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Evaluation of packaging materials under vacuum for potential use as internal cushioning for semiconductor industry vacuum machinery

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EVALUATION OF PACKAGING MATERIALS UNDER VACUUM FOR POTENTIAL USE AS INTERNAL CUSHIONING FOR SEMICONDUCTOR INDUSTRY VACUUM MACHINERY

BY
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MATERIALS UNDER VACUUM EVALUATION OF PACKAGING FOR POTENTIAL USE AS INTERNAL CUSHIONING FOR SEMICONDUCTOR INDUSTRY VACUUM MACHINERY

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ABSTRACT

This study explores a concept for applying basic packaging materials to an environment of high vacuum. This study identified three basic packaging materials and exposed them to a high vacuum environment to identify visual effects caused by the vacuum. In semiconductor and data storage industries, the machinery needed to ultimately create a computer chip often contains vacuum chambers. A common practice of the industry is to ship this machinery while under a state of high vacuum. There are parts inside these vacuum chambers that need protection from the effects of shock and vibration. By placing a sample of packaging material inside a chamber, pumping the chamber to a state of high vacuum, pumping the chamber back down to atmosphere and opening the chamber, a visual inspection of the material can identify that the material itself has failed to maintain its structure. The conclusion of this study identified one material that may warrant further, more precise research and testing for the possibility of use as a cushioning material under vacuum.

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INTRODUCTION

There is a unique packaging concern that exists within electronics industries. This concern involves airborne contamination. Particle contamination is one of three types of airborne contamination, the other two being gaseous and organic contamination.

Airborne contamination is anything other than the air itself that can corrupt a working machine. The more intricate and sensitive the equipment and situation, the higher the need is to control contamination (Blake 1). A good example is a hospital operating room. Any airborne contamination that enters an exposed incision during an operation can cause infections and blockages that can be fatal. The same principle can be applied to two other similar environments: computer rooms and ultra clean manufacturing facilities such as facilities for semiconductors, circuit designs and precision instrumentation.

As stated previously, there are three types of airborne contamination: gaseous, organic and particulates. Gaseous contaminations include chlorine, hydrogen sulfide, ozone, sulfur dioxide, and other chemicals that corrode electronic components. These gases can corrode both metallic and non-metallic materials.

An example of gaseous contamination comes from a unique source, a hand. Human skin contains sulfur, and this gaseous material, though in harmless quantities to human skin, can eventually spread and corrode aluminum and steel. One fingerprint can produce enough sulfur to spread over and contaminate a 36"x36" aluminum surface in three days. The sulfur will also spread to computer chips, lodging itself in between circuits and in between adhesive-sealed parts, interrupting both electrical conductivity and the flow of electricity. Sulfur, when pumped under vacuum, can outgas which can result in corroding of vacuum pumps (see appendix M).

Chlorine is another gas which can be transferred by clothing and drinking water. Chlorine has been known to cause stress cracks in structural steel. There have been reports of fatalities caused by structures collapsing from stress-cracked steel beams (Charles, Congleton and Shushan 1).

The second type of airborne contamination is organic. The largest source of airborne organic contamination is the incomplete combustion of fossil fuels, more specifically petroleum. Airborne petroleum will cause electronic interruption to chips and erode materials in much the same way as gaseous contaminants do. Another source of organic contamination is the oxidation of plastics and rubbers.

The third type of airborne contamination, particulate contamination, is also known as dust. To illustrate an example of dust contaminating a working machine, consider a volcano. When a volcano erupts, ash spreads over the immediate area covering everything, rendering cars, generators, phone lines, streetlights useless. This is exactly what happens in an ultra clean manufacturing facility with the presence of particulate contamination, only on a much smaller scale. Anytime a printout is thrown into a wastepaper basket, a beard is scratched, a box is set down and opened, dust is created, which will eventually cover the surrounding equipment. The dust will gather on working mechanisms, which can cause the mechanisms to jam and fail. The dust will gather on computer chips and block the flow of current. The dust will settle on adhesive-sealed, integrated circuitry, corrupting the adhesion.

There are five primary types of mechanisms of particulate wear: abrasive, erosive, adhesive, fatigue and corrosive wear (Pall 1). Wear will degrade the performance of system components. For example, a fluid gear pump is very dirt sensitive, and any particulates that find their way inside a gear pump will lock up the gears, thus increasing the wear rate. The temperature of the mechanism will rise, resulting in leakage. The oil pump pressures will drop, reducing efficiency.

Abrasive wear is caused by particles getting in between adjacent moving surfaces. Abrasive wear causes dimensional changes, leakage, lower efficiencies and a generation of more particles. Particles of equal size to a clearance space between two moving surfaces will enter the clearance space and act as a cutting tool that removes material from the moving surface. Particles slightly larger than the clearance space will block the flow of lubricants to the surface space, thus generating heat and friction, eventually shutting down the mechanism. A chain reaction of abrasive wear will occur when 'work hardened' particles, not removed from the parent surface, re-circulate and cause additional wear.

Erosive wear is caused by particles that imbed on a component surface and begin to remove material from the surface due to momentum. This is similar to abrasive wear only these particles imbed on the surface. Erosive wear is prevalent primarily in valves and components with high velocity flows.

Adhesive wear is primarily caused by surface to surface contact. An example of adhesive wear is abrasive wear caused by blockage from oils due to oversized particulates.

Fatigue wear is the result of repeated stressing caused by clearance-sized particles trapped by the two moving surfaces; much like abrasive and erosive wear, in fatigue wear, cracks form and spread after repeated stressing. Even without additional particulate exposure these cracks spread.

Corrosive wear is the result of water or other chemicals corroding surfaces. Rust is a good example of corrosive wear. The corrosion of certain chemicals can cause erosion, smoke, degradation and even explosions.

There are common types of particulates as well as common sources. Metallic particulates enter the environment from floors, rotor brushes in vacuum cleaners, air conditioning units, printers and people. The main problem of metallic particulates is that they conduct electricity, thus potentially causing short circuits. This particulate usually enters the ultra clean environment in the form of rust.

Carbonaceous particulates come in the form of smoke from tobacco, printer toners, and automobiles (carbon paper created a great amount of carbonaceous particulates back when carbon paper was widely used). This form of particulate is both conductive and combustible. Fibrous organic particulates are natural-based fibers, such as wool or cotton, and usually derive from clothing or incorrect cleaning or packaging materials. The main problem with these particulates is that they absorb moisture and can cause electronic circuits to fail. This is especially frustrating because a short circuit from fibrous particulate contamination is almost impossible to detect because the heat generated from a short circuit can cause particulate disintegration. Paper dust is another particulate. Not only can paper dust attract moisture, but paper dust is also attracted to magnetic fields. The last of the common particulates are construction particulates. These originate from concrete erosion, sand, plaster, sheetrock, brick or any material used in building the outside of the clean facility. Any cracks, or perforated floor tiles can release these particulates into the atmosphere. Construction particulates mainly cause abrasive contamination.

To properly illustrate the high cost of particulate damage, one fully operational silicon wafer coating machine with stations for different coatings and thicknesses can cost up to three million dollars. One of these machines can produce a wafer in six minutes. One wafer can house, conservatively, twenty computer chips. Computer chip makers sell hard drives for a unit price of 300 to 400 dollars. With the price and quantity of the chips, there is, conceivably 80,000 dollars of sales not being made for every six minutes that a tool is shut down due to particulate damage.

SITUATION

The product in question is a thin-film, coating device that operates in a particulate-free environment. The device, called a 'cluster tool' (figures 1 and 2), deposits very thin (measured in angstroms; there are ten million angstroms in one centimeter) layers of various metals onto a 200mm or 300mm round wafer made of conductive or semi conductive materials such as silicon (CVC Handbook 55). This is one of many steps that eventually transform this 'wafer' into a computer chip (see appendix A). These metals are used for their light weight (see appendix B) in order to create smaller computer chips from these wafers. These cluster tools have the ability to accept a wafer from a central, wafer-handling unit, move the wafer into a vacuum chamber, create a vacuum inside the chamber and then heat a certain metal to the point that the metal atoms escape via the 'mean free path' of the atom (Redhead 20), or the path an atom travels until it hits another object of it's size, and deposit onto the wafer. This is known as the 'deposition of metals' (Cable 130). The cluster tool then will transfer the wafer back to the central wafer handler unit to be either transferred to another cluster tool or back to the operator. These cluster tools weigh from 1500 to 8000 lbs and measure anywhere from 30"x30"x30" to 40"x80"x50". These cluster tools all contain water pumps, vacuum pumps, and cryo pumps to create the vacuum (see appendix C).

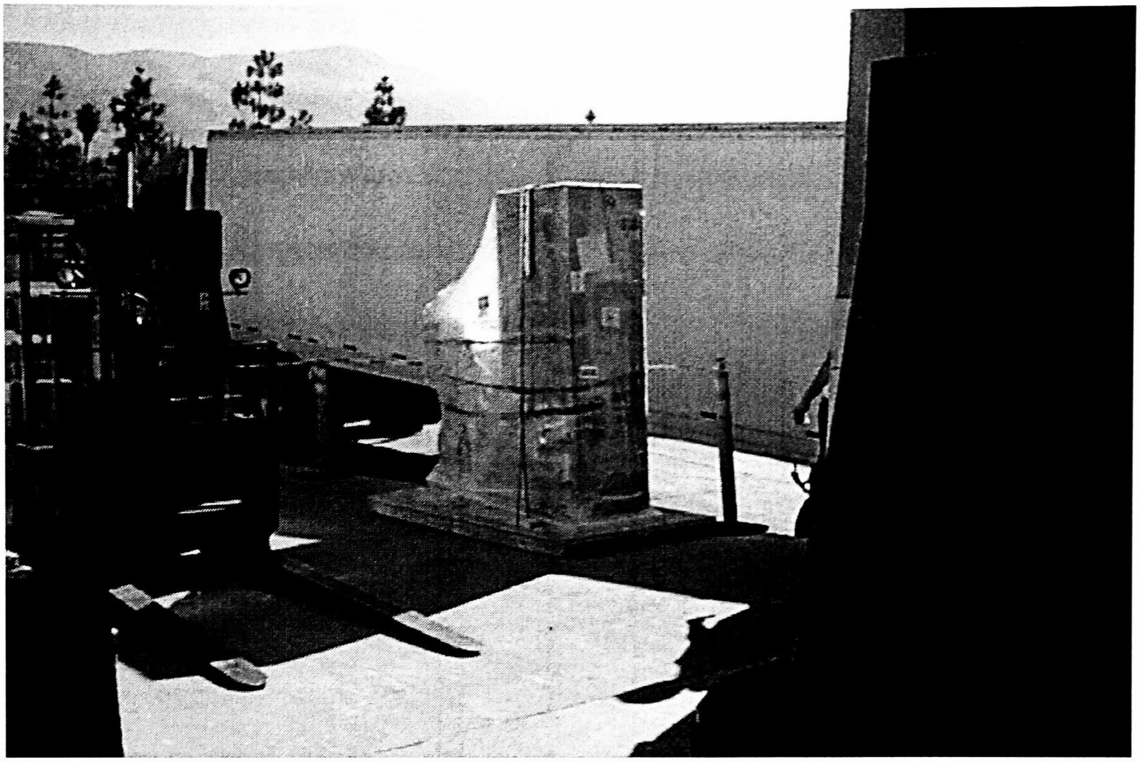


Fig. 1 A CVC cluster tool, skidded and wrapped at customer site.

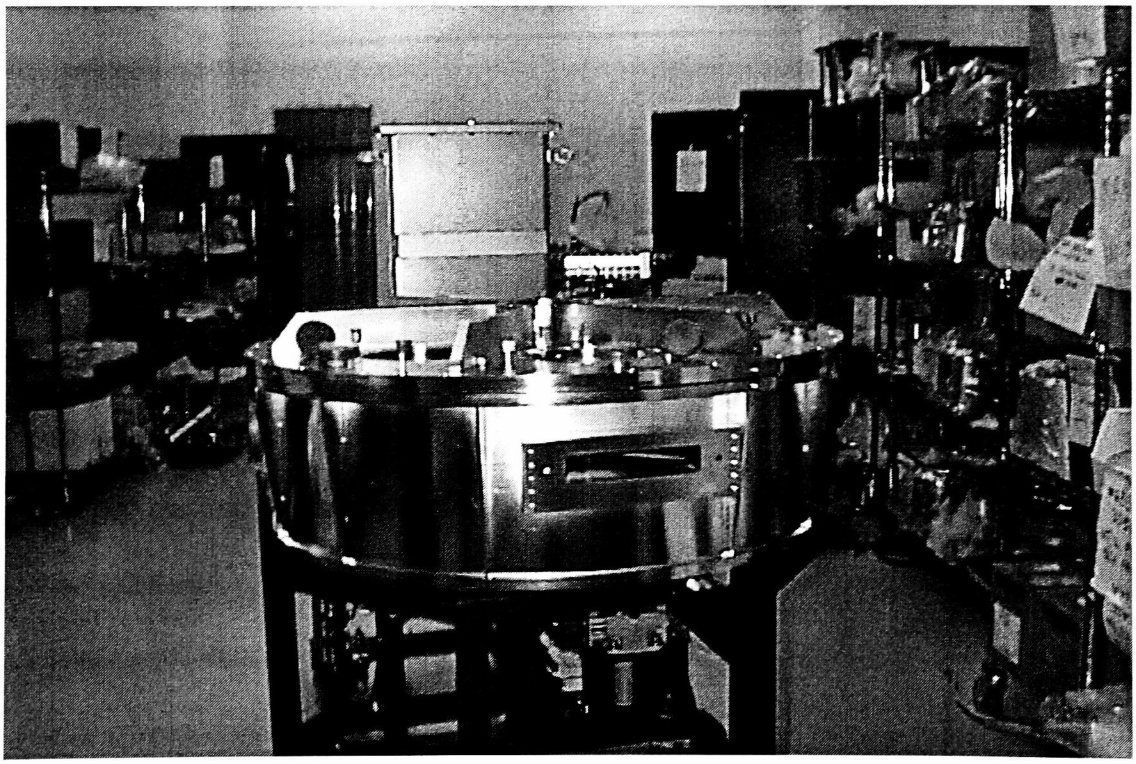


Fig. 2 A CVC cluster tool chamber, sealed closed.

Cluster tools operate in particulate-free environments. A particulate free environment is a standard rated 'cleanroom' (see appendix D) that is filtered and maintained to only contain a certain number of particulates per cubic foot inside the room. Particulates, by this standard, are any organic or inorganic materials foreign to the room and measuring .5 microns or less. The cleanroom is maintained to the particular rating it has by several means.

1) HEPA (High Efficiency Particulate Air) filters filtrate the air being introduced into the room. HEPA filters are replaceable, extended-media, dry-tape filters in a rigid frame having a minimum particle-collective efficiency of 99.97% for .3 micron-sized particles (Cleanrooms East Proceedings 447). A micron, or micro-inch, is equal to one millionth of a meter, or 0.00003937 inches. (Horton, Jones and Holbrook 2408).
2) Air is constantly blowing down and out of the room. Air from the outside passes through the HEPA filters, located in the ceiling, then blows downward.
3) Material entering and staying inside the room is monitored and controlled. Anything that is and will be entering a cleanroom has the potential of introducing particulates to the room. By having all personnel wear cleanroom clothing prior to entering a cleanroom and having all cleanroom personnel exposed to blowing, filtered air to remove particles off clothing (called an air shower) prior to entering a cleanroom, the potential for having particulates enter a cleanroom via

a person can be controlled. Using cleanroom packaging methods such as double bagging and vacuum sealing parts prior to sending a part into a cleanroom can control particulate exposure from objects.

4) Actions of the personnel inside the cleanroom are controlled. Having personnel walk slowly, refrain from scratching and/or sneezing, and not removing clothing inside the room will also reduce the possibility of personnel introducing particulates from their own bodies into a cleanroom. These actions reduce the amount of particulate inside the room and maintain the level of particulate inside the room at any given time. The cleanroom rating is monitored by air gathering particle counters (see appendix M).

As described in the introduction, particulate control is crucial to the operation of cluster tools. Particulates will keep the tool from working properly, as well as contaminate the product. The tool will be unable to maintain the vacuum it is supposed to achieve with particulates inside the vacuum, by the particulates corrupting any seals inside the chamber, or by contaminating any pumps and lines and other equipment both inside and connected to the tool, thus contaminating the room.

Particulates will also contaminate the clothing of the operator, who will then contaminate anything else inside the cleanroom that person touches. Any particulate contamination at all requires re-cleaning of the cleanroom, all equipment, hoses and lines inside the cleanrooms and any adjoining cleanrooms. This results in losses in time and money.

Each cluster tool contains a vacuum chamber that performs the deposition of the thin film inside the chamber (figure 3). As stated, it operates in a super clean environment, but more importantly for this discussion, this vacuum chamber needs to arrive to the customer in this super clean environment because the customer is not paying to re-clean this chamber once it is purchased. This means that the chamber must be shipped while under vacuum. The vacuum chamber is sealed, pumped down until it reaches vacuum, and then shut under vacuum and shipped. This way the customer will receive a cluster tool that is clean and ready to operate in a cleanroom.

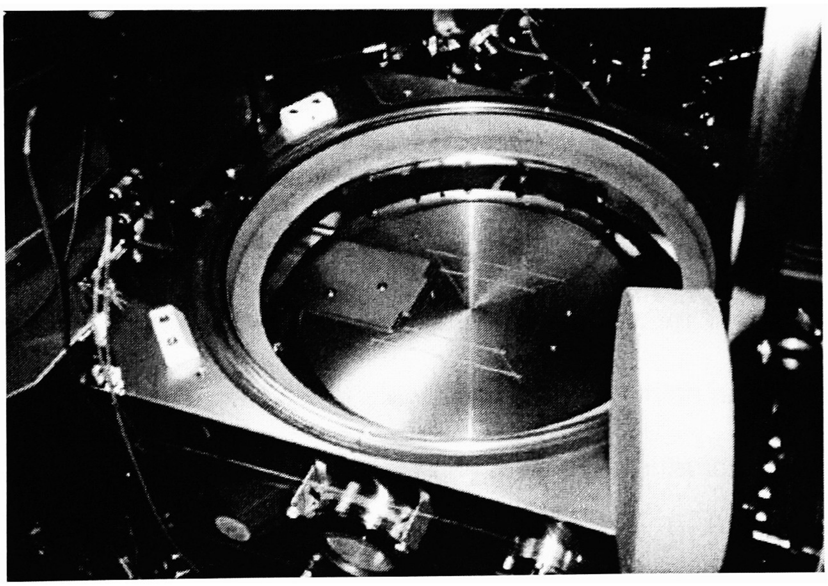


Fig. 3 The inside of an open CVC PVD cluster tool chamber.

The vacuum chamber contains different parts based on the specific deposition methods to be used. There are stainless steel parts that contain surface finishes to produce the seal. Surface finishes on metals scratch very easily and any cross-directional scratch to the sealing surface groove will cause a leak in the vacuum. There may also be copper parts that allow for conductivity and heating properties inside the chamber. Copper can also scratch very easily with contact. If the vacuum chamber uses light as a heat source, then there may be quartz inside the chamber, which is very fragile. Some chambers have viewports, which also may contain either quartz or other glass. The carrier that holds the wafer may be made of titanium for strength. All of these parts are in close contact with each other and are susceptible to shock and vibration during transportation. The wafer itself sits on a pad that allows the wafer to be transported in and out of the chamber and raised or lowered into the transfer chamber and into the elevator which will carry the wafer to the tool opening. These pads are on springs and elevation systems which can suffer shock and vibration damage if not secured properly inside the chamber.

SAMPLE PROBLEM

Shock and vibration can affect a cluster tool. Appendix E shows actual damage inflicted on a CVC cluster tool in March 1998 when lag bolts securing a cluster tool on a wood skid failed to perform during transportation. Four cluster tools were shipped on a flatbed truck to Londonderry, Northern Ireland. The packaging from New York to Heathrow, London Airport performed adequately, but on the final leg of the trip through the winding roads of Ireland on a flatbed truck with no air-ride suspension, one of the four cluster tools crashed through its crate. The cluster tool suffered major damage and had to be completely replaced.

The last page shows that although the actual vacuum chamber portion of the tool itself sustained minimal exterior damage, there was major internal damage to the chamber. The chamber itself was scratched. Scratches inside a chamber are valleys which actually add to the total space inside the chamber, This addition of space will require a greater vacuum to operate, and will add to pumping time. The plate that the target was bonded to was scratched and damaged. Scratches will not allow the chamber to seal. The end effector, or the plate the wafer sits on, was damaged. The wafer itself could not sit properly inside the chamber, compromising the thickness of the deposition.

The following are other examples of possible shock and vibration damage to a vacuum chamber worth noting. Glass may shatter and work its way into hoses and lines, as well as scratch other parts. The carrier can bend, thus rendering it unavailable to hold the wafer. Copper may chip, creating particulates and it could bend, thus possibly compromising the movement of the carrier.

Currently, there are problems with industry standard materials used in interior packaging of semiconductor equipment. Solid plastics such as Teflon are one standard material used. It is used in blocks or tubes to hold parts in place during transportation. The main benefit of Teflon is that it does not create particulates. It is also rigid enough to hold metal parts in place. A third benefit is that it can withstand extreme temperatures and humidity. Problems arise in its ability to scratch, chip and crack metals and glass during transportation. Another problem is its cost. It is very expensive in relation to its use (see appendix F).

Another generally accepted material used is polyethylene film. It is inexpensive, does not create particulates, and can be cut in any shape and size. The problem with polyethylene film is, like any plastic film, polyethylene film contains additives which can outgas, or, when exposed to a heated environment, will create vapors which will contaminate anything inside the vacuum. According to a publication from the October 1998 issue of Micro, " The concern in the semiconductor industry is that outgassing of these additives can contaminate, and potentially corrode, tool components that come in direct contact with packaging films" (Graves and Lin 1). These additives can contaminate the chamber, the wafer, and any hoses and lines inside the chamber. Contamination requires re-cleaning, costing time and money. Another problem with polyethylene film is that it is only a film; it can prevent scratches, but it will not cushion.

Polyvinylchloride film is also used. This has the same benefits as other films but is generally stronger and easier to cut and form around metal parts. The one major problem with polyvinylchloride is that this material is strongly suspected of causing stress cracking in stainless steel. Charles, Congleton and Shushan have stated that stainless steels in neutral chloride solutions can stress crack even at room temperature (Par. 2). Although this article points to liquid chloride, one should also at least consider chloride in other forms as well. The article points out that research is needed regarding the relationship of chlorine to metals, and given this statement, all chlorine-related materials should be regarded as possibly unsafe when introduced to a steel environment.

SUBPROBLEM

There are basic packaging materials that can be used for interior protection of vacuum chambers that can protect from the effects of shock and vibration at a low cost, but are not acceptable for several reasons. One is that they may create particulates under vacuum. Wood-based products will definitely create particulates. Rubbing these products will cause flakes. The vacuums usually achieved in these chambers reach 1torr x10^{-8}. Historically, there have been vacuums as high as 2torr x10^{-14} (Redhead 1). 1 torr is equal to 1/760th of one standard atmosphere (Varian 6), and 'torr' stands for torricellean vacuum (Cable 1). And temperatures can reach below 150 degrees C (Scott 1) (see appendix G). Another reason for unacceptability is that basic packaging materials may lose their structurability under vacuum which would result in crushing or bending, thus losing their ability to protect the items inside the chamber.

Packaging foams may or may not have these unacceptable characteristics under vacuum (see appendix H). Their open-celled makeup may create particulates under vacuum. There may be particulates, either in foam structure or in foreign matter inside the open cells that can escape into the chamber. The structure of the foam itself may fail under vacuum due to the low pressure and low temperatures (this is stated as *may* have these characteristics due to the lack of data on this topic). There are no publications, articles or journals to be found addressing this issue to date.

There may be an opportunity here to introduce packaging foams as a use inside vacuum chambers for protection. Introductory, or pre-screening tests are needed to identify the visual effects of packaging foams under vacuum. If, under vacuum for a set length of time, packaging foams leave a visible presence of particulate inside a chamber, then the use of packaging foams for protection under vacuum cannot be considered. But if there is no visible presence of particulates after a test, then perhaps more research is warranted. The use of a particle counter, or a broader test of packaging materials may be warranted. The same holds true regarding the structure of packaging foams. A visual test of foams under vacuum for a set period of time should be conducted to look for obvious crushing or bending of material. If so, then the use of these materials for protection can be ruled out, but if there are no visible signs of bending or crushing, then further testing and research may be warranted.

HYPOTHESIS

"Polymeric foams do not produce particulates which cause damage to micro chips when under vacuum".

TEST DESIGN AND METHODOLOGY

Three packaging foams are to be tested. Two are from foam stock, a 2 pound per square inch density polyethylene foam piece and a polyurethane foam. Piece The third is a randomly selected, brand name foam material called T-board. This material has a 2 lb. per square inch density HDPE foam core with a metallocene foam exterior (see appendix I). The hypothesis is that these packaging materials may satisfy product demand, meaning no visible particulate generation and no visible failure in material structure.

The test will be conducted using an existing CVC Products cluster tool. A CVC technician will operate the cluster tool while the engineer will set up the parameters and record the results. The three packaging materials mentioned above will be tested.

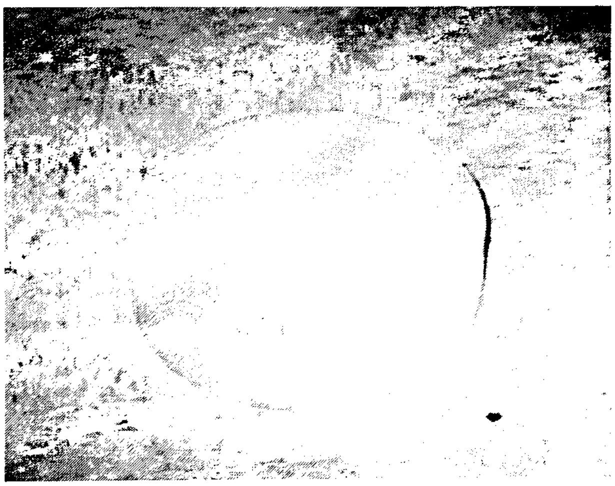


Fig. 4 Polyethylene foam.

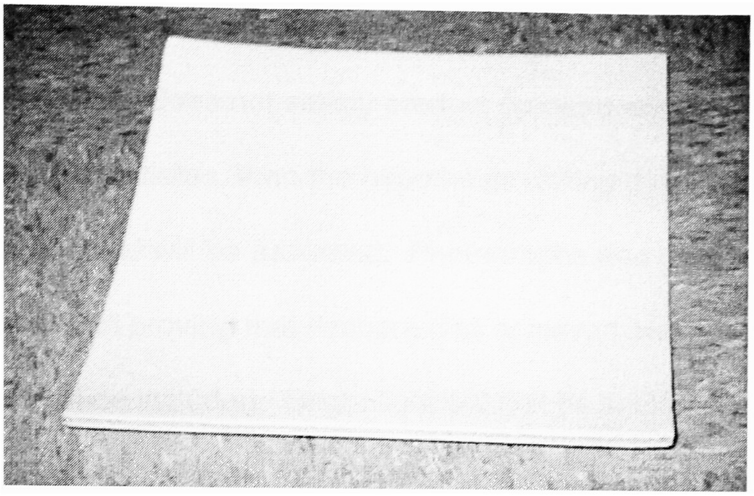


Fig. 5 Example of T Board.

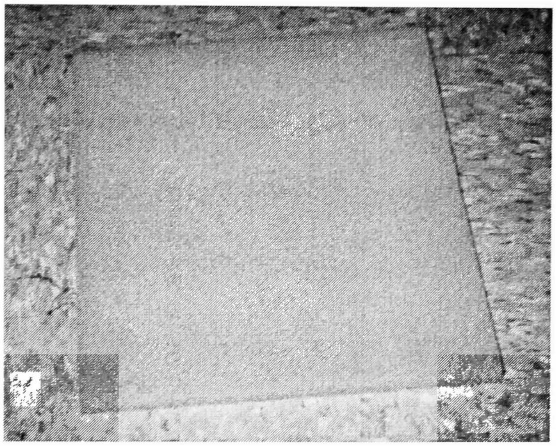


Fig. 6 Polyurethane foam.

Each material will be placed inside a chamber. The chamber will then be sealed, pumped down to a specified state of high vacuum and left in that state for one minute. One minute is chosen because this is a pre-screening test for visible effects only. Once the material has been exposed to a state of vacuum for one minute, then the process will be shut down, the chamber will be vented out and the packaging material will be removed. The material will be inspected for any visible particulate generation. If any particulates appear, the hypothesis that the material does not satisfy product demand will be assumed. If there are no visible particulates, then the hypothesis stating the material may satisfy product demand will be assumed. Photographs and generated test data from the cluster tool proving that vacuum was achieved and the correct length of time was met will be included. Bright light will first be shined into the chamber, and then the chamber will be inspected for particles.

TEST

TEST #1

1) Date: 10/5/98
2) Time: 9:15 a.m.
3) Location: CVC Products, Rochester, NY Production Facility, CAR 3 test area
4) Operators: A. Baisch; Manufacturing Engineer, J. Sefranek; Process Technician
   Principal Advisor: Mr. Patrick Borrelli, PhD. CVC Products Inc.
5) Tool used: PVD Process Tool VE# 8240
6) Room Temperature: 70 degrees
7) Humidity: 30%
8) PE foam inserted into chamber at 9:20 a.m.
9) O-ring inserted into chamber for seal at 9:20 a.m.
10) Total time material was under high-vacuum 00:60:00
    Rate of rise test took longer 1st time.
11) End of test was at 9:40 a.m.

Result: PE crushed inward several inches. No visible particles inside chamber.

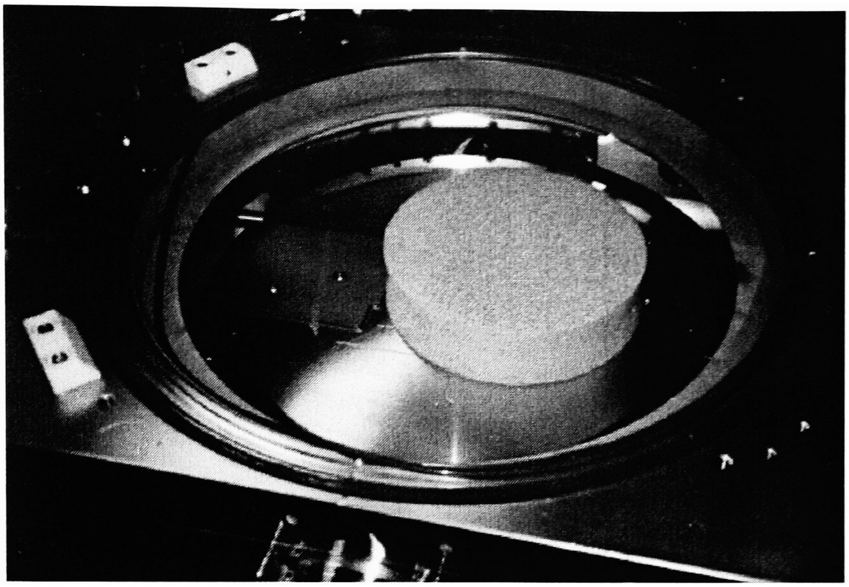


Fig. 7 Polyethylene foam pad inside the chamber, immediately following the test.

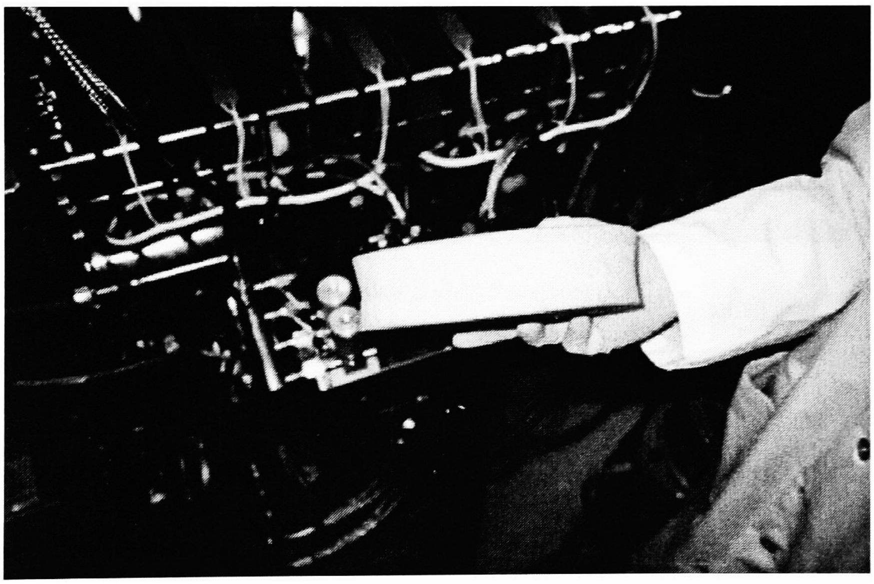


Fig. 8 Polyethylene foam sample, crushed inward, after the test.

Refer to appendix J for test data.

TEST #2

1) Date: 10/5/98
2) Time: 9:50 a.m.
3) Location: CVC Products, Rochester, NY Production Facility, CAR 3 test area
4) Operators: A. Baisch; Manufacturing Engineer, J. Sefranek; Process Technician
5) Tool used: PVD Process Tool VE# 8240

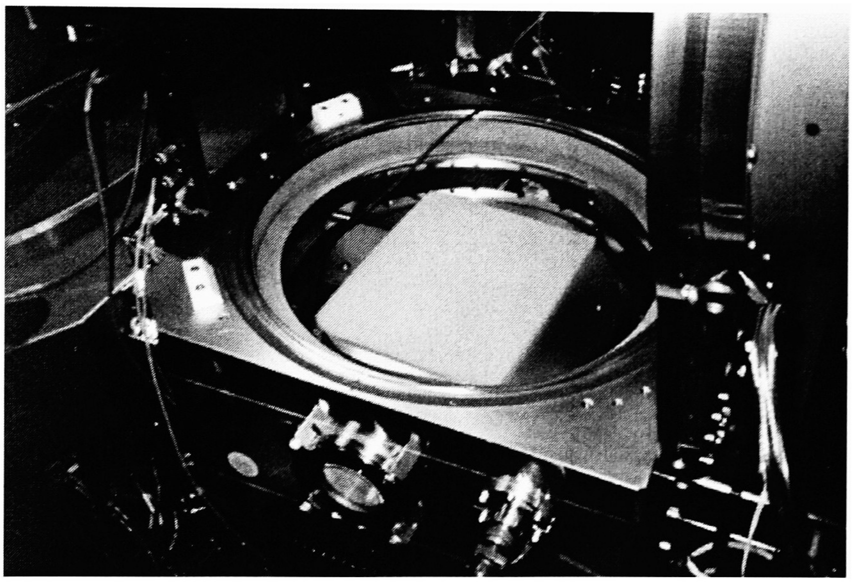


Fig. 9 Polyurethane foam sample placed inside the chamber.

6) Opened chamber at 9:50 a.m
7) Inserted o-ring into chamber for seal and closed at 9:53 a.m.
8) Start up at 9:55 a.m.
9) Total time the material was under high vacuum was 00:01:07
10) End of test was at 10:05 a.m.

Result: no effect on material, no visible particulates.
Refer to appendix K for test data.

TEST #3

1) Date: 10/5/98
2) Time: 10:17 a.m.
3) Location: CVC Products, Rochester NY Production Facility, CAR 3 test area
4) Operators: A. Baisch; Manufacturing Engineer, J. Sefranek; Process Technician
5) Tool used: PVD Process Tool VE# 8240

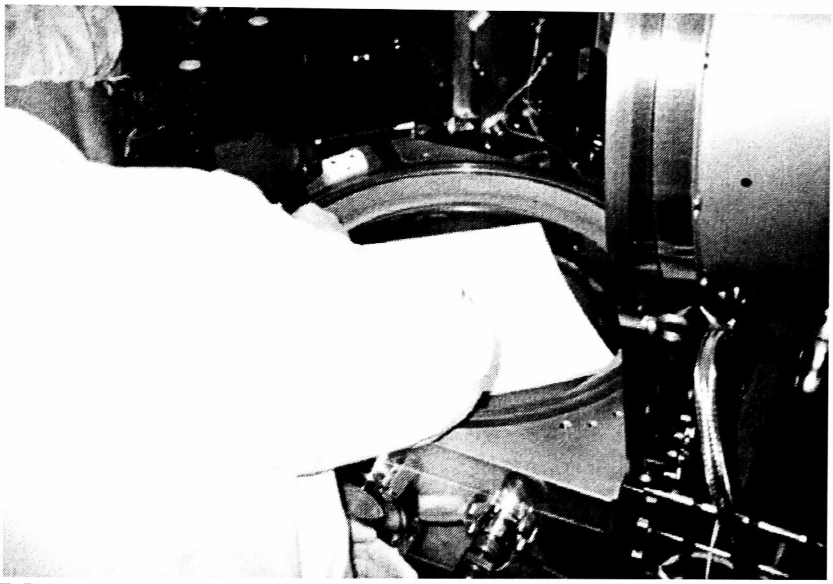


Fig. 10 T-Board sample, inside the chamber, immediately after the test.

6) Chamber was opened at 10:17 a.m.
7) Inserted o-ring for seal and closed at 10:20 a.m.
8) Test was finished at 10:26 a.m.
9). Total time of material under high vacuum was 00:01:02
10) End of test was at 10:31 a.m.

Result: Bent material. There was crunching and compression on ends. By observing up close inside the chamber with a bright light, no flakes or visible material could be seen inside the chamber. Any visible flakes or visible materials observed inside the chamber would have resulted in test failure of the hypothesis.

Fig. 11 This is the T-board sample, bent upward two inches, after the test.

Refer to appendix L for test data.

RESULTS AND CONCLUSION

Test Parameters	PE Foam	PU Foam	T-Board
Visible Particulate			
Structure Failure	x		x

One major observation was that none of the materials tested left any visible residue. Therefore, all three met the statement of the hypothesis. However, given the identified lack of research in the field on materials and shock fragility, this result warrants further testing with more precise measuring equipment, such as particle counters.

There is a complication that the hypothesis did not account for. The polyethylene, being a semi-closed cell material, did crush inward on itself (see figure 8). This could suggest failure of the material to perform a protective function in the field; therefore, this material should not be considered for further testing.

The T-board material did bend forward (see figures 10 and 11). Although the T-board did not leave any residue in the chamber, the bending causes some concern as to failure to protect in transit. This product should not be considered for further testing for packaging applications under vacuum.

The polyurethane material did not suffer any damage, and appeared not to leave any material in the chamber. This suggests that this material may be a candidate for further evaluation as possible protective material for devices, parts, and products that are under vacuum and in transit.

BIBLIOGRAPHY

American National Standards Institute, ANSI /ASQC. Q9001-1994. Philadelphia: ANSI, 1994.

American Society for Metals. Metals Handbook, 8th edition. Metals Park, Ohio: American Society For Metals, 1964.

American Standards And Test Measurements. ASTM 4169. Philadelphia: ASTM, 1995.

American Standards And Test Measurements. ASTM D3332-88. Philadelphia: ASTM, 1988.

American Standards And Test Measurements. ASTM D999-91. Philadelphia: ASTM, 1991.

Argonne National Labs. Doc#410201-00095 Technical Specification for Vacuum Requirements of Ultra High Vacuum Devices for Beamlines. Chicago: Argonne Nat. Labs, 1995.

Blake, Carol. "Microcontamination in the Computer Room". July 1998: 1. http://www.accessfloor.com/micro/default.htm.

Cable, J. Wesley. Vacuum Processing In Metalworking. New York: Reinhold, 1960.

Charles, E.A., J. Congleton and S.M. Shushan. "The environment assisted cracking of diffusion bonded stainless to carbon steel joints in an aqueous chloride solution". Corrosion Magazine. October 1996: 1.

Cleanrooms Magazine. Cleanrooms '98 Proceedings. Baltimore: Penn Well Publishing, 1998.

Curbell Plastics Materials Handbook. Rochester: Curbell Inc., 1997.

CVC Products, Inc. S900001-0001. Rochester: CVC, 1998.

CVC Products, Inc. CVC Factory Acceptance Data Sheet. Rochester: CVC, 1995.

Duke, W.M. and Vance, R.W. Applied Cryogenic Engineering. New York: John Wiley, 1962.

Graves, Sarah and Steve Lin. "Comparing the Molecular Contamination Contribution of Clean Packaging Films". Micro Magazine. Oct. 1998: 1.

Hobson, J.P., E.V. Kornelson and P.A. Redhead. The Physical Basis of Ultrahigh Vacuum. London: Chapman and Hall, 1968.

Horton, H.L., F.D. Jones and Erik Oberg. Machinery's Handbook. 23rd ed. New York: Industrial Press, 1988.

Pall Corporation. "Fundamentals Of Filtration: Erosive Wear". 1996. < http:// www.pall.com/applicat/aerospace/ew.htm >.

Pall Corporation. "Fundamentals Of Filtration: Chain Reaction of Abrasive Wear". 1996. < http:// www.pall.com/applicat/aerospace/ew.htm >.

Pall Corporation. "Fundamentals Of Filtration: Technical Study: NADS Piston Pump Wear Test". 1996. < http:// www.pall.com/applicat/aerospace/ew.htm >.

Pall Corporation. "Fundamentals Of Filtration: Effect on Pumps". 1996. < http:// www.pall.com/applicat/aerospace/ew.htm >.

Scott, Russell. Cryogenic Engineering. Princeton: D. Van Nostrand, 1959.

Semiconductor Equipment Materials International. SEMI E49-195. San Jose: SEMI, 1995.

U.S. Department Of Defense. FED 209-E. Washington: U.S D.O.D, 1987.

U.S. Department Of Defense. MIL 2651. Washington: U.S D.O.D, 1987.

U.S. Department Of Defense. MIL 2073. Washington: U.S D.O.D, 1988.

U.S. Department Of Defense. MIL 1246. Washington: U.S D.O.D, 1987.

Varian Associates. Basic Vacuum Practice 3rd edition. Lexington: Varian Associates, 1992.

Wiley, J.A. Handbook of Packaging Engineering. John Wiley & Sons, 1986.

APPENDIX A

Electronic Applications of Vacuum Deposited Metals and Metal Compounds

COATING MATERIAL	APPLICATION	COATING THICKNESS, MICRONS
ALUMINUM	CONDUCTOR	.01 TO .2
BISMUTH	CONDUCTOR	.05 TO .5
CADMIUM	CONDUCTOR	.05 TO 1
CHROMIUM	RESISTOR	.002 TO .1
COLUMBIUM	SUPERCONDUCTOR	.05 TO 1
COPPER	CONDUCTOR	.01 TO .2
GERMANIUM	SEMICONDUCTOR	.05 TO 1
GOLD	CONDUCTOR	.01 TO .2
INDIUM	CONDUCTOR	.05 TO .2
LEAD	CONDUCTOR	.05 TO .2
MOLYBDENUM	CONDUCTOR	.05 TO .2
NICKEL	CONDUCTOR	.05 TO .2
PLATINUM	CONDUCTOR	.01 TO .2
SELENIUM	SEMICONDUCTOR	.5 TO 100
SILICON	SEMICONDUCTOR	.5 TO 10
TANTALUM	RESISTOR	.01 TO .2
TIN	SUPERCONDUCTOR	.05 TO .2

This chart is taken from Metals Handbook, 8th edition, American Society For Metals. This chart is included to identify conductors, resistors, semiconductors and superconductors. As I have identified in the introduction and shown here in this chart, copper is a true conductor of electricity, one with little resistance to electrical current. A semiconductor material, such as silicon, is semi-conductive, a material that falls somewhere between a true conductor and a resistor. A superconductor is a material that will have zero resistance below a certain temperature.

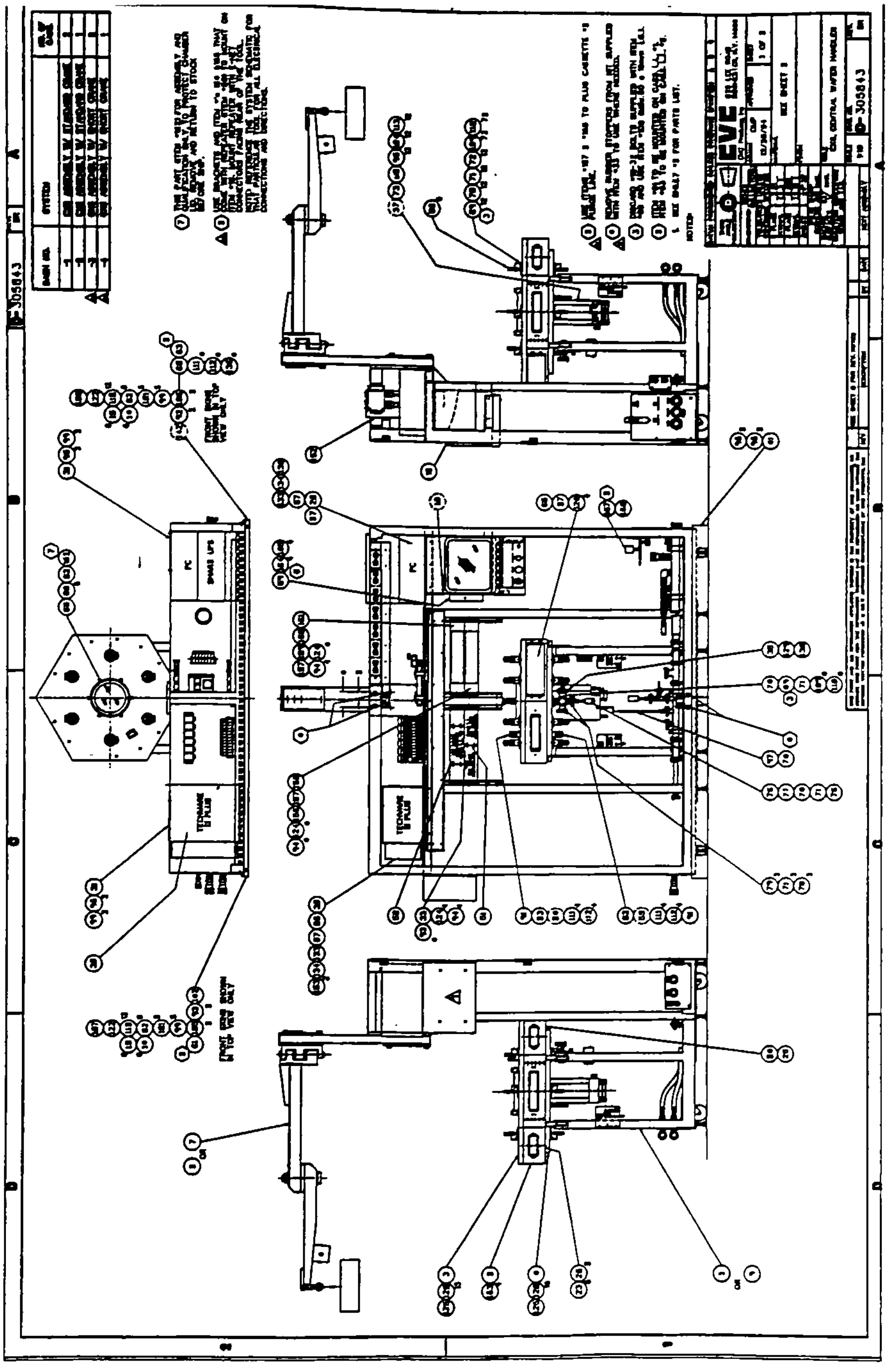
APPENDIX B

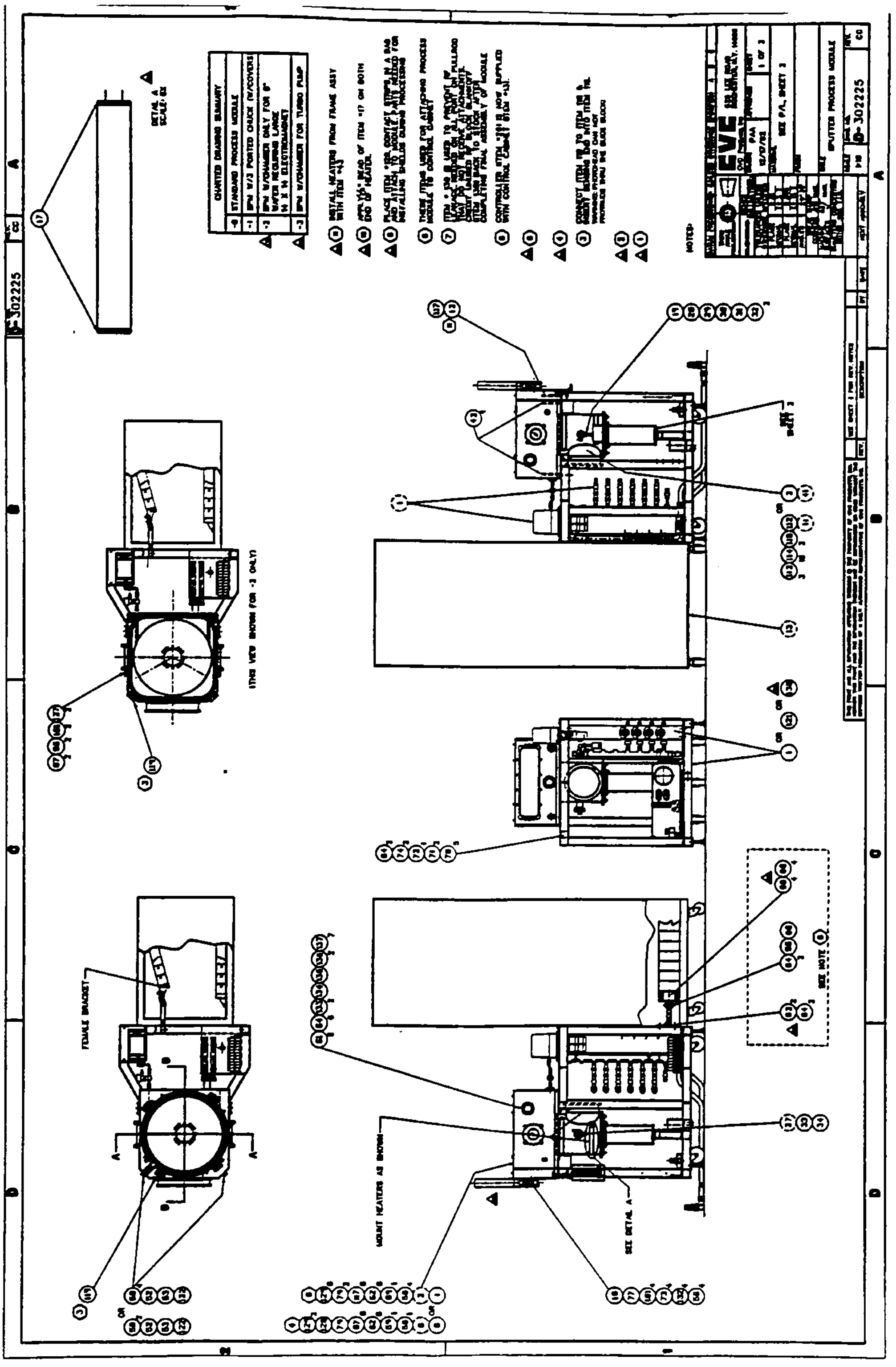
Weights Of Metals

MATERIAL	WEIGHT PER LBS./FT^3 (FROM MACHINERY'S HANDBOOK, 23RD ED.)
ALUMINUM	168.5
COPPER	554.7
GOLD	1204.3
SILICON	54.3

This chart is included to identify why some semi-conductive materials, such as silicon, would be desirable for use in manufacturing smaller, lighter electronic components such as computer chips.

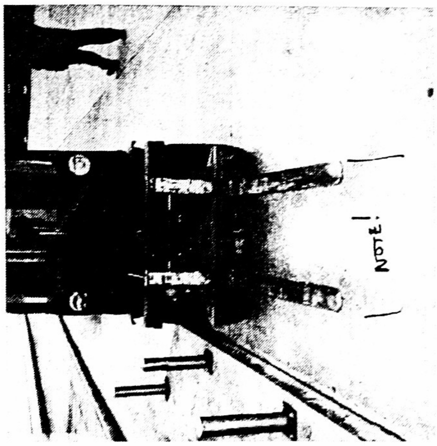
Engineering Drawings Of CVC Cluster Tools

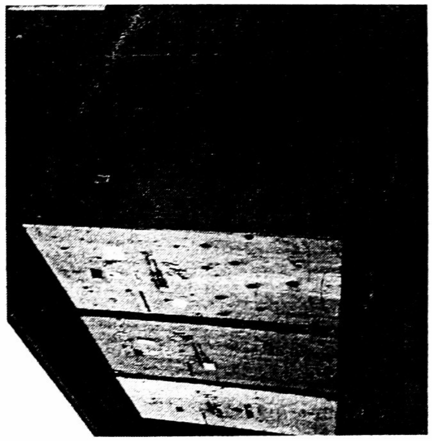


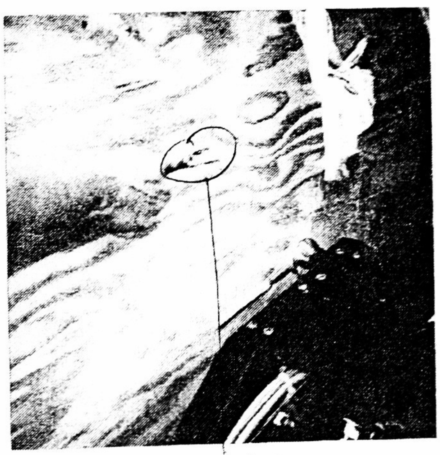


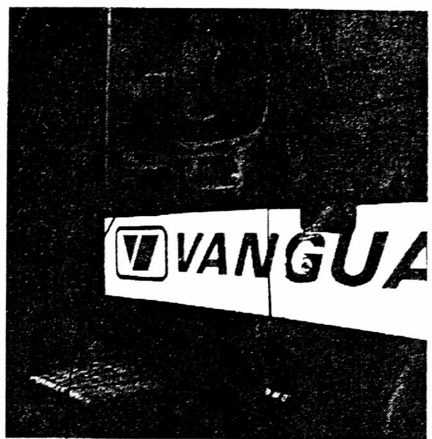
FEMALE BRACKET
MOUNT HEATERS AS SHOWN
SEE DETAIL A
CHARTED DRAWING SUMMARY
SPUTTER PROCESS MODULE
D-302225

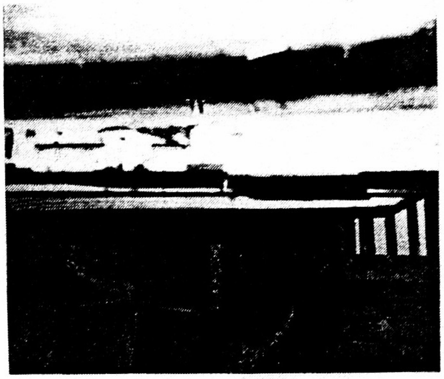
Shock And Vibration Damage, CVC Cluster Tool, 3/31/98, Londonderry, Northern Ireland

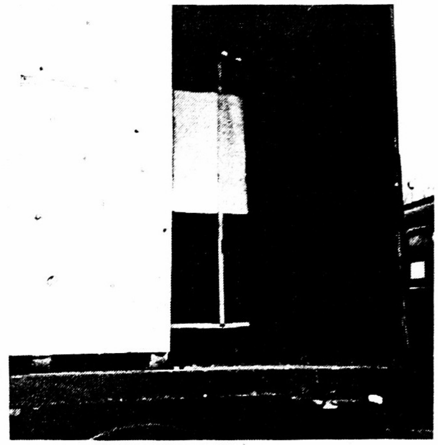








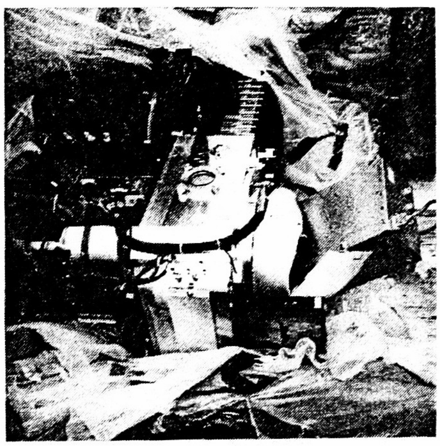


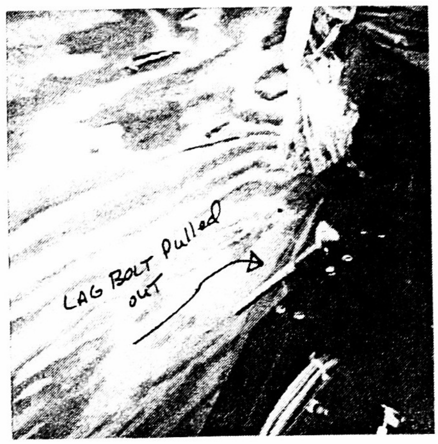


≈ 5'

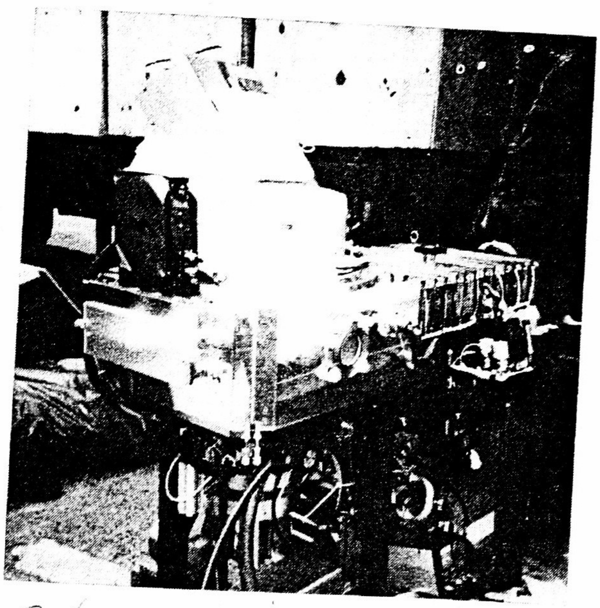
Ground

SIDE LOAD TRUCK





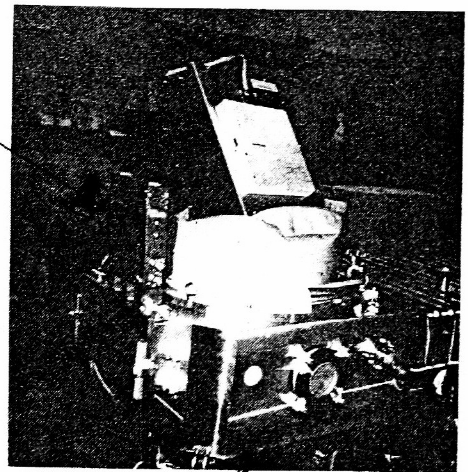
C/C 31/3/98



C/C 31/3/96

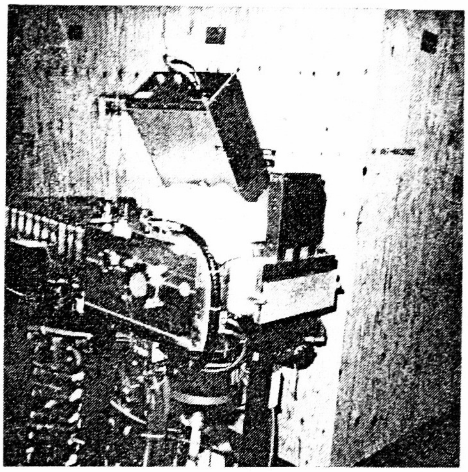
chamber

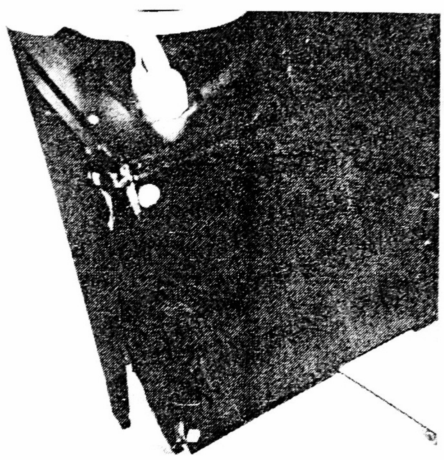
internal damage



DAMAGE FROM SHUTTER PISTON

minimal ext. damage





APPENDIX F

Costs, Teflon PTFE, Polyurethane, Polyethylene, Silicon Rubber, PVC

These are costs of virgin PTFE extruded rigid tubing (from Curbell Plastics Engineering Plastic Materials Guide).

OD (INCH)	ID (INCH)	PRICE PER FOOT (1-96')	PRICE PER FOOT (97' AND OVER)
.250	.125	$1.73	$1.42
.500	.375	$3.36	$2.75
.750	.500	$10.16	$8.31
1.00	.750	$12.00	$9.82
1.25	1.00	$15.24	$12.47
1.5	1.25	$18.36	$15.02
1.75	1.5	$21.49	$17.58

These are comparative properties of foam cushioning materials (taken from The Wiley Encyclopedia of Packaging).

MATERIAL	COST RAW MATERIAL, PER LB.
EXTRUDED POLYETHYLENE	$2.50-2.75
EXTRUDED POLYURETHANE	$2.00-2.50
MOLDED POLYETHYLENE	$2.00-2.25
MOLDED POLYURETHANE	$2.00-2.25

This is a price quote, offered by Web Seal, Inc. Rochester, NY. 6/12/96.

"GRAY SILICON SHEETS, 50 DUROMETER, 3/32'X38'X48", 20 PIECES, $86.57 EA."

These prices identify the costs of silicon rubber from polyethylene and polyurethane foams. These are identified to show the need for inexpensive packaging materials in the semiconductor industry.

APPENDIX G

Comparative Temperature Resistance, Polyethylene to PVC

These are comparative properties, taken from the Laird Plastics thermoform plastics solution selector. Taken from the Laird Plastics product catalog.

MATERIAL	COLD TEMPERATURE, F
POLYSULFONE	-150
PE	-131
PVDF	-80
PVC	-34
PP	-34

This is a very basic chart from a plastics fabricator that rates temperature performance of materials. This is included because cryogenic pumps operate at colder than -150 degrees C temperatures. This shows how PE stands a better chance of performing in a cryogenic environment than PVC does.

APPENDIX H

Cushioning Materials Chart

MATERIAL	CLEANLINESS	ADVANTAGES	DISADVANTAGES
PAPER:			
NEWSPRINT	POOR	CHEAP	SHIPPING WEIGHT HIGH
KRAFT	FAIR	BULKIER	SAME

MATERIAL	CLEANLINESS	ADVANTAGES	DISADVANTAGES
OPEN CELL:			
POLYURETHANE	GOOD	LIGHTWEIGHT	COMPRESSES EASILY
POLYURETHANE FOAM IN PLACE	FAIR	COST EFFECTIVE	MESSY

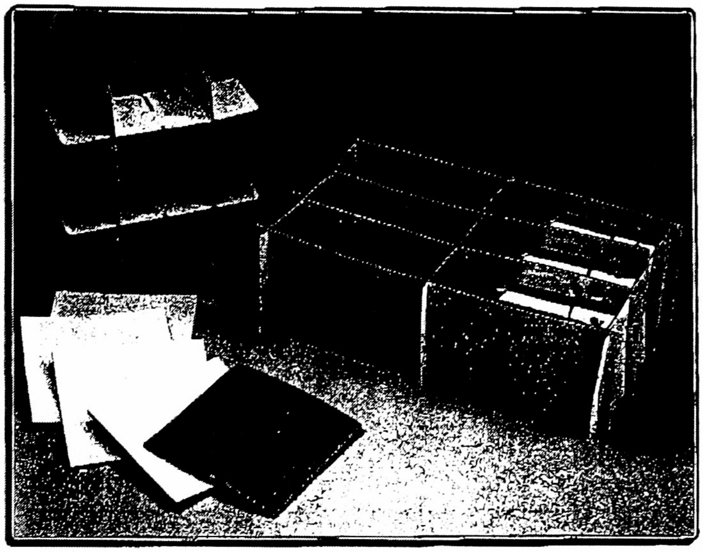
MATERIAL	CLEANLINESS	ADVANTAGES	DISADVANTAGES
CLOSED CELL:			
PE FOAM	GOOD	UNIFORM	EXPENSIVE WHEN THICK
PE PLANK	GOOD	RESILIENT	REQUIRES FABRICATION

This chart was taken from an Astro-Velcour Inc. advertisement titled "Focus on a Changing Environment". This is intended to identify that polyurethane is an open cell material and polyethylene is a closed cell material. Open cell material is material that consists of open air pockets from the air expansion in the manufacture, and closed cell material is a more solid exterior surface after air expansion. This chart also identifies that polyurethane compresses easily, which this thesis will determine is not the case under vacuum. In fact, it is polyethylene that compresses easily under vacuum.

T-Board Specification Sheet

HIGH PERFORMANCE PACKAGING MATERIALS

T-BOARD™



100% RECYCLABLE PREMIUM GRADE PACKAGING SHEETS

Recently introduced to the packaging industry, T-Board is a engineered metallocene plastomer composite.

Consisting of a rigid, high density polyethylene foam core, sandwiched between a "skin-soft" metallocene-based foam exterior, T-Boards's multi-layer construction makes it the ideal material for use as partitions and/or tier pads in packaging totes.

Competitively priced with cardboard and plastics, T-Board fully meets the automotive requirements for "Class A" surface protection. This means that T-Board will not in any way (physically or visually) affect the surface quality of any product packaged within.

T-Board is 100% recyclable. Presently, many of T-Boards's counterparts are not readily recyclable due to their multimaterial constructions. T-Board, however is a monomaterial composite. This construction eliminates the necessity to separate dissimilar materials prior to recycling.

APPLICATIONS:

PACKAGING TOTES

CELL PARTITIONS

INSULATORS

DIE CUT SHAPES

VACUUM FORMED PARTS

TIER PADS

SPECIFICATIONS:

THICKNESS:

5/16" (8.0 MM) - STANDARD
3/32" (2.4 MM) - STANDARD
7/32" (5.5 MM) - STANDARD
OTHERS - SPECIAL ORDER

SHEET DIMENSIONS:

48" x 72" - STANDARD
48" x 96" - STANDARD
OTHERS - SPECIAL ORDER

COLORS:

WHITE - STANDARD
OTHER COLORS - SPECIAL ORDER

MATERIAL ADVANTAGES

• 100% recyclable • CFC and HCFC-free • Meets the requirements of the Clean Air Act of 1990 regarding Class I and Class II ozone depleting substances • Provides "Class A" surface protection • Lightweight • Easily fabricated • Low water absorption • Superior chemical resistance • Nondusting • High resistance to U.V.breakdown • Impervious to rot • Washable • Nontoxic, nonskin irritant

Test #1 Data:

PAL Data Log Report File: PUMP

Started at 9:53:43 on Monday, 10/5/98. Dir: /dd/PM.PAL/DATALOGS

Elapsed Time hh:mm:ss	Chamber Pressure (Torr)	Ion Pressure (Torr)
00:00:00	7.6E+02	-6.5E-11
00:00:20	4.1E+01	-6.8E-11
00:00:40	1.9E+00	-7.1E-11
00:01:00	4.5E-01	-7.4E-11
00:01:20	2.7E-01	-7.6E-11
00:01:40	2.0E-01	-7.9E-11
00:02:00	5.3E-04	1.7E-04
00:02:20	6.7E-05	1.2E-04
00:02:40	2.7E-04	1.1E-04
00:03:00	3.3E-04	9.3E-05
00:03:20	4.7E-04	8.4E-05
00:03:40	4.7E-04	5.0E-05
00:04:00	5.3E-04	6.8E-05
00:04:20	6.0E-04	6.0E-05
00:04:40	6.0E-04	5.4E-05
00:05:00	6.7E-04	4.9E-05
00:05:20	6.0E-04	4.5E-05
00:05:40	6.7E-04	4.1E-05
00:06:00	6.7E-04	3.8E-05
00:06:20	6.0E-04	3.5E-05
00:06:40	6.7E-04	3.3E-05
00:07:00	7.3E-04	3.0E-05
00:07:20	7.3E-04	2.8E-05
00:07:40	7.3E-04	2.6E-05
00:08:00	6.7E-04	2.5E-05
00:08:20	6.0E-04	2.3E-05
00:08:40	6.7E-04	2.2E-05
00:09:00	6.7E-04	2.0E-05

For this test and the two following tests, only the first two categories are important. The first category is the present time of the test and the second category is the chamber pressure at that time. What this shows is that at 2:00 there was a sudden change in chamber pressure due to the foam crushing *inward. At 8:00 minutes the pump sustained a consistent vacuum and that is when we started counting the one minute interval of pumping at high vacuum.*

APPENDIX K

Test #2 Data:

PAL Data Log Report File: PUMP0064

Started at 9:32:58 on Monday, 10/05/98. Dir: /dd/PM.PAL/DATALOGS

Elapsed Time hh:mm:ss	Chamber Pressure (Torr)	Ion Pressure (Torr)
00:00:00	7.6E+02	-1.5E-10
00:00:20	2.8E+01	-1.5E-10
00:00:40	1.3E+00	-1.5E-10
00:01:00	4.7E-01	-1.5E-10
00:01:20	3.7E-01	-1.6E-10
00:01:40	3.3E-01	-1.6E-10
00:02:00	3.0E-01	-1.6E-10
00:02:20	2.8E-01	-1.6E-10
00:02:40	2.7E-01	-1.6E-10
00:03:00	2.5E-01	-1.6E-10
00:03:20	2.4E-01	-1.6E-10
00:03:40	2.3E-01	-1.7E-10
00:04:00	2.3E-01	-1.7E-10
00:04:20	2.2E-01	-1.7E-10
00:04:40	2.1E-01	-1.7E-10
00:05:00	2.1E-01	-1.7E-10
00:05:20	2.0E-01	-1.7E-10
00:05:40	2.1E-01	-1.7E-10
00:06:00	2.4E-03	-1.8E-10
00:06:20	1.3E-04	5.7E-05
00:06:40	0.0E+00	4.8E-05
00:07:00	-1.3E-04	4.4E-05

What this test showed is that the foam did not crush inward, and its open cell qualities allowed for lower chamber pressures and a more consistent rise than the previous test. Ample vacuum was achieved at 6:20 minutes and thus the one minute interval of vacuum pumpdown started at that time.

Test #3 Data:

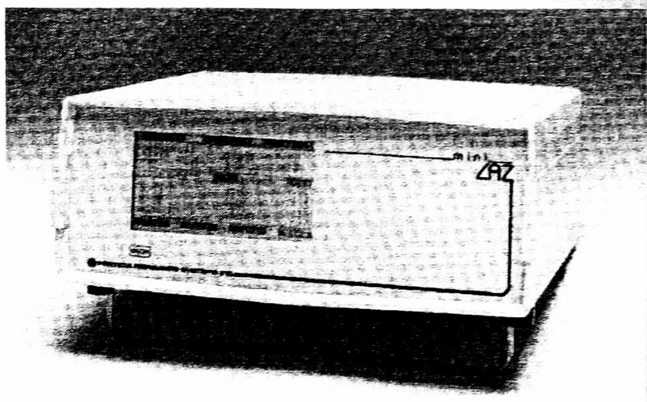
PAL Data Log Report File: PUMP0068

Started at 10:18:01 on Monday, 10/05/98. Dir: /dd/PM.PAL/DATALOGS

Elapsed Time hh:mm:ss	Chamber Pressure (Torr)	Ion Pressure (Torr)
00:00:00	7.6E+02	-5.7E-11
00:00:19	3.2E+01	-6.0E-11
00:00:39	1.5E+00	-6.3E-11
00:00:59	3.9E-01	-6.6E-11
00:01:19	2.4E-01	-6.9E-11
00:01:39	6.9E-02	-7.2E-11
00:01:59	1.3E-04	5.8E-05
00:02:19	4.0E-04	4.5E-05
00:02:39	5.3E-04	3.9E-05
00:02:59	5.3E-04	3.6E-05
00:03:19	6.7E-04	3.4E-05
00:03:39	6.0E-04	3.3E-05
00:03:59	7.3E-04	3.2E-05
00:04:19	6.0E-04	3.1E-05

This test showed similar results to test #1. There was a significant change in pressure at 01:59 minutes, caused by the bending of the material. The inconsistent pressure changes identify the closed cell material. Unlike test #2, the chamber sustained a high enough vacuum at 3:19 minutes to begin the one minute interval of pumping under vacuum.

Particle Counter Example



PORTABLE AEROSOL PARTICLE COUNTER
Model miniLAZ

The miniLAZ is a portable aerosol particle counter designed specifically for cleanroom applications. Its lightweight construction, less than 15 pounds, and small footprint allow the operator to easily handle the unit when performing spot monitoring functions. The miniLAZ is a five channel instrument with the smallest particle sensitivity available at 0.3 or 0.5 microns at a flow rate of 1 CFM. A back-lit LCD with a touchscreen front panel is used to control the miniLAZ and to display particle data. The entire instrument is finished with a smooth surface that is resistant to most cleaning solvents used in cleanroom environments.

FEATURES

- Front panel touchscreen
- Lightweight
- Portable
- High flow rate

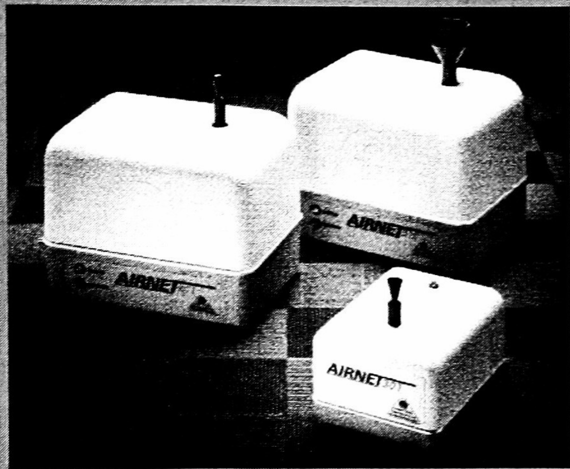
The software for the miniLAZ is designed using the touchscreen pop-up menu selections to simplify the instrument's operations. Most of the configuration parameters are displayed on the main screen. As the miniLAZ starts collecting the sampled data, the information is available in several modes: differential and cumulative raw counts or normalized differential and cumulative counts per cubic feet or cubic meters. The flow rate is depicted as either cubic feet per minute or cubic meters per minute.

Up to 500 samples can be stored in the miniLAZ. This allows the user to transfer the particle count information to any IBM compatible program for post processing. Other software functions include Federal Standard 209E air cleanliness calculations and settable alarm limits with audible capabilities.

Two 4-20 mA inputs are standard features on the miniLAZ to allow for temperature and relative humidity sensors. Other interface capabilities include one RS485/RS232 port for supporting PMS or KERMIT communications protocol or a disk drive unit. One RS232 serial port is used for connecting an external printer. In addition, the miniLAZ has a dedicated port for a *touch memory*™ wand for scanning predetermined locations within the cleanroom area. A memory chip containing specific identification attributes regarding a sampling location can be programmed and scanned by the user to increase monitoring efficiency. The miniLAZ will operate using line or battery power. It will accept 85-264 volts or will take an optional battery pack that can be recharged from within the unit.

AEROSOL PARTICLE SENSORS

Model Airnet



Particle monitoring within cleanroom facilities has reached a new level. PMS' new aerosol sensors offer a small footprint and superior data transmission capabilities. These instruments provide unparalleled performance for measuring contaminants continuously at multiple locations within a cleanroom environment. PMS' new *Airnet* family of aerosol particle sensors, provides a full range of sizing sensitivities starting at 0.2 microns at flow rates from 0.1 or 1.0 CFM. Two or four channels are available to enable an operator to analyze specific sizes of interest. These compact sensors are constructed out of a nonshedding material and do not contain a pump or fan to ensure noncontaminating operation. The *Airnet* sensors are versatile in design and can be mounted on the wall or on a level work surface. There are built-in status indicators to display power, laser and flow activity on each unit for easy viewing. Each *Airnet* sensor is powered using 24 volts, which eliminates the need for running conduit throughout the cleanroom.

Data collected by the *Airnet* sensors can be transmitted in several ways. There is an Ethernet connection that allows particulate information to be sent directly on the network to a workstation for real-time analysis. PMS offers a facility monitoring software package called *Facility-View* that provides a comprehensive account of the environmental conditions within a cleanroom environment. For situations where a stand-alone configuration is needed, particulate data can be transmitted to a touch screen data acquisition system called *Data Touch*. The operator views all collected data on one screen representing a tabular display, time plot, status conditions and system parameters.

■ FEATURES

- Small footprint
- Sizing sensitivities from 0.2 - 5.0 microns
- Sample flow rates at 0.1 and 1.0 CFM
- Two or four channel configuration
- Ethernet connectivity
- Three channel 4-20mA output
- Low voltage
- Status indicators
- Versatile mounting options
- Smooth exterior surface
- Interfaces to a data acquisition or monitoring control system

■ APPLICATIONS

- Cleanroom monitoring
- Facility certification
- Trending analysis
- Episodic event tracking
- Statistical process control analysis

Service bulletin on fingerprints, Varian Corporation.

WARNING

A Fingerprint

Many a thief has lost his freedom as the result of **a misplaced fingerprint.** Many an otherwise good vacuum system has lost its performance as the result of **a misplaced fingerprint.**

An ordinary fingerprint has an outgassing rate of about 1×10^{-5} torr liters per second. At 1×10^{-10} Torr, pumping speed of about 10,000 liters per second would be required just to pump the gas from this **single fingerprint.** A 41-inch diameter orifice leading to the pump would be required so as not to conductance-limit the pump.

High-temperature bakeout will, of course, partially remove the fingerprint. **Might it not be better to avoid the fingerprint in the first place?**

WARNING

varian
vacuum products

121 Hartwell Avenue
Lexington Massachusetts 02173