagnifies the gun crossover to form another crossover known as the "lens crossover". As the condenser lens is excitation is increased the electrons form the crossover earlier and the crossover size is reduced. But there is also a reduction in the electron current as the middle aperture blocks most of the beam current as the beam is diverging near the aperture. This forces the user for a trade off between smaller beam diameter and larger beam current.

1.114The Objective Lens

The Objective lens simply demagnifies the lens crossover into another crossover known as the "probe". This too is a magnetic lens which is used for fine focussing of the beam(Probe formation). As the beam enters the objective lens it is deflected electromagnetically using the deflection coils and corrected for the aberration known as astigmatism. The objective lens also has an aperture known as the "final aperture". This size of this aperture is important to decide the depth of focus achievable. The smaller the size of the final aperture the better would be the depth of field.

1.115The Deflection coils

The electron beam has to be deflected either to form an image (Raster scan) or to write a pattern (Vector scan). This is achieved using two sets of deflection coils which produce mutually orthogonal fields to deflect the incoming electron beam. The electro beam in the column and that in the display CRT are scanned simultaneously to produce a one to one mapping of the signals from the SEM on to the display CRT.

1.116 The Stigmator coils

The focussing action of the preceding lenses causes an aberration known as the astigmatism. Physically this means that the cross section of the electron probe is not circular. This has to be corrected as this may lead to fuzzy images in the SEM mode and unequal exposures in the orthogonal directions during the Electron beam writing. This correction is provided by the set of coils known as the stigmator coils. These coils are excited to produce fields in mutually orthogonal directions which follow the following relationships:

$$Bx = R \, CosO$$

$$By = R \, SinO$$

Where Bx and By denote the mutually orthogonal fields produced by the coils. R is related to the field necessary to produce the corrected beam diameter and O is the phase relationship between the fields. The astigmatism is corrected by controlling R and O independently.

1.12 The Detection System

On the Lebes there are provisions for detection and measurement of the specimen emitted signals as well as the electron probe parameters. These are categorised as the Signal and Probe detection systems.

1.121 Signal Detection System

The interaction of the electrons with the sample produces various signals like Secondary and back-scattered electrons, X -rays etc Lebes has the secondary electron detector (Everhart Thornley Detector) in service. (There is also a Semiconductor detector for detecting the back-scattered electrons but it is not mounted.) The Secondary electron detector has a grid mesh at about +300 Volts potential (Needed to select most of the secondary electrons whose energy is typically < 50 eV). The secondaries attracted by this grid are accelerated to 10 KeV energy and impinge on to the scintillating material coated on to a light pipe. The light produced due to scintillation is carried by the light pipe and falls onto the photocathode of the Photomultiplier tube.(PMT) The PMT converts the photon signal to electrons and amplifies the electron current to detectable levels. This current is converted to voltage and sent to the video system for processing and imaging. The signal gain achieved by this detector system is typically of the order of 10+4.

1.122Probe detection System

This is placed on the specimen holder and is isolated from the rest of the stage. This is a tiny isolated copper cup with a copper grid mesh (grounded) over it. The copeer mesh is used for measurement of the probe current and diameter. The electron probe can be made to fall in to the cup fully or partly. The collected current is transferred to the specimen current processor module for amplification and display/imaging.

1.13 The Specimen Stage

The specimen holder is mounted on a stage which can be moved independently in the orthogonal directions in the horizontal plane. The stage is driven by two stepper motors which are have a nominal stepping accuracy of +- 1 micrometer. The stage is backlash corrected. This is accomplished by always initiating the step counter from a fixed value. Thus the errors due to backlash are always constant and not cumulative. There are limiting switches (four of them) which protect any damage possible due to over drive. These motors can be driven either manually (using a joystick) or under the computer control.

1.14 The Vacuum System

The vacuum system used to evacuate the electron optical column is based on a diffusion pump backed by a mechanical pump. There is provision for either manual or automatic control. The vacuum system is controlled by the vacuum system module which also senses the pressure at various points in the column and sets the interlocks and timings. (For details refer to AUTOSCAN manual) There is a liquid nitrogen trap which is used to condense and trap

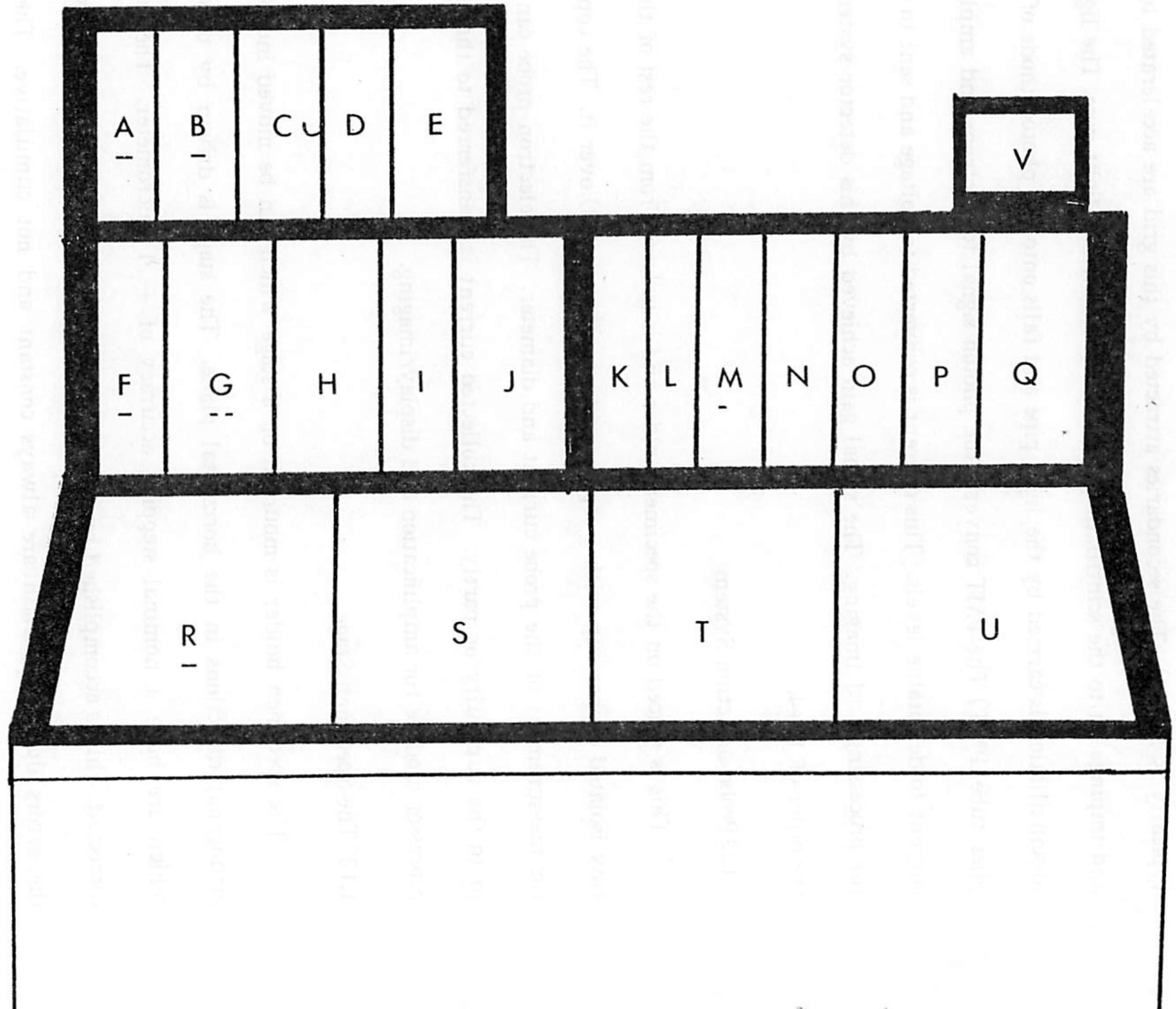

FIGURE - 1

any back-streamed diffusion pump vapour which otherwise could contaminate the column and also cause poorer vacuum.

1.2 The Electronics Console

This subsection describes various electronics modules and their utility. The Lebes instrument can be used in the following modes of operation:

a. SEM Mode

b. Measurement and Correction (MAC) Mode

c. Electron beam Lithography (EBL) Mode

For the sake of easy comprehension the description groups some of the modules. The order of grouping of the modules has nothing to do with their physical location on the console but on the basis of their common utility during the various modes of operation of the Lebes instrument. Some modules which have common utility are dealt separately. The alphabetic references (eg. L-Q is for Electron source control) to the modules are as per the physical locations shown in figure 1.

1.21 SEM Mode Modules

These modules are used for the routine SEM operations and include the controls for electron gun, Lenses, analog scan generation, magnification, signal detection, video processing and display.

1.211 Electron Source Control (L-Q)

This module controls the electron gun parameters. The accelerating voltage can be selected from any of these values:

Accelerating Voltages: 2.5, 5, 10, 15, 20, 30 KV

The filament heating current is controlled by the potentiometer marked as filament temperature. The filament emission current and the filament life (related to the decreasing resistance of the filament) are monitored by two meters on this console. This module is interlocked to the vacuum system and does not get activated unless the pressure in the gun region is sufficiently low.

1.212Lens Control (L-S)

This module houses the controls and monitor for the Condenser and the objective lenses. The Stigmator controls are also on this module. The Objective lens can be focussed in three successively finer controls which produce overlapping currents. Typical objective current is in the range of 1 Ampere.

1.213Scan Generator (L-I)

This module generates the raster scan necessary for the SEM imaging on both the viewing CRTs(L-T and L-U) and in the SEM column. The scan speeds can be varied in 5 steps. There are 5 modes of operations of this modules.

Normal, Window, TV, Linescan 1, Linescan 2

Normal mode produces the full screen raster. The window mode generates a window on the screen whose size and position can be selected using the two double potentiometers at the bottom right of the module. The TV mode is not functional. The Linescan 1 mode is used for generating a horizontal line (Both in the column and on the display). This is useful for waveform monitoring and some measurement purposes. Linescan 2 is not used. There is a switch on this module which cuts of all scans to the coils when in the spot mode. There is a separate provision for the Recording of micrographs. In this mode this module produces very slow scans which are necessary for photography on Record CRT(L-R). The two white press buttons on the top of the module are used to start or stop a Record scan.

1.214Magnification Control (L-H)

This Module controls the magnification of the displayed SEM image when the selector switch on the field control module (L-J) is in the remote magnification position. The magnification is achieved by reducing the size of the raster in the column in steps decided in proportion to the push button switches on this module. There is a magnification multiplier meter which gives a multiplying factor necessary depending on the vertical distance of the sample holder from the final aperture. The magnification vernier is used for fine increments in the magnification. There are two potentiometers which can be used for fine shifts of the magnified image by a few microns.

1.215Collector Control (L-O)

This module produces the necessary voltages for the secondary electron (SE) detector system. These include the SE collector grid voltage (+300 V), the Scintillator potential (+10 KV) and the PMT dynode and anode voltages (Max. 2 KV) The PMT voltage can be varied with the help of the multi-turn Potentiometer marked "contrast" on this module. This controls the contrast of the image obtained on all the CRTs.

1.216Video Amplifier (L-P)

This module amplifies and processes the SE signal obtained from the PMT. The dark level control simply adds or subtracts some d.c. voltage to or from the signal. This effectively controls the Brightness of the image on all the CRTs. The detector chain introduces some non-linearity in the process of amplification. The selection of any of the two middle push button switches on this module introduces a compensating non-linearity factor known as "Gamma factor". This compensation is only approximate and subjective. On selecting the Auto mode this module sets the optimum values of contrast and brightness and assures the safety of the PMT from excessive voltages possibly fed by the user in pursuit of higher contrast.

1.217Vacuum Control Module (L-B)

This module controls the operation of the vacuum pump and has the vacuum logic. The interlocking electronics throughout the Lebes machine is activated if the vacuum conditions are favorable. The vacuum valves can be activated either in the manual or in the automatic mode. There is a map of the column and various valves on this modules. The LEDs on this map when ON indicate that the particular valve is open. The general scheme of operation in the Automatic mode is described as follows. When the evacuation switch is pressed, the valve V2 opens and the mechanical pump (which is always running) starts the rough evacuation of the column. When the pressure is about 10-3 torr the valve V3 opens and evacuates the diffusion pump line. After a delay of about 30 seconds(Provided the Diffusion heater is hot enough and the cooling water and dry air supplies exist) the high vacuum valve V1 opens thus connecting the column to the diffusion pump. The chamber pressure is monitored using ion gauges. The gauge output is constantly compared to a set level which corresponds a pressure of 10 -4 torr. When this pressure is reached the interlocks to the display and the electron source supplies are activated and the machine is ready to use. On pressing the Vent switch the Valves V1 through V3 close and valve V4 is open to let dry air into the chamber and the column. The vacuum interlocks are automatically disabled.

1.218Diagnostics Module

This module is connected to various test points in the Lebes hardware. On selecting different settings of the selector switch various voltages and waveforms can be monitored. The Voltages are be immediately displayed on the auto-ranging meter on this module. The waveforms (eg. The scans and the video waveforms) can be monitored by connecting the BNC output on this module to a suitable oscilloscope. This module is very useful for the preliminary troubleshooting.

1.22 MAC Mode Modules

For the purpose of exact dose control while exposing a resist surface with the electron beam, it is necessary to know to the best accuracy the probe current and the electron beam diameter. It is also necessary to be sure of the raster distortions and provide the necessary corrections. The modules described in this sub section deal with the above measurements and corrections. There is a channel selector switch on the Module L-R. In the CH 1 mode the secondary electrons are imaged. On setting to CH 2 the signals from the cup are imaged.

1.221Specimen Signal Processor (L-L)

This module collects the very low level signals from the cup and amplifies them and displays them on a calibrated meter. This is essentially a picoammeter. The current could be read in 9 ranges. There is a provision for adjusting the zero reading of the meter when the inputs are shorted and ground. This is necessary for accurate reading of the probe current. There is also an alarm buzzer which gets activated whenever the cup is in contact with some voltage source or shorted to ground.

1.222Derivative Amplifier (L-M)

This module differentiates the input signal (The time constant be selected using the selector switch on the module) and feeds back to the system through the channel 2 (CH2). The output signal is a mixture of the input signal and its derivative. The percentage of derivation could be selected using the bandswitch on this module. This module is used during the measurement of the beam diameter.

1.223Manual Video Amplifier (L-K)

This module is used for imaging and measurement using the specimen current. Various signals could be selected as inputs to this module but only the cup current input is connected to it. There is a switch marked "Wf". When activated this produces the video waveform on the CRT 2 (L-T). The controls on this modules are used during filament saturation and during beam diameter measurement.

1.224Dual Scan System (L-D)

This module generates two mutually orthogonal scans in the column and on CRT 1 (L-U). In this mode the video information from these two scans is displayed on the CRT 2 (L-T). The two linescans can be made either independently or together. These scans are used to scan the mutually perpendicular edges of a grid element and the video signal from the cup is displyed. The horizontal and vertical positions of these scans can be changed using the marked multi-turn potentiometers on this module. CAUTION : NEVER CHANGE THE GAIN POTENTIOMETER SETTINGS ON BOTH HORIZONTAL AND VERTICAL LINE CONTROLS. These have been calibrated to scan a known dimension and the beam diameter measured is related to this settings. In the "High resolution" mode the scan lengths are reduced and the risetime of the video signal seen on the CRT (L-t) indicates the beam diameter in the two directions. The stigmator controls on Lens control module (L-S) have to be used if the beam diameters in the two directions do not match.

1.225Dynamic Correction module (L-E)

This module is used to correct for the raster non-linearity. The raster used is not always ideal. As a general case the voltage waveforms generating the raster can be written as:

X' = aX + bY + cX**2 + dY**2 + e

Y' = fX + gY + hX**2 + iY**2 + j

The above equations represent a real raster with intermodulation of horizontal and vertical components. For an ideal raster all the above coefficients except "a" and "g" have to be reduced to zero. The coefficients "b" and "f" denote the linear intermodulation of the scans. This results in so called "Trapezoid" distortion. The coefficients "c", "d", "h" and "i" constitute the non-linear component of the intermodulation. These are classed as the Barrel and Pincushion distortions. These non-linearities are corrected using sample with very fine gratings and imaging their "Moire fringes" made while scanning. The distorted image of the sample (which is assumed to have perfect mutually perpendicular edges) informs the raster distortions present. Various controls on this module are used to correct for a raster nearest to the ideal. The computer is used for this purpose and has a program named as "MOIRE" on the hard disc. CAUTION: LEBES HAS BEEN CORRECTED FOR A GOOD RASTER. IN CASE THE RASTER TO BE CORRECTED ANY MORE, DO NOT CHANGE THE SETTINGS OF THIS MODULE WITHOUT FOLLOWING ALL THE RELEVANT LITERATURE (REFER TO LEBES SOFTWARE MANUAL).

1.23 EBL Mode Modules

These modules are used for electron beam writing, Re-registration, exchanging data with the computer and partly for beam related measurements. The computer data is converted to the vector scan signals and these signals drive the deflection coils. On the lebes four registration marks (Used for re referencing the writing area at the next level of mask writing) are made at the corners of the EBL field. These are scanned over and detected for aligning the wafer back to the previous location and orientation with respect to the undeflected position of the beam. This process is known as the re-registration.

1.231 Field Control Module

This module controls the field size when not in the Remote Magnification mode. There is a switch on this module which selects the mode of operation of the Lebes machine. There are following modes possible:

1.2311 Remote magnification In this mode the control is transferred to the analog scan generator (L-I). The System works only as an SEM and the raster field is not calibrated for electron beam writing.

1.2312 SEM In this mode SEM images can be obtained with the field sizes equal to or in proportion of the raster used for electron beam lithography. This is done by built in scan generator for this purpose. The electron beam in the column is unblanked.

1.2313 EBL This is the electron beam lithography mode. Vector scan is generated using the data from the computer and the EBL scan generator (L-G). Beam is blanked and unblanked only on the computer command. Rest of the hardware works as in the SEM mode.

The controls marked as "shift", "align" and "^ field" for both x and y directions (horizontal and vertical) are used to slightly change the position, shape and the size of the raster field. These are needed during re-registration.

1.232 EBL Registration Module (L-N) This module, under the computer control generates registration scans at the positions specified by the computer (At present at the four corners of the EBL field). The size of the registration scan area can be chosen as either 0.5, 1.0 or 2.0 percent of the lebes field size (0.5mm x 0.5mm). The registration scan are produces with video modulation on both the visual CRTs. On CRT 2 (L-T) the scans are in actual size with respect to the lebes field. On CRT 1 (L-U) the four scans or magnified and the images of the four corners of the lebes field registration coordinates are displayed. The multiturn potentiometers on this module are used to move these four scans to fit into the right relative positions. (Anti clockwise scanning of the four corners). The images of the registration marks obtained so are aligned using the controls on the field control module (L-J).

1.233 EBL Scan Generator This module receives the pattern data from the computer and converts it into the vector scan signals. The positioning data is converted using two 16 bit DACs. The deflection data is converted (in accordance with the field control module (L-J)) by a 12 bit DAC. This module also generates the blanking signals necessary while stepping the beam or during stage motion. There is another mode selection switch which should be always on the EBL mode.

1.234 Computer Interface (L-F)

This module converts and interacts between the computer and the EBL scan generator (L-G). There are no controls on this module.

1.3 The Stage Control Console

This console contains the execution hardware and the display of stage position. The current X and Y position of the sample holder table is displayed in millimeters with a least count of .001 mm. These values can be reset using the two white push button switches for each value. To achieve this the selector switches on this console are to be set to any setting other than Remote and the white push buttons pressed simultaneously. CAUTION: IT SHOULD BE NOTED THAT ONCE THE STAGE POSITION COUNTER IS RESET, THE POSITIONS OF THE CUP HAS TO BE EXPERIMENTALLY FOUND AGAIN AND THIS VALUE ENTERED IN THE FILE KNOWN AS "CUP" ON THE HARD DISK. NEVER RESET THE COUNTERS DURING THE EXPERIMENT OR BETWEEN TWO LEVELS OF MASK EXPOSURES.

The lower part of this control contains some hardware for the stepper motor drives, field correction electronics and the deflection power amplifiers.

1.4 The Computer, peripherals and software

Lebes is interfaced with a Perkin Elmer 1625 computer system. It has a 16 bit architecture and capable of handling data transfers of data up to 5 MB through the parallel ports.

The write up here covers only superficially the functions and details of the peripherals and the operating system software. Refer to the literature available on the 1625 system.

1.41 Peripheral devices

There are two hard disk drives, one fixed disk drive(DSC 2) and one replaceable disk drive(DSC 1).The operating system and some of the execution software resides on Disc 2 (also referred to as FIXD). Disk 1 (also called PACK) has most of the executable and use generated files.

There is a Magnetic tape drive which is used for storing large data files which can not be put on the hard disk due to memory limitations. The patterns developed using the CAD systems can also be transferred to Lebes through Magnetic tapes.

There is a character printer which is hooked up to the computer through standard serial port.

Finally there is a CRT terminal which is the user port for developing, editing, formatting, and executing the pattern files and also to control the Lebes machine through the computer.

1.42 Software This sub section describes only the details of the programs useful for the operation of Lebes machine. The details of operating system and the spooler are elsewhere in some of the 1625 software manuals.

1.421 LEBES

This is an execution program that requires the input of pattern data on a file in the hard disc or the Magnetic tape. There are provisions for the entry of the exposure and blanking data such as exposure time per point, number of points to skip, the box, line, spot delays and the mode of the writing. The beam can be incremented either spot by spot or a continuous scan (slew) can be made. There is no control over exposure when slew scan is used. The stage coordinates can also be set and the stage moved under the control of this program. This program can be used for the re-registration routine too. When executing this routine the program looks for a file named REREF.000. It is necessary to prepare this file before hand which must have the coordinates of the re-reference scans. When this program is executed prompts for many data inputs. A <RETURN> would make the program to assume either the last data value or the default value preset.

1.422PATTERN

This program is helpful in generating the pattern data files. There are 15 possible commands which control various parameters. (viz. device blanking, pattern fill-up mode, exposure time, number of points to be skipped, box, line and spot delays, stage position etc.) For these commands refer to the Lebes software manual. The pattern file accepts data in blocks. Each block size should not be more than 16. PATTERN can also be used for editing the files developed by it. Only the data attributes to any command in the file can be changed. NOTE: IT IS NOT POSSIBLE TO CHANGE A COMMAND DURING EDITING it is suggested that some null commands (0) be used while developing a data file. These do not have any format for data attributes and can be changed to any other command later if needed. CAUTION: SKIP THE INPUT (<RETURN>) WHEN THE COMPUTER PROMPTS " IS THE LOGGING OF COMMANDS DESIRED ". If an "yes" is entered the manual data are written over the disc volume and may overwrite some files if the disc is full.

1.423CHANGE

This program helps in changing any particular command number throughout the pattern data file. This also extends the attribute field to suit the new command data attribute format. This program accepts the files developed using the PATTERN program, prompts for the old and new commands, replaces the old command by the new one and saves it into another user named file. The only disadvantage with this program is that it can not selectively change a particular command in the pattern file.

1.424STEP

This program can be used to step and repeat a pattern defined by a file generated using the PATTERN program within the Lebes field (0.5 mm x 0.5 mm). CAUTION: THE OUTPUT

OF THIS PROGRAM IS USUALLY A VERY LARGE FILE. IT IS NECESSARY TO STORE THE OUTPUT FILE ON TO THE MAGNETIC TAPE AND NOT ON ANY OF THE HARD DISCS. THE DISCS ARE NOT FILE PROTECTED AND ANY OVERWRITE MAY CRASH THE SYSTEM. Refer to the 1625 system literature and software manual for saving large files developed using this program directly on to the magnetic tape.

1.425EDIT16

This is an editor program for developing and editing execution programs like those described above. It uses the assembler codes of the 1625 system. For details refer to 1625 software manual and LSI 11 series Assembler guides.

Section 2.0

This section describes the various steps involved in the process of electron beam lithography. A typical electron beam lithography flowchart is shown in figure 2.

The first step for electron beam lithography is to prepare the necessary pattern data file. Some methods for data preparation and storage are described in Section 3.0. For direct write purposes the wafer is coated with an electron resist and pre-baked at specific temperature for specific time which depend on the resist and material of the substrate. Prebaking is essentially done to remove the solvent content left on the substrate during spin coating. The Wafer with the electron resist is loaded into the specimen chamber after making some scratches at some wafer edge. These scratches are used for later focussing on the wafer. The column is evacuated and the beam is saturated. (Beam is turned on after moving the stage such that the cup is under the final aperture. This can be achieved by storing the relative stage coordinates of cup position in a computer file before hand.) The beam current falling into the cup is measured and set to the desired value by varying the condenser lens current. (The data of necessary beam current is decided before hand on the basis of the dose computations and the beam current limitations of the machine for a given beam diameter. The Beam diameter is measured using the "Cup crossing technique". Stage is now moved such that the edge of the

```
        Pattern data development and storage
                              |
 ---> Coat Wafer with Resist and pre-bake
*|************|*****************
*|          Load Wafer on to stage              *
*|                            |                  *
*|  Measure beam current/diameter and focus on Wafer     *
*|                            |                  *
*|   ----------> Move stage                   *
*|   |                        |                  *
*|   |        Is it first level ?  -> NO -> Reregister   *
*|   |                        |              |       *
*|   |                      YES              |       *
*|   |                        |              |       *
*|   |                    Expose  <-----------       *
*|   |                        |                  *
*|   -- YES <-  To Step and Repeat ?              *
*|************|*****************
 |                        NO
 |                         |
 |   Unload Wafer develop post-bake and process
 |                         |
 --------- YES -- Next Level ?
                           |
                          NO
                           |
                          END
```

Wafer is in the field of view. The edge of the wafer is scanned in the SEM mode until the scratches made earlier (or some other focussable artifact) is in the field of view. The focus controls are varied for getting the best possible image of the artifact at the lowest field size. This refocussing on the wafer is necessary because of the small variations in the working distances as the stage is moved such that the beam falls on the wafer instead of the grids of the cup. The Lebes is set in the EBL mode (The beam is blanked) and the stage is moved to the preset exposure coordinates. The registration routine is entered for all the masking levels other than the first. After aligning the registration marks the pattern is exposed on the wafer under the computer control. The beam is unblanked whenever necessary under the computer control. If step and repeat operation of exposure is desired, then The above steps are repeated after moving the stage in known steps of increments and reregistration for all masking levels other than the first. The Wafer is unloaded and developed in suitable resist as per the design and post-baked at specific temperature for specific time which depend on the resist and the substrate material. Further processing or done as for the device design steps and all the above steps are repeated if another masking is desired. The description and procedure of operation of Lebes cover only those steps that are enclosed under the "*" boundary.

Section 3.0

This section describes the pattern Writing strategy of the Lebes Instrument.

3.1 The Field Structure

The pattern writing process is structured into the following steps: The various chips (major fields) to be written on the wafer are accessed by mechanical movement of the stage. The maximum major field size of the Lebes is limited to 0.5 mm x 0.5 mm . This is the area on wafer that can be written over without moving the stage. The major fields are divided in to minor fields which are accessed by the deflection and positioning of the electron beam. For the purpose of accuracy and minimum distortion the fill-in field (minor field) size is much smaller and limited to 31.25 um x 31.25 um. Within each minor field the pattern are written in manhattan geometries. In Lebes the beam positioning in the major field is done using a 16 bit DAC. This defines a positioning resolution of 65536 points or approximately 76.3 Angstroms. Each pattern is broken into the primitive features made of rectangles. These rectangles are filled-in by stepping the electron beam over the tiny area in any one of the following fill-in modes:

a. Spiral

b. Raster

c. Serpentine

The fill-in is done using a 12 bit DAC which has 4096 steps. The spiral and serpentine modes of fill-in save a lot of fly-back time that is necessary in the Raster mode of fill-in. When the size, of the rectangle to be filled-in, exceeds 4095 steps (or 31.25 um) in either of the deflection directions, the pattern is automatically broken into many minor fields containing the parts of the rectangle and these parts are then filled-in

3.2 Stepping Distance

It is not always necessary to deflect the beam in 76.3 Angstroms steps. There is provision on Lebes to chose the number of exposure points to be skipped while drawing a line or filling an area. The LEBES program prompts with a question RESOLUTION ? If N be the number entered at this stage then the spacing between two exposure spots is given by 76.3*N angstroms(stepping distance). This skipping becomes useful while filling a large area of resist where an average exposure could be used for each spot without losing pattern resolution. The advantage of skipping many exposure points lies in the reduction of the throughput time as the total spot and line delay time are significantly reduced. CAUTION: IT HAS BEEN EXPERIMENTALLY FOUND THAT THE STEPPING DISTANCE CHOSEN SHOULD NOT BE LARGER THAN ABOUT HALF THE BEAM DIAMETER. The evident disadvantage of increasing stepping distance is the increase in the exposure non-uniformity over the exposure area.

3.3 Exposure

The LEBES program requires another number (M) which sets the exposure time (Dwell time) per exposure spot. This number can be either entered manually or put in the pattern data file. The exposure time is related to M as follows:

$$Te = 0.1 * (1 + M)$$

where Te is the exposure time in microseconds

For evaluating the dwell time the necessary exposure dose (charge deposited per unit area) must be known. There are various methods for evaluating the Threshold exposure dose for a given set of resist, substrate, beam energy, beam diameter and development conditions and these have been tabulated in related literature. For a complex patterns spaced close to each other the exposure in one area affects the charge deposited elsewhere. This is termed as the proximity effect. This forces the designer to specify the exposure dose of the various regions of the whole pattern after correcting for the proximity effect. There are various literature and programs available for the evaluation of the proximity corrected dose. The reader is referred to the literature in this field (eg. Papers from Parikh and more recent work by A.chen and report by P.R.Deshmukh) In most of the simpler cases the average dose needed can be found from the resist data (supplied from the manufacturer) or from literature describing the particular resist. The average dose can be related to the exposure time as:

$$D(av) = 1.72 * Ib * te / N ** 2$$

Where D(av) is the average dose in micro coulombs per square centimeter, Ib is the beam current in picoampere, Te is the exposure time in micro seconds and N is the number of points to skip.

The above relation is not valid for single lines or area smaller than 2 um x 2um. It is suggested that the above relation be used only for isolated large areas.

Section 4.0

This section briefly describes the pattern development methods and tools used.

The pattern data could be generated using either a CAD tool (Kic terminal, for example) or directly on the Lebes instrument.

4.1 KIC Terminal and software

The patterns can be developed and laid out on the Kic terminals and saved as layer files (.kic files). (Refer to kic manual for details) A program called "kictocif" converts these files into a data format known as Cal-tech Intermediate Form (.cif files) (Refer to /cad/man/man1/kictocif.1) kictocif prompts for defining the value of the grid to grid spacing (Lambda). The cif files are operated upon by a program called "ciftomann" which reformats the cif files into the format suitable for the chosen pattern generator.(.pg files) (Refer to /cad/man/man1/ciftomann.1) The pg file data are processed to generate smaller rectangles to fit into the Lebes minor field (if the pattern is larger than a minor field) and stored on to a tape using the "lebesgen" program. The data generation and processing as summarised as shown in figure 3.

The Pattern development using Kic terminal is useful when large and complex pattern structures are involved. The patterns thus developed can be reformatted to suit the Lebes and stored on a magnetic tape for use whenever needed. Single lines can not be drawn using his method as the conversion software breaks down all the linewidths (or lengths) into rectangles of minimum width of two units.(Refer to cadman/ciftomann) Another limitation of this method (while drawing long lines with small widths) is that the smallest value of "Lambda" (The spacing between two grid cells on the Kic terminal) that can be chosen without overflow

Pattern data generation

KIC		.kic		.cif		.pg		Mag
	—>		—kictocif-->		—ciftomann-->		-lebesgen->	
Terminal		files		files		files		Tape

is .001 um. This means that the minimum linewidth that can be drawn using this method is limited to 200 Angstroms. At these extreme conditions the application of this method generates large percentage of data inaccuracies due to relatively large rounding off errors which occur during data scaling and reformating.

4.2 Pattern generation on Lebes

As described in the earlier section the program PATTERN can be used to develop the pattern built using rectangles as primitive features. PATTERN understands 15 commands. All values entered must be integers but entered in floating point format (i.e. every number should be followed by a decimal point) The pattern file is structured in blocks having binary records each of 256 bytes length. Every block can take a maximum of 15 commands. Each command has maximum 8 words. The first word of a command is the command number and the following 7 words are used for command arguments. Word 121 holds the number of commands in the block and word 128 has a value = 1 if there are more blocks to follow and a value = -9999 for the last block.

The following is the list of command numbers used to make a pattern file:

Command number	Description

1. Sets the blanking parameters.

   Has one argument which has the following values:

   1 = unblank beam

   4 = unblank view CRT

   5 = unblank beam and CRT

16 = unblank record CRT

17 = unblank beam and record CRT

21 = unblank all

2. Resolution: Sets the increment value or stepping the beam.
Single argument.

3. Spiral Rectangle: Draws a rectangle in spiral fill-in mode.
The arguments are the lower right corner coordinates, width and height.
Four arguments.

4. Stage motion: Stage is moved to the coordinates specified. (in micrometers)
Two arguments.

5. Wait: This must be given after every stage motion.
This introduces enough delay for the

stage to settle.

No arguments.

6. Exposure time: This is related to the dwell time as 0.1*(1 + M) micro seconds. M is the integer argument.

7. Raster Rectangle: Draws the rectangle in the raster fill-in mode. The four arguments are lower right corner coordinates, width and height.

8. Raster square: Same as command 7. Four arguments are right hand corner coordinates, size and resolution.

9. Serpentine rectangle: Draws a rectangle in the serpentine fill-in mode. four arguments are as in command 3 or 7.

10. Box delay: Single argument which defines defines the multiple of 3 microsecond delay increment after drawing a rectangle.

11. Line delay: Single argument that defines multiple of 3 microsecond delay after drawing a line.

12. Point delay: Beam stepping delay given as = 0.1*(7 + n) microseconds. n is the integer argument.

13. Mode: Single argument which sets the step mode scan for m = 0 and sets the slew mode scan for m = 2.

16. To initialise the minor field DACs. Two arguments each <= 4095.

17. To initialise the major field DACs. Two arguments each <= 65535.

These commands can be used while making the pattern file. The only limitation is that large files can not be developed using PATTERN because of memory limitations on the hard discs. CAUTION: MAKE SURE THAT THE OPERATING VOLUME IS "PACK" (DSC1:). ANY OVERFLOW ON VOLUME "FIXD" COULD CRASH THE SYSTEM.

Section 5.0

5.1 General instructions

1. Login
2. Check all the settings of the diagnostics module.

3. Check and set the following settings:

a. Set the cup switch on the column OFF.

b. Set the filament temperature potentiometer on the electron source control module to minimum.

c. Select the accelerating voltage (Typ. 20 KV) by pressing pressing the push buttons on this module. (GREEN BUTTON FOR 20 KV).

d. Set the multiturn potentiometer on the collector control to read about 4.00

e. The toggle switch marked "Wf" on the manual video amplifier to NORMAL position.

f. Set the switch on the field control module to SEM position.

g. The field size selector to position marked "1".

j. The visual mode selector on the scan generator module to NORMAL position.

h. The visual rate selector on scan generator module to RAPID position.

i. The toggle switch on scan generator module to NORMAL position.

j. Press the two push buttons marked "8" and "10+4" on the magnification control module.

k. Set the Toggle switch on EBL scan generator to EBL position.

l. The toggle switch at the bottom of dual scan module to OFF position.

m. The vacuum module set in the AUTO mode and monitor the LEDs marked "MP", "V2"," V1" and "DP" are ON.

n. The pressure monitored (on the meter L-V) should be less than 10-4 Torr.

o. The diagnostic module selector switch is set to STANDBY position.

p. Increase the brightness controls of the visual CRTs till full rasters appear on them.

q. Check and note down the coordinates indicated at the Stage control console.

r. Check whether the last user has logged off the computer.
(The keyboard has no control over the terminal)

s. Set the toggle switch on the joystick OFF.

5.2 Starting the computer

1. Press the INIT switch on the top of the computer console.
   (The computer does the initial self checking and boot-strapping routine).
2. Wait till the computer prompts as:

   ENTER DEVICE OD ?

   enter:

   DSC2.003 <Return>

The computer displays the status of various devices connected to it and when ready prompts with a "*".

3. When the prompt appears enter the following:

   SE TI MM/DD/YY, HH:MM:SS <Return>

   SE PA 1/E800 <Return>

   TA .BG <Return>

   These commands set the time, the memory partition and the flag which tells the computer to do the tasks in the background.

4. To activate the Hard discs and select the working volume type:

   MA DSC2:,ON,OS <Return>

   MA DSC1:,ON <Return>

   V PACK <Return> (IMPORTANT)

   These commands turn on the Discs (FIXD & PACK) and allow access to the operating system.

   To check the status of all the devices type:

   D D <Return>

5.3 Loading the Wafer

1. Check the coordinates os the stage displayed on the stage console.

   a. If these are 00.000 and 00.000 then proceed to step 2.

   b. If the values are non zero then type in the following:

   LEBES <Return>

   The computer executes the LEBES program and prompts:

ENTER STAGE COORDINATES IF YOU WISH

enter:

0.,0. <Return>

The stage coordinates change and the stage moves to the desired position.

If the stage stops without reaching the 0,0 position and any of the stage limit LEDs on the stage control module is lit then follow the stage resetting routine (   ) and return to step 2.

2. Press the VENT button on the Vacuum control module.

3 Wear gloves.

4. Wait for 3 minutes and open the chamber door.

5. Loosen the screw tightening the wafer holder to the stage (A).

6. Gently slide out the wafer holder from the stage.

7. Disconnect the wire leading out of the cup to the specimen chamber.

8. Loosen the screw of the wafer clamp (B) on the wafer holder and lift the wafer clamp up.

9. Mount the wafer on the wafer holder such that the flat of the wafer just touches the two pegs on the wafer holder.

10. Make small scratches on the surface of the wafer edge near the cup.

11. Push the wafer clamp down and tighten the screw

(B).

12. Check again for any visible gaps between the wafer flat and the two pegs.

    If there are any gaps load again.

13. Load the wafer holder on to the stage by sliding it back on to the stage and tighten the screw (A).

14. Close the chamber door and keep it pressed and depress the EVAC switch on the vacuum control module.

15. Move the stage such that the beam axis passes through the cup.

    This can be done using the computer.

    The computer is prompting with a question:

    DO YOU WISH TO RE-REFERENCE ?

    To skip the question enter:

    <Return>

    The Computer Prompts selection of mode or to exit the program.

    enter:

    A <Return> (Selection of Auto mode)

    The computer prompts with a question:

    ENTER FILENAME

    enter:

    CUP <Return>

    The computer reads a file called files for the coordinates of the cup and moves the stage.

5.4 Beam generation and saturation

1. Wait for the pressure in the column to fall to about 5x10-5 Torr.
2. Press the RED push button on the source control Module.

   The indicator in the meter marked accelerating voltage slowly rises and settles at 20 KV.
3. Increase the emission current upto 175 uA by turning the emission control knob clockwise.
4. Press the red button on the collector control module.

   The image of the grid over the cup should appear on the visual CRT.
5. Focus the image using the Objective lens controls marked "COARSE", "MEDIUM" and "FINE" (lens control module).
6. Set the visual mode to "LINESCAN 1", The visual rate to SYNC on the scan generator module.
7. Set the toggle switch on the manual video amplifier to "Wf" position.

   The CRT 2 should now display the linescan waveform and the CRT 1 the linescan image across the grid.
8. Decrease the emission current potentiometer to minimum and increase again while looking at the video waveform on CRT 2.

   Stop increasing the emission current when the video waveform amplitude registers a peak.

The meter marked the filament life now indicates the approximate percentage of filament life due.

9. Focus the linescan waveform again (if necessary) for sharpest possible waveform risetimes.
10. Set the visual rate to "RAPID" , Visual mode to "NORMAL" and waveform switch to "NORMAL". Normal image should reappear.

5.5 Probe Current Measurement

1. Decrease the field size by setting the field size selector to position 0.1.
2. Move the stage using the joystick(Select medium speed) such that one full grid element (hole) is displayed on the visual CRT.
3. Set the Visual rate to SYNC and the visual mode to LINESCAN 1.
4. Set the toggle switch on the field control module to SPOT position.
5. Set the field size to minimum at 0.03 on the field control module.
6. Check for the zero reading of the meter on the specimen current processor module.
   If not zero set to zero using the ZERO ADJUST potentiometer on this module.
7. Set the cup switch (on the column) to ON position.
8. Read the probe current on the meter on the

specimen current processor module after selecting the proper range.

9. Set the probe current to the desired value using the CONDENSER LENS CONTROL on the lens control module.(Typical value for optimal beam diameter and dose is 500 picoamperes)
10. Change the SHIFT potentiometers on the scan generator module.

    The probe current should be constant.

    If not, the beam is falling partly into the cup

    Go back to visual mode and move the stage to center the grid element.
11. Set the field size to 0.1 and the Spot switch to Normal.
12. Set the switch on the manual video amplifier to Wf.
13. Focus the beam using the MEDIUM/FINE objective lens controls for the sharpest waveform risetime.
14. Set the field size to 0.03.

    Select Spot mode and read probe current again.

    If the Probe current has changed again (more than 5%) then go to step 9 and repeat.

15\. Lock the condenser lens control, note down its settings and the stage position.

15\. Set the Spot switch to NORMAL.

16\. Set the field size to 1.

5.6 Probe diameter measurement

1. Select Waveform mode.
2. If the linescan is not across a row of grids move the beam using the SHIFT controls on the scan generator module to scan across the grid elements.
3. Depress the CH2 button on the Record CRT module. The linescan waveform of collected current should appear on the CRT2.
4. Using the CONTRAST and BRIGHTNESS controls on the manual video amplifier module, adjust the level and amplitude of this waveform such that the waveform lies between the two outer horizontal lines drawn on the CRT2.
5. Set the toggle switch at the bottom of the Dual scan module to LOW RESOLUTION mode. Two mutually perpendicular scans appear on the CRT1. The cup signal generated by these scans are displayed on CRT2.
6. Move the two lines using the X and Y SHIFT controls controls (for both horizontal and vertical lines) such that these lines scan across the center of one grid element and the rising edge of the two waveforms lie in the region bounded by two vertical lines drawn on CRT2. (Take care that the linescan is not over

any artifact on the grid).

7. Set the switch to HIGH RESOLUTION mode.
   Two spots(which are in reality very tiny scans) appear on CRT1.
8. Adjust the Horizontal shift of the Horizontal line and the Vertical shift of the vertical line such that the rising edges of the two waveforms appear in the field of view on CRT2.
9. Set the Stigmator AMPLITUDE to about 0.5.
10. Using the medium and fine objective lens controls focus the beam to observe the sharpest risetime of these waveforms.
    If the slopes of the two rising edges are same and also the sharpest, then go to step 13.
11. change the stigmator phase by rotating the dial marked PHASE until the slopes of the two rising edges are about the same.
12. Try to sharpen these edges by changing the FINE control of lens control module.
    If the slopes do not match at their sharpest risetimes then increase the stigmator Amplitude slightly and go to step 11.
13. Set the selector switch marked TIME CONSTANT on the derivative amplifier module to extreme clockwise position.
    The derivative signal of the linescan waveforms appear on the CRT2.

14. Vary the FINE control of the objective lens on the lens control to observe the simultaneous variation of the two waveform shapes and peaking. If this does not happen, set the Time constant to zero and go to step 10.
15. Set the time constant to zero.
16. Measure the beam diameter as the horizontal distance between the points where the rising edges of the waveform cross the inner two horizontal lines drawn on CRT2.
    The absolute value of the beam diameter can be found by comparing with the gap between the two vertical lines drawn on CRT2.
    These lines are calibrated to be 0.1 um apart at these settings.
17. Note down the settings of the objective lens controls and the stage position.
18. Set the switch at the bottom of the of the Dual scan module OFF.
    Depress CH1 switch on the Record CRT module.
    Set the Wf switch to normal.
    Select the Rapid scan and standard mode.
    The image of the grid appears on the visual CRTs.

5.7 Focussing on Wafer

1. Move the stage using the joystick controls such that (From the cup to edge: increase X and

decrease Y) the edge of the wafer is in the field of view.

2. Search for the scratches made on the wafer or any small artifact on the wafer nearest to the wafer surface.

3. Focus the image by controlling the MEDIUM and FINE objective lens controls at the smallest field size (0.3).

4. Lock the objective lens controls and note down their settings.

5. Note down the stage positions.

6. Set the mode switch on the Field control module to EBL mode.

The display and beam are blanked off.

5.8 Exposure

1. If the pattern data to be exposed is on magnetic tape then go to sub-section 5.10 and return to step 2.

2. If the pattern is to be stepped and repeated skip step 3.

3. The LEBES program now prompts for the stage coordinates.

Enter the coordinates of the major field in the wafer plane where the pattern is to be exposed and press:

<Return> (Note: The values must be given in micrometers followed by a decimal

point.)

4. The LEBES now prompts as:

   DO YOU WISH TO RE-REFERENCE ?

   In case of first level exposure enter:

   <Return>

   and skip step 5

5. If re-reference is needed enter:

   YES <Return>

   go to section 5.11 and return to step 6.

6. The LEBES prompts for mode of operation.

   MODE: A (AUTO), E (EXIT), <Return> (CONTINUE)

   If the pattern writing parameters explained in the last section are already in the pattern file then enter:

   A <Return>

   and go to step 14.

7. If the parameters such as resolution, exposure and various delays have to be manually entered the enter:

   <Return>

8. LEBES now prompts as:

   IS THE LOGGING OF COMMANDS DESIRED ?

   enter:

   <Return>

9. LEBES now prompts:

   ENTER NUMBER OF POINTS TO SKIP, RESOLUTION

   enter the value.

10. The next prompt is for the exposure time
    multiplier.
    Enter the value.

11. The next prompts are for the box, line and spot
    delays.
    These values are to be decided depending on the
    pattern size and the resolution.
    (Typical values for patterns smaller than
    10 um x 10 um set spot delay = x1,
    line delay = x1 and box delay =x1)

12. Select the STEP mode (=0) when LEBES prompts
    for MODE.

13. Any of the above data entry steps could be
    skipped by entering <Return>.

14. The LEBES now prompts for the stage coordinates.
    if no step and repeat is needed skip this by
    entering <Return>.

15. Skip the next prompt and select the auto mode.

16. LEBES prompts as:

    ENTER FILENAME

    If the pattern file is on the hard disk then
    simply enter the filename and <Return>.
    If the file is on the magnetic tape then type in:

    MAG1: <Return>

17. If in the step and repeat mode LEBES prompts:

    TO STEP AND REPEAT ENTER DX, NX, DY, NY

    Where DX and Dy are the stepping distances in micrometers and NX and NY make the pattern to step and repeat in (NX+1) and (NY+1) times in the X and Y directions respectively.

18. After the pattern exposure LEBES prompts with the next stage locations.

    If the pattern is to be repeated manually then go to the begining of this section.

19 After all exposures switch off the beam energy. and move the stage to the 0,0 position.

20. Skip all the LEBES prompts until the EXIT choice and enter:

    E <<Return>>

21. Wait for 10 minutes and Vent the column and unload the wafer.

22. Set the wafer holder back into the stage and evacuate the column and follow the log off routine (5.11).

5.9 Mounting the tape on tape drive

1. Turn the tape drive power ON.
2. Load the tape following the instructions on the tape drive.
3. Press LOAD switch on the tape console.
4. Wait till the ONLINE light turns ON.
5. If the pattern to be exposed is not the first file on the magnetic tape then do the following:

   Quit LEBES program.

   enter:

FF MAG1: <Return>

as many times as is the file sequence number of the pattern file on the magnetic tape.

6. Run LEBES program again.

5.10 Re-registration

1. Set the selector switch on the EBL registration. module to 2% position.
2. If the re reference scan parameters are set then go to 6.
3. skip all prompts until LEBES prompts for number of points to skip.
4. From here on enter the following data:

   Resolution = 10.

   exposure = 2.

   Box delay = 200.

   Line delay = 200.

   mode = 0.

   spot delay = 30.
5. Skip the stage movement prompt.
6. When the computer prompts for the re referencing routine enter:

   YES <Return>
7. The registration scans appear on the four corners of CRT2.
8. Set the toggle switch on the EBL module to expand mode.

   Four magnified images appear on the CRT1.

9. Using the SHIFT controls on this module arrange the scanning sequence of the magnified rasters on CRT1 such that it match with that of the scans on CRT2.
10. Move the stage using the joystick at the lowest speed and try to get the image of any one of the registration mark or its part on to the screens.
11. Once the registration mark image or its part appears on the screen try to bring the registration marks such that their inner limbs touch the edges of the square drawn on CRT1.

    This is accomplished using the following controls:

    a. X and Y SHIFTS

        All four images can be microshifted in either directions.

    b. X and Y ALIGN

        The two top horizontal images can be moved with respect to bottom pair (X align) and the two left hand pair could be moved with respect to the the right hand pair.

    c. X and Y FIELD

        The field size in X and Y directions could be controlled.

12. Quit the re-registration routine by entering:

    <Return>

5.11 LOG OFF routine

1. Check that all the Lebes settings are as per sub-section 5.1.

2. Enter:

    CA <Return>

    MA DSC1:,OFF <Return>

    MA DSC2:,OFF,OS <Return>

   The CRT terminal is logged off.

3. Log out.

———oOo———