JWS-7500/7700

Wafer Inspection Systems

JEOL

Serving Advanced Technology

Wafer Inspection Systems

JWS-7500 Wafer Inspection SEM System/JWS-7700 CD and Inspection SEM System

1. Background of development

Since 1992, the establishment of a mass production setup of 16Mb and 64Mb DRAMs has been urgently needed in the VLSI production line. The key to mass production is the development of an inspection equipment that meets requirements such as 1) the shrinking of circuit patterns with the improvement of the scale of IC integration, 2) realization of three-dimensional device structures, and 3) increase of the wafer size and wafer throughput for higher productivity. The design rule of the DRAM memory cell is 0.6 to 0.45 μm with the 16Mb DRAM and 0.4 to 0.35 μm with the 64Mb DRAM, as a result of which the need of inspection with the scanning electron microscope (SEM) is now increasing.

Complementary inspection of VLSIs by means of observation and CD (critical dimension) measurement is effective for correctly grasping the state of resist patterns obtained, etching state of oxide layers, and pattern defects arising from contaminant particles on the wafer surface, and feeding back the results to the VLSI production process. To meet this market need, we have developed a CD measurement and inspection SEM system, the JWS-7700, following the previously commercialized wafer inspection SEM system, JWS-7500.

We shall here describe the techniques common to the two models.

2. Outline of the systems

The JWS-7500 is intended to be used for observation of memory cell surfaces and the JWS-7700 also for CD measurement of photoresist as inspection equipment for some processes in VLSI production lines. They employ a thermal field emitter (TFE (ZrO/W)), which has an excellent electron beam stability. Before employing it, we replaced the cold type fied emission (CFE) electron source installed on a SEM, with a TFE and carried out resolution evaluation of secondary electron images at 1 kV acceleration. As a result, it was found that there was almost no resolution difference between CFE and TFE at probe diameters of 7 to 10 nm. The JWS-7500/7700, which incorporate a lens with epochal performance and functions, assure high resolution, 10 nm, even when the specimen is highly tilted. TFE requires 12 to 24 hours before it gets stabilized after emission start-up. After that, the probe current is very stable.

Although the lifetime of TFE is influenced by the setting of the heating current as with the tungsten filament, it is around 5000 hours. Since the systems are capable of automatically logging and recording the beam conditions including the probe current, routine system management is quite easy.

The operating vacuum pressure in the gun chamber is 2×10^{-7} Pa with higher allowance. This has made it possible to provide only one intermediate vacuum chamber. Also, use of low accelerating voltages has made the gun chamber small, resulting in the compact size of both systems.

Below is given a description of the entire systems.

Fig. 1 shows a general view of the JWS-7700 system and Fig. 2 its block diagram. The basic function of the SEM is controlled by a microcomputer, which is connected via a

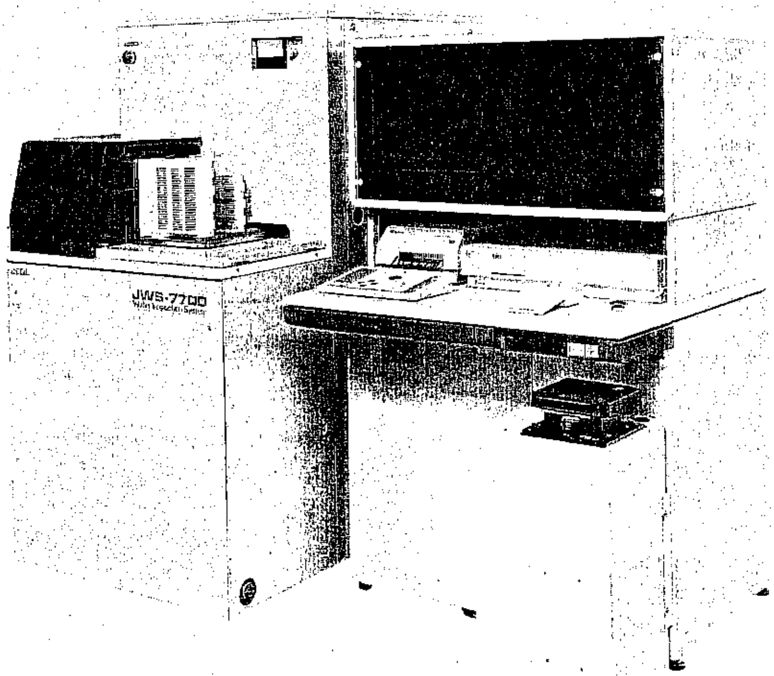


Fig. 1. External view (JWS-7700).

GP-IB interface to an EWS (engineering workstation) or a PC (personal computer) that acts as a host computer. In the host computer are stored filed inspection conditions such as the observation and CD measurement positions on wafers, tilt angle, and beam conditions. The keyboard is used for filing, but image observation can be carried out simply by operating the control panel and a tracker ball. TV accumulated images acquired on the frame memory (FIS) can be written on a removable disk and the stored images for inspection standard can be read out on the screen as necessary. There are provided two scanning speeds—TV scan and slow (photo) scan.

- The four-axis specimen stage is compucentrically controlled by the host computer, to rotate the specimen around the field of view. The stage positioning accuracy in the X and Y axes is better than ±10 μm.
- As shown in Fig. 3, wafers are exchanged one by one; however, a system throughput of 14 wafers/hour has been achieved. The prealignment of wafers is carried out during the vacuum evacuation of the wafer loading chamber and finished by the time evacuation is completed. The total time required for wafer load/unload is 100 seconds. Fig. 4 shows a time breakdown of the throughput. Seven sites (positions) including global alignment points were observed for 17 seconds each.

  In order to improve the throughput, the evacuation time for the loading chamber has been reduced by the following means:
  - The volume of the loading chamber has been reduced (to 0.6 ℓ).
  - A rotary pump (RP) with large pumping capacity has been employed.
  - The switching time from RP to TMP has been reduced.
  - A turbo molecular pump (TMP) has been provided under the loading chamber.
  - At the time of wafer load/unload, valves 8 and 9 are kept closed so as to keep the loading chamber filled with nitrogen gas till wafers are taken in or out of the chamber.

  As a result, the evacuation time for loading has been reduced to 30 seconds and the nitrogen gas venting time for unloading to 10 seconds. Fig. 5 shows a schematic diagram of the main vacuum system, and Fig. 6 shows changes in the vacuum pressure in the specimen chamber evacuated by this vacuum system. It is seen that a sufficiently high vacuum is maintained during inspection. Since the airlock valve V7G on the gun chamber is closed from wafer take-in to inspection, a drop of the vacuum pressure exerts no adverse influence on the emitter tip.
- Prevention of contaminant particles is as important as the improvement of throughput.

  For the wafer handling system, therefore, the following countermeasures have been employed to reduce the number of sliding portions.
  - Beltless system (at the atmosphere, a vacuum chucking type)
  - Holderless system (in the vacuum chamber, chucking by the dead weight of wafer itself)
  - Rotatable robotic arm
  - Holding a wafer by chucking its edges (in the specimen chamber).

  For the vacuum system:
  - SUS piping has been employed for the N_2 gas flow route
  - The unevenness of the inner walls of the loading chamber has been reduced and consideration has been given

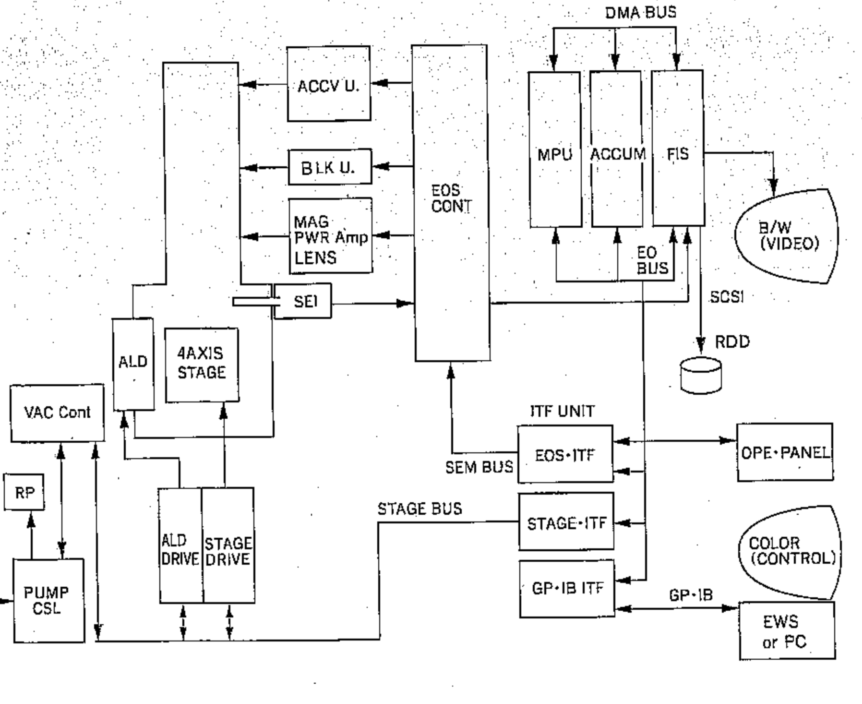


Fig. 2. System block diagram.

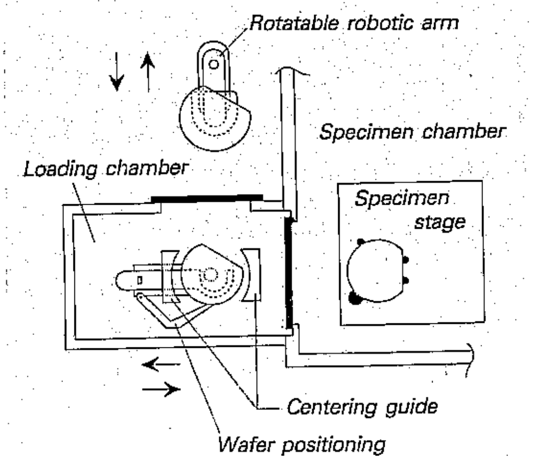


Fig. 3. Loader system

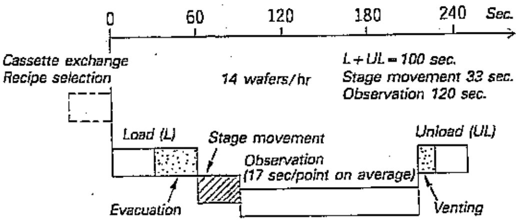


Fig. 4. Breakdown of throughput

to the position and direction of the nitrogen gas inlet port. In addition, pressure-type O rings have been employed for valves 8 and 9 to avoid O ring sliding.

By employing these design considerations, the number of contaminant particles (0.2 μm or larger) was reduced to approx. 10 on the surface of a 6-inch wafer and 3σ = approx 10. In this measurement, another wafer, which is not to be loaded, was put in a cassette to monitor that it was not contaminated under down flow. Since it was known in a preliminary experiment that there was a high possibility of wafers being stuck with an abnormally large amount of contaminant particles at the time of venting, we designed a slow vent mechanism, but it was found that there was no need to apply it.

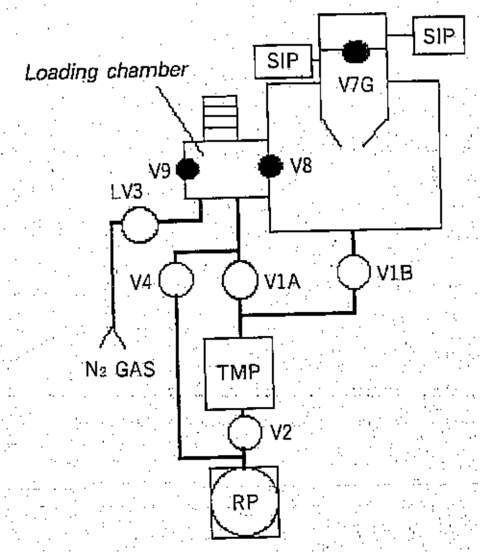


Fig. 5. Schematic diagram of main vacuum system.

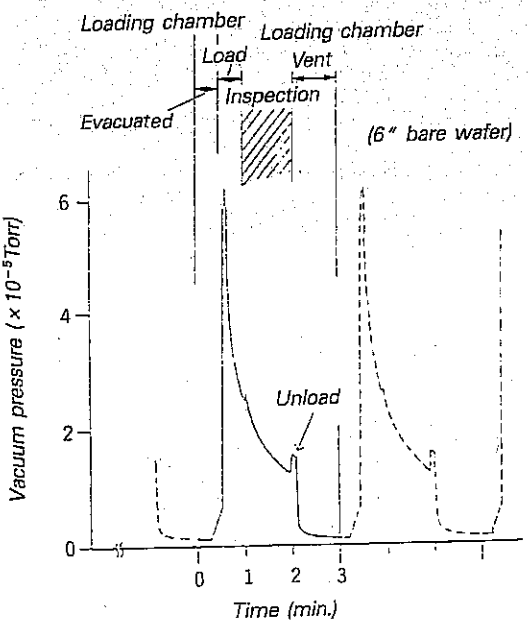


Fig. 6. Changes of vacuum pressure in specimen chamber.

3. Features, Principal Specifications and Main Applications of JWS-7500 and -7700

Features

- A newly-developed super conical objective lens does not deteriorate the resultion even when a 200 mm wafer is tilted from −15° to 60° during observation.
- A thermal field emitter features extremely high stability over a long or short period of time, freedom from image fluctuation, and superb reproducibility of CD measurement.
- High wafer throughput has been achieved partly because wafer prealignment is carried out during the evacuation of the loading chamber and partly because the specimen stage drive speed has been increased up to 30 mm/sec.
- Great operational ease has been realized due to well-designed operation screens on the host computer CRT.
- The compact electron optical column and a magnetic shield for it has markedly increased the resistance to the stray fields from peripheral equipment, which result in image distortion.
- Provision of an automtic logging function for the elecctron beam conditions and a beam alignment value memory has made routine instrument management and maintenance certain and easy.

Principal specifications

Secondary electron image resolution	10 nm (1 kV, −15 to 60°)
Accelerating voltage	0.5 to 3.0 kV
Lens system	4-stage
Objective aperture	One (fixed)
Working distance (WD)	Fixed
Specimen stage driving speed	30 mm/sec (max.)
Maximum specimen size	200 mm
Specimen tilt angle	−15 to 60°
Throughput (5-site observation)	10 or more wafers/hr
Maximum allowable stray magnetic field	AC 3 mG

Main applications

- Production line, pilot line, and R&D of 16Mb and 64Mb DRAM
- Monitoring for quality control
- Process monitoring
- CD measurement and defect inspection

4. Features of electron optical system

Semiconductor inspection systems require many performance and functional features not available with the conventional SEM:

- High resolution: The specimen can be tilted up to 6°, where the same resolution as with a horizontally held specimen can be obtained. With the conventional SEM, the working distance (WD) increases with the tilt angle, thus lowering the resolution.
- Resistance to stray field: The resistance to stray field and to floor and acoustic vibrations must be markedly enhanced.
- Easy operation: Satisfactory results must be obtained regardless of operator skill. Axis alignment, focusing, astigmatism correction, contrast/brightness adjustment must be automatically controlled or presettable. In addition, the controllability of the electron optical system must be improved.
- Easy maintenance: It is necessary to reduce the number of units requiring maintenance and the frequency of maintenance as well as to facilitate and speed up maintenance.

All of the above requirements make it difficult to design an electron optics system. However, the fact that specimens are limited to wafers, and the use of low accelerating voltage were merits in the mechanical and electrical design of semiconductor inspection systems.

■ Super conical objective lens with short WD

When the specimen is tilted to 60°, the space for the objective lens is limited to the shaded area shown in Fig. 7. With the conventional lens that uses polepieces, it is difficult to reduce WD to less than 40 mm. As a result, the spherical aberration coefficient, Cs, becomes approx. 200 mm and the chromatic aberration coefficient, Cc, approx. 60 mm. To solve this problem, we attempted to put to practical use a conical lens having no inner magnetic polepiece, which was proposed by T. Mulvey about 20 years ago. The advantage of this lens is its ability to freely change the axial field distribution by adjusting the distribution of a coil wound around its conical surface. As a result of optimization by computer simulation, Cs 33 mm, Cc 15 mm, and 400 ampere turns (3 kV) were obtained. The increase of the coil temperature was successfully held to below 30°C only with natural cooling by thermal conduction. Another difficulty is that strict axial symmetricity is required for each coil turn—a factor that has hindered the practical use of this type of lens. With the JWS-7500 and 7700, this problem has been solved by developing a special precision coil winding means.

■ Optimized lens system

The condenser lens system is composed of two electrostatic lenses. This has made it possible to obtain a probe current range covering 3.5 orders (from 0.5 pA to 1 nA). Also, the absence of hysteresis due to the use of the electrostatic lenses, allows highly reproducible current control. Fig. 8 gives an example of probe current control by means of the double condenser lens system. The figure indicates that the design purpose to change the current in a geometric series with respect to the probe current code numbers is realized with high accuracy. Fig. 9 is given as another example showing the high controllability. In this figure, the reproducibility was measured by alternately selecting two conditions at 20-minute interals—2 kV accelerating voltage and 11 pA probe current; and 3 kV and 4 pA. It is seen that changeover between the two conditions was carried out instantaneously and that the current reproducibility is satisfactory.

As is well known, the field emission type electron gun has high brightness yet a small electron source diameter; therefore, it requires a special measure to obtain large probe current. In the large current mode, the total magnification of the lens system becomes more than 1, so if the 1st condenser lens has a large spherical aberration coefficient, the probe current becomes large rapidly. In order to reduce this spherical aberration, the 1st condenser lens has been brought as close

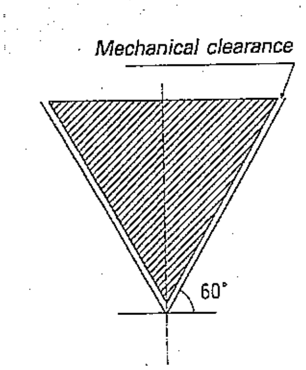


Fig. 7. Space allowed for objective lens.

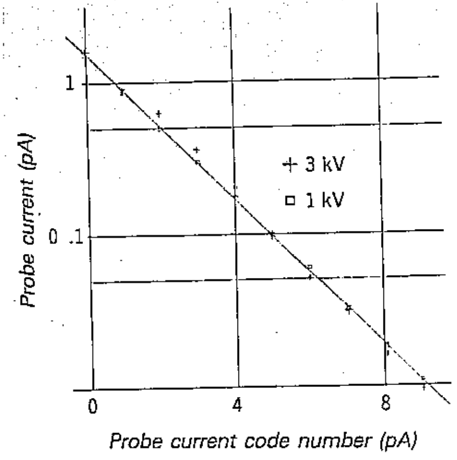
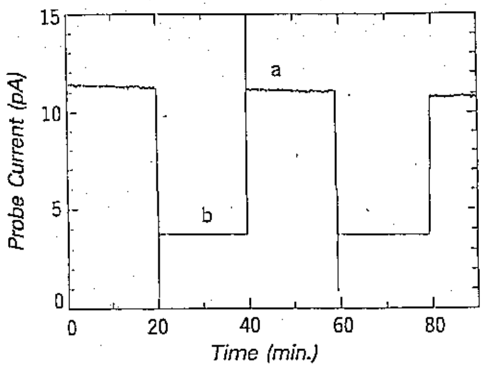


Fig. 8. Control of probe current by double condenser lens.



Conditions a ..... 1 kV, 11 pA
Conditions b ..... 3 kV, 4 pA

Fig. 9. Conditions changeover of electron optics system and probe current reproducibility.

to the emitter as possible. As a result, an almost constant probe diameter has been obtained in the above current range.

Aperture angle control lens.

When the accelerating voltage or probe current is varied, the optimum aperture angle also changes. Conventionally, several apertures with different diameters have been used by mechanical exchange. Along with their exchange, however, it has been necessary to readjust aperture centering, image brightness, and contrast. With the JWS-7500 and -7700, which are intended for use by unskilled operators, automation of this section is essential. For that reason, we used a fixed aperture and added another lens (Aperture Control Lens: ACL) under the aperture so that the optimum aperture angle can be obtained at any time. Fig. 10 shows the operating principle of ACL. Since the probe current does not change even when the focal distance of ACL is changed, a job to decide on the optimum aperture angle experimentally was carried out easily. The points where the image is best were obtained and tabulated. ACL was also made electrostatic to avoid the influence of hysteresis.

Also, the aperture was constantly heated to make it free from contamination. This consideration has realized a column which is maintenance free over a long period of time.

Magnetic shield

In a clean room, there is generally a stronger stray field and lower accelerating voltages are used than in an ordinary SEM environment. In addition, the allowable amount of beam shift is nearly 0. Therefore, a clean room needs a strict magnetic shield.

Ordinarily, the magnetic shielding for the SEM is carried out outside the column. However, as the column has many protrusions including the evacuation manifold, inevitably necessitating the provision of cut-out portions. Also, the section of the column which is inserted in the specimen chamber cannot be shielded easily. With the JWS-7500/-7700, therefore, a shield cylinder is provided also within the column. Since the outer diameter of the lens section was made small by employing the electrostatic lens, the magnetic shield pipe was easily built into the vacuum. Since the length of this inner shield cylinder is large as compared with its diameter, little magnetism enters the cylinder from its end, thus making it possible to obtain a great shield effect. Although the specimen chamber is made of thick iron, a large hole for accepting the column is made over the observation point. This section was effectively shielded by magnetically connecting the outer shield for the column and the top shield plate for the specimen chamber. Fig. 11 shows measurement results of the magnetic shield effect.

Improvement of vibration resistance

Improvement of the vibration resistance requires measures such as lowering the instrument's center of gravity and increasing the rigidity, as well as selecting an adequate vibration isolator. The JWS-7500/-7700 are each provided with a large specimen chamber that allows observation of the entire area of a 200 mm wafer, and the chamber occupies the most of the weight of each instrument. We have therefore reduced the height of the specmen chamber as much as possible. Besides, the employment of an objective lens having short WD and low aberration coefficient has eliminated the need to change over WD. As a result, a specimen stage with a fixed WD and high rigidity has been realized. The fixed WD has made image magnification correction and rotation angle correction unnecessary, thus bringing a merit in instrument design. In addition, the overall length of the column was made small for increasing the rigidity and reducing the inertia moment. The reduction of the column length also helps reduce the influence of stray field.

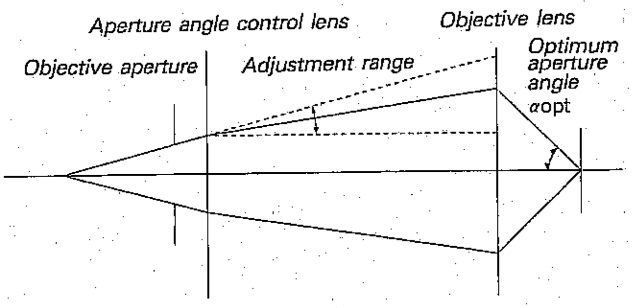
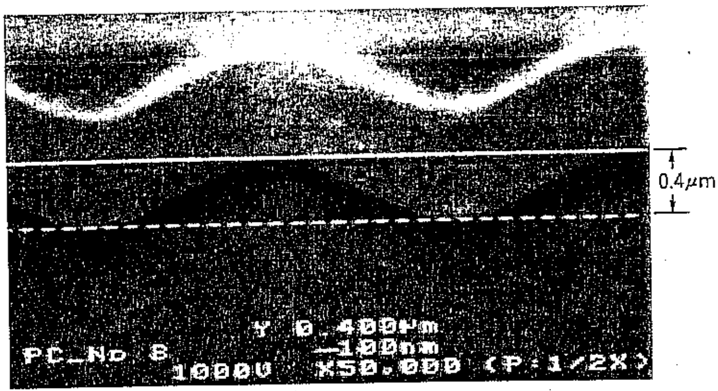
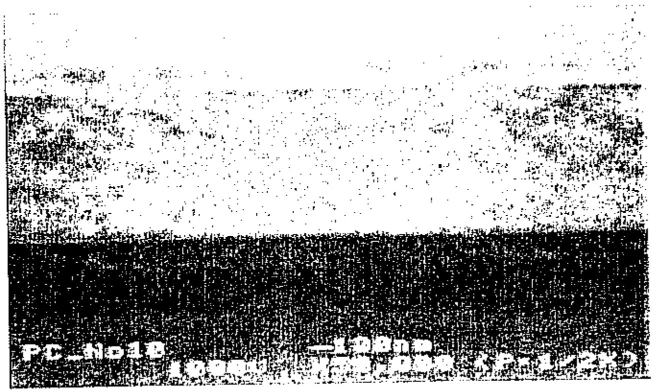


Fig. 10. Operating principle of aperture angle control lens.



a) With no magnetic shield



b) With magnetic shield

Fig. 11. Magnetic shield effect (externaql magnetic field 10 mG, accelerating voltage 1 kV)

5. Applications

A secondary electron image with a resolution of 10 nm is shown in Fig. 12. The image is of Al-evaporated Latex on a silicon chip, taken in the photo scan mode (80 sec).

Fig. 13 shows a resist pattern on polysilicon, taken at a tilt angle of 55° and in the photo scan mode. The unevenness of the resist walls and of the substrate is clearly seen. Since the specimen can be tilted up to 60° with WD kept fixed, there arises almost no image shift out of the field of view. Also, high resolution can be maintained.

Fig. 14 is a TV accumulated image of a resist contact hole on silicon oxide, observed at a tilt angle of 15° (a video printer output of a TV image accumulated on a frame memory). It is seen that the bottom of the contact hole can be observed. The number of frame accumulations is 128.

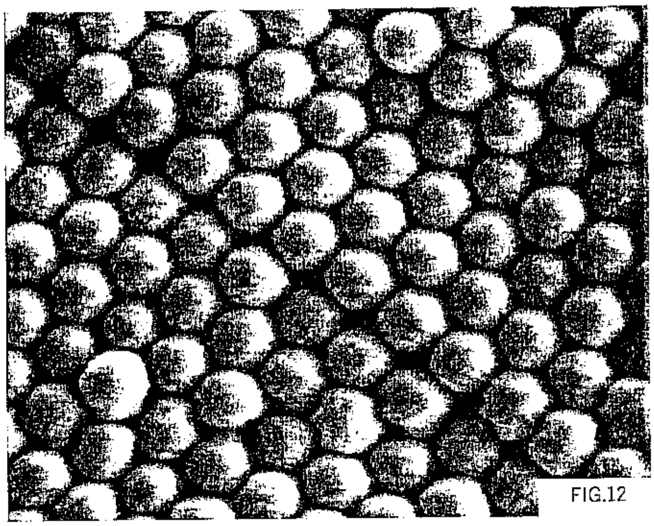


FIG.12

Fig. 12. Secondary electron image resolution.

Accelerating voltage 1 kV, magnification X50,000, 0.2 μm Latex (Al coated)

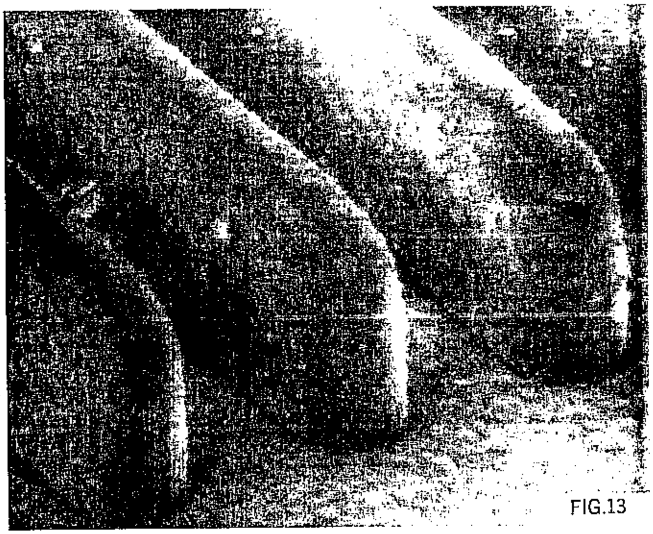


FIG.13

Fig. 13. Photoresist on polysilicon.

Accelerating voltage 1.4 kV, magnification X24,000, specimen tilt angle 55°

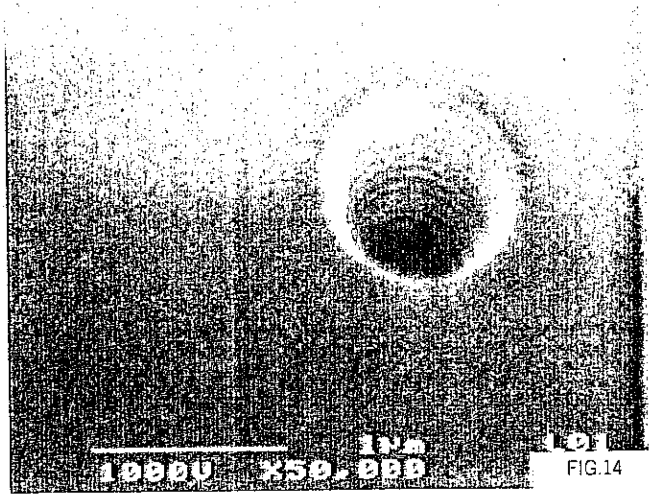


FIG.14

Fig. 14. Photoresist on SiO_2

Accelerating voltage 1 kV, magnification X25,000, specimen tilt angle 15°