NANOLINE IV USERS' MANUAL

CHAPTER 1

GENERAL INFORMATION

The NanoLine IV Critical Dimension Measurement System (see frontispiece) is a computer-controlled scanning photometric microscope instrument, designed for measuring line widths, gaps, holes, and registration alignment. The instrument is intended for, but not limited to, high quality, non-destructive on-line testing in integrated circuit fabrication. The effective measurement range is 0.5 to 10 micrometers with a 100X microscope objective; measurement of larger features is possible with 10X and 50X objectives. The NanoLine IV is fast, automatic, flexible, and highly repeatable and accurate. That is, variation in measurements due to systematic and operator-induced errors have been minimized.

1.1. SYSTEM COMPONENTS

The principal component of the NanoLine IV system (Figure 1-1) is a standard trinocular microscope with a densitometer head attached to the camera mount at the top. The microscope (Figure 1-2) has a 6-by-6-inch XY travel stage that can accommodate a variety of mask and wafer holders, several of which are included with the system. The stage is moved vertically either by a stepping motor controlled by a microcomputer, or manually from the keyboard.

The standard optical configuration consists of two 10X binocular eyepieces, a projection eyepiece for transmitting the image into the densitometer head, and three objectives (10X, 50X, and 100X). Koehler illumination, which incorporates two condensers and two iris diaphragms, is best for high resolution; in the NanoLine IV it is provided in reflected light by a vertical illuminator.

Optional equipment includes transmitted-light illumination; an optical image rotator that enhances two-dimensional registration alignment on masks and wafers without direct operator handling;

either an X-Y plotter or a strip-chart recorder; a clean-room version of the standard printer; and a data communication interface for remote recording and interpretation of measurements.

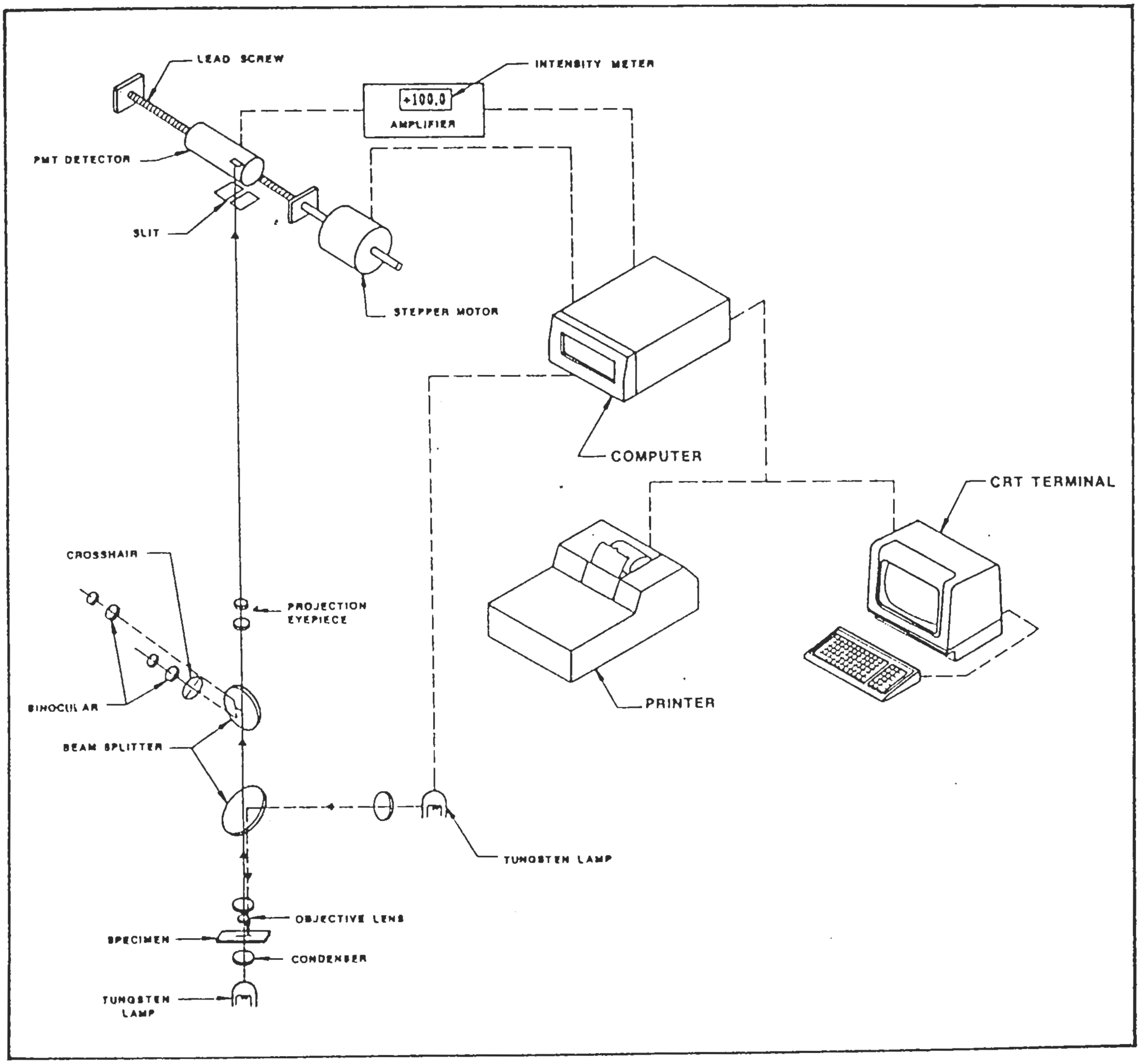

Figure 1-1. NanoLine IV Organization

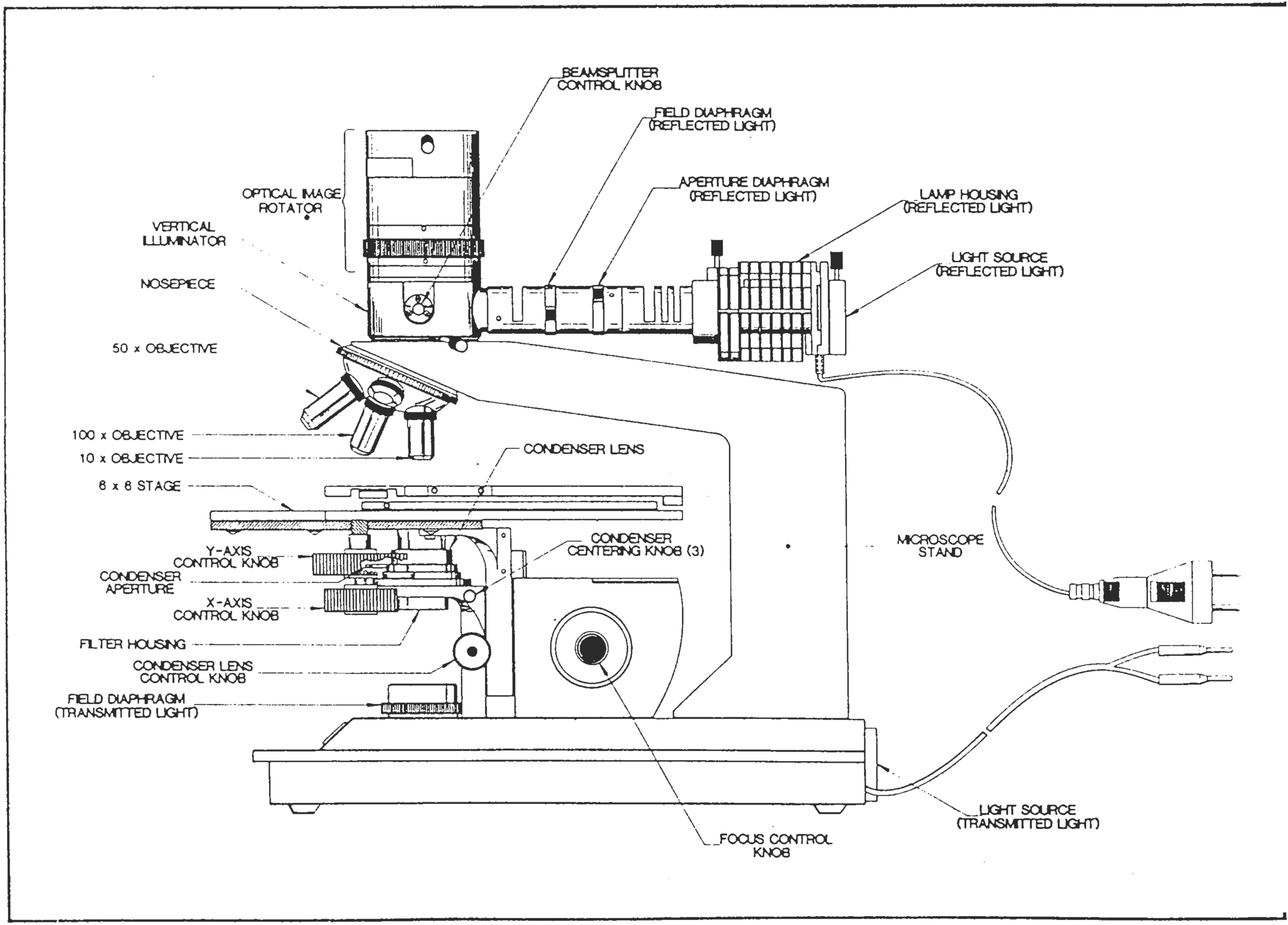

Figure 1-2. Side View of Microscope

The operator's access to the system is through the terminal and keyboard, and thence through the microcomputer, which includes an 8085 microprocessor, a 12-kilobyte main memory, and a read-only memory containing the software that controls the microcomputer. The microcomputer controls the motion of stepping motors, sets gain adjustments automatically, and performs the mathematical computations needed to determine linewidth. In addition, the microcomputer controls the stage position during manual and automatic focus; turns lamps on and off; displays menus and prompts on the screen; processes information from the keyboard; stores statistical data and test parameters; and sends data to the printer and an optional X-Y plotter or strip-chart recorder. A battery backup for the memory provides power for a matter of weeks if primary power fails, preventing loss of data in such an event. A power-fail detection circuit controls the battery backup and protects the memory and its data when primary power voltage sags without actually failing.

1.1.1. DENSITOMETER HEAD

The densitometer head (Figure 1-3) contains an integrated photo amplifier (IPA) attached to a lead screw driven by a stepping motor. During measurements, the image of the sample is focused by the projection eyepiece onto the IPA. The IPA views a portion of the image through a scanning slit, which traverses the entire image as the stepping motor turns the lead screw. The output signal of the IPA is converted by a quantizer circuit board to digital form.

1.1.2. PHOTOINTENSITY METER

The red digital meter at the front of the densitometer head shows the relative photointensity detected by the IPA. Its main function is to aid in troubleshooting. Its indication is not a measure of the absolute photointensity, but a value that has been scaled by the computer. At the beginning of each reference scan, the quantizer gain is set so that the photointensity is slightly above 50. This reference value is stored in the computer's memory. Then the output of each measurement scan is relative to the value of the most recent reference scan. During the scan, the photointensity meter is updated every half-second to show the relative photointensity from point to point.

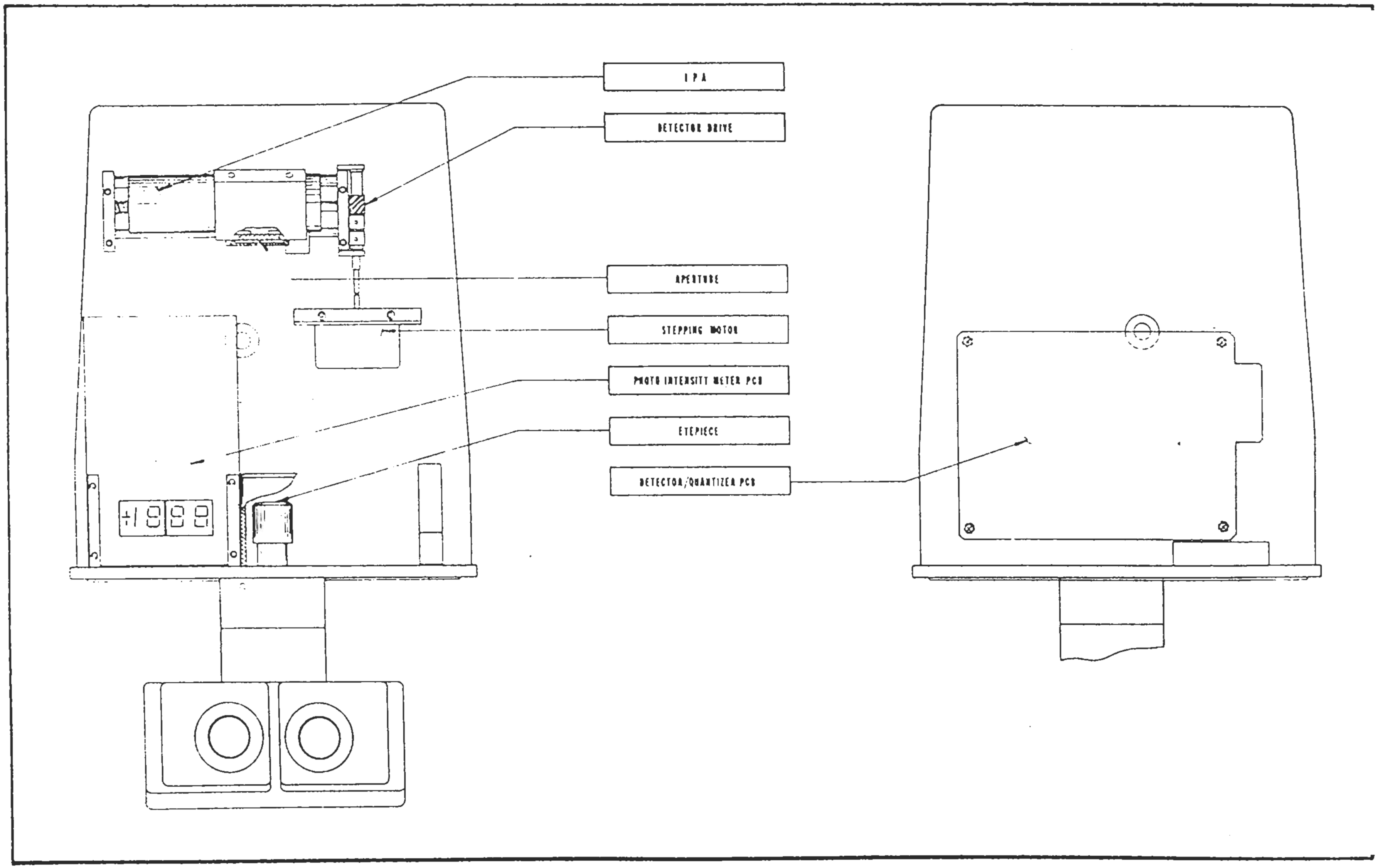

Figure 1-3. Densitometer Head

1.1.3. INTEGRATED PHOTOAMPLIFIER (IPA)

The IPA measures the intensity of a light source. It contains a photomultiplier tube that converts light energy into electric current, and a high-voltage power supply. The response is highly linear over a range of more than 1000:1. That is, if two photointensities differ by a factor of 1000, then the two outputs from the IPA also differ by a factor of 1000. This linearity eliminates the need for calibrated corrections to the densitometer head signal.

1.1.4. SCANNING SLIT

The scanning slit is etched into an opaque glass disk embedded in the bottom of a housing that is also a mount for the IPA. The standard scanning slit spans 4 micrometers at 100X magnification on the scanned surface (40 um at 10x). Three other sizes are available for special applications, but they are not ordinarily field-installable.

1.1.5. DETECTOR/QUANTIZER

The detector/quantizer circuit controls the processes in the densitometer head. These include stepping motor control, analog-to-digital signal conversion, generation of timing and photointensity outputs for the meter PCB and an analog output for testing, reception of gain settings from the computer, and transmission of a digital signal that represents the light intensity.

1.1.6. TRINOCULAR TUBE

The trinocular tube is at the top of the microscope just below the densitometer head. It includes a mount for the oculars and the projection eyepiece and attaches the head assembly to the microscope. A light path selector in the trinocular splits the light to the two oculars (20%) and the projection eyepiece (80%).

1.1.7. PROJECTION EYEPIECE

The projection eyepiece, which has a 5X magnification, is at the top of the trinocular, and focuses the image approximately 12 cm above its lens, in the plane of the scanning slit. A cylindrical cover on the top of the trinocular prevents dust from the head interior from falling on the projection eyepiece. A small hole at the top of the dust cover transmits light from the projection eyepiece to the slit.

1.1.8. OCULARS (Eyepieces)

The NanoLine IV is equipped with two 10x eyepieces or oculars. One contains a lens with a crosshair and should be mounted on the right; the other eyepiece is a standard ocular. They are mounted in receptacles that are part of the interpupillary adjustment assembly. The latter sets the distance between the two oculars, which generally changes from one operator to another, because their eyes have different separations. Operators can also correct for individual variations in vision with a diopter ring.

1.1.9. IMAGE ROTATOR (Optional)

Two-dimensional registration is simplified by the image rotator, which contains a prism that reorients the image. This feature offers a quick, easy method to align an edge or feature with any orientation on the sample with the crosshair. The image rotator is mounted on the top of the vertical illuminator, and controls the orientation of the image with a ring that rotates the image. On some models of the NanoLine IV the image rotates through somewhat more than 180 degrees; on others the maximum is just over 90 degrees. In either case, best results are obtained if rotation is limited to 90 degrees or less.

1.1.10. OBJECTIVES

The MS Plan Olympus objectives used in the NanoLine IV have high resolving power and optical compatibility in relation to the instrument's critical imaging and detection design (Table 1-1). They have been corrected for lateral chromatic aberrations and for field curvature flatness. The 10X and 50X objectives can be centered to the 100X lens, while the 50X and 100X lenses are protected by a spring-loaded design that reduces the likelihood of "objective crash" damage. All three objectives are parfocally mounted, removing the need to refocus when switching objectives.

Table 1-1 -- NanoLine IV Objective Lens Summary

Power	Numerical Aperture	Working Distance, mm.
10X	0.30	9.0
50X	0.80	0.45
100X	0.95	0.30

The working distance (between the tip of the objective and the surface being viewed) is very small in the case of the 100X objective -- less than four times the thickness of this page. Inadvertently raising the stage such a small distance is dangerously easy; the physical contact may scratch the lens, and the surface of the sample may carry residues of etchant or other harmful substances that can ruin an objective.

Two important quantities are related to the numerical aperture: resolution and cone of light. In light with a wavelength of 500 nanometers (0.5 micrometers, or microns), which is blue-green, the resolution of the 100X objective is about 0.26 um. The cone of light is the group of rays diverging from a point on the sample and intercepted by the objective lens. The numerical aperture, which has a range of 0.0 to 1.0, is a measure of the sharpness of the tip of the cone; a large numerical aperture describes a cone that is blunt and nearly flat. This flattened cone is the reason why the NanoLine IV cannot measure the distance across the bottom of a hole at high magnification: the instrument can't see into the hole. This is a fundamental limitation of optics, not a reflection on the quality of the NanoLine IV.

1.1.11. BASE AND STAGE ASSEMBLY

The microscope base supports the microscope and stage. Bases for models with and without the transmitted-light option are slightly different: the transmitted-light option includes the housing for a light source and path and a mount for a transmitted-light field diaphragm.

The microscope stage supports various wafer and mask holders. It can be moved in the X and Y directions for locating features to be measured. The system includes three mask holders, designed to hold three standard sizes of masks. Each mask holder is mounted by sliding the holder beneath the stage brackets. Rotational alignment can be done with either the standard wafer rotator or the optional image rotator.

The stage position in autofocus is controlled by a motor in the focus drive assembly, which, in turn, is under operator control from the keyboard. Manual adjustment is also possible.

1.2. COMPUTER

The computer (Figure 1-4) stores all parameters, user tests, statistics, and the data from the current background reference and crosshair alignment in its memory. In the event of loss of primary power for any reason, battery power preserves the data in the memory, which is made with power-stingy CMOS technology. Memory is preserved for weeks in this way.

The computer's principal functions are to communicate with the operator via the terminal; to communicate with the densitometer head; and to control the microscope stage to focus an image:

1. For operator communication, the computer processes operator's instructions, displays menus and parameter information, and provides the prompts and warning messages for the system.

2. For densitometer communication, the computer processes the digital output of the quantizer at each step of the scan, controls the operation of the stepping motor, and sets the reference level in the quantizer.

3. For microscope focusing, the computer drives the four windings on the autofocus motor.

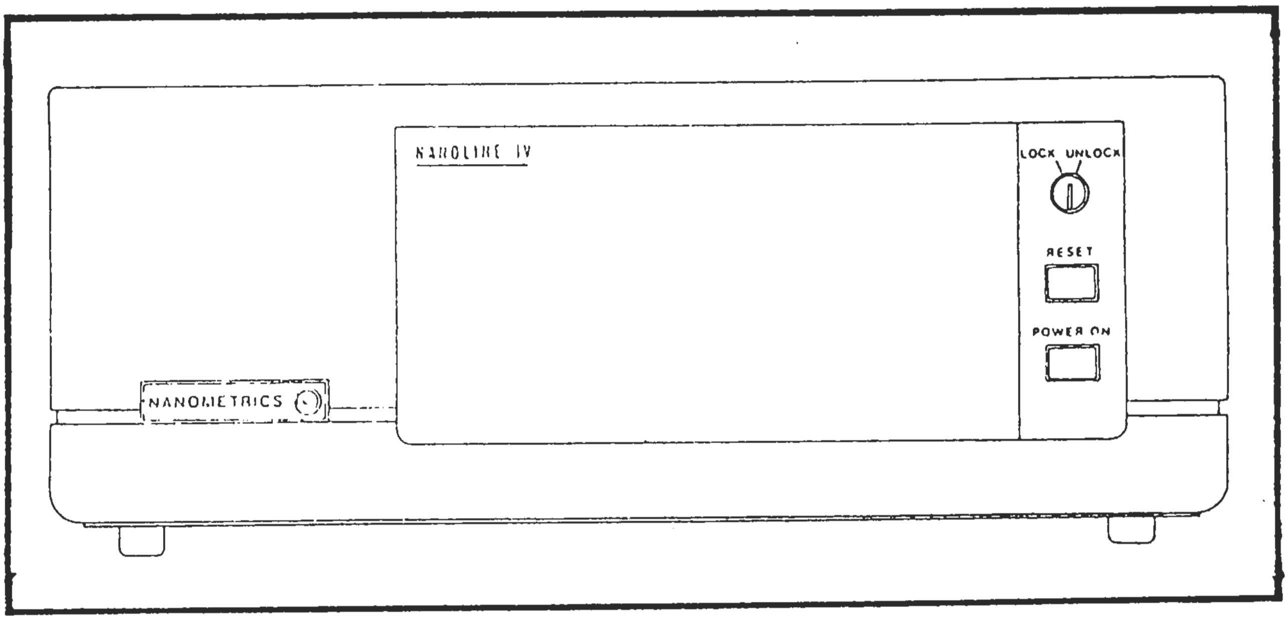

Figure 1-4. Front View, NanoLine IV Computer

The terminal is the operator interface with the system. It has a green phosphor screen, detached keyboard, and an external contrast control. The screen displays 80 columns and 25 lines.

A 21-column printer is included with the system to produce permanent records of measurements and test statistics. Two models are available: a standard version that prints on inexpensive aluminized tape, and an optional clean-room version that uses plastic tape. Both tapes are 2-1/4 inches wide, much like adding machine tape. Whenever a measurement is made and the operator chooses to accept the measurement, the printer prints the sample identification, the test name and the result of the measurement. When a user test or a test's statistics are erased, and when all the tests are reset, the printer prints all the information before removing the data from memory. This not only provides documentation for the records, but also provides a backup against accidental reset.

1.3. AC POWER OUTLETS

Two 3-prong AC power outlets for plugging in the terminal and printer are on the rear of the computer. When the system is switched off by the main power switch, power is removed from the AC outlets. Pressing the reset button, however, has no effect on the AC outlets. The voltage and frequency of the power from these outlets is the same as the input voltage and frequency to the system.

Table 1-2 -- SPECIFICATIONS

Range of line widths:	100X: <0.3 to 10 um 50X: <1.0 to 20 um 10X: <5.0 to 100 um
Nominal slit height:	100X: 4.0 um 50X: 8.0 um 10X: 40 um

Threshold variable between 1% and 99%
AutoFine (TM) Automatic Optical Focus
Nonvolatile Memory -- Battery-backed CMOS
One- and Two-Dimensional Registration measurements available
Statistical Testing
Optional Data-Link II (SECS II compatible)

Edge-Sensing Programs (ESP):

1. Mask, Dark Line
2. Mask, Light Line
3. Wafer Minimums
4. Wafer Insides
5. Wafer Outsides
6. Pitch, Dark/Light
7. Pitch, Light/Dark
8. Pitch, Minimums

9. Pitch, Insides
10. Pitch, Outsides
11. Wafer, Min/Inside
12. Wafer, Min/Outside
13. Wafer, Inside/Min
14. Wafer, Inside/Outside
15. Wafer, Outside/Min
16. Wafer, Outside/Inside

All programs include routines for rough or faint lines

Precision: One sigma value better than 0.007 um for chrome photomasks (measured with Nanometrics calibration mask, included with each NanoLine IV instrument).

Scan Time: Less than 5 seconds
Focus Time: From 5 to 30 seconds

Power: 250 watts
100 volts $\pm$ 10%, 115 volts $\pm$ 10%;
220 volts $\pm$ 10%, 240 volts $\pm$ 10%; 48 to 62 Hz.

Temperature: 65 to 85 degrees F (18 to 30 degrees C)
Less than 3 degrees F (2 degrees C) variation from temperature at calibration

Humidity: Maximum 90% non-condensing

Dimensions:

	Inches			Centimeters		
	H	W	D	H	W	D
Microscope & densitometer	31 3/4	13	17 5/8	80.64	33.02	44.77
Computer:	17 1/2	18 7/8	23 1/2	19.05	47.94	59.69
Terminal:	14 1/4	16 1/2	14	36.2	41.9	35.6
Keyboard:	3	16 1/2	7 1/2	7.6	41.9	19.0
Standard printer:	6	7 1/2	10 3/8	15.24	19.05	26.35
Clean-room printer:	3 1/16	7 3/8	6 1/8	7.82	18.75	15.54
X-Y plotter:	5 5/16	17 3/16	10 1/2	14.5	43.7	26.6
Chart recorder:	4 3/4	9	10 1/2	11.38	22.50	28.75

Weight:	Microscope & densitometer:	37.5 pounds	(17.0 kg.)
	Computer:	24.3 pounds	(11.0 kg.)
	Anti-vibration stand:	26.5 pounds	(12.0 kg.)
	Terminal:	30 pounds	(13.6 kg.)
	Keyboard:	4.5 pounds	(2.04 kg.)
	Standard printer:	10 pounds	(4.53 kg.)
	Clean-room printer:	3.5 pounds	(1.59 kg.)
	X-Y plotter:	16 pounds	(7.2 kg.)
	Chart recorder:	7.5 pounds	(3.4 kg.)

Clearances: Sufficient space at rear for routing cables
No contact with wall or adjacent furniture that might transmit vibration