A Comparison of Manual and Automated Access to Microenvironments

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ABSTRACT

Floor space in a Class 1 or better cleanroom costs approximately \$2000 to \$3000 per square foot to construct. Operating costs for these rooms are equally expensive. It is also true that even the best cleanroom facility may be subverted by sources of contamination within the cleanroom itself.

Due to these factors, many new semiconductor fabs are built with provisions to isolate wafer processing areas from the rest of the factory by means of various enclosures, which may be grouped into the category of wafer isolation technologies. These include cluster tools, clean-tool units mounted directly on equipment (microenvironments), and equipment surrounding clean air enclosures (minienvironments).

For each configuration, critical considerations include wafer transport and loading. Wafer transport mechanisms must keep wafers stringently clean and protect wafers from breakage. Typical methods of wafer cassette transport include standard mechanical interface (SMIF) pods, run boxes, and open cassettes.

This paper examines the relative cleanliness of various modes of accessing microenvironment enclosures at varying cleanliness levels of ambient air surrounding the microenvironment. Ambient air cleanliness tested ranges from Class 10 to Class 10,000.

Wafer cleanliness is measured through the use of a wafer surface scanner to measure particles per wafer pass (PWP). Access methods tested include a swinging door, SMIF robot arm, flexible curtain, and Manual Access Port (MAP). (Manual Access Port and MAP are registered trademarks of Briner/Yeaman Engineering, Inc.)

INTRODUCTION

Since the successful installation of a minienvironment/standard mechanical interface (SMIF) system at Taiwan Semiconductor Corporation (TSMC) in Hsin-Chu, Taiwan, researchers have been investigating the effect of microenvironments on wafer cleanliness; explaining the cost savings anticipated from energy and air handling reductions; and attempting to measure yield improvements from converting existing fabs to fully isolated systems. [1,2,3,4]

Expensive, fully automated SMIF systems are not necessary to reap substantial benefits from isolation technologies.[5] Potential users of isolation technologies are searching for information relating wafer cleanliness to various "manual and automated alternatives for the loading and transporting of product within the microenvironment system."[6]

This paper compares the effectiveness of several manual transport and cassette handling methods with the fully automated alternative (SMIF) at several different levels of airborne cleanliness using particles per wafer pass (PWP) as a measurement variable. The results of this experiment show that the more expensive robotic system is not required to achieve excellent PWP measurements.

EQUIPMENT AND FACILITIES

For this experiment, a microenvironment test lab (see Figure 1) was set up and incorporated the following:

- a 6-ft x 8-ft variable-cleanliness cleanroom.
- a wafer surface scanner enclosed in its own microenvironment.
- a test microenvironment enclosure, with a replaceable front panel to allow for alternative access means.
- a table on which to store lot box or pod-contained test wafers during the study.
- an ambient air cleanliness monitoring system, consisting of a 1 cfm airborne particle counter, a multiplexer, and six sampling ports throughout the cleanroom and test microenvironment.

The variable-cleanliness cleanroom was kept small to allow for airflow balancing. ULPA filters and blower units

Keywords: microenvironment, minienvironment, PWP, isolation, SMIF, MAP, cleanroom

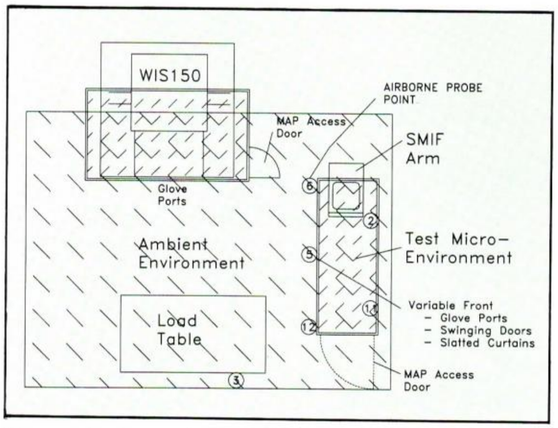

Figure 1. Environment schematic.

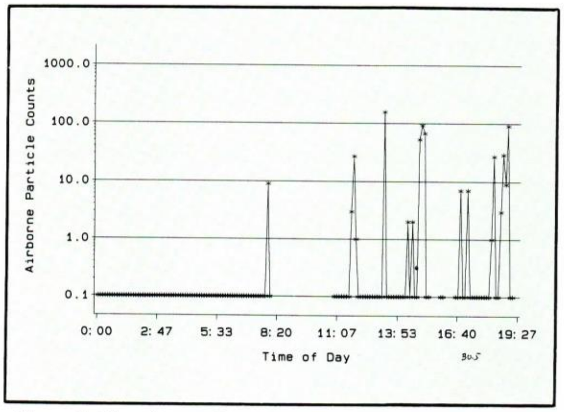

Figure 2. Cleanliness of inside test microenvironment via multiplexer on PMS Micro-LPC110.

were set up in the ceiling. Plastic sheeting was used for walls, ending approximately (20 cm) 1 ft from the floor. Airflow was somewhat turbulent, but generally flowed down from the ceiling, past the front of the microenvironments and table, and out under the walls below knee level.

Controlled degradation of cleanroom air was achieved through the injection of office air through a ceiling-mounted network of PVC pipes. The quantity of HEPA-filtered air was also varied to control environmental cleanliness.

An Aeronca WIS150 Wafer Inspection System with automatic gain control was used to track the number of particles on the wafers. Flats on wafers were aligned to reduce measurement variability. The instrument was calibrated prior to the experiment, and a calibration wafer was monitored throughout the experiment to guard against instrument "drift."

The surface scanner was enclosed in a microenvironment of its own, with Manual Access Port (MAP) access to protect the wafers during the measurement process. Data were sent via an RS232C port to a computer data log.

The test microenvironment enclosure was constructed of clear acrylic sides with full ULPA filtration of incoming air. The front panel of the enclosure could be easily removed and replaced to change between vinyl curtain, hinged door, and MAP access. A SMIF arm was permanently mounted on one side of the microenvironment. At both ends of the microenvironment, cleanliness levels of better than Class 1 at 0.1 μm diameter particles were verified.

Figure 2 shows the level of airborne particle counts inside the test microenvironment during the first day of testing. Particle counts (all sizes) remained consistently at zero when the chamber was at rest. Excursions are visible during setup changes to the experiment and to a lesser degree during the experiment.

Air flowing over the load table was monitored to ensure that it maintained the appropriate cleanliness level for the portion of the study in progress.

The particle counter used to monitor the air in this study was a PMS LPC110 airborne particle counter. Clean antistatic tubing was fixed in various positions inside and outside the test microenvironment. Air samples were monitored throughout the experiment. Six ports of a 12-port multiplexer were used. The multiplexer cycled regularly through those six ports so that each location was measured approximately once every 6 min. Data were sent via an RS232 port to a computer data log.

All surfaces were thoroughly cleaned before use, and extensive background airborne particle counts were obtained in the days preceding the running of the experiment.

MEANS OF MICROENVIRONMENT ACCESS

Two sets of independent variables were controlled throughout this experiment, the means of access to the microenvironment enclosure, and the cleanliness of the air surrounding the enclosure. Four types of access mechanism were compared.

SMIF Arm

This method used a 100-mm Asyst SMIF arm and a 100-mm SMIF pod. The SMIF arm was mounted to the end of the test microenvironment with the port plate alcove accessible from the ambient area.

The access cycle started by moving the pod from the storage table, placing it on the arm port plate, and pushing the load button on the SMIF arm. The SMIF robot then released the pod latching mechanism and slowly lowered the cassette into the microenvironment. Using an inside move, the gripper mechanism then placed the cassette on the surface of the microenvironment while closing the SMIF pod.

Immediately upon completion of the load cycle, the unload cycle was initiated which reversed the procedure and left a loaded pod at the port. The pod was then manually moved back to the storage table for the completion of one access cycle.

Manual Access Port

A Manual Access Port (MAP) uses ergonomically designed oval ports fitted with arm-length GORE-TEX stretch gloves. (GORE-TEX is a registered trademark of W.L. Gore & Associates, Inc.) The ports are designed to fit the equipment and to accommodate various-sized operators loading the equipment. The gloves have an extremely low tendency to generate airborne particulates in use[7] and stay comfortably dry when used by a succession of cleanroom operators.

The access cycle started by moving the closed run box into the microenvironment through a hinged door on the end of the enclosure. Immediately following, the operator donned the gloves and opened the run box. The cassette was then removed from the box and placed on the surface of the microenvironment at the opposite end. (All access experiments placed the cassette in essentially the same area of the microenvironment.) The operator then doffed the gloves and redonned them for the unload cycle.

Unloading involved placing the cassette back in the run box, doffing the gloves, and removing the run box through the hinged door and placing it on the storage table.

Swinging Door

The swinging door (approximately 40 cm by 30 cm high) was located directly in front of the cassette resting location inside the microenvironment.

The access cycle consisted of opening the run box on the storage table and placing the cassette inside the microenvironment through the swinging door. The door was closed, then opened to begin the unload portion of the access cycle. The cassette was removed and placed in the run box, which was then closed to complete one cycle.

Plastic Curtain

The plastic curtains completely covered the front of the microenvironment and consisted of 150-mm slats with 50-mm overlap. The access procedure was the same as that of the swinging door except in the manner of actually opening the microenvironment.

AMBIENT AIR CLEANLINESS

The other controlled variable was the level of cleanliness in the cleanroom air outside the microenvironments. As described previously, the air cleanliness was controlled by ULPA filtering the air entering the cleanroom through ceiling-mounted filters for the cleanest level and then adding a controlled quantity of unfiltered air through a system of PVC pipes. The quantity of ULPA-filtered air was also varied to degrade cleanliness.

Table 1. Cleanliness of Ambient Air Measured Via Multiplexer on PMS Micro-LPC 110

PROBE	TARGET CLEANLINESS	No. PARTICLES/FT2 => 0.5 MICRON MEAN	STD. DEV.	N
3	CLASS 10	* 194.37	400.08	163
	CLASS 1000	1894.94	1978.26	134
	CLASS 10K	5445.60	3464.12	111
5	CLASS 10	9.38	55.86	114
	CLASS 1000	2178.84	2325.66	103
	CLASS 10K	5991.13	3478.51	111
6	CLASS 10	21.47	90.84	114
	CLASS 1000	482.09	1187.37	104
	CLASS 10K	6403.79	3832.51	111
12	CLASS 10	73.52	308.18	115
	CLASS 1000	1205.55	2197.74	102
	CLASS 10K	5288.41	4037.40	111

*The somewhat high levels reflect elevated counts prior to the start of the experiment

Three distinct levels of air cleanliness were used, loosely referred to as Class 10, Class 1000, and Class 10,000. This designation does not imply certification to FED-STD-209D, but rather that particles per cubic foot of 0.5 μm or larger were controlled to approximately the indicated level (see Figures 3 and 4, and Table 1). In other words, for Class 10,000, 10,000 particles/cu ft represents an average value rather than an upper limit.

Cleanroom attire worn by the test operator was also changed with the cleanliness of the cleanroom. At its cleanest level, an expanded PTFE cleanroom garment system was worn; at the middle level, a polyester garment system was worn; and at the dirtiest level, street clothes were worn.

The graphs in Figures 3 and 4 illustrate the shifts in airborne particle counts in the variable cleanliness cleanroom as the test progressed. (Because a log scale was used, a value of one-tenth was added to the zero counts so that they could be plotted. All points plotted at one-tenth actually represent counts of zero particles.)

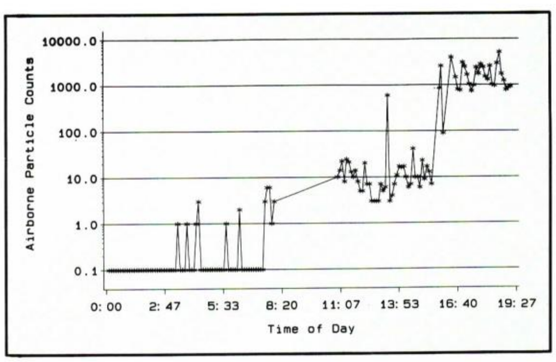

Figure 3. Cleanliness of ambient air measured via multiplexer on PMS Micro-LPC110.

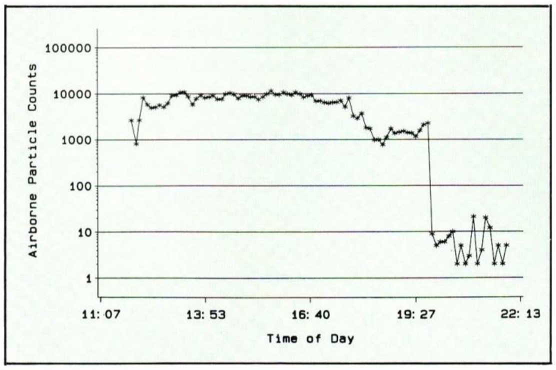

Figure 4. Cleanliness of ambient air measured via multiplexer on PMS Micro-LPC110.

Table 2. Preliminary Results Measurement Variability

	MEAN No. OF PARTICLES	AVG. STD. DEV. OF 3 MEASURES
BEFORE SIMULATED LOADING		
SWINGING DOOR	46.8	2.77
MANUAL ACCESS PORT	63.1	3.37
SMIF SYSTEM	51.4	3.73
AFTER SIMULATED LOADING		
SWINGING DOOR	179.2	5.58
MANUAL ACCESS PORT	64.4	4.51
SMIF SYSTEM	52.6	3.09

Testing was conducted over a period of three days, starting with the cleanest ambient (Class 10), then progressing to the two dirtier levels.

The order was then reversed, progressing cleaner to Class 1000, then back to Class 10,000.

This arrangement helped to avoid changing the ambient cleanliness any more than was absolutely necessary, while keeping the dual setups and changes in the test order required for a well-designed experiment.

RESPONSE VARIABLE

The indicator of access method cleanliness used was particles per wafer pass (PWP). Clean 100-mm test bare silicon wafers with an edge exclusion of 5 mm (3/16 in.) were used in this study. The defect channel (T2) corresponding to particles of 0.3 µm to 2.00 µm was used as a response variable. Surface scans were taken before and after 10 passes of the loading procedure. The total number of particles PWP is one-tenth that figure.

Because the variability of measured particle counts on wafers is significantly affected by the quantity of particles counted, only wafers with fewer than 100 particles were used. As soon as any wafer in the cassette of 10 wafers measured higher than 100 particles, the entire batch of 10 wafers was discarded, and a new set was started.

STATISTICAL CONSIDERATIONS

The experimental design used for this experiment is described as a split plot design. The levels of ambient cleanliness are the plots. The order of access means was randomized within the plots. Two replicates of the experiment were run. For each replicate, 10 wafers were tested at all 12 combinations of four access means and three levels of ambient cleanliness for a total of 240 measurements for the entire experiment.

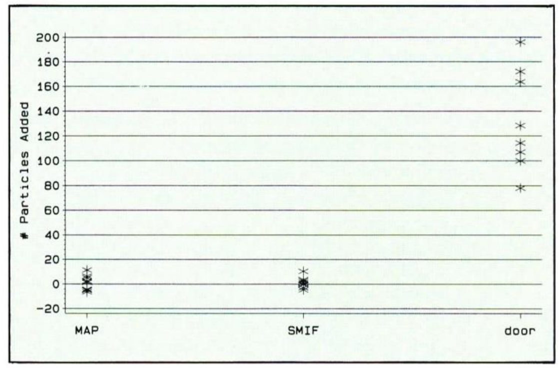

Figure 5. Preliminary experiment—particles added in 20 passes—ambient air: Class 2000.

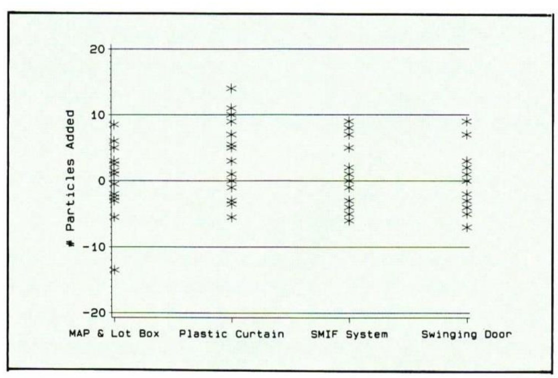

Figure 6. Cleanliness of access methods measured for 10 wafer passes—ambient air: Class 10.

Perhaps the most important factor determining the success of an experiment is the signal-to-noise ratio, the signal being the difference resulting from the variables measured, and the noise consisting of the variability in the system from all sources not being studied. The goal is to exaggerate the effect of the measured variables, while reducing or neutralizing the effects of other sources of variability.

The signal that we wanted to measure (particles added PWP) is ordinarily quite small, so the effect of the signal was exaggerated tenfold by performing each loading procedure 10 times before measuring the added particles. In order to predict and account for other sources of variability, a preliminary experiment was run.

PRELIMINARY EXPERIMENT

For the preliminary experiment, the variable access cleanroom was set up close to its dirtiest configuration (Class 10,000). A clean lot of test wafers was divided into three sublots and scanned three times. Each of the sublots was put through a simulation of 20 loading cycles using one of the access modes and rescanned three more times.

This procedure allowed us to estimate the variability due to measurement on the same unchanged wafer (and to look for increases in particles due to measurement alone). We were also able to investigate the variability in particles added from wafer to wafer, and to estimate the expected magnitude of the signal (measured as the number of particles added per wafer)..

The variability due to the measurement process was slightly better than predicted by Barclay Tullis in the *Handbook of Contamination Control*.[8] One standard deviation in measurement was anticipated to be equal to the square root of one-half the mean count.The measurement variability is tabulated in Table 2.

Results from the preliminary experiment are presented in Figure 5. It was clear from this graph that a difference in access means could be detected, at least at the dirtiest ambient condition.

An encouraging result of the preliminary experiment was that no significant increase in particle counts was associated with the measurement process itself. This was not unexpected, because the WIS 150 surface scanner was enclosed in its own microenvironment within which wafers were protected from exposure to particle-laden air.

RESULTS

Results are presented in Figures 6, 7, 8, and 9, and in Table 3. Each point on the graphs represents the difference in particle counts before and after loading on a single wafer.

At the cleanest ambient tested (Figure 6), only the plastic curtain access shows a significant number of particles added (that is, by Student's t-test, the number of particles added is significantly greater than zero).

Table 3. Particles Added Per Ten Wafer Passes (Particles Sized Between 0.3 and 2.0 μm)

Average Number of Particles Added
t Value for: Mean = 0
Probability > |t|

		SMIF SYSTEM	MAP and LOT BOX	SWINGING DOOR	PLASTIC CURTAIN
CLASS 10	AVG	0.5	0.45	0.45	* 3.55
	t	0.587	0.404	0.487	2.909
	p	0.56	0.69	0.79	0.01
CLASS 1000	AVG	− 0.075	− 0.2	* 7.0	* 7.5
	t	− 0.092	− 0.282	5.44	7.18
	p	0.927	0.78	0.0001	0.0001
CLASS 10K	AVG	1.3	1.5	* 40.15	* 52.0
	t	1.574	1.949	4.876	9.477
	p	0.132	0.066	0.0001	0.0001

*Indicates averages are significantly greater than 0 at a 95 percent confidence level.

At both Class 1000 and Class 10,000 (Figures 7 and 8), both the swinging door and the plastic curtain show a significant number of particles added, while the results for the MAP, Lot Box, and SMIF-Arm System remain statistically indistinguishable from zero. This is a reassuring set of results because, with the appropriate isolation technology, wafers can be effectively protected even in relatively high ambient conditions. The data very strongly support the current industry trend of downgrading the overall factory level of cleanliness while boosting the isolation performance where it really counts—at the wafer.

Figure 9 represents a summary of results over all three ambient conditions in one bar chart.

DISCUSSION

For every ambient cleanliness level, both the SMIF-Arm and the MAP performed extremely well, with PWP values indistinguishable from zero.

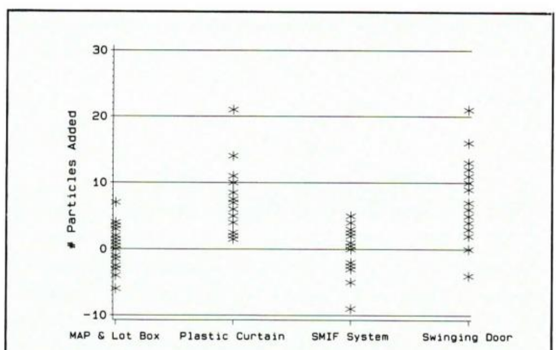

Figure 7. Cleanliness of access methods measured for 10 wafer passes—ambient air: Class 1000.

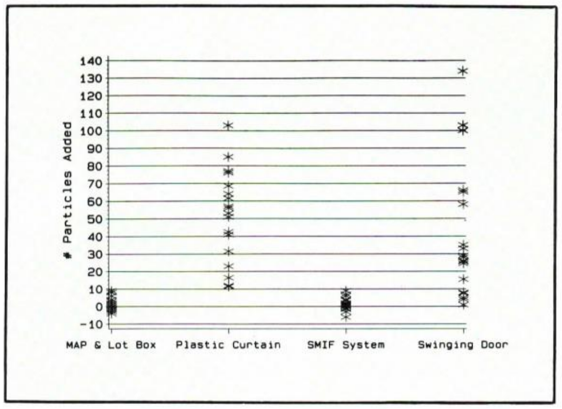

Figure 8. Cleanliness of access methods measured for 10 wafer passes—ambient air: Class 10,000.

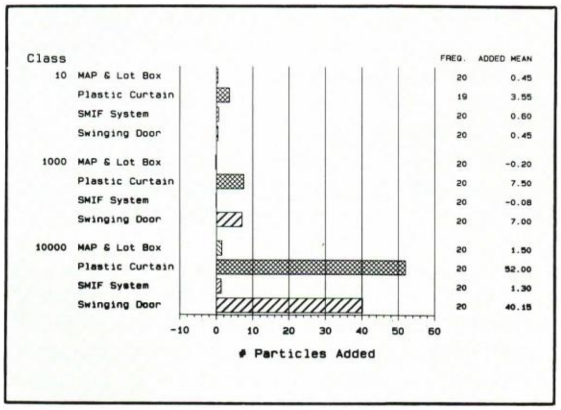

Figure 9. Cleanliness of access methods measured for 10 wafer passes.

The swinging door and plastic curtain did not perform as well, resulting in average PWP values ranging from 0.5 to 5. When assessing the potential for yield degradation, it is necessary to remember that the effect of additional particles will be cumulative over the many times that a lot of wafers is loaded into the equipment.

CONCLUSIONS

The results of this experiment show that the ability to maintain wafer cleanliness during access to a microenvironment is virtually independent of ambient conditions when a complete isolation type of access is used, and is dependent on the ambient conditions when the access mean is not 100 percent isolated. Both the MAP and the SMIF approaches clearly demonstrated the ability to transport wafers with virtually no surface contamination regardless of the ambient conditions. The swinging door and slatted curtains, however, showed significantly higher particle deposition rates when the ambient environment was of a lower quality.

Additionally, no PWP differences could be detected between the manual (MAP) and automated (SMIF) access means.

Every effort should be taken to provide a consistently isolated environment for the wafers in order to avoid inadvertent contamination from outside the microenvironment. Both the MAP and SMIF methods have been shown to be effective means of keeping the wafer clean.

Future studies should evaluate the accumulation of particles smaller than 0.3 µm on wafers due to loading and unloading procedures and perhaps examine ambient cleanliness levels between Class 10 and Class 1000.

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REFERENCES

1. Shu, C.Y., and Lu, L.C., "Designing, Operating a Submicron Facility with Isolation Technology," *Microcontamination* (March, 1992).
2. Tolliver, D., "Manufacturing Paradigm Shift Underscores Need for Microenvironmental Tack," *Microcontamination* (July, 1991).
3. Greiner, J., "Isolation Technology: Finding the Right Combination," *CleanRooms* (March, 1992).
4. Crouzet-Pascal, D., "Evaluating the Impact of SMIF Isolation Technology in ASIC Production," *Microcontamination* (May, 1991).
5. Wiegler, N., "Using the LEAPP Concept to Upgrade an Existing Cleanroom," *Microcontamination* (October, 1991).
6. Baechle, T., Fosnight, B., Marvell, G., Lynch, M., "Effectiveness of Using Mini-Environments to Meet Increasing Environmental Specifications," Burlington Technical Bulletin, IBM General Technology Division (October, 1991). (Submitted for publication in *Microcontamination*.)
7. Mitchell, K., "Glove Performance Results During Simulated Usage," *CleanRooms* (September, 1991).
8. Tullis, B., "Particle Contamination by Process Equipment," *Handbook of Contamination Control in Microelectronics*, D. Tolliver (Ed.), Noyes Publications, Park Ridge, New Jersey (1988).

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