# FEO

# FAB ENGINEERING & OPERATIONS

In Association with:

International SEMATECH ISMI Manufacturing Initiative

Surplus Equipment Consortium Network, Inc. SEC/N®

Fab Owners Association

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FEO

Fab Engineering & Operations Magazine

# WELCOME to Issue 4 of FEO magazine.

Greetings, and welcome to the fourth edition of FEO – still the only journal concentrated on mainstream manufacturing. After almost a year working at the business end of the semiconductor market, some things have become abundantly clear. One is that there remains a stigma of “old fab” attached to the mainstream – in short, if it’s not 300 mm/ 193 immersion/high-k/metal gate-related, it’s considered “old” by almost all not directly involved. This bias creates a “them & us” feeling of anonymity among the 150/200 mm communities, and begs the question: Where is the sub-90nm equipment going to come from? In our eyes, it seems foolhardy to expect 70%+ of the industry to attempt to convert to 300 mm when business models for devices such as ASICs, analog and the like simply do not support the wafer start volumes, or indeed, the profit margins necessary for the 300 mm fab.

So what does this mean? Will processor, DRAM and flash memory manufacturers be the only ones left that can afford a fab? Will everyone else become fab-less? We at FEO don’t claim to know the answers to these questions, but a hunch tells us to “follow the money,” and if a way can be found to keep 200 mm viable (i.e., new 200 mm equipment suppliers emerge – perhaps this is how China gets into the OEM market?), these “old” fabs will be around for the foreseeable future.

We hope you enjoy this issue!

The FEO team

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"Design of experiments (DOE) provides statistical tools for fab engineers to improve their operations. But they needn't restrict their studies only to process factors."

**Mark J. Anderson** – Stat-Ease, Inc.
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# EDITORIAL PANEL

The following pages contain the photos and brief biographies of ***FEO's*** Panel Members. We would like to extend our sincere gratitude for their belief in our idea and their willingness to help us bring this magazine to fruition. ***FEO*** magazine would not have become a reality without their support, guidance and wisdom.

## *Gary Alexander*

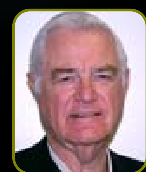
**Managing Principal, AMC Intl., LLC; Executive Director, SEC/N®**

Gary Alexander is Founder/Managing Principal of AMC Intl., LLC, which independently consults on secondary market topics with organizations and government agencies worldwide. He is participating in U.S Department of Commerce/WTO and ANSI-ISO task forces on increasing trade opportunities and developing standards for the global secondary market. He is also Executive Director of SEC/N, the global trade association of the semiconductor industry for secondary market equipment and related services.

## *Julia Bussey*

**Senior Scientist, AMEC Geomatrix, Inc.**

Julia Bussey helps companies develop sustainable business practices to reduce their costs and footprints, as well as to improve their efficiency. She has the unique experience of having been in their shoes and also having been in government, focusing on air and waste issues, so she brings 25 years of experience to the table for creative and practical solutions.



## *C. Richard Deininger*

**General Partner, Taylor-Deininger Partners, Inc.**

Dick brings 50 years of successful executive management and business experience to the high tech industry. He is one of the general partners in Taylor-Deininger Partners, Inc. (TDP) consultancy and the owner principal of Deininger and Associates, LLC consultancy. He holds a BSEE degree from Newark College of Engineering and is a senior life member of IEEE, Tau Beta Pi and Eta Kappa Nu.

## *Bill Funsten*

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Bill Funsten has 33 years of experience in semiconductor processing, defect metrology, yield improvement and contamination control. He is currently program manager, contamination control at Spansion, Inc. Mr. Funsten has a B.S. degree in materials engineering from UCLA.

## Kevin Gray

**Senior Etch Line Maintenance Supervisor, Cypress Semiconductor**

Kevin Gray is a Senior Etch Line Maintenance Supervisor at Cypress Semiconductor. In 1991, he joined the U.S. Navy, becoming a nuclear electrician aboard the Submarine USS Michigan. Kevin co-authored "Polymer control in a LAM TCP 9600 Aluminum Etch Chamber" at ISSM 2001. He became a Maintenance Supervisor in 2004 and has led the Fab Owners Association LAM 9600 team since March 2007.

## L. T. Guttadauro

**Executive Director, Fab Owners Association; President, FOA Purchasing Partners, Inc.**

L.T. is the executive director of the Fab Owners Association (FOA), a not-for-profit, mutual benefit corporation, providing a forum for fab owners and associates to discuss/act on common manufacturing issues, and president of FOA Purchasing Partners, Inc. (PPI) a group purchasing organization (GPO) for the semiconductor industry. L.T. is a graduate of Columbia Pacific University.

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Bob Henderson is a site statistician at Samsung Austin Semiconductor. He holds a Ph.D. and an M.S. in mathematical statistics from Southern Methodist University, as well as an M.B.A. from the University of Delaware. Bob has authored or co-authored approximately 20 articles and two books on the use of statistical methods or approaches in semiconductor and other industrial settings.

## Chris Howington

**Supply Chain Re-Engineering Manager, Freescale Semiconductor**

Chris Howington has over 20 years in the semiconductor industry in manufacturing and supply chain leadership roles. He is currently Supply Chain Re-Engineering manager at Freescale Semiconductor. Previous experience includes management roles at TSMC, National Semiconductor and AMD. Mr. Howington has a B.S. in mathematics from The University of Texas at Austin.

## Scott Kramer

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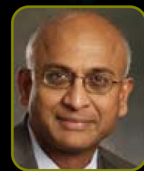
Scott Kramer is the director of International SEMATECH Manufacturing Initiative (ISMI), a subsidiary of SEMATECH, overseeing the Equipment Productivity, Fab Productivity, 300mmPrime/450mm, Metrology, and Environment, Safety and Health programs. He joined SEMATECH in 1994 as Fab Manager of the Advanced Technology Development Facility (ATDF). Mr. Kramer holds a B.S. in mechanical engineering from the University of Missouri and an M.B.A. from the University of Utah.

## Matthew Nadeau

**Director of Manufacturing, NEC Electronics America, Inc.**

Matthew Nadeau is the director of manufacturing at NEC Electronics, America, Inc., in Roseville, Calif. He joined NEC in 1989 and worked as a process engineer in the Dry Etch and Wet Etch areas before starting his work in the manufacturing environment. Matthew received his B.S. in chemical engineering from the University of California at Davis.



## Murty S. Polavarapu

**Senior Principal Engineer, BAE Systems Semiconductor Technology Center; Manassas, Va.**

Murty Polavarapu is a senior principal engineer at BAE Systems Semiconductor Technology Center in Manassas, Va. Over the last 23 years, he has worked on developing and manufacturing advanced CMOS memory and logic products. His current interests include development of phase change memory technology and application of nanotechnology to meet the needs of the Department of Defense, particularly for space-based applications.

## Bill C. Smoak

**Vice President of Operations, Intersil Corporation**

Bill Smoak is the vice president of operations for Intersil's silicon wafer fab site in Palm Bay, Florida. He has 28 years of semiconductor manufacturing experience in engineering, development, manufacturing systems and operations roles with Harris Semiconductor and Intersil. Primary experience has been in SOI materials and high-performance analog processes. Bill holds a B.S. in materials science and engineering from the University of Florida.

## Christopher Tan

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Christopher Tan joined Chartered Semiconductor in 1996, and is currently leading its supply chain integration and reengineering initiatives from the customer service, planning, industrial engineering, purchasing and logistics functions. He has a B.S. in economics from UOL from the Singapore Institute of Management.

## Paul Tan

**Manager, TSMC Fab 12 Facilities**

Paul Tan has 16 years of experience in the semiconductor industry. In addition to facilities management in Fab 12, he concurrently served as water group leader on the Facilities Technical Board. His previous roles include technical manager for facilities design in TSMC future fabs, facilities director in SSMC, and UPW application manager in ionics.

## Mario Tellez

**Equipment Service Manager, ON Semiconductor**

Mario Tellez is an equipment service manager with ON Semiconductor. He obtained his B.S. in electronic engineering and completed various studies in project management. Mr. Tellez has 20 years of semiconductor-equipment-related experience in photo, implant, diffusion, etch and backgrind. He has held various roles including lead technician, equipment engineer and equipment service management.

## Kevin Venor

**Manufacturing Development Engineering Manager, Avago Technologies**

Kevin Venor is the manufacturing development engineering manager for Avago Technologies in Fort Collins, Colo. He has more than 20 years of experience in the semiconductor industry and has held various positions in R&D, manufacturing and business development at Hewlett Packard, Agilent Technologies, SEMATECH and Avago Technologies.

## Yonathan Wand

**Manufacturing Vice President/Israel General Manager; Numonyx**

Yonathan Wand is Numonyx Manufacturing Vice President and Numonyx Israel General Manager, in charge of Fab1. In his 28 years in the semiconductor industry, he has lead Fab18 to achieve world-class LY, DY and cost, and lead a factory to achieve single-digit DPM defects levels for automotive products. He holds a B.Sc. in chemistry from Tel-Aviv University and an MSc. in applied chemistry from the Hebrew University in Jerusalem.

## Mike Weiby

**Corporate Environmental, Health and Safety Manager; Integrated Device Technology, Inc. (IDTI)**

Mike Weiby has 8+ years managing ISO 14001 and environmental programs, injury/illness prevention, emergency response, business continuity and risk management/loss control plans. He has an M.B.A. from Portland State University, a Master of Industrial Safety degree from the University of Minnesota-Duluth and a Mechanical Engineering degree from the University of Wisconsin.

## Greg Westby

**Purchasing and Materials Manager, Integrated Device Technology**

Greg Westby is the purchasing and materials manager at Integrated Device Technology's 200 mm wafer fabrication facility in Hillsboro, Ore. Mr. Westby earned his M.B.A. from the University of Portland and has over 19 years of semiconductor experience, 12 of which are in procurement and materials management.

## Gregory D. Winterton

**Process Development Manager, TI's DLP® group**

Greg Winterton is the Process Development Manager for TI's DLP group. Greg has responsibility for the development and production of TI's next-generation spatial light modulator MEMS devices. Greg is a 23-year veteran of the semiconductor industry with experience in process engineering, equipment engineering, manufacturing, technology transfer, and quality and reliability assurance on wafer diameters from 125 mm to 300 mm.

## Juergen Woehl

**General Manager/VP Manufacturing, International Rectifier; Temecula, CA**

Juergen Woehl is the general manager/VP manufacturing of International Rectifier Temecula site in Southern California. Previously, he held management positions at IBM, Infineon, SEMATECH and ON Semiconductor. Juergen has over 25 years in the semiconductor industry, in engineering, manufacturing and R&D. He has a B.S. in chemistry from the Fachhochschule in Aalen, Germany, and an M.B.A. from St. Edwards University in Austin, Texas.


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# Business Infrastructure

**Equipment Selection: The Forgotten Lean Principle**

**Juergen Woehl**
International Rectifier

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## Yonathan Wand
*Manufacturing Vice President/Israel General Manager; Numonyx*

Lean Manufacturing principles are being deployed in many semiconductor companies. In a recent survey by the Lean Learning Center, over 70 percent of the semiconductor companies' executives surveyed stated their companies are "continually using Lean Manufacturing principles."

Over the last few years, tools like waste walks, Kaizen events, Kanban system, 5S application and value stream mapping have been used to achieve waste elimination and cycle time reduction – the two main tenets of Lean Manufacturing. More recently, the Lean principles of direct observation, systematic waste elimination and systematic problem solving have been used in semiconductor technology development; for example, in the standardization of design kits and device-model process flows at IBM East Fishkill (Debra Vogler, Solid State Technology, July 28, 2008).

The author of the article in this section claims buying the right equipment at the right time should be perceived as an additional Lean Principle, as it leads to waste elimination. He describes and analyzes several decision-making tools, and concludes that the methodologies can be used within the Lean Manufacturing framework as a selection method to assist in buying Lean equipment at the right time.

While we can argue if this approach will be widely used in the semiconductor industry's tool selection process, it is evident that Lean Manufacturing principles will be more and more utilized in a wide variety of areas. As competition becomes fierce, and being cost-effective and efficient are musts, Lean Manufacturing will become the preferred platform by many semiconductor companies.

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# Equipment Selection: The Forgotten Lean Principle

**Juergen Woehl** – International Rectifier


## *Abstract*

Lean production is directly descended from and is frequently used as a proxy for Toyota Production System (TPS) (Shah & Ward, 2007, p. 5). Many have claimed to have found the key to decode TPS and to teach Lean Manufacturing (Spear & Bowen, 1999). Many factors have been described to provide in their totality the input factors for Lean Manufacturing (Shah & Ward, 2007), but none has explicitly pointed out the importance of the tool selection process. The author of this paper argues that buying the right equipment at the right time should be posted as an additional important Lean principle, as being lean means manufacturing without waste. Buying a piece of equipment at the wrong time often means wasting capital when the equipment is not fully utilized. Equipment that is flexible and can be used for multiple products and processes can be better utilized and should be preferred compared with specialized equipment which is not flexible.

The author will briefly revisit Lean Manufacturing and will review current methods regarding buying the right equipment at the right time. The author looks at the elements of the equipment selection, the qualitative decision matrix, the cost of ownership (CoO) calculation and the return on investment (ROI) calculation, asset utilization and finally, evaluates return on gross fixed assets (ROGFA), a new decision-making tool (PRTM, 2008, p. 5) to improve asset utilization. ROGFA is more a strategic instrument to improve the total asset utilization of the manufacturing site (Myers, 2007). The author will conclude that the above-mentioned methods should be used as an integral part of the decision process, and that buying the right equipment at the right time should be posted as an additional important Lean principle.


## *Introduction*

The translation of executive decisions and requests into smooth, cost-effective production calls for a strong presence of Lean Manufacturing in order to survive in today's competitive global environment (Emiliani, 2000). Enabling manufacturing to work like clockwork (Spear & Bowen, 1999) is the challenge of every plant manager and the prerequisite for any successful company having a large manufacturing arm. Quality at the right place using the lean approach and partnerships with the suppliers (Bragg & Kumar, 2003) are also paramount to the Lean approach. Soriano-Meier and Forrester (2002) summarize nine principles of Lean Manufacturing. Shah and Ward (2007, p. 23) described 10 factors that constitute the philosophy of Lean Manufacturing. They define Lean Production as an integrated sociotechnical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer and internal variability. They define continuous flow, total productive maintenance and shop floor troubleshooting skills, involving customers, reduced setup time, statistical process flow, Kanban and pull system, just-in-time, supplier feedback on quality, and delivery performance as the 10 key Lean principles. They believe that these 10 factors are sufficient to represent Lean Manufacturing.

The author of this paper postulates that buying the right equipment at the right time is another important decision in the semiconductor industry, and should be posted as an additional important Lean principle. Improvement in productivity, increase in capacity, improvement in quality and better technical capability are the major reasons why companies buy new equipment. Besides embracing Lean manufacturing, buying the right equipment is strategically important and can contribute to a company's success or failure. Therefore, the question needs to be asked: What decision-making tools should be used to make the best possible and most objective decision in buying equipment for a semiconductor manufacturing plant to enhance its Lean status? Research shows that determining which equipment to buy is arrived at either via a decision matrix (Altier, 1999), where different key parameters are weighted and compared between the different available tools (Colwell, Friedmann, & Carmichael, 2000); or using a cost of ownership calculation (Heilala, Montonen, & Helin, 2007). Another method, a return on investment (ROI) calculation (Vos, 1968), can be performed to justify the financial need for the equipment. In order to get capital approved, often the ROI needs to be achieved in under one year. Downturns can make the ROI time shorter, and upturns can make it longer. The latest method found in literature for equipment selection is return of gross fixed assets (ROGFA). Myers (2007) describes that determining ROGFA is achieved by constructing a matrix to compare companies and to benchmark them, showing that per industry, certain ROGFA matrices indicate certain financial performance. This author concludes that all methodologies have their place in Lean Manufacturing as potential selection methods to buy Lean equipment, and that buying the right equipment at the right time should be posted as an additional important lean principle.

## *Decision Matrix*

As previously mentioned, a typical decision for selecting the right equipment can be arrived at with the support of a decision matrix. Russell and Taylor (2006, p. 300) describe location factor rating as the usage of a decision matrix with weighting factors using an Excel spreadsheet. Colwell et al. (2000) describe the research vendor selection process as a quantitative decision matrix for increasing value both for buyers and sellers. The authors provide a real-life example of the importance of the vendor selection process using decision matrices. The authors have developed a "vendor selection matrix" that quantitatively weights and measures potential vendors against key criteria for successful research and segmentation. This matrix can be used as an example for decision matrices in all areas where decisions must be made; only using different criteria.

The author of this paper has used the same method in many technical decisions in the semiconductor industry. In a fictive example, three different pieces of equipment were selected to show in detail how a decision matrix works.

The weighting factors are predetermined by the decision-making group before the different pieces of equipment are even discussed. In our example, capital cost is the most important factor for the company, so the group gave it a 9 out of 10 points (with a "10" signifying the highest importance). Technical capabilities, the relationship with the supplier and maintenance cost are the next most important criteria, where the group gave these criteria 8 out of 10 possible points. The least important factor was the usage of electricity, probably because that is a relatively small number. If a member of the group suggests a factor which the other group members think is not important, the factor can still be listed, but will get a low weighting factor (as in our case, electricity). A low weighting factor will therefore have very little weight in the decision process, but it gives individuals the option to make their voices heard.

After the different suppliers have presented their tools, the decision group will score each piece of equipment on a scale of 1–10. For every parameter, the weighting factor is multiplied by the scoring factor and the sum of all these products is determined per equipment type. The equipment type with the highest score should be the one recommended to management to buy.

Figure 1 portrays the factors the evaluation team deemed most important. It shows that supplier C's equipment should be selected and purchased. The advantage here is that it is a transparent system, and that management can provide its input to set up the weighting factors. The technical experts provide their subjective judgments after meeting the different equipment suppliers and fill out the scoring factors. Weight times scoring gives the result per equipment and per parameter. The results need only be tallied; the winner is the supplier with the highest score. Using this method helps in buying the right equipment at the right time, which should help companies invest their money wisely, and therefore, stay Lean in choosing the right equipment.

| Equipment Selection Parameters | Weight 1-10 | Score 1-10 Equipment A | Weight Score | Score 1-10 Equipment B | Weight Score | Score 1-10 Equipment C | Weight Score |
|---|---|---|---|---|---|---|---|
| Capital Cost | 9 | 9 | 81 | 7 | 63 | 9 | 81 |
| Installation Cost | 5 | 5 | 25 | 4 | 20 | 9 | 45 |
| Chemical Usage in $/yr | 4 | 4 | 16 | 3 | 12 | 10 | 40 |
| Electricity Usage | 1 | 2 | 2 | 5 | 5 | 8 | 8 |
| Footprint | 2 | 6 | 12 | 6 | 12 | 9 | 18 |
| Technical Capability | 8 | 8 | 64 | 2 | 16 | 5 | 40 |
| Throughput Parts/hr | 7 | 2 | 14 | 1 | 7 | 6 | 42 |
| MTBF | 7 | 3 | 21 | 3 | 21 | 7 | 49 |
| MTTR | 7 | 6 | 42 | 5 | 35 | 8 | 56 |
| Relationship with Supplier | 8 | 3 | 24 | 5 | 40 | 9 | 72 |
| Estimated Yearly Maintenance Cost | 8 | 10 | 80 | 6 | 48 | 9 | 72 |
| User-friendly Software | 5 | 2 | 10 | 10 | 50 | 5 | 25 |
| Total | | | 391 | | 329 | | 548 |

Figure 1. Example of Decision Matrix for Equipment Evaluation

## *Cost of Ownership*

As Heilala et al. (2007) describe, CoO is a SEMI standard metric used to evaluate unit cost-effectiveness of semiconductor equipment (SemiE35, 2001). They provide theories for total cost of ownership (TCO) methodology in assembly system trade-off analysis, and show benefits of the methodology as decision support in system selection. Cost of ownership includes overall equipment efficiency, system life-cycle costing and assembled unit cost analysis (including cost of bad quality and rework).

CoO was developed to address the economic and productive performance of a wafer fabrication tool by estimating the total life-cycle cost of a specific process step (Dance, DiFloria, & Jimenez, 1996). The standardized method has become a common reference between equipment suppliers and equipment users in the semiconductor industry.

RESULTS

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Fixed Costs | $96,800 | $15,718 | $15,718 | $15,718 | $15,718 | $14,843 | $14,843 | Asset Fully Depreciated | Asset Fully Depreciated | Asset Fully Depreciated |
| Recurring Costs | $64,035 | $65,956 | $67,935 | $69,973 | $72,072 | Asset Retired | Asset Retired | Asset Retired | Asset Retired | Asset Retired |
| Yield Costs | $0 | $0 | $0 | $0 | $0 | Asset Retired | Asset Retired | Asset Retired | Asset Retired | Asset Retired |
| **Total Costs** | **$160,836** | **$81,674** | **$83,653** | **$85,691** | **$87,790** | **$14,843** | **$14,843** | **$0** | **$0** | **$0** |
| Cumulative Fixed Costs | $96,800 | $112,518 | $128,236 | $143,954 | $159,672 | $174,515 | $189,358 | $189,358 | $189,358 | $189,358 |
| Cumulative Recurring Costs | $64,035 | $129,992 | $197,927 | $267,900 | $339,973 | $339,973 | $339,973 | $339,973 | $339,973 | $339,973 |
| Cumulative Yield Costs | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| **Cumulative Total Costs** | **$160,836** | **$242,510** | **$326,163** | **$411,854** | **$499,644** | **$514,487** | **$529,330** | **$529,330** | **$529,330** | **$529,330** |

| | |
|---|---|
| Useful Life of Equipment, yrs | 5 |
| Tool Throughput, wafers/yr | 277,200 |
| Composite Yield | 1 |
| Equipment Utilization, dimensionless | 0.9855 |
| Total Cost, $ | $529,330 |
| Total CoO, $/wafer | $0.3875 |

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yearly Cost $/wafer | $0.5887 | $0.2990 | $0.3062 | $0.3137 | $0.3214 | Asset Retired | Asset Retired | Asset Retired | Asset Retired | Asset Retired |
| **Cumulative Cost $/wafer** | **$0.5887** | **$0.4439** | **$0.3980** | **$0.3769** | **$0.3658** | **$0.3767** | **$0.3875** | **$0.3875** | **$0.3875** | **$0.3875** |

Note: Yearly cost per wafer only has meaning for years in which the equipment is used to produce wafers.

Figure 2. Summary Sheet of a Typical Cost of Ownership Calculation (SemiE35, 2001)

The CoO model is more complex than the decision matrix. In Figure 2, Dance et al. considered more than 100 input parameters; capital cost, engineering salaries, training cost, installation data, qualification cost, material usage costs, consumable cost, labor to operate equipment cost etc., are all included. The authors then used different spreadsheets for different categories: a sheet with fixed costs; one tab with recurring or variable costs; another one with quality or yield costs; and a summary tab. Every piece of equipment is shown with a $/part total cost, which can then be compared with its competitors. Figure 2 shows in year one an additional cost of $0.3875 per part produced when this particular machine is being bought. Other equipment will then see the exact same CoO calculation, just with different numbers. At the end, all equipment would have a final cost per part number and can be compared.

Often, equipment suppliers share these costs with their customers to show how their equipment rates in comparison with their competitors. Sharing these details is also helpful as a training tool for the engineers to learn about the equipment in more detail. The CoO model is often put into the decision matrix to better quantify the matrix. Using the CoO method helps in buying the right equipment at the right time, specifically in finding the lowest cost per part, which should help the companies invest their money wisely and therefore, stay Lean in choosing the right equipment.

## Return on Investment Calculation

After the decision is made regarding what kind of equipment to buy and determining how much it will cost to operate, a company must show a certain ROI before it commits its funds to acquire certain capital equipment. Vos describes in his article "Return on investment concept as a management tool" (1968) that investment divided by income results in the years to recover. Vos describes ROI more as a financial instrument and shows what the recovery time is for the investment. As the author further explains, ROI uses forecast sales in order to arrive at the proper ROI number; that is, determining the right time to buy a piece of equipment. Typically, ROI calculation uses a detailed CoO input to calculate the exact ROI, meaning that it is only as good as the input parameters. Therefore, the more accurate the CoO calculation, the more precise the ROI calculation can be. Vos describes ROI thusly: investment divided by income equal years to recover. This means that, for example, equipment for a $1 million investment, which saves $500 thousand/year on improved quality (yield), will need $1 million/$500 thousand = two years to recover the investment. Here we have again a relatively simple number – years to recover – which tells us which piece of equipment has the shortest ROI and would therefore be the preferred tool. Using the ROI method facilitates making smart equipment purchasing choices because it factors in sales forecasts as well as the additional revenue or savings the tool will result in. This should help a company invest their money wisely and therefore, stay Lean in choosing the right time and the justification to buy equipment.

## Equipment and Lean

Spear and Bowen (1999) researched the Toyota production system and came to the conclusion that for many companies, the workings of Toyota still remain a mystery. Many other industries have tried to adopt Toyota's system, but few have managed to imitate it successfully. The authors believe that the secret lies in the detailed and repeatable systems the company uses, in that every production step needs to be performed by every employee exactly the same way.

This brings us to the next level: How flexibly can a piece of equipment be used in manufacturing? This can be determined neither by CoO nor ROI calculations, but instead by using a decision matrix. Hartman (1999) explains that the economic life of an asset is dependent on its utilization – an operational decision. Traditional replacement models assume fixed levels of asset utilization to determine minimum cost replacement schedules, preventing analysis of different utilization/replacement scenarios that may lead to lower overall cost solutions. He describes a model that simultaneously determines tactical (replacement) and operational (utilization) decisions in a general and flexible manner. Olsen (2004) describes in his article of Lean Manufacturing management the relationship between practice and firm-level financial performance, and the relationship between Lean Manufacturing management practices and business financial performance, which is examined through the use of empirical surveys and archival accounting. He further describes how operations measures include asset and employee productivity, gross margin ratio and two measures of aggregate cycle time. But his research did not determine whether better asset utilization was associated with financial performance of the companies.

## ROGFA

Myers (2007) describes that return of gross fixed assets (ROGFA) can be determined by constructing a matrix comparing companies and benchmarking them, showing that per industry, certain ROGFA matrices indicate certain financial performance. He argues that what matters to most companies isn't how much they spend, but how well they spend. To identify those that are most adroit at balancing capital spending with customer demand, the author ranks the 20 largest companies in 15 capital-intensive industries by ROGFA, which roughly equates to the ratio of operating profits to capital spending. He further explains that in many industries, a high ROGFA correlates with strong performance in key areas, such as sales growth and shareholder return.

## Combining ROGFA and Lean

Myers' argument (2007) that what matters to most companies isn't how *much* they spend on capital but how *well* they spend is a Lean principle of waste reduction. Getting the absolute maximum out of the equipment is pure waste elimination. If all equipment in manufacturing is highly utilized, the costs are lower than in a comparable manufacturing operation with lower equipment utilization. Therefore, asset utilization should be a Lean parameter. That ROGFA does not include depreciation makes the equipment performance even more transparent in a Lean way. It should be mentioned that the author of this paper believes that used equipment for lower capital cost should be at lower cost in a ROGFA calculation. Buying cheap is smart and should be reflected. Because ROGFA roughly equates to the ratio of operating profits to capital spending, Shapiro et al. (2003) determined that in many industries, a high ROGFA correlates with strong performance. It can also be seen as a reflection of how much a company earns on its property, plant, and equipment (Myers, 2007). This contradicts somewhat the research of Olsen (2004), who did not find a relationship to asset utilization. As Lean Manufacturing has been adopted by most of the manufacturing industries, it is explained by Russell and Taylor (2006) as a means of doing more with less. ROGFA tries to do the same thing from asset utilization, showing how much manufacturing gets out of its assets. Therefore, the conclusion can be synthesized that Lean Manufacturing needs to use ROGFA as a strategic decision-making instrument when buying equipment and to further improve Lean Manufacturing. Scholarly research in this area to prove that ROGFA is improving the performance of Lean Manufacturing companies still needs to be conducted.

## *Pros and Cons of All Methodologies*

### *Decision Matrix*

As with all methods, there are several pros and cons for every method discussed herein. The pro of the decision matrix is that it is relatively simple, can be summarized on one page and can help in building consensus. When a company constructs decision matrices, management can always modify the numbers or input parameters in its capital release meeting, and will therefore feel a part of the decision. Soft items like relationships can be quantified, and count as much as quantitative hard-dollar numbers, such as increased revenue. Flexibility and other Lean methods can be judged and put into a decision matrix. No other method has that advantage; that is probably why this is a popular method. This author compares a decision matrix with a Balanced Score Card approach, where soft skills are being treated like hard skills.

The disadvantage of a decision matrix is that it is often qualitative and a "best guess," as opposed to quantitative numbers. The weighting factor is subjective, and it is difficult to argue, for example, how important capital is in comparison with training. A decision matrix is therefore, an important method to use to buy the right equipment at the right time, but other methods are needed to be able to improve the Lean status of the manufacturing site.

### *Cost of Ownership*

The advantage of the CoO method is its detail. Engineers are forced to include all input parameters into a cost model and calculate in detail the costs per part. A cost-per-part number gives a very common number to the manufacturing group, and managers can add the cost number to the existing costs per part to see what their new cost-per-part number will be. Customer relationships, customer satisfaction and other soft skill parameters cannot be calculated into a CoO model. Strategic advantages would be considered in a decision matrix, but cannot be used in a CoO model either. Although the CoO model is the most detailed method to determine costs per part, it fails to be a final decision-making tool for management. Therefore, CoO typically is part of the decision process, and can be a part of the decision matrix, but cannot replace it.

### *Return on Investment*

Return on investment provides a very practical number – the number of years when this investment is paid back. Vos (1968) describes that the major advantages of ROI are its simplicity in calculation and its easiness to explain. I would add that ROI looks at future revenue to calculate the return of investment, which is not done by the other methods. Vos also describes the disadvantages in that it neither reveals the true earning power of the investment nor does it consider the time value of money. I would add to the authors' argument that customer impact, such as elimination of customer returns, is hard to factor into the ROI calculation, and the finance group can reject a proposal based on ROI numbers because such things as customer satisfaction are not included in this ROI calculation. ROI is basically a go/no-go method, determining whether a project will go forward or not. It is therefore, a part of a method which decides the improvement of the Lean status of a manufacturing site, but not necessarily to what extent.

### *ROGFA*

ROGFA looks at asset utilization, which can be easily correlated to return on assets, a common ratio number, which is being watched by investors. ROGFA's advantages are, therefore, the close adherence to the financial statements, and how manufacturing can be measured compared with the financial statements. One can benchmark ROGFA using the financial statements of different companies to see which one can get more out of its assets.

ROGFA's disadvantage is that it does not consider the depreciation of the equipment, and the manufacturer must be careful with new investments, because ROGFA always looks at the original purchasing price.

Because the author of this paper argues that buying the right equipment at the right time should be posted as an additional important Lean principle, and that being Lean means manufacturing without waste, ROGFA is a relatively good measure for one parameter of Lean manufacturing: asset utilization.

## *Discussion/Conclusion*

In this work, the author has analyzed decision matrices, cost-of-ownership calculations, return-on-investment calculations and ROGFA, which all play an increasingly important role in capital-intensive industries. The author has synthesized these findings and shown that all of these measures have their strengths and weaknesses, and most importantly, are a part of Lean manufacturing. None of them, when used exclusively, has the capability to choose the Lean-est equipment, or determine when to buy it. They should be used in conjunction with each other to make a judicious choice. Buying a piece of equipment at the wrong time often means wasting capital when the equipment is not fully utilized. Equipment which is flexible and can be used for multiple products and processes can be better utilized and should be preferred compared with specialized equipment which is not flexible. Therefore, the author concludes that all methodologies have their place in Lean Manufacturing as a selection method to help buy Lean equipment at the right time, and that buying the right equipment at the right time should be posted as an additional important Lean principle.

## *Acknowledgments*

The author would like to thank Capella University for its assistance.

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# Asset Utilization



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**Paul Tan**
*Manager, TSMC Fab 12 Facilities*


Necessity is the mother of invention, as the saying goes.

In the May issue of Fab Engineering & Operations, Steve Cook of CH2M HILL gave us a good rundown of factors surrounding the decision to convert a fab to the next wafer size.

In this issue, Mark Crabtree of NEC Electronics America continues to share with us his experience in overcoming the obstacles of the conversion of his fab after the decision was made to do so. In the February issue, he detailed the issues involved in overcoming the weight and sizes constraint. Here, the creativity involved in overcoming the height constraints is discussed at length.

Also in this issue, Mark Anderson of Stat-Ease, Inc., discusses the creative use of design of experiments (DOE) – not only in improving operations, but in uncovering "sweet spots" where multiple fab process specifications can be optimized.

# Mixture DOE for Optimal Plasma Etch

**Mark J. Anderson** – Stat-Ease, Inc.


## Abstract

Design of experiments (DOE) provides statistical tools for fab engineers to improve their operations. But they needn't restrict their studies only to process factors: Adjustments in formulations may prove to be beneficial as well. This article demonstrates how to uncover "sweet spots" where multiple fab-process specifications can be met in a most desirable way. It offers a real-life, semiconductor manufacturing case study that illustrates how to apply powerful response surface methods (RSM) for mixture design and statistical analysis. The resulting predictive models pinpointed a reformulation of plasma that produced more precise etch specifications (smaller offsets in critical dimensions) at greater throughput (selectivity).


## Designing a Mixture Experiment That Covers All the Bases

To illustrate how to apply mixture design, we present a relatively simple study that involves three gases used in a single-wafer plasma etching process.[1] The experimenters first performed a screening design on five process factors – power, pressure, overetch, hard bake and the $SF_6$/He gas-mixture ratio. This was done via a 16-run half-fraction of a two-level factorial design ($2^{5-1}$) with four center points added for estimation of pure error. (For amusing, but informative detailings of this multifactor process screening template, see how the author applied it to reliably start a small engine for a vital piece of yard equipment.)[2,3]

As a result of this initial process study, the fab engineers knew where to best set the first four factors listed above. However, they decided to follow up by doing an in-depth investigation of the three components of the gas mixture within ranges of partial pressures shown below (in microtorr – symbolized "μm"):

A. $SF_6$, 100 to 160 μm
B. He, 100 to 160 μm
C. $N_2$, the remainder as ballast to bring total pressure up to the fixed total of 650 μm.

They entered these mixture design specifications into a personal computer software package developed for this purpose.[4] The first thing it did was some simple arithmetic on the slack variable C to determine that it must range from 330 to 450 μm to satisfy the total constraint – the fixed total pressure, 650 μm, of all three gaseous ingredients in the mixture. Then, using a distance-based criterion, the program selected a variety of blends from within the constrained region.

Table 1 shows the experimental design in a convenient layout that identifies the blends by type. The actual run order for experiments like this should always be randomized to counteract any time-related effects due to aging of material, etc. Also, we recommend that you always replicate at least four blends to get a measure of error. In this case, the experimenters reran each of the blends at the vertices of the feasible mixture region at different times at random intervals throughout the experiment (never one right after the other). The experimenters expected the mixture to exhibit "strong nonlinear behavior," so they made sure the design included many levels (five) of each of the two active ingredients (components A and B).

The geometry of this mixture experiment region can be seen in Figure 1.

The points labeled "2" are the vertices of the constrained region, each of which was replicated. The gas levels can be tracked by following the gridlines. For example, the replicated vertex at the lower right is blend number ("ID") 1 with the minimum levels of components A ($SF_6$) and B (He) of 100 µm each, which causes the ballast gas C ($N_2$) to achieve its maximum amount of 450 µm. (For further practice with trilinear graphs, see how the author applied mixture design to develop an optimal formulation for homemade play putty.)[5,6]

| ID | Location | A: $SF_6$ µm | B: He µm | C: $N_2$ µm | Off-Spec Microns | Selectivity Ratio |
|---|---|---|---|---|---|---|
| 1 | Vertex | 100 | 100 | 450 | 0.26 | 0.91 |
| 2 | Vertex | 100 | 100 | 450 | 0.30 | 0.88 |
| 3 | Vertex | 100 | 160 | 390 | 0.23 | 0.77 |
| 4 | Vertex | 100 | 160 | 390 | 0.23 | 0.76 |
| 5 | Vertex | 160 | 100 | 390 | 0.62 | 0.84 |
| 6 | Vertex | 160 | 100 | 390 | 0.68 | 0.87 |
| 7 | Vertex | 160 | 160 | 330 | 0.33 | 0.99 |
| 8 | Vertex | 160 | 160 | 330 | 0.36 | 1.02 |
| 9 | Center Edge | 100 | 130 | 420 | 0.27 | 0.91 |
| 10 | Center Edge | 130 | 160 | 360 | 0.31 | 0.91 |
| 11 | Center Edge | 130 | 100 | 420 | 0.39 | 0.87 |
| 12 | Center Edge | 160 | 130 | 360 | 0.30 | 0.99 |
| 13 | Check Blend | 115 | 115 | 420 | 0.23 | 0.91 |
| 14 | Check Blend | 145 | 145 | 360 | 0.26 | 0.91 |
| 15 | Centroid | 130 | 130 | 390 | 0.34 | 0.92 |

Table 1. Design Matrix and Data for Gas-Plasma Mixture Experiment

## *Fitting a Predictive Model*

As shown below, the two responses (designated mathematically as "Y") were fitted via least-squares regression to a special form of polynomial equation developed for mixtures (detailed in a textbook by Cornell)[7]:

$$\hat{Y} = f(A, B, C, AB, AC, BC)$$

We call this simply a "mixture model." This particular one contains second-order terms (AB, AC and BC) that fit nonlinear blending behavior. Note that the function, unlike ones used to graph responses from a process, contains no intercept term, thus accounting for the overall constraint that all mixture components must sum to one. The "$\hat{Y}$" (referred to by statisticians as "Y-hat") represents the predicted response. It's the dependent variable. The independent variables (A, B, C), sometimes represented mathematically by X's, are typically converted from their original metric, such as 0 to 100 percent, to a coded

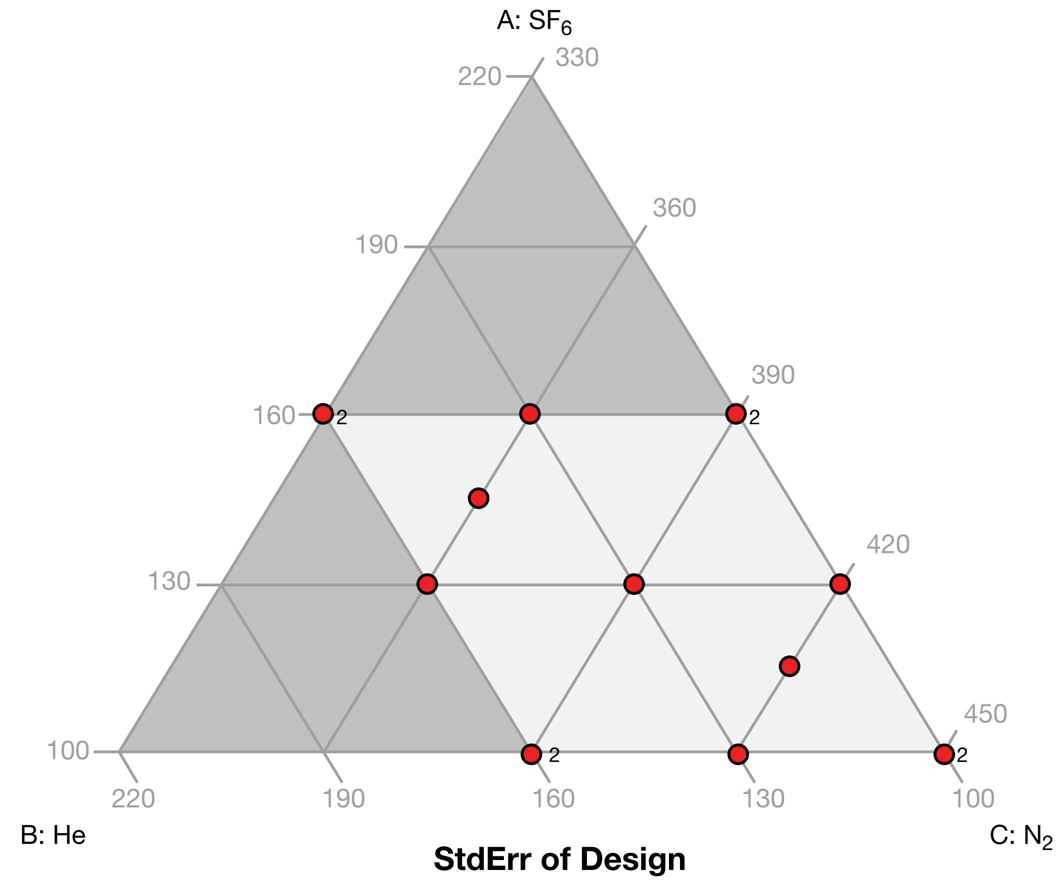



Figure 1. Location of Experiment Blends Within Feasible Mixture Space

format going from 0 to 1, thus facilitating interpretation of the resulting coefficients. For example, the first blend in Table 1 (ID#1), a vertex, is coded as (0,0,1). The fitted coded equations, both of which exhibited outstanding model statistics, are:

$$\text{Off spec} = 0.95A + 0.93B + 0.28C - 2.45AB - 1.39BC$$
$$(p=0.002,\ R^2_{adj} = 0.82)$$

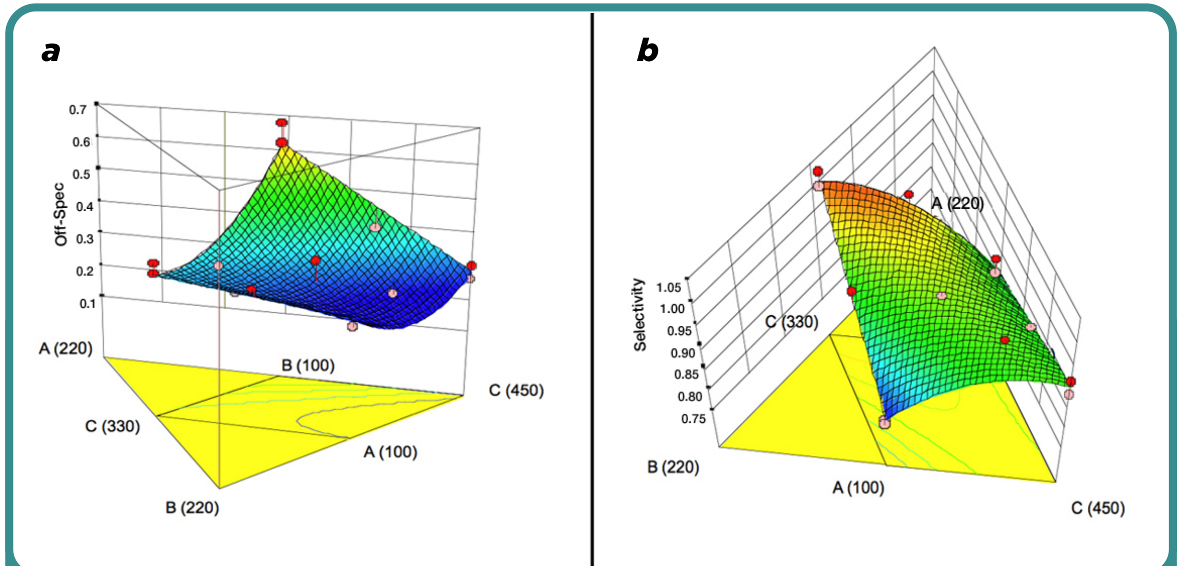
$$\text{Selectivity} = 0.81A + 0.27B + 0.90C + 1.86AB + 0.76BC$$
$$(p<0.0001,\ R^2_{adj} = 0.89)$$

Neither model contains the nonlinear blending term AC, because in both cases their probability values (“p”) at levels of 0.66 and 0.54, respectively, far exceeded the generally acceptable significance threshold, which typically must fall below 0.1 to be considered worthy of publication. However, whether an insignificant individual term like AC is kept in the model or not ultimately makes little difference.

## *Response Surface Graphs Tell the Story*

The mixture models become the basis for response surface graphs, which can be generated from the mixture DOE software – no need to be bogged down in the mathematics: The pictures tell the story! The graphs provide valuable insights about the formulation. Figures 2a and b show 3D representations of the two responses, with 2D contours projected below them, as a function of the three gases used in the plasma-etching process on single wafers. They are rotated to provide a better view of the curvatures.

Experiments like this are designed to locate the “sweet spot,” where quality requirements are met at greatest productivity. In this case, the fab engineers were tasked with reducing “off-spec” below 0.25, while maintaining selectivity at 0.85 or higher. Figure 3 shows the region where these response criteria are achieved. It includes an actual run,




Figures 2a, 2b. Response Surfaces for the Two Responses: Off-spec (2a - left) and Selectivity (2b - right)

ID#9, run at a center edge point. The flagged point is another possibility – one of many that are predicted to meet the requirements of the single-wafer etching process. However, anything outside the operating window exceeds 0.25 in off-spec and/or fails to achieve the desired 0.85 selectivity.

The most desirable gas mixture, pinpointed via a computer search, is pictured in Figure 4 – 100 μm of $SF_6$, 118 μm of He with 432 μm of $N_2$ as ballast to bring the total pressure up to its fixed total of 650 μm.

The ramps translate the predicted responses of off-spec and selectivity, 0.2 and 0.9, respectively, to their relative desirabilities. In this case, the quality of achieving a highly desirable (low) level of off-spec comes at price – the productivity in terms of selectivity does not come out as high as the fab engineers might have hoped. By placing more importance on one response versus another, the optimal blend can be biased, but this must be done judiciously as dictated by the needs of manufacturing and the customer.

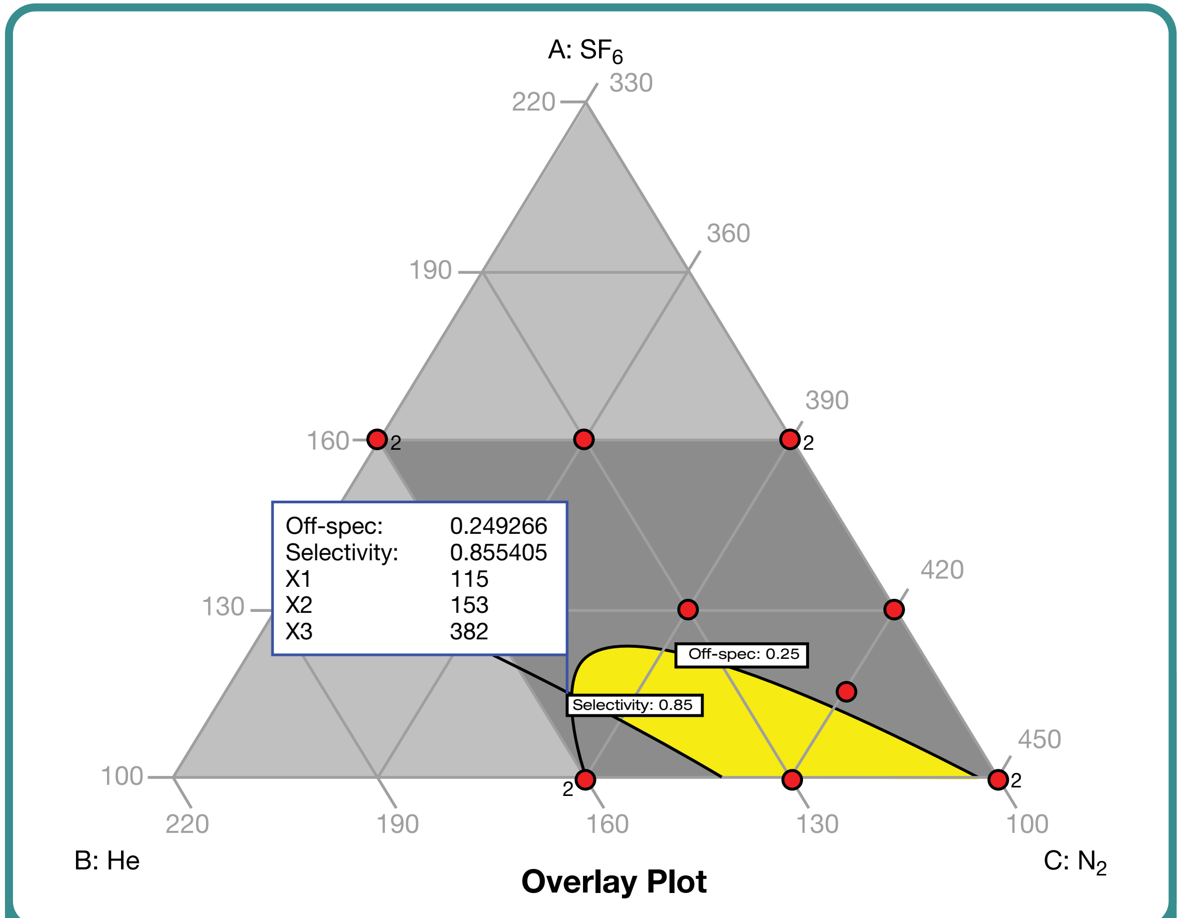



Figure 3. The Sweet Spot for Achieving Low Off-Spec With High Selectivity

In this case, the fab engineers found that their reformulated plasma gas significantly improved the performance of the single-wafer etching process, thus validating the results of their mixture experiment.

## Conclusion

By using DOE methods tailored for mixture design, fab formulators can greatly enhance their exploration of alternative blends. Then with the aid of RSM, they can discover the most desirable combination of components within the feasible mixture space.

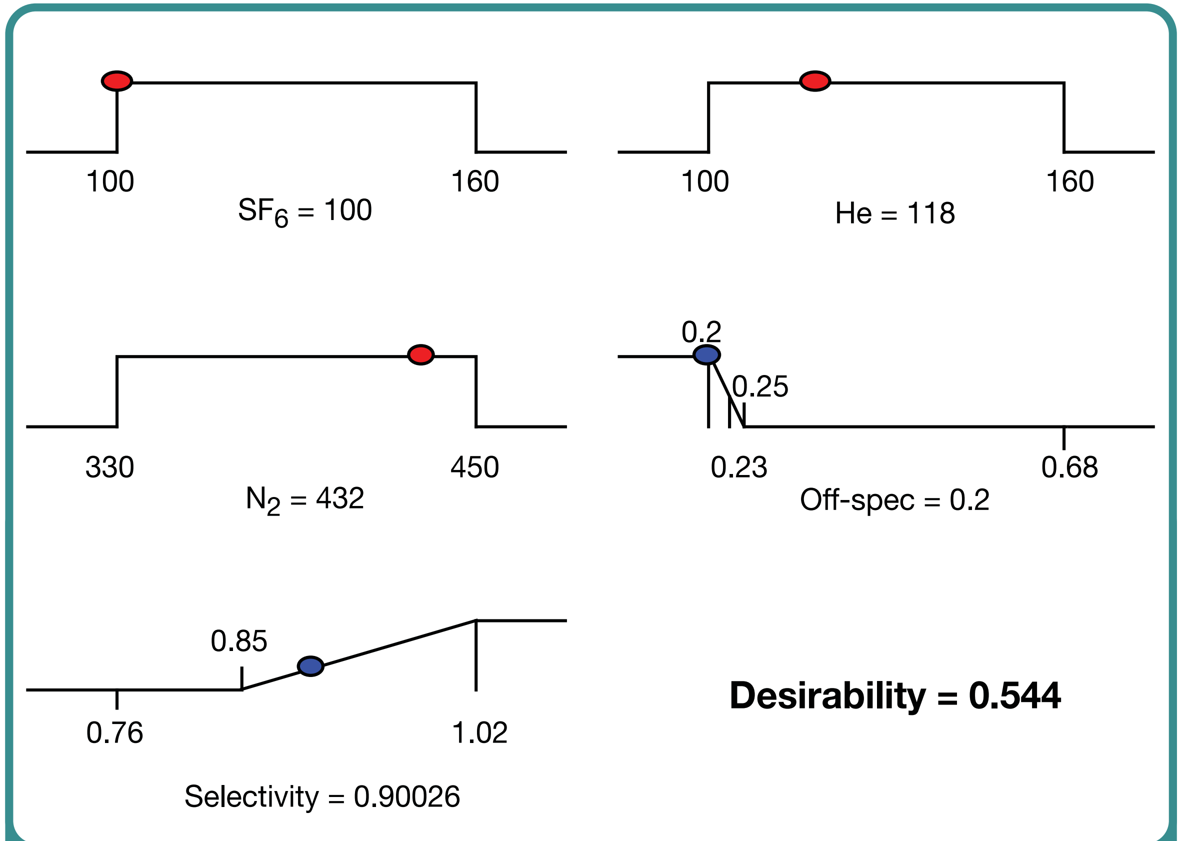



Figure 4. Most Desirable Mixture of the Three Gases

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## About the Author

***Mark J. Anderson***

Mark J. Anderson is a chemical engineer, and principal of Stat-Ease, Inc. He co-authored the two-part series of engineering primers DOE Simplified[2] and RSM Simplified.[8] He has written numerous articles on design of experiments, many of which can be seen online or ordered as reprints. ■

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# Installing 8-inch Equipment in a 6-Inch-Generation Fab: Raising the Roof

**Mark Crabtree** – NEC Electronics America, Inc.

## *Abstract*

Installing 8-inch equipment in a semiconductor fab with 6-inch equipment can be a viable option to increase production capacity or to produce higher-technology devices. However, fabs in the 6-inch generation may not be designed to accommodate the larger and heavier 8-inch tools. An article in FEO vol. 2 described an alternative method for installing the heavier equipment. This article describes how a fab's ceiling can be modified to accommodate the larger assembled height of some taller 8-inch equipment.

This article, a continuation of an article published in the February issue of FEO, further describes the measures taken by NEC Electronics America to move 8-inch equipment into its 6-inch-generation wafer fab. Because the transport elevators at NEC Electronics America's wafer fab in Roseville (Calif.) were designed for 6-inch equipment, they could not be used to move some of the heavier and larger 8-inch equipment because of weight and size limitations. Additionally, since NEC Electronics America is still running its 6-inch line, the move-in distance needed to be minimized to reduce the impact to production during the move. To overcome these challenges, we opened an entrance point in the wall of the building, near the equipment's final position. An elevated platform with a sufficient load capacity was constructed at fab level, and used to move the heavier 8-inch equipment.

Another challenge involved the assembled height of the equipment. In an effort to conserve expensive cleanroom space, equipment manufacturers have made some 8-inch equipment taller than their 6-inch counterparts. Consequently, even though the equipment can be moved into the fab in pieces, the final height may be taller than the ceiling of the fab. One example is 8-inch lithography equipment. One vendor's 8-inch stepper is not only taller than the 6-inch stepper, but also requires maintenance access to the top of the equipment. This article will describe how NEC Electronics America adapted the ceiling of its fab to accommodate the taller equipment – with minimal impact to its 6-inch wafer production line.

Raising the ceiling height for the taller equipment involves raising the HEPA filters. There are different methods for HEPA ceiling filtration. Among these are fan filter units (FFU), ducted-air designs and open-plenum designs. Conceptually, the FFU design should be the most flexible system to modify, and have the least impact on surrounding production equipment, because each filter has dedicated fans. The ducted-air HEPA design would require small sections of the fab that share the same air supply duct to be idled during the modification, and would have a greater impact than an FFU system. Sufficient space above the HEPA filters would also be required to accommodate the raised ducting. Making modifications to an open-air plenum HEPA ceiling would cause the greatest impact to airflow, however. With the open-air plenum design, large areas of the fab share air supply fans. The supply fans pressurize the air above a large section of HEPA filters. Removing any of the filters allows large amounts of unfiltered air to escape, drops the air pressure above all of the other filters, and reduces the airflow in a large area of the fab.



NEC Electronics America uses an open-area plenum design; hence, its move-in team was challenged to raise the ceiling while minimizing the impact to concurrent 6-inch wafer production.

After the equipment layout was complete, the areas requiring ceiling modifications were identified. These areas needed to be enclosed to prevent unfiltered air from entering the production area and a pressure drop in the plenum during the time when the filters were removed. The standard barrier used to isolate a work area from construction, equipment move-in or equipment assembly consists of a cleanroom-approved plastic sheet attached to a PVC pipe frame. These barriers are referred to as soft barriers. These soft barriers alone would not be sufficient to isolate the area where a HEPA filter was removed, because the force created by the pressure differential between the filtered and unfiltered areas would collapse the barriers. Consequently, a solid barrier, constructed from the same materials as the fab walls, was selected to isolate the HEPA ceiling construction area.

The execution of the barrier construction was critical to minimizing the impact of the ceiling modification on concurrent 6-inch wafer production. Since the solid barrier would take several days to complete, a soft barrier was first installed to isolate the solid barrier construction area. A soft barrier construction area normally can be installed and qualified in less than two hours. During the soft barrier construction, production equipment in the vicinity of the construction zone was idled and covered to prevent contamination. Once the soft barrier was erected, all of the construction materials for the solid barrier moved in and the surrounding area re-qualified, the construction of the solid barrier could progress without further interruption to production.

The solid barrier incorporated an airlock that would be used by workers to enter the

Figure 1. Raised Section of the HEPA Support Structure Inside the Solid Construction Barrier

construction area during the time the HEPA filters were removed. The airlock would prevent unfiltered air from entering the cleanroom and, when combined with covering on the perforated floor, would maintain the pressure differential that would occur when the filters were removed. Laminar flow and particle counts were monitored outside the enclosure during the filter removal and perforated floor covering process to ensure that there were no excursions outside of the enclosure. Once the HEPA filters were removed, the support structure for the filters was raised and a vertical barrier was installed to bridge the gap between the raised and standard ceiling (see Figure 1).

HEPA filters were reinstalled or replaced, depending on their condition. The perforated floor covering was removed and the enclosed room was requalified for particle counts and laminar flow (see Figure 2).

Once the raised ceiling area was qualified, the solid barrier was dismantled within the soft barrier area. Production equipment in the vicinity was again idled and covered during the dismantling of the soft barrier, the move out of the construction material and a second qualification of the area.

Fortunately the majority of the 8-inch equipment did not challenge NEC Electronics America's 6-inch-generation ceiling height, because raising the ceiling in an

Figure 2. HEPA Filter Installation Complete, Inside Soft Construction Barrier

open-air plenum is both costly and disruptive to production equipment in the vicinity of the construction. However, without the option to raise the ceiling, 8-inch production would not be possible without the higher-cost option of building a new facility.

## *About the Author*

***Mark Crabtree***

Mark Crabtree is an equipment engineering manager responsible for masking, implanting, sputtering and sorting at NEC Electronics America's semiconductor manufacturing plant in Roseville, Calif. He joined NEC Electronics America in 1994 as an equipment engineer in masking and wet etching before becoming a manager. Mark received a B.S. in mechanical engineering from the University of California at Davis; has a professional engineer's (P.E.) license in mechanical engineering in the state of California; and holds three patents in the semiconductor industry. ■

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FEO

# Fab Productivity



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**C. Richard Deininger**
*General Partner, Taylor-Deininger Partners, Inc.*

Both articles in the Fab Productivity section of this issue of FEO illustrate the need to continually reduce costs as well as to improve manufacturing efficiencies.

The article by Galbiati, et al. describes the framework and standards needed to implement advanced process control. R2R control is in use in numerous fabs worldwide to improve productivity. This paper shows the beneficial results which are achieved by implementing R2R control. *Its benefits have been demonstrated overwhelmingly over and again in so many fabs; why are so many companies resisting its use?*

The article by James Ignizio proposes a methodology for Lean Manufacturing to reduce costs and improve factory performance. Each paper details good examples of how to decrease costs and increase efficiency. Are manufacturers too busy to address these obvious solutions?

At SEMICON West 2008, 565 participants registered to attend the panel on Fab Productivity. The area of continuous improvement to fab operations proved timely. Many companies are under severe ASP pressure, and the best way to stay viable in that scenario is to aggressively manage the operation. The panel described the value of improvement, and provided specific information on two key ways to rapidly implement improvements in fab areas. Three customers shared their experiences with both techniques. Details are available on www.TD-partners.com.

Now more than ever, management needs to look at proven ways to make the operational improvements required to reduce costs and improve productivity.

# Fab Productivity



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## Matthew Nadeau
*Director of Manufacturing at NEC Electronics America, Inc.*


All of us who work in the semiconductor manufacturing industry have an ongoing challenge to create a company culture that fosters continuous improvement. When outside business conditions such as pricing pressures, competitor advances and new customer requirements pose threats that could adversely impact our operations, we need to have rapid, self-initiated approaches in place to overcome them. Companies that excel in this area typically promote decision making at the lowest levels of an organization, and encourage individuals and teams to engage in improvement activities without being prompted.

People who work in manufacturing environments long enough will eventually encounter many quality or productivity improvement systems. Some companies fall into the trap of reacting to the latest trend and putting a new "system du jour" in place without fully understanding the underlying forces and cultural changes driving the need for improvement. However, companies that are successful in creating a workplace that promotes continuous improvement are those that focus not on the system itself but rather on the end goals that the system must achieve.

In "Lean Manufacturing in the Semiconductor Industry: Proceed With Caution – Part 2," the author urges readers to look beyond the rules of Lean Manufacturing and instead focus on incorporating the science of manufacturing into improvement activities. In "R2R in DCVD – Part 2," the authors continue their discussion about the benefits of implementing advanced process control to improve process stability.

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# Lean Manufacturing in the Semiconductor Industry: Proceed With Caution – Part 2

**James P. Ignizio** – Manufacturing Science Consultant

Click here to to view part 1


## *Abstract*

Lean Manufacturing is a methodology proposed for improvement of factory performance. Recently, Lean has received attention in semiconductor manufacturing. Employed *properly*, Lean might improve semiconductor factory performance. *It is not, however, a panacea*. To achieve *successful* and *sustainable* improvement, one must be aware of its scope and limitations. If not, Lean may cause more problems than it solves. In this paper, the applicability of Lean in semiconductor manufacturing is investigated. Part I (published in FEO vol. 3) addressed the matter of a fundamental premise of Lean: *balanced production lines*. In this second part of the paper, the appropriateness of CANDO is examined and the employment of the Waddington Analysis is discussed.


## *1. CANDO ... and Potential Consequences*

Henry Ford and his staff were insistent on workplace organization and tidiness, and this was one of the lessons imparted to Toyota (e.g., in their visits to Ford plants preceding World War II). Today the focus of majority of the efforts supporting initiation of Lean Manufacturing appear to be devoted to workplace organization; i.e., via CANDO (**C**leanup, **A**rranging, **N**eatness, **D**iscipline and **O**ngoing improvement).

CANDO efforts are among the most easily facilitated tasks undertaken by novice Lean teams. *Before* (i.e., messy workplace) and *after* (i.e., clean, uncluttered workplace) photographs are taken and presented to management to document the success of the CANDO effort.

On the surface it would seem irrational to suggest that anything but positive benefits will be accrued from tidying up the workplace. After a properly conducted CANDO procedure, everything is clean and neat, tools are in the right place and even the chance of an unsafe event has likely been reduced. Unfortunately, the conduct of a CANDO event may not lead to the degree of factory performance improvement the Lean team *could* accomplish.

To explain how a CANDO event may not result in the benefits promised, consider the consequences of a CANDO effort conducted for an actual workstation (which happened to consist of a single machine). Figure 1 is a plot of workstation downtime in the 168 hours following the workstation's weekly preventive maintenance (PM) event, following the accomplishment of a CANDO effort.

The plot of workstation downtimes versus clock time following a PM event reveals existence of the *Waddington Effect*. Specifically, there is *an increase in unscheduled downtime (i.e., repairs) in the time period immediately following the PM event* and then, after a period of time, the situation appears to "settle down." More specifically, there is an indication the PM event may actually be inducing rather than suppressing unscheduled repairs.

It may be observed that in the hours immediately following the PM event (i.e., between zero and about 32 hours following the PM), the hours of *unscheduled* downtime significantly increase and then gradually return to a "normal" rate (i.e., of about one to two repair hours every eight hours). Since PMs are intended to reduce, if not eliminate, unscheduled repairs, this is disconcerting. Furthermore, although not depicted in Figure 1, the CANDO event conducted for this workstation – while substantially reducing workplace clutter – failed to mitigate the Waddington Effect existing prior to conduct of the CANDO.

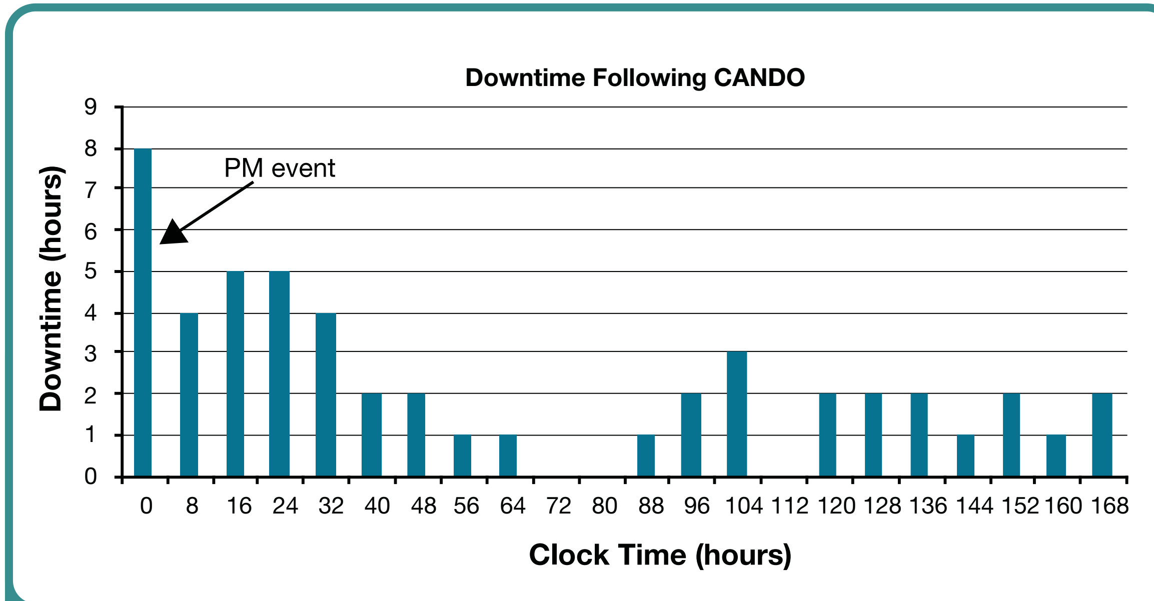


Figure 1. Waddington Effect Plot – Following CANDO

The Waddington Effect exists, *often to a substantial degree*, in semiconductor manufacturing. PM events on machines result, too often, in *inducement* of unscheduled downs (although this fact is seldom comprehended). This usually means the PM event was either 1) improperly performed (e.g., conducted too fast, too sloppily and/or by an insufficiently trained maintenance team), or 2) was due to poorly written PM specifications (i.e., PM specifications that are not $C^4U$ compliant). A $C^4U$-compliant specification is one that is **C**lear, **C**oncise, **C**omplete, **C**orrect and **U**nambiguous.

Surprisingly enough, ***existence of the Waddington Effect in semiconductor manufacturing is often due to poorly written (non-C⁴U-compliant) PM specifications.***

What then has this to do with CANDO?

If a Lean team performs a CANDO event for a workplace, the result is invariably a cleaner, neater, less-cluttered and perhaps even safer work area. But if this event is undertaken ***before*** the specifications for the PM events are made $C^4U$ compliant, the result may be that the CANDO effort ***simply results in the faster conduct of a flawed maintenance event.***

Figure 1, as mentioned, is a plot of downtime (scheduled and unscheduled) for a workstation *following* a CANDO effort. Unfortunately, in a rush to produce some nice before-and-after photographs, no effort was made to determine if the PM event might be producing a Waddington Effect. While the CANDO effort did serve to de-clutter the workspace, the cycle time

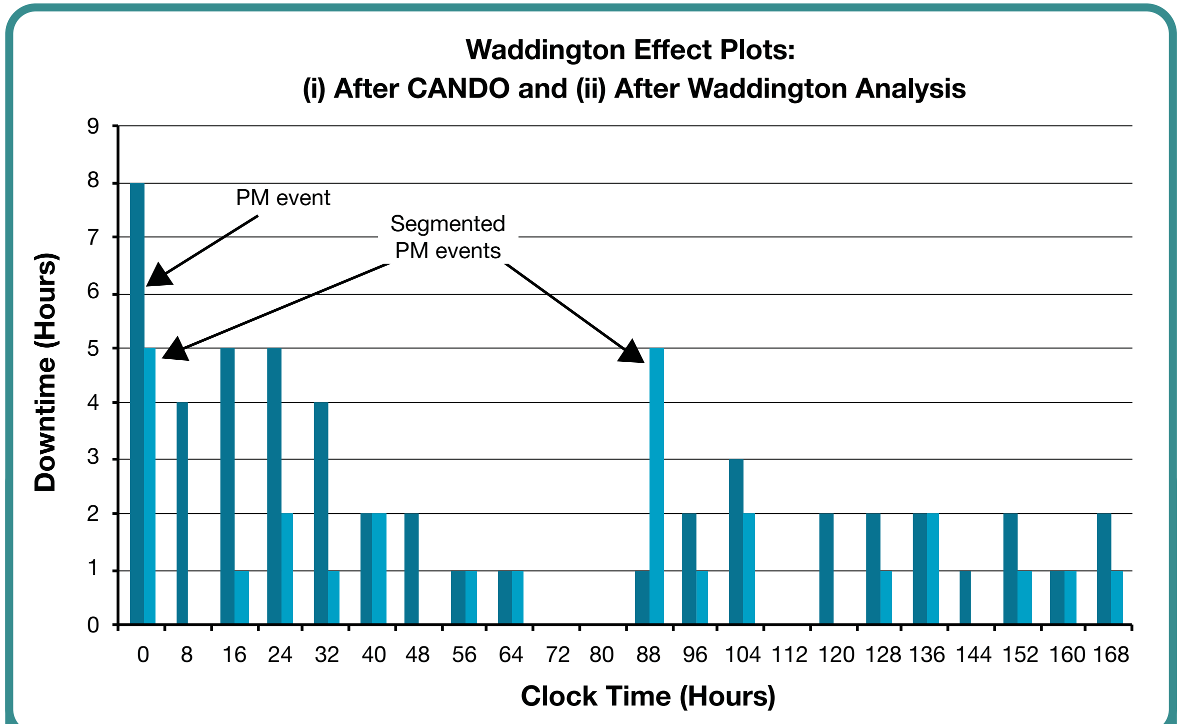


Figure 2. Downtimes After CANDO and Then After Waddington Analysis



performance of the workstation itself remained disappointing. Some months later, it was decided to investigate the performance of the workstation. A *Waddington Analysis* (a procedure designed to develop $C^4U$-compliant PM specifications as well as to divide, when possible, long PM events into shorter ones) was performed.

Figure 2 compares the average profile of downtimes incurred after the original CANDO with those achieved after a Waddington Analysis. The dark-blue bars represent downtimes for the workstation after the original CANDO. The light-blue bars are downtimes achieved following the Waddington Analysis.

In Figure 2, note that, *originally*, the PM event required eight hours on average (the left-most white bar in the plot). Via the Waddington Analysis, the PM specification was not only made $C^4U$ compliant, but the revised PM was divided into two five-hour segments. The first segment was conducted at the beginning of the week (starting at time zero), and the second in the middle of the week (starting at roughly time 84 hours).

The results of implementing a CANDO event *without first performing a Waddington Analysis versus performing a Waddington Analysis* are shown in Table 1. As seen, there is a dramatic improvement in workstation performance simply by means of ***first*** performing a Waddington Analysis.

The results for this workstation are not atypical. The message is that one should perform a Waddington Analysis (e.g., establish $C^4U$-compliant PM specifications, including the elimination of nonvalued-added PM steps, and divide, whenever possible, long PM events into shorter ones) ***before*** conducting a CANDO event. Such advice often falls on deaf ears because:

- The importance, and even existence, of a Waddington Analysis is not widely known;
- It takes more time, effort and experience to conduct a Waddington Analysis than just a CANDO event; and
- CANDO before-and-after photographs are

| | Workstation Average Weekly Downtime (both scheduled and unscheduled) | Workstation Average Availability |
|---|---|---|
| CANDO Only | 50 hours | 70% |
| Waddington Analysis Followed by a CANDO | 27 hours | 84% |

Table 1. CANDO Only *versus* Waddington Analysis, Followed by CANDO

usually all that are needed to convince management (and the Lean team) that "something good" has been achieved.

## *2. The Consequences of Suboptimization*

Another reason for the high failure and disillusionment rate of Lean Manufacturing is that there is an emphasis on the *philosophy* of Lean without an appreciation of the *science* of manufacturing. Lean Manufacturing is, to some factory managers, attractive because there is little need for mathematical models. Most Lean Manufacturing training programs, in fact, focus primarily on guidelines, rules and slogans. These are accompanied by case studies (e.g., before-and-after photos, results of "Kaizen" events) that supposedly illustrate how Lean should be implemented.

As an advocate of Lean Manufacturing (***if performed properly and if balanced with a knowledge of the science of manufacturing***), my concern with the typical Lean Manufacturing training course is that the emphasis is on how to apply the Lean philosophy, guidelines, and rules with little attention paid to 1) *why* and *how* a Lean activity works, and (ii) in particular, the *limitations* of the concept. To clarify these concerns we return to the 5-workstation model discussed in Part I of this paper (FEO vol. 3).

In section 3, it was demonstrated that an *unbalanced* production line may, and usually is, superior in terms of factory cycle time and inventory, to a balanced line. It was shown that when each of the machines in the 5-workstation factory were set at their highest possible process rates (e.g., 25, 40, 100, 25 and 60 units per hour, respectively), while the flow of jobs was maintained at the takt rate (20 jobs per hour), factory cycle time was 22.41 percent less than the best results of a balanced line.

While this particular unbalanced production line was shown to be superior to any balanced line, there is a better solution. If we set the process rates of each workstation as indicated below, the performance of the factory is optimized.

- workstation A = 25 units/hour
- workstation B = 40 units/hour
- **workstation C = 38.258 units/hour**
- workstation D = 25 units/hour
- workstation E = 60 units/hour

The only difference between the optimal solution and best previous solution is the establishment of the process rate for workstation C. Previously we set that rate at its maximum level; i.e., 100 units/hour. In the optimal solution, however, the process rate of workstation C is 38.258 units/hour.

The "maximum speed" of the *unbalanced* production line resulted in 51.04 days average cycle time and an average of 1,020.72 units of inventory. The optimal (*and still unbalanced*) production line has an average factory cycle time of 50 days and average factory inventory level of 1,000 units. While an improvement of just 2 percent may not seem significant, it is the message sent by this result that is important.

The 5-workstation model has demonstrated the fact that an increase in capacity (e.g., via increasing a workstation's availability and/or process rate) of a single workstation may actually *degrade* overall factory performance. While the degradation was relatively small in the simple 5-workstation model, it can be markedly more so in real-world factories.

Thus, when a Lean Manufacturing team decides to conduct a Kaizen event to, for example, increase availability of a workstation, they *may* unknowingly be degrading factory performance. Without appreciation of the science of manufacturing, this fact may prove difficult to convey.

## *3. Observations and Recommendations*

While there are other potential problems in implementation of Lean within semiconductor manufacturing, that discussion can be addressed in a separate paper. It should, however, be obvious that ***there is more to the improvement of factory performance than just the implementation of Lean***. This is particularly true when the crucial difference between synchronous/tightly coupled factories and asynchronous factories (e.g., semiconductor factories) is understood.

It merits re-emphasizing that Lean, like any methodology/philosophy for factory performance improvement, is not a panacea. Unless both the scope and limitations of Lean are fully understood, more harm than good may result.

A few recommendations for avoiding problems caused by the improper implementation of Lean in semiconductor manufacturing follow:

- Be wary of Lean Manufacturing consultants (or Lean training courses) that emphasize the *philosophical* aspects of the topic (e.g., lists of guidelines, rules and slogans) while dismissing the crucial importance of a need for an appreciation of the ***science*** underlying the performance of factories. In short, be wary of promises of "quick and easy" solutions.
- Be aware of such phenomena as the Waddington Effect and of the impact of poorly crafted PM specifications on the inducement of unscheduled down events [Waddington, 1973].
- Become familiar with the Hawthorne Effect [Roethlisberger and Dickson, 1939]. All too often the results obtained by Lean Manufacturing ... or any other attempt to improve factory performance ... *are transitory or illusionary*.
- Always employ valid, *load-adjusted* measures of factory performance [Ignizio, 1980, 1993, 1995 and forthcoming] to properly evaluate results of performance improvement efforts. Recognize the limitations associated with such nonload-adjusted metrics as factory moves, inventory turnover and cycle time.
- Don't expect to become an expert in any credible method for factory performance improvement in a few days, weeks or even months. Expertise takes years – and, frankly, not everyone has the aptitude to achieve the level of knowledge required.
- Don't limit your education in performance improvement to just Lean. Without an in-depth appreciation of the ***science*** of manufacturing you will neither be prepared to deal with nor understand *the cause* of the most significant problems in the factory.
- Don't expect methods that work in tightly coupled production systems to always, or even necessarily, deliver similar benefits for asynchronous process flows.
- Obtain the support, and encourage the involvement of, senior-level management. Without that support and involvement, chances for other than transient factory performance improvement are negligible.

## *4. Summary and Conclusions*

If the history, scope and limitations of Lean Manufacturing are understood and appreciated – and if the philosophy, guidelines, rules and slogans of Lean are balanced with a knowledge of the *science* of manufacturing – the method can prove to be effective in factory performance improvement. Otherwise, the chances for significant and sustainable improvement are reduced. This is particularly true in semiconductor manufacturing.

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# R2R in DCVD – Part 2

**Matteo Galbiati, Giuseppe Fazio, Silvia Zoia and Flavio Crippa** – Numonyx

Click here to to view part 1

## *Introduction*

In the first part of this article (in FEO vol. 3), we introduced, as a general overview, the run-to-run methodology and scopes, and discussed the run-to-run pilot project and its main objectives, showing the process model adopted. In this second part, we present the system integration with automation, and how a run-to-run system can be placed into a production scenario. At the end of this article, we dicuss our results and show how much a well-tuned run-to-run control can help keep in control even the finest processes.

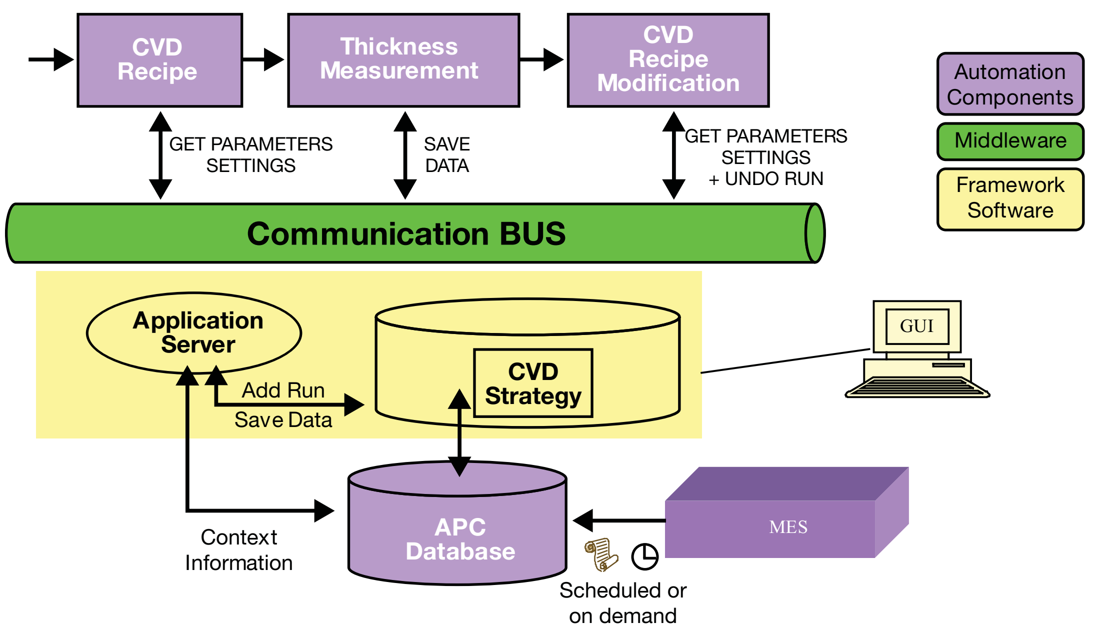


Figure 1. Integration in ST Automation

## *Integration With Automation*

To implement an advanced process control (APC) like a R2R control, we need to introduce a dedicated framework that must be compatible with the internal automation structure (see Figure 1).

This framework is a software application that enables engineers to set up control strategies for processes via user interface. In order to let the control strategy work automatically, the R2R framework system needs to be integrated with the existing factory equipment and manufacturing execution system. The R2R controller should communicate with the automation environment and MES to perform the following tasks:

- Download the process goals from MES to the controller;
- Download the computed settings to the equipment;
- Upload process information from the tool to the controller;
- Upload wafer responses from the metrology tool data to the controller.

The APC database is used to store context information such as technology, process, event, thickness targets and limits extracted periodically from the MES database. The communication to the process tools and metrology tools is established through the automation's cell controllers. The communication between the APC framework and the

| Processes | Thickness (Normalized) | Deposition Time (sec) | Correction Time Deadband (Normalized Thickness) |
|---|---|---|---|
| 1 | 0.68 ± 0.012 | ~ 107 | ~ 5.35 (0.0340) |
| 2 | 0.29 ± 0.005 | ~ 45 | ~ 2.25 (0.0145) |
| 3 | 0.45 ± 0.010 | ~ 68 | ~ 3.40 (0.0225) |
| 4 | 0.89 ± 0.012 | ~ 138 | ~ 6.90 (0.0445) |
| 5 | 0.10 ± 0.017 | ~ 18 | ~ 0.90 (0.0050) |
| 6 | 0.05 ± 0.001 | ~ 10 | ~ 0.50 (0.0025) |
| 8 | 0.40 ± 0.007 | ~ 60 | ~ 3.00 (0.0200) |
| 9 | 0.08 ± 0.004 | ~ 15 | ~ 0.75 (0.0040) |
| 10 | 0.09 ± 0.004 | ~ 18 | ~ 0.90 (0.0045) |
| 11 | 0.14 ± 0.005 | ~ 22 | ~ 1.10 (0.0070) |
| 12 | 0.15 ± 0.007 | ~ 30 | ~ 1.50 (0.0075) |
| 13 | 0.58 ± 0.012 | ~ 85 | ~ 4.25 (0.0290) |
| 15 | 0.07 ± 0.010 | ~ 12 | ~ 0.60 (0.0035) |

Table 1. Row Data of Thickness and Deposition Time on a Chamber

automation environment is through a communication bus, exchanging standard virtual factory equipment interface messages.

## Production Scenario

As shown in the analysis in the “DCVD Model” section in Part 1 of this paper (in FEO vol. 3), inspected processes can be well described with only one deposition rate, and this deposition rate can be extended to other similar tools (see Table 2 in Part I). In this scenario, it is quite easy to set up a common strategy with little differences from chamber to chamber and to have a good correlation on the entire process family.

## Results and Discussion

Advanced process control has been implemented, as a pilot project, on two tools with three different process families. In Part I of this paper, we showed analysis and data only on one of these families, but behavior is quite the same for each process family. As result, we can consider the last month in which R2R control has been applied in production. As shown in Table 2, even if the observed time isn’t too long, we can see that R2R control is able to decrease, or at least not increase, the number of out of controls on a process which is very well centered on the target.

| **NO R2R** | | From | 23/6 | to | 22/7 | |
|---|---|---|---|---|---|---|
| Mean | EWMA | Run Out | Run Tot | **% Out** | **%Mean** | Num CC |
| 3 | 1 | 3 | 8059 | **0.04** | **0.04** | 1158 |
| **R2R** | | From | 23/7 | to | 31/8 | |
| Mean | EWMA | Run Out | Run Tot | **% Out** | **%Mean** | Num CC |
| 2 | 1 | 2 | 8890 | **0.02** | **0.02** | 1204 |

Table 2. Data on Statistical Process Control Without R2R and With R2R

| **Recipe UPLOAD** | |
|---|---|
| Without APC R2R<br>Time estimate: **30 minutes** | With APC R2R<br>Time estimate: **2 minutes** |
| • Manual new deposition time calculation<br>• Manual deposition time correction on equipment<br>• Rebuilding test<br>• Manual recipe UPLOAD | • Automatic event to calculate new deposition time<br>• Automatic recipe correction<br>• Automatic recipe UPLOAD |

Table 3. APC R2R Control Test Time vs. NO R2R Control Test Time

## Process Control Without R2R and With R2R

However, as shown in Table 3, an R2R control performed, even only on tests, is able to improve chamber up time. In fact, the manual test procedure takes about 30 minutes, in the best case, while the automatic procedure is faster and takes only two minutes. Moreover, because this procedure is completely automatic and the deposition time is calculated directly from the time read on the recipe, the probability of human error is reduced to zero. This can prevent having incorrect deposition time as shown in Figure 3 in Part I of this paper.

The main benefit obtained by R2R control is to keep the process as close to the target as possible. Results are shown in Figures 2 and 3. Here we can see the differences between processes, with their own natural variability, without an R2R control, and with the same processes controlled with the R2R tool. After few measures performed with the R2R control (measures needed to compensate natural variability and R2R off-line setup), processes are closer to the target value with less spread variability.

In Figure 4, we can see one more example of human error: In this case, the human

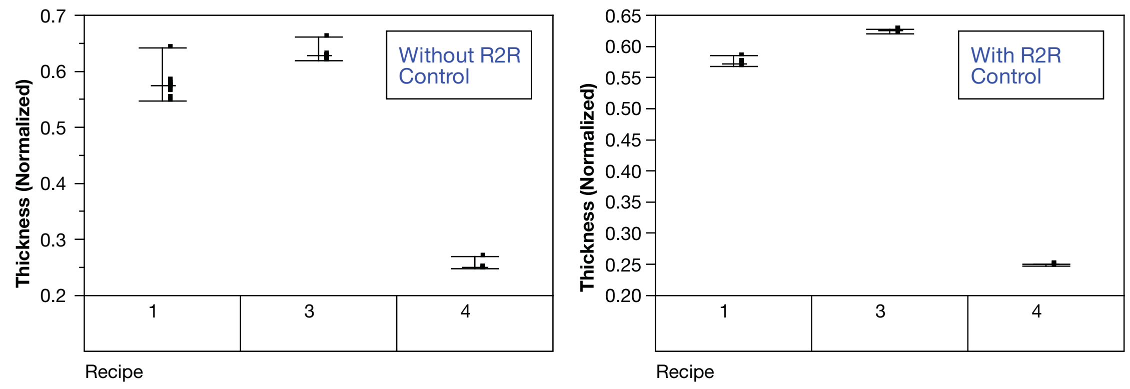


Figure 2. Variability on Normalized Thickness Without R2R Control and With R2R Control

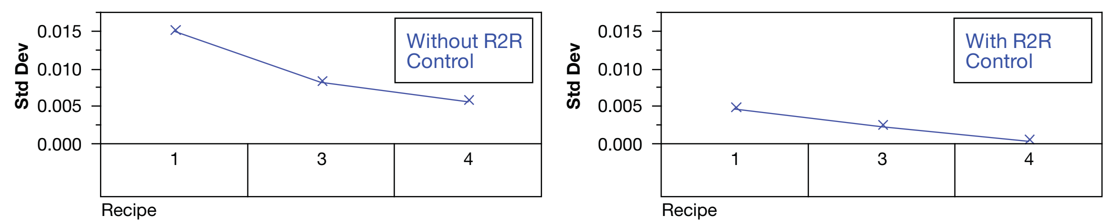


Figure 3. Standard Deviation on Thickness Without R2R Control and With R2R Control

error is to insert a test on a recipe while the measure refers to another recipe. This error, with the R2R control, is prevented by the automation which selects and links each test to its own correct control chart.

Once the R2R control is consolidated and deployed on each tool, we can consider extending the R2R control in two different ways:

- Consider deposition rate on one recipe to correct parameters on each recipe of the same family → this can improve machine up time and reduce the number of wafer tests.
- Implement a "real" R2R control on production lots instead of on test chips → this can improve quality by centering output parameters on each processed lot, and can reduce the number of wafer flat tests to zero (wafer test can be used only after maintenance).

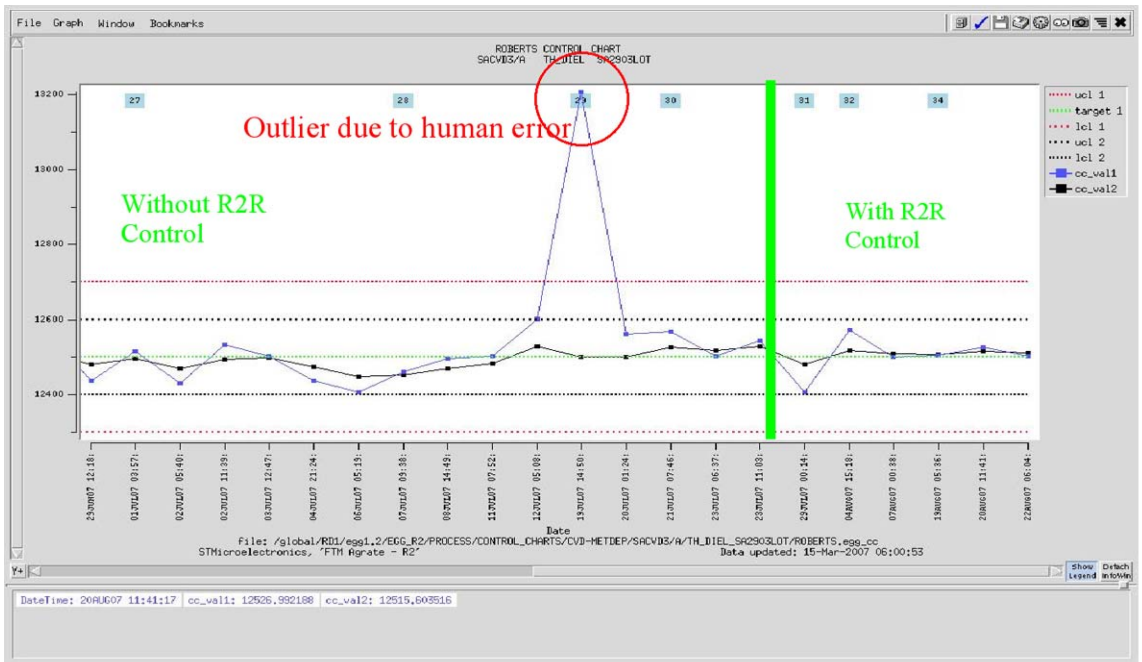


Figure 4. Variability Reduction Obtained With R2R Control

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# Quality Control

## Advanced Diffuser Technology Helps Reduce Vent-Up Times

**Chris Vroman, Chris Quartaro, Marshall Randolph**
Entegris, Inc.

## Tool Optimization for Improving Productivity and Yields

**Victor K. F. Chia**
Balazs NanoAnalysis

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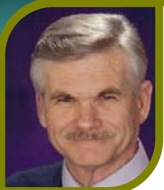

**Bill Funsten**
*Program Manager, Contamination Control; Spansion, Inc.*

Quality measures such as sort yield and device performance can be significantly impacted if particle source troubleshooting is not quick and effective. Surface particle scanning tools, delivering raw particle counts, have long been employed in support of process tool qualifications and particle monitors. However, process engineers also need tools for elemental analyses in order to quickly understand the cause and impact of contaminating events, and discern, for example, if a particle or residue originates from materials inherent in the equipment, or from foreign sources.

Analytical tools employing TXRF, ICP-MS and EDX techniques are now routinely used to baseline tool contaminants and identify probable sources of excursions. Qualitative and quantitative data obtained by such techniques forms an essential part of comprehensive quality programs, well expanding into the control of individual tool components and materials. The paper by Dr. Chia gives an example of how the laser ablation ICP-MS method has been applied to tool-build-material quality and degradation studies.

Most improvement efforts for particle reduction in process tools in recent years have focused on 300 mm tools. For many companies, however, 200 mm tools continue to carry significant production volumes on mature process technologies. In such an environment, reducing sources of particulates can lead to immediately measurable yield or throughput improvements, increasing overall margin. The article by Vroman et al. presents one such example with a vacuum loadlock upgrade that offers great potential to solve a known particle issue in 200 mm tools.

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**Robert K. Henderson**
*Site Statistician, Samsung Austin Semiconductor*

Traditional quality control has generally focused on managing processes to sustain established performance levels (i.e., process control); however, the articles in the Quality Control section in this edition of FEO discuss approaches to actually improve process performance. Both of the articles are directed toward reduction of particles and defects in semiconductor processing.

"Advanced Diffuser Technology Helps Reduce Vent-Up Times," by Vroman, Quartaro and Randolph of Entegris, uses the disciplines of materials science and flow dynamics to introduce a means to limit particles in the process from reaching the surface of the wafers.

"Tool Optimization for Improving Productivity and Yields," by Dr. Victor Chia of Balazs NanoAnalysis, focuses on the reduction of the potential number of defect sources inherent in the process, through efforts to identify low particulate materials to be used by the suppliers of the processing equipment.

Whereas traditional process control efforts are generally focused on the less-ambitious task of more closely maintaining an established level of performance, process improvements such as those suggested in these two articles are generally of more value than mere improvements in process control, as they can change the expected performance level of the process.

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# Advanced Diffuser Technology Helps Reduce Vent-Up Times

**Chris Vroman, Chris Quartaro, Marshall Randolph** – Entegris, Inc.


### *Abstract*

A major initiative is under way in the semiconductor industry to find the most cost-effective way to reduce vent-up time in loadlock chambers while significantly increasing wafer throughput and tool productivity in deposition and etch process tools. This paper describes the effectiveness of gas diffuser technologies such as those available from Entegris, which have been shown to allow rapid venting of loadlock chambers, resulting in increased tool productivity, production and overall equipment effectiveness without additional particle-related yield loss.


Wafer throughput and particle counts are key metrics for any semiconductor manufacturer's yield enhancement programs. Recent advancements in diffuser technology have helped manufacturers enhance these metrics while improving the attributes for most vacuum processes. These processes include dry etch, chemical vapor deposition (CVD), physical vapor deposition (PVD), rapid thermal processing (RTP) and Epitaxial deposition (Epi).

Execution of membrane diffuser technology dramatically decreases required vent time and has become a highly effective tool upgrade option. An early implementation of this technology was used on 200 mm batch-style loadlocks that had an inherently large internal volume. The loadlock was prone to long vent cycles to prevent particle contamination.

As the industry transitioned to a 300 mm wafer platform, factories increased their development of single-wafer loadlocks (SWLL) in an effort to boost tool throughput. Gas diffusers with ultrafine filtration membranes solved these issues. Compared with the 200 mm batch-style loadlocks, the SWLLs had extremely low internal volumes and were designed to cycle vacuum to atmosphere very quickly. With the low volumes inherent in the SWLL, the velocity of the incoming vent gas became critical, since any particles on the bottom of the loadlock chamber would easily sweep onto the wafer should they be hit with a high-velocity gas. Particles are typically present in the loadlock due to mechanical wafer-handling devices and environmental exposure. Gas diffusers allowed a large, uniform volumetric flow rate of gas into the loadlock chamber at low downstream gas velocities.

While now standard on most 300 mm loadlocks, the majority of 200 mm tools in the field do not utilize membrane diffusers. Typically, a screen, frit and/or soft vent procedure is used to control the flow into the loadlock. However, these tools can now be retrofitted with membrane diffuser technology. The result is a large reduction in particle count while maintaining throughput levels at a low cost with minimal downtime.

### *Standard 200 mm Tool Venting Technology*

The method most widely established to control particle disturbance on 200 mm semiconductor vacuum process tool platforms is a two-step venting process, which implements a "soft" vent followed by a standard vent. The soft vent is typically conducted using a second line equipped with a flow restrictor to minimize the flow rate and bleed gas into the chamber until a certain pressure is reached inside the loadlock. This helps reduce the disturbance of particles. Once a set pressure is reached in the loadlock, a second valve is actuated to complete the venting process and bring the pressure of the loadlock to atmosphere. Depending on the volume of the loadlock chamber, the soft vent stage alone can take anywhere from a few seconds to several minutes to complete.

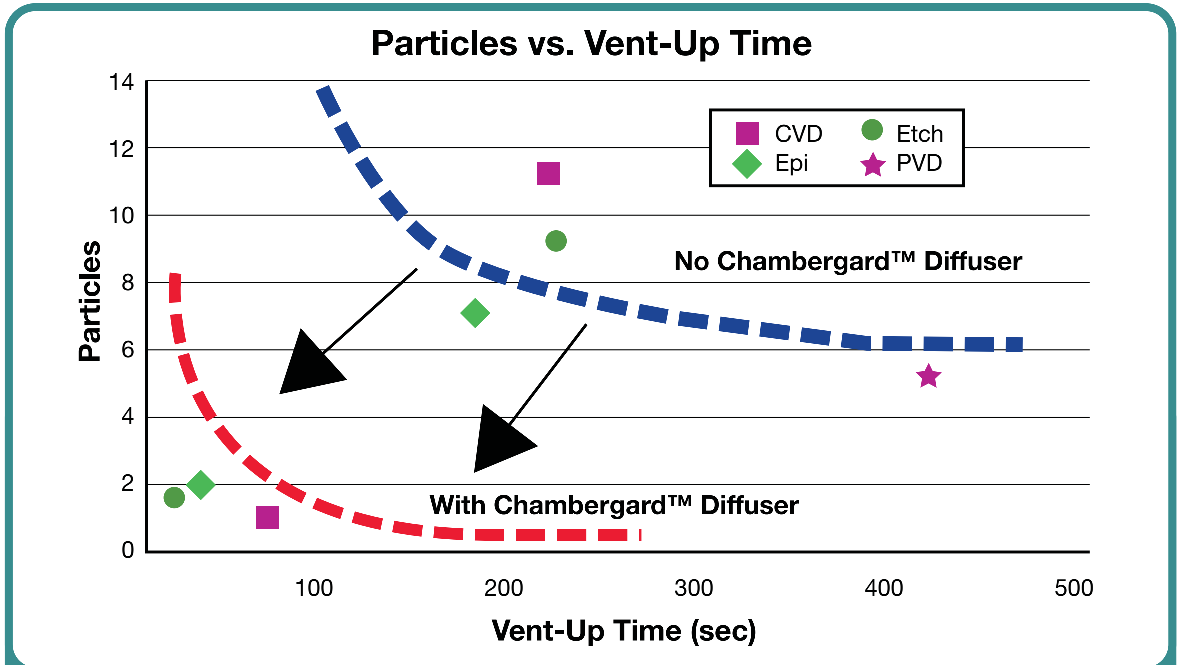


Figure 1. Benefits of Retrofitting 200 mm Process Tools by Enhancing Particle Performance and Reducing Loadlock Vent Time

This method is often acceptable. However, there are cases where 200 mm tool owners are required to increase wafer throughput due to capacity constraints or to enhance overall equipment effectiveness (OEE). While many of the critical variables that influence wafer throughput are fixed (such as the process times, robot speed and loadlock pump down speed), the time to vent up the loadlock may become the rate-limiting step to wafer throughput. This is especially true with shorter process times or with common dual batch loadlock configurations. One approach is to provide a rapid pressure increase by boosting the flow rate of gas. However, with a standard screen or open porous material, the gas velocity at the chamber entrance will be high and nonuniform, resulting in the disturbance of unwanted particles that have settled in the chamber.

The situation also occurs where vent-up time is not a throughput-limiting step. In this case, the tool owner is faced with more stringent particle requirements or observes a spike in particles on the wafers in the loadlock. The focus then becomes yield enhancement, and the goal is to reduce the particle adders on the wafers. Common approaches to the particle problem on installed system loadlocks have included complete loader rebuilds, performing additional series of wet cleans, upstream filter replacements and screen diffuser replacements, which often do not yield the desired goal.

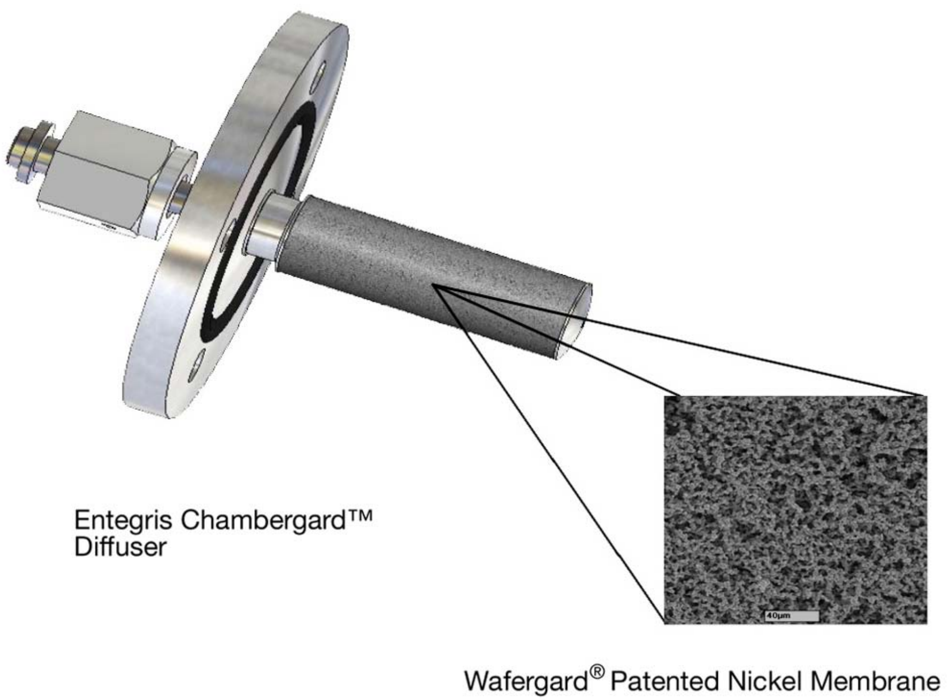


Figure 2. Nickel Diffuser Membrane

## *200 mm Tool Upgrade Solutions*

A 200 mm upgrade solution with Entegris' membrane diffuser technology allows a rapid but controlled vent-up of loadlocks, cool down, transfer and process chambers from vacuum to atmospheric pressure while protecting the wafer integrity. Entegris' Chambergard™ diffusers have successfully reduced vent times on a variety of 200 mm vacuum process tool platforms by an average of 65 percent and significantly reduced particle adders – all by maximizing the volumetric flow and minimizing the velocity of ultrapure gas.

Figure 1 shows the benefits of retrofitting 200 mm process tools by enhancing particle performance and reducing loadlock vent time.

Chambergard products are designed using fine porous media, which uniformly spreads the gas flow across a large area, resulting in lower velocities at the chamber entrance. The patented porous media also serves as a particle filter, removing particles down to 0.003 μm from the incoming gas at high volumetric flows. The result is ultraclean, diffused gas delivered to the process chamber, which minimizes on-wafer defects.

The nickel diffuser membrane (Figure 2), used in Chambergard diffusers, has been shown to be effective in all environments, including poly and oxide etch processes where highly corrosive gases are used.

The effects of the Chambergard technology on vent time can be seen in Figure 3. The red trace shows the two-stage process and how the slow vent stage delays the vent to atmosphere. Conversely, the black trace of the diffuser depicts a rapid, single vent to atmosphere. The Chambergard

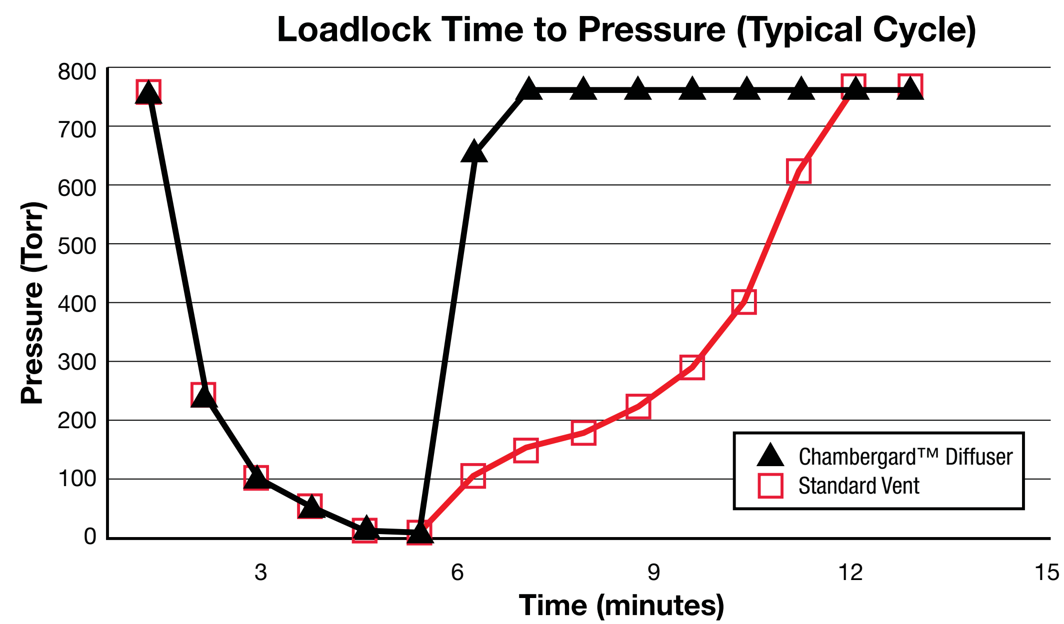


Figure 3. Effects of the Chambergard Technology on Vent Time

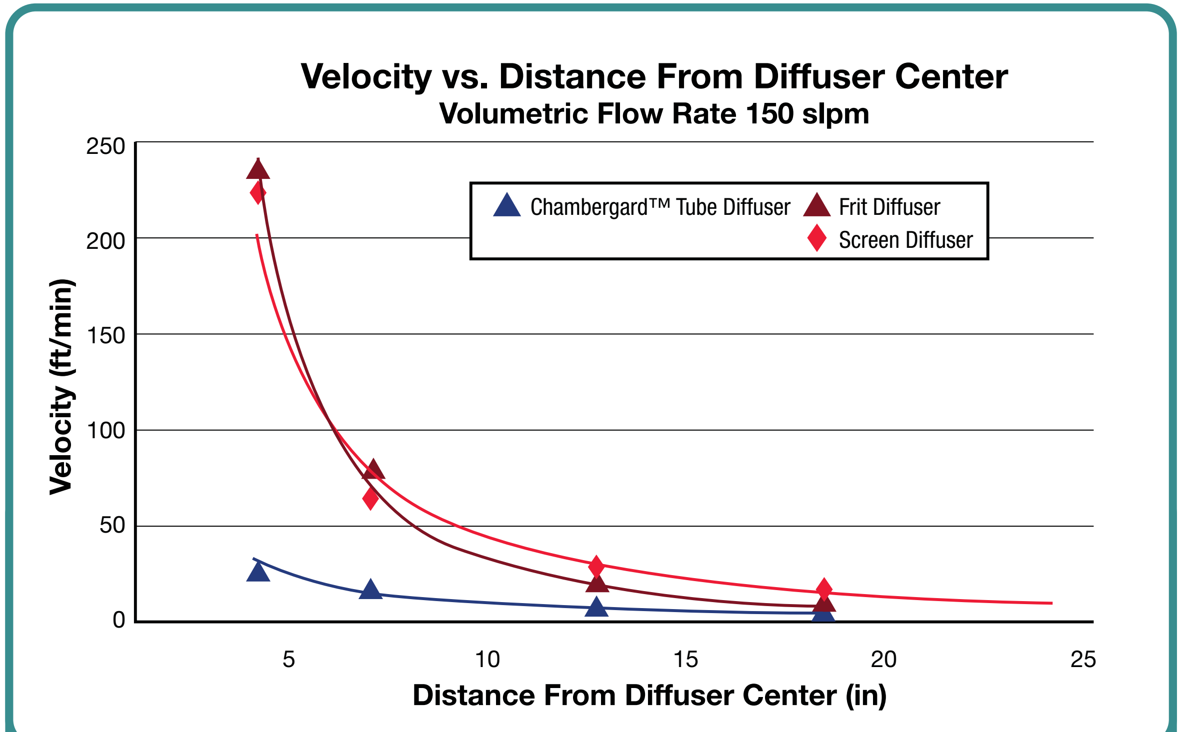


Figure 4. Comparison of the downstream velocity between the patented Entegris diffuser membrane and more open, conventional porous diffusers. The fine pore structure of the Chambergard diffuser allows much lower velocities for a given upstream volumetric flow rate. Lower gas velocities are desirable to minimize the chances for particle disturbance during chamber vent-up.

diffuser allows the duration of the soft vent to be significantly reduced or even eliminated, and increases the volumetric flow rate into the loadlock to dramatically reduce the overall vent cycle. It should be noted that the Chambergard diffuser does not affect the pump down cycle.

As previously discussed, the significant decrease in vent time does not come at the expense of higher velocities and particle disturbance, as typically seen with screens or coarse porous frits. With the Chambergard diffuser technology, high volumetric flows can be achieved with low uniform gas velocities. The membrane media is designed to uniformly spread gas flows across a large area relative to a standard gas line, a series of drilled holes or coarse screens.

Figure 4 shows a comparison of different components used to create uniform flow. The measurements were taken using an ultrasonic probe in the fluid path exiting the component. The results show how the membrane diffuser is more effective compared with a frit or screen under the same volumetric flow conditions.

In addition, Figure 5 shows a typical velocity profile and flow vectors for a disk-type filter membrane diffuser. For an inlet flow of about 100 standard liters per minute (slpm), the downstream velocity is less than 50 feet per minute, at a distance of only 5 inches from the face, or entrance, to the loadlock chamber.

The result of lower velocities is the decrease in particle counts (or adders) to the wafer while in the loadlock chamber. Figure 6 shows particle results taken on wafers prior to and after installation of the diffuser technology on a 200 mm loadlock. The combination of an ultrapure filter and fine membrane gas diffuser allowed this dramatic reduction in particle occurrence.

One of the most difficult questions to answer is precisely what velocities are acceptable with respect to particle re-entrainment. This is a problem compounded by the various mechanisms that adhere a particle to the surface and the varying sizes and shapes of these particles. This can make it extremely difficult to determine the

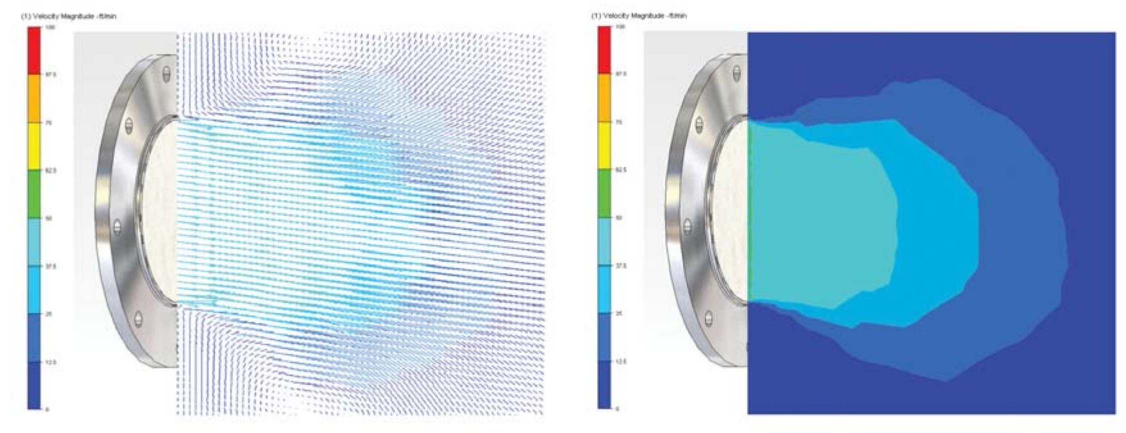

Figure 5. Typical Velocity Profile and Flow Vectors for a Disk-Type Filter Membrane Diffuser

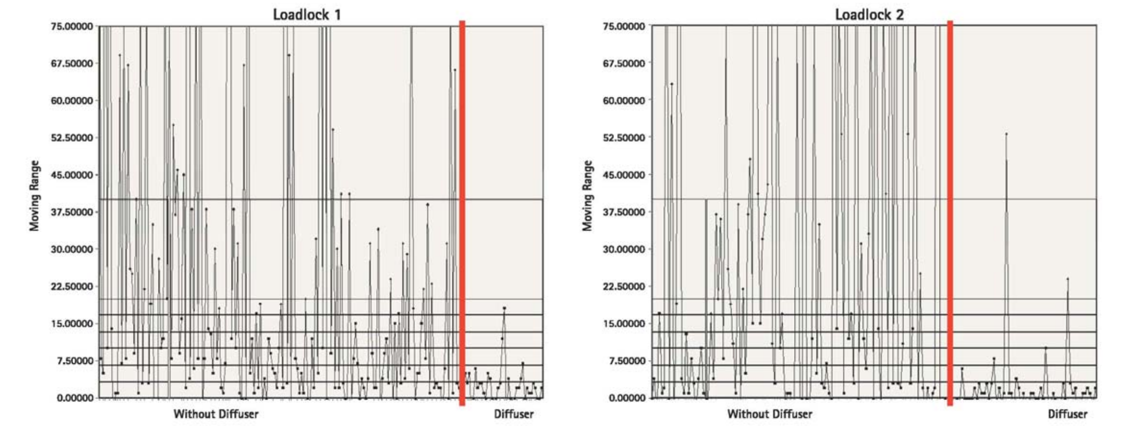


Figure 6. Particle Results Taken on Wafers Before and After Installation of the Chambergard Diffuser on a 200 mm Loadlock

flow required to lift a particle. In addition, since the fluid flow conditions are dynamic, the boundary layer conditions also are active and contribute additional uncertainty in the fluid force available to lift a particle. Methods to resolve these issues are being investigated, but they are beyond the present scope.

## *Considerations for Optimal Venting Conditions*

To determine optimum venting is a relatively difficult analytical problem to fully solve. Physical geometries are fairly complicated, making computational fluid dynamics (CFD) modeling difficult. Additionally, fluid flow may be present in various flow regimes, including molecular flow, viscous flow (both laminar and turbulent) and even as shock wave fronts. Lastly, the size or adhesiveness of settled particles on the floor or walls of a loadlock or chamber make it difficult to determine the exact target for nearby fluid velocities to minimize re-entrainment.

| Process | Wafer Size | % Vent Time Reduction | % Reported Particle Reduction |
|---|---|---|---|
| **CVD** | 200 mm | 62% | 91% |
| | 200 mm | 51% | 62% |
| | 150 mm | 40% | |
| | 150 mm | 72% | |
| **AVE CVD** | | 56% | |
| **Etch** | 200 mm | 71% | no change |
| | 200 mm | 79% | 80% |
| | 150 mm | 67% | factor of 3 |
| **AVE Etch** | | 72% | |
| **PVD** | 200 mm | 72% | factor of 10 |
| | 200 mm | 58% | |
| **AVE PVD** | | 65% | |
| **Epi** | | | |
| **AVE Epi** | 200 mm | 77% | |
| **Overall AVE** | | 65% | |

Table 1. Summary of Reported Results of Chambergard Diffusers on 200 mm Tools Where Reductions in Wafer Contamination and Vent-Up Time Were Observed

Simplified CFD models can provide a general picture of the fluid flow in a loadlock or chamber, leading to the best compromise between short vent time, minimal fluid velocity, physical placement of a diffuser, shape of the diffuser, chamber or loadlock geometry and vent-up parameters (e.g., soft vent use).

Venting is by nature a dynamic process that considers the complexity of the fluid density in the loadlock or chamber, which is continually varying. It's a good practice to combine analytical results with actual tests to understand the general processes and the particle reduction a diffuser installation may offer.

The controlled permeability of the diffuser membrane also helps by making the fluid flow uniform across the membrane, and offers proper resistance to flow in this configuration. The design engineer controls diffuser location during install, membrane shape and membrane permeability.

An additional consideration is the nature of the Reynolds Number and that the loadlock chamber to be vented starts at high vacuum and ends at atmospheric pressure. Ideally, an application would like to see laminar flow for as much of the vent cycle as possible. Since the Reynolds Number is a direct function of velocity and density and each change in opposite direction throughout the vent cycle, the Reynolds Number during the viscous flow portions will not vary dramatically. It will be higher in the beginning and lower at the end. This is due primarily to the fact that the differential across the diffuser membrane is higher in the beginning of the vent cycle than at the end. This is because the loadlock chamber is at lower pressure in the beginning of the cycle than at the end, whereas the diffuser inlet pressure is essentially constant.

This leads to one more technique to optimize the vent-up. Specifically, applications want, within reasonable constraints, to have a high differential pressure across the diffuser. The higher this differential is, the less the velocity variation from the beginning of the cycle to the end. For example, suppose the application has a diffuser inlet pressure of 70 psig in case 1 and 10 psig in case 2, and designs each diffuser to vent a given loadlock chamber in the same time. The case 1 diffuser will see a change in differential pressure from approximately 85 psid to 70 psid, while the case 2 diffuser will see 25 psid decreasing to 10 psid from the beginning of the vent cycle to the end. (Of course the case 1 diffuser is much "tighter" than the case 2 diffuser, given the same surface area.) Therefore, the mass flow rate of the case 1 diffuser varies much less than in case 2, and the velocity also varies less. While this may be an extreme example, it shows that higher diffuser differential is better.

## *Examples of Successful Diffuser Retrofits*

Entegris' Chambergard diffusers have been installed onto a variety of 200 mm and 150 mm semiconductor tool platforms that cover a range of processes. These processes include dry etch, CVD, PVD and Epi. In all cases, the vent time was decreased significantly and, where reported, particle adders to the wafer were reduced.

Table 1 is a summary of reported results of Chambergard diffusers on 200 mm tools where reductions in both wafer contamination and vent-up time were observed. On a typical batch loadlock, vent times as high as seven minutes were reduced to less than three minutes, with particle generation decreased by a factor of 10 with no negative effect on pump down speed. The exact increase in wafer throughput depends on several factors. Typical results reported have ranged from a 6 percent to more than 10 percent increase in wafers per hour.

## Discussion of Results

Referring again to Figure 1, when selected data points from etch, CVD, PVD and Epi are plotted as particle adders (measured on the wafer) versus loadlock vent-up time, the benefits of the diffuser product can be easily seen. The figure shows intuitively what can be expected. As the vent-up time of the loadlock is decreased, the number of particle adders increases – regardless of the venting method. After the installation of the Entegris Chambergard diffuser, a significant improvement in both vent-up time and particle adders is realized, resulting in a shift of the curve down and to the left.

## Conclusions

The studies clearly show the benefits of retrofitting 200 mm and 150 mm process tools with a Chambergard diffuser in applications where loadlock vent-up time is a rate-limiting step and/or particles in the loadlock are an issue. With relatively minimal downtime and modest initial investment, the return on investment is high, given the potentially significant increase in wafer throughput.



## References


1) Entegris Technical Bulletin, "Optimizing Vacuum Chamber Vent Up: An Applications Guide for Diffusers," 2001.
2) http://www.reed-electronics.com/semiconductor/article/CA300814


## About the Authors

### Chris Vroman

Chris Vroman is a senior product marketing manager for Entegris' Gas Microcontamination Control business. He has 11 years of semiconductor industry experience, with degrees in mechanical engineering and material science, as well as an M.B.A. In addition, he holds several patents in the area of filtration membrane research and development for ultra high-purity gas components.

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### Marshall Randolph

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# Tool Optimization for Improving Productivity and Yields

**Victor K. F. Chia, Fuhe Li** – Air Liquide-Balazs NanoAnalysis


## Abstract

Tool cleanliness is a prerequisite for increased production ramp, reduced tool downtime and high process yields. Any materials used in the build of material (BOM) must be verified to be clean both in the bulk of the material and on its surface after machining and cleaning. Bulk analyses are destructive due to the nature of the test and the information required. In contrast, surface analyses should be nondestructive so the part may be reused after surface cleanliness testing, or re-cleaned if the test indicates the part does not pass its cleanliness specification. Wafer tool specifications are in place for particles and metals by the OEMs. Particle specification depends on the method of wafer clamping, and wafer metal specification for tool acceptance is typically in the range of 1-5x$10^{10}$ atoms/$cm^2$. No generally accepted organic specifications are in place. Currently, there are no accepted tool parts particle, metal and organic specifications. Very few machine shops, cleaning houses, OEMs or fabs have developed baseline tool parts cleanliness specifications. This paper describes key analytical techniques for bulk and surface characterization of tool parts.


## Introduction

In the sub-100nm technology node, even irreducible differences in the components of identical tool chambers can influence yield and mean time between failures (MTBF). Advanced process control is required to minimize systematic and random variability in hundreds of active tool parts or build of material (BOM). Tool cleanliness is a prerequisite for clean processing; it is an invisible condition that can change the integrity of the wafer surface during processing. The overall equipment productivity in fabs is only ~60 percent. Tool downtime relating to contamination issues includes unscheduled equipment stops, wafer tests, equipment PM, equipment setup time and equipment startup standby time. The current focus is to increasing profit margin that requires fabs to maximize yield and increase overall equipment productivity and wafer throughput. This places greater emphasis on having cleaner tools, and deliberate selection of BOM is essential because any surface and bulk contamination is a contamination source. In addition, a systematic approach using advanced characterization techniques must be applied when an escalation occurs to quickly identify and resolve the tool contamination.

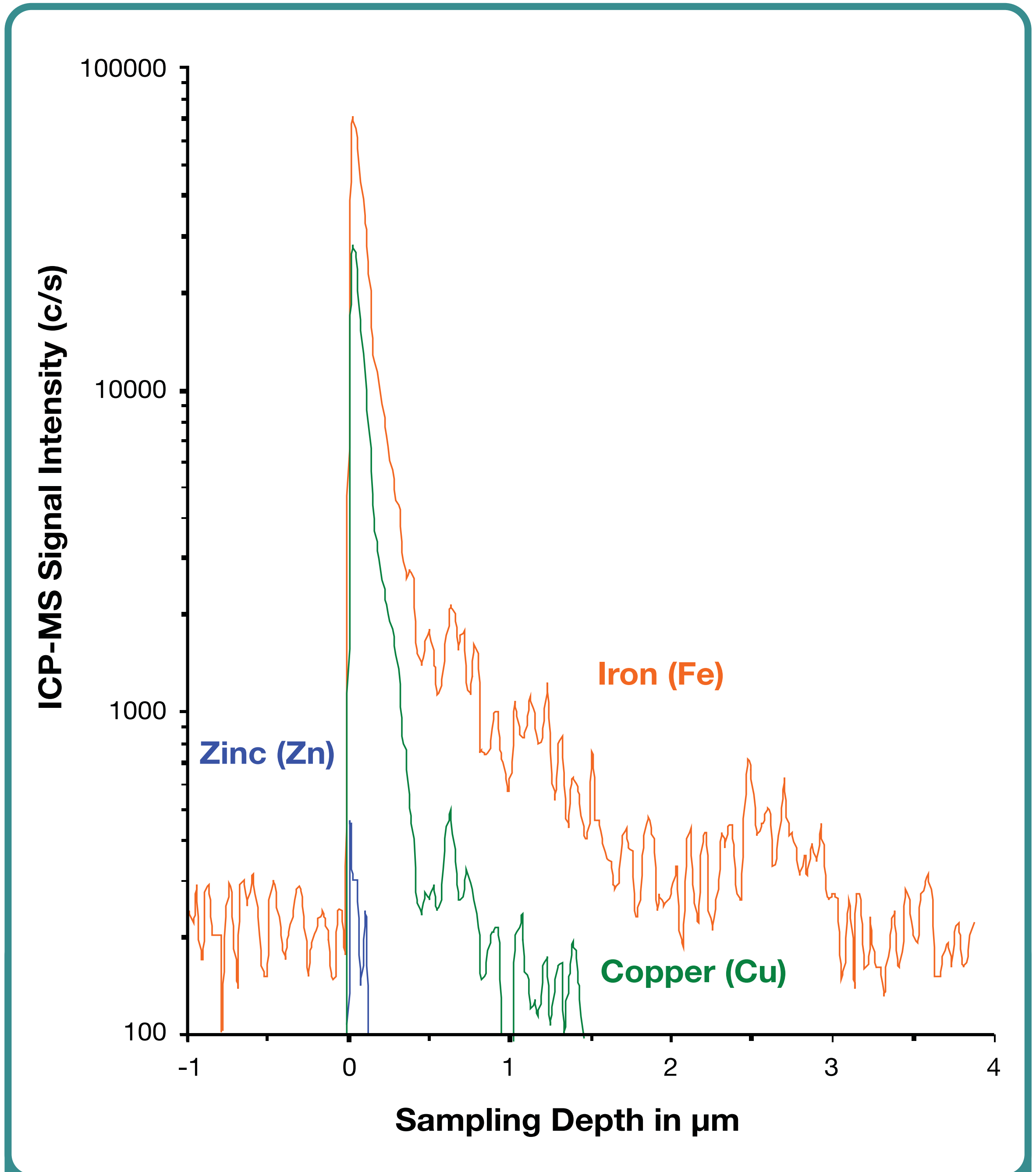


Figure 1. Laser Ablation ICP-MS Depth Profile of Ceramic

## *Material Selection and Bulk Cleanliness*

A complete characterization of starting materials for machining tool parts is necessary. Bulk contamination can migrate to the surface during thermal treatment or after many cleaning cycles that involves the removal of the material. Materials such as ceramic, quartz and O-ring vary in bulk cleanliness by vendors and by lot-to-lot. Traditional O-rings with inorganic fillers such as $SiO_2$, $BaSO_4$, ZnO, Carbon or $TiO_2$ will shed metallic particles onto the wafers after ~6,000 wafer counts. Laser ablation ICP-MS (LA ICP-MS) can determine bulk metal composition, so a low metallic concentration filler O-ring can be selected for use. Alternatively, an O-ring using organic-filled material can be used to extend MTBF to 20,000 wafer counts. Ceramic and quartz parts must be bulk-characterized to ensure the bulk contaminants are present at low concentrations, as these contaminants will eventually become near or at the surface of the tool part after many cleaning cycles or after extended plasma etching and will migrate to the wafer surface during processing. Figures 1 and 2 show LA ICP-MS profiles of ceramic and quartz analyzed to several microns in depth. Quality differences of materials provided by vendors have been revealed by LA ICP-MS and demonstrated to be the root cause of wafer contamination during processing.

Machined parts are likely to have major surface and subsurface contamination from machine lubricant oil; metal cross-contami-

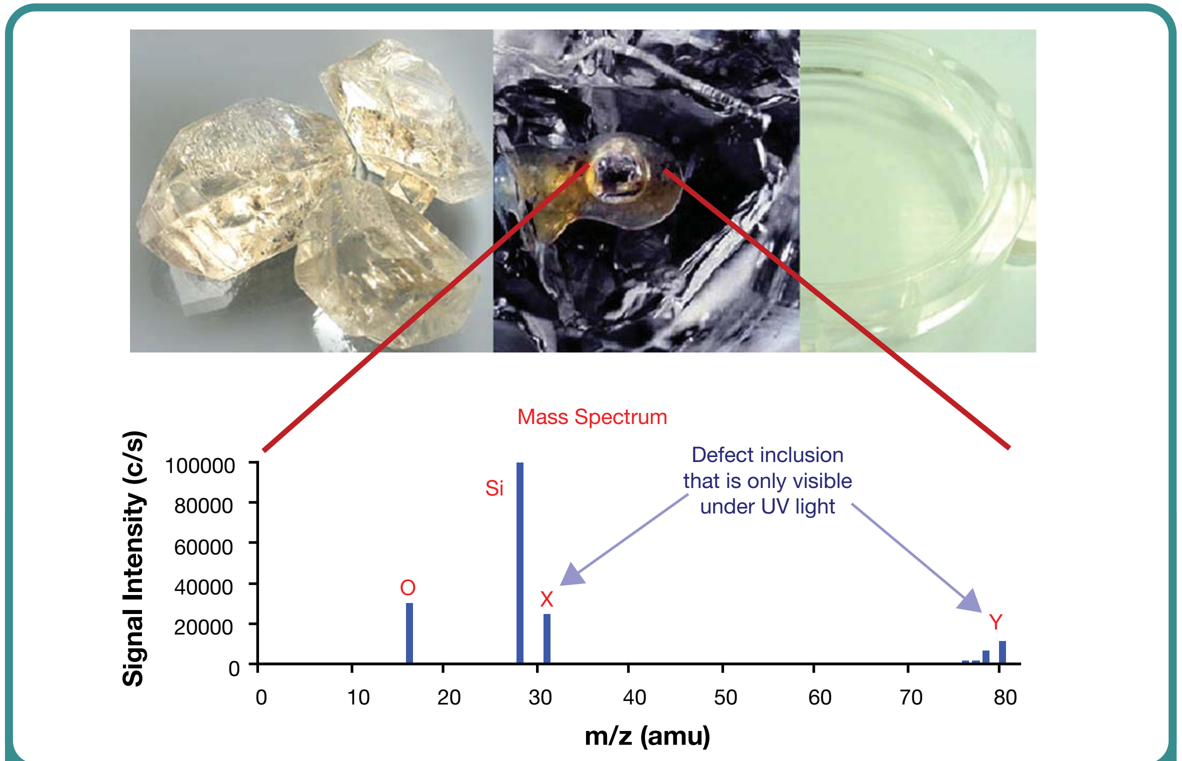


Figure 2. Laser Ablation ICP-MS Bulk Elemental Survey of Quartz

nation from drill bits; water and solvent residues from rinsing; and contamination from the oven during thermal treatment to relieve stress. Contamination on machined parts may be ranked in importance thusly: Organic > Particle > Metal > Anion.

These machined parts will be precision cleaned, resulting in minor surface contamination remaining typically from handling, cleanroom environment and packaging. The contaminants of concern are Metal > Particle > Organic > Anion. It is important when making a decision regarding material selection and component design that both functionality and its cleanliness requirement are taken into account. A simple material contamination cycle is shown in Figure 3.

## *Tool Parts Characterization*

Table I shows the chemical surface test methods that are nondestructive, wherein the part may be used in the tool after it has passed cleanliness qualification without additional cleaning. Common test methods used are summarized in the table.

Table 2 shows the physical surface test methods that are destructive and used primarily on coupons in R&D of cleaning recipes and material compatibility studies; first on particles, and then if absolutely necessary, on real parts. Common test methods used are summarized in the table.

Additional surface techniques frequently used include:

- UV (black) light: visual inspection for residue polymer on the surface
- Profilometry: surface roughness and surface layer thickness

## *Case Study*

After a weekend predictive maintenance event, the base pressure increased, and Cl was detected at $5x10^{13}$ at/cm² instead of $5x10^{10}$ at/cm² by TXRF. All metal concentrations measured by TXRF were at or below $5x10^{10}$ at/cm² (the wafer cleanliness specification). Chlorine on the wafer was not from insufficient rinsing after acid cleaning that included the use of HCl, since no residue ionic Cl was detected on the wafer surface from UPW extraction and ion chromatography of the extract aliquot. The chlorine was determined to be from an organo-chloride compound using full wafer TD GC-MS.

Interestingly, a static wafer that was left on the ESC for one hour in the tool showed no Cl by TXRF, while a dynamic test with a wafer cycled through the tool showed surface Cl at $5x10^{13}$ at/cm². This experimental observation will reveal its significance once we identify the contamination source.

The organo-chloride compound was identified as a common flame retardant. Flame retardants are often used on foam cushions, sofas and beds to prevent them

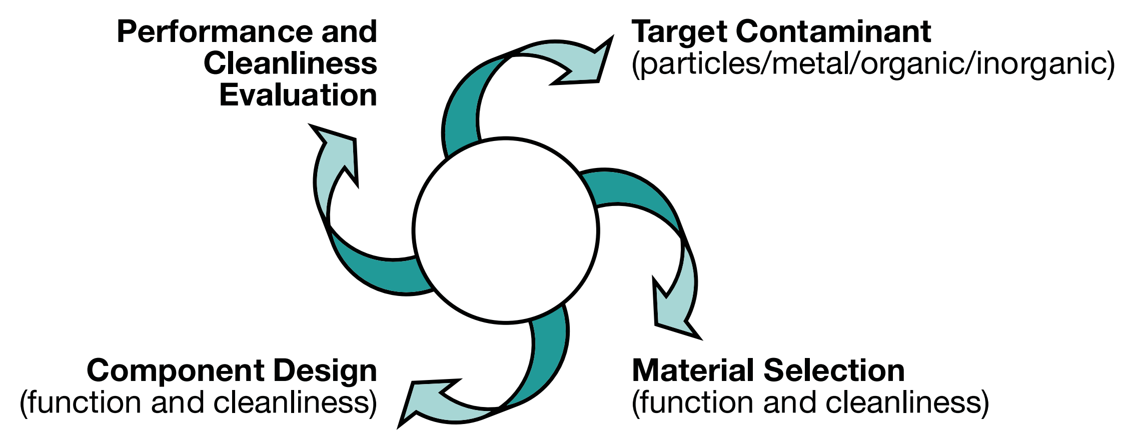


Figure 3. Material Contamination Reduction Cycle

| SEMICONDUCTOR PROCESS | | | |
|---|---|---|---|
| Wafer Production<br>Thermal<br>Oxidation/Film<br>Photolithography<br>Etch<br>Doping/Ion Implant<br>Dielectric<br>Deposition<br>CMP | Metal | Acid extraction & ICP-MS | 1 |
| | Metal | UPW extraction & ICP-MS | 2 |
| | Metal | Drop scan etch & ICP-MS | 3 |
| | Organic | Solvent extraction & GC-MS | 4 |
| | Organic | Solvent extraction & NVR/FTIR | 5 |
| | Ionic | UPW extraction & Ion Chromatography | 6 |
| | Particle | UPW extraction & LPC (SEM-EDS) | 7 |

1. Metal – whole surface extraction
2. Metal – extraction efficiency less than acid
3. Metal – localized surface acid extraction
4. Organic – solvents to extract organic residue and UPW/TOC
5. Organic – weight of NVR and organic identification
6. Ionic – whole surface extraction
7. Particle – whole surface particle counting and identification

Table 1. Chemical Surface Test Methods (Nondestructive)

| SEMICONDUCTOR PROCESS | | | |
|---|---|---|---|
| Wafer Production<br>Thermal<br>Oxidation/Film<br>Photolithography<br>Etch<br>Doping/Ion Implant<br>Dielectric<br>Deposition<br>CMP | Metal | AES | 1 |
| | Metal | TXRF | 2 |
| | Metal | VPD ICP-MS | 3 |
| | Metal | SIMS | 4 |
| | Metal | TOF-SIMS | 5 |
| | Organic | Full Wafer Outgassing TD-GCMS | 6 |
| | Organic | TOF-SIMS | 7 |
| | Organic | XPS | 8 |
| | Ionic | XPS | 9 |
| | Particle | FE-AES | 10 |

1. AES: 30-50 Å, at percent DL, elemental survey, conducting surface
2. TXRF: 30-50 Å, $10^9$-$10^{15}$ at/cm², elemental survey, flat surface
3. VPD ICP-MS: $SiO_2$, $10^7$-$10^{15}$ at/cm², elemental survey
4. SIMS: any depth, $10^8$-$10^{15}$ at/cm², elemental specific
5. TOF-SIMS: monolayer, $10^7$-$10^{15}$ at/cm², elemental survey, any surface
6. Full Wafer Outgassing: ng/cm², organic survey on selected wafer surface
7. TOF-SIMS: monolayer, ng/cm², organic survey, any surface
8. XPS: 30-50 Å, at percent DL, elemental/chemical state survey, nonconducting surface
9. XPS: 30-50 Å, at percent DL, elemental/chemical state survey, nonconducting surface
10. FE-AES: 10nm spatial resolution for elemental characterization

Table 2. Physical Surface Test Methods (Destructive)

from catching on fire. After reviewing the BOM, the root source of the organo-chloride compound was eventually traced to a vibration isolation pad that was blue in color. The BOM specified a black vibration isolation pad that does not outgas. This was confirmed by outgasing the blue and black isolation pads by ATD GC-MS using the industry standard method, IEST WG-CC031. The outgased organic compounds from the blue isolation pad matched the wafer outgased organic signature.

The static and dynamic wafer test results now become clear. No water leaks if you hold a wet sponge. However, if you squeeze the sponge lightly or even shake the sponge with your hand, some water will leak out. This is the case with the vibration isolation pads. When the wafer handler is static, the pads are not active and do not outgas. In contrast, when the wafer handler is moving and transporting the wafer, the pads are adsorbing any vibrations produced, and in the process, they will compress and outgas. So, even though the design specification for vibration insulation was met using the blue pad, its bulk properties were not investigated, resulting in a contamination escalation.

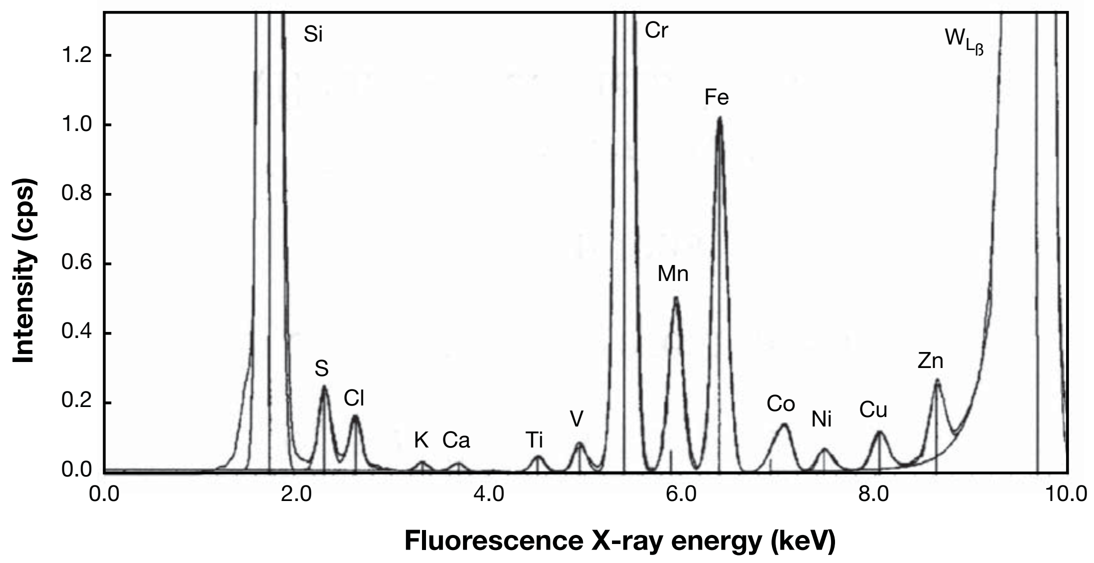


Figure 4. TXRF Spectra of Wafer Processed in the Tool

## Conclusion

All tool components and parts must be designed using materials that are compatible both to its function and cleanliness. This means individual tool parts in the completed build tool must have cleanliness specifications for its technology node. The smaller the technology node, the cleaner the tool must be. One way of establishing a parts cleanliness baseline is to select a tool that passes all particles, metal, ionic and organic wafer testing. If the tool passes these wafer acceptance tests, then the individual part cleanliness is likely to be acceptable too. This paper described the test methods for surface and bulk material characterization. Most importantly, the surface test methods are nondestructive, and when carried out with meticulous care, the part may be packaged with a certificate of analysis (CoA) and returned to the end user for installing into the tool. The case study illustrates the consequence of not having a part cleanliness specification. If OEMs, fabs and their supply chains operate with parts cleanliness specifications, they will maximize their yield and increase overall equipment productivity and wafer throughput, which in turn will increase their profit margins.

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Dr. Victor K. F. Chia is a director at Air Liquide-Balazs NanoAnalysis, responsible for advancing surface contamination technologies, global sales and international business development. He received his Ph.D. in analytical chemistry from the University of California, Santa Barbara and was a postdoctoral fellow at Lawrence Berkeley Laboratory. Dr. Chia has published over 40 papers and co-authored several chapters on SIMS and contamination characterization.

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# Environmental Health & Safety



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**Mike Weiby**

*Corporate Environmental, Health and Safety Manager; Integrated Device Technology, Inc. (IDTI)*


The Triple Bottom Line[1] (TBL) refers to the "sweet-spot" intersection of environmental, social and economic performance. In the financial community, regulatory changes are driving increased transparency with financial reporting. In a similar fashion, voluntary and regulatory movements are driving increased transparency with social and environmental performance. If you happen to find yourself in any one leg of the electronics and electrical equipment (EEE) supply chain, the impacts of regulatory and customer-driven expectations for environmental and social performance are clearly present. The two articles in this issue of Fab Engineering & Operations describe the changing landscape for EEE companies interfacing within the three elements of the Triple Bottom Line: environmental, social and economic performance.

The article by Eric Simmon, Mike Cox, Matt Aronoff and John Messina of the National Institute of Standards and Technology, describes primarily how EU environmental directives are influencing manufacturing and materials used in products worldwide. The article describes efforts EEE companies are taking towards managing manufacturing materials and the supply chain, as well as information related to product creation.

Subsequently, the article by Julia Bussey of AMEC Geomatrix, Inc. (formerly Geomatrix Consultants) describes how early adoption of sustainable business practices can lead to improved financial performance. This article also lays out a roadmap for companies wanting to implement sustainable business practices.

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# Environmental Trends Affecting Electronics Manufacturing


**Eric Simmon[1], Mike Cox[2], Matt Aronoff[1], John Messina[1]**

[1]National Institute of Standards and Technology, [2]Agilent Technologies


In the early days of electronics, manufacturing was focused on the product and process instead of the impact of manufacturing on the environment. Over time, environmental factors have become an increasingly important aspect of electronics and electrical equipment (EEE) manufacturing. In the 1960s and 1970s, environmental awareness was just beginning.[1] Then in the 1980s regulations began to go into effect to limit the environmental and health effects of manufacturing.[2] In the 1990s, the electronics industry came under the scrutiny of legislators. Today environmental concerns have a major influence on modern electronics manufacturing.

Companies that in the recent past were primarily concerned with satisfying environmental regulations are finding that environmental responsibility and environmental resource usage are of equal concern. Looking forward, manufacturers will be faced with the need to make changes to their products and processes to accommodate all three factors, and to exchange information across the supply chain so that any new environmental objectives are met without sacrificing desired levels of product reliability and quality.

Finally, the products and manufacturing practices themselves need to be modified using a holistic systems-based approach that looks at everything from design to raw materials to product disposal and everything in between. Indeed, these three factors – environmental regulations, environmental responsibility and environmental resources – are key factors driving electronic products, manufacturing processes and information management.

## *Environmental Regulations*

As early as the 1970s, both governmental and nongovernmental bodies (NGOs) have become increasingly concerned with reducing society's environmental impact. Factors such as the short product cycles of electronics resulting in high disposal rates and potentially hazardous material entering landfills led legislators to target the electronics industry. The end result was that several governmental bodies around the world began crafting environmental laws and regulations designed to limit the environmental impact of manufacturing electronics.

Two of the earliest examples of this trend occurred in 2003, with the European Union (EU) directive 2002/95/EC[3] on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS), and directive 2002/96/EC on waste electrical and electronic equipment (WEEE).[4] RoHS established allowable concentration limits for several chemicals of concern, including cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyl and polybrominated diphenyl ether. The WEEE directive established end-of-life EEE handling, reuse and recycling requirements and reporting obligations, and also introduced principles of environmentally friendly product design. In response to this legislation, key materials in electronics products had to be replaced, and material information that the EEE industry previously considered irrelevant had to be collected and managed.

Due to the prevalence of international supply chains, the effect of these laws and regulations are being felt well beyond the borders of the countries that enacted them. While the RoHS and WEEE directives focused on consumer EEE within the EU community, ensuring compliance requires cooperation of supply chain partners, even if they lay outside of the EU. Unfortunately, since the directives apply to the final producer of the product and not of the upstream suppliers, the motivation to share information is not the same at all levels of the supply chain, nor across all sectors and geographies of the EEE industry.

Beyond these product material regulations, there are new types of environmental laws such as the EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation,[5] seeking to modify environmental impact by managing chemical risks; and the EU Energy-using Products directive (EuP),[6] seeking to reduce energy usage through the product life cycle. The EuP is part of the EU's Integrated Product Policy, which seeks to limit the environmental effects of a product's life cycle by assessing all phases of a products' life cycle and taking action in the form of regulations and voluntary agreements, including labeling and design guidelines.

The EU legislation is not the only body to enact environmental legislation. The electronics industry has to respond to new and upcoming regulations being established all over the world. For example Japan, China and California are working on establishing versions of RoHS,[7] and many other countries are looking at the impact of all types of manufacturing, product usage and disposal on the environment. This trend will have a growing effect on the EEE industry, and many companies are being proactive in addressing environmental concerns.

## *Environmental Responsibility*

Within the general population, there is a growing awareness of society's effects on our ecosystem. As a result of this growing environmental awareness, not only are consumers' personal habits changing, but their buying habits are changing as well. These environmentally conscious consumers, along with NGOs, have a substantial effect on the electronics industry.

Many companies are proactively altering their business practices to draw in these more environmentally conscious consumers. Companies in the electronics industry have begun to advertise compliance with environmental regulations to gain a competitive advantage. For example, several hard drive manufacturers began advertising that their parts were RoHS compliant even before the directive went into effect. Another good example is the Energy Star program,[8] a voluntary labeling standard. This allows companies to advertise that their products meet strict energy-efficiency guidelines and in turn will save consumers money on their utility costs. As long as environmental concerns continue to influence consumers' buying decisions, more and more companies will change their manufacturing processes and product designs to increase revenue.

## *Environmental Resources*

The third area has a more direct impact on a business' bottom line. Resources used in every stage of electronics manufacturing must be properly managed. As natural resources are depleted, the costs of using those resources will grow and will directly impact a company's bottom line.

The impact of natural resources on financial objects can easily be seen in the rising cost of petroleum. The change in the price of a barrel of oil, which dramatically increased from 2006 to 2008, along with the fact that petroleum is used in so many different aspects of electronics manufacturing, has left manufacturers struggling. Rising oil prices affect industry not only through the obvious cost of transporting products through the supply chain, but also through rising production and material costs. Most factories use significant amounts of electricity, and that electrical power is often generated using fossil-fuel-fired generators, which will have to be factored into production costs. Material costs will go up as well; plastics, which are ubiquitous in electronics products (often comprising over 50 percent), are made from petroleum.

It is clear that companies will have to make major changes to their production lines quickly to combat the effects of rising petroleum costs or face going out of business. In fact, the cost savings of outsourcing to countries with inexpensive labor and then shipping the products around the globe will be diminished, if not eliminated, and companies that cannot react quickly enough may face severe challenges in the future.

## *EEE Manufacturing*

Electronics and electrical equipment manufacturing must change to accommodate environmental factors. Products, processes and associated information management systems all need to be modified to meet new requirements.

### *Product*

Modifying products to meet new requirements requires time and money to ensure the changes do not cause functional or reliability problems. New materials and product formulations introduce uncertainties with regard to engineering form, fit, function and manufacturability. Testing these new solutions also has financial impacts for EEE manufacturers and suppliers; significant amounts of time and money must be spent to ensure the changes do not adversely affect the final product. For example, as lead was used in solder (used in almost all electronics products), the solder needed to be replaced with a lead-free material. However, the lead-free solder suffered from several critical issues, including vibration-induced failures and shorting caused by tin whiskers. Even after much research into new types of lead-free solder and testing to determine the properties and reliability of the new solder, the lead-free versions are just beginning to approach the reliability of traditional lead solder.[9]

### *Process*

Not only are products affected, but manufacturing processes are as well. New components and materials have different manufacturing parameters. Old equipment often cannot be used because of functional differences and contamination from chemicals that are no longer acceptable for use. The process itself might also be changed to use fewer resources or produce less waste.

The changeover to lead-free solder had

major effects on manufacturing processes. The lead-free solder required higher temperatures that could not be generated in older solder baths (and the lead solder baths were contaminated by lead anyway). An unintended side effect of switching to the lead-free solder was an increase in energy usage to heat the lead-free solders to the higher temperatures required. These higher temperatures could also potentially damage the circuit boards and components during the soldering process.

### Information Management

Companies will need to implement flexible information management systems that will allow them to track resources and manage environmental impact. This information can be used to manage regulatory compliance, alternative material selection, recycling, cost efficiency and product redesign. To fully optimize the system, information must flow from the raw material providers through the supply chain all the way to the recyclers, and from the repair and warranty center and manufacturing plants to the product designers.

This type of high-flexibility supply chain information management includes the following:

1. Communication of requirements and expectations, such as guidelines and codes of conduct
2. Ascertaining, registering, assessing and reporting the chemical substance content of materials, components and products
3. Industry end-of-life treatment and reporting schemes
4. Expanded environmental-attribute design rules, materials libraries and qualification requirements
5. Expanding the availability of environmentally friendly alternative materials, components and products

Each of these addresses a different need within information management, but taken together, the entire system can be optimized to maximize efficieny of the electronics manufacturing process.

## Conclusion

Including environmental requirements in the electronics manufacturing process, from regulatory compliance, to resouce allocation, to gaining a competative advantage, is now an integral part of the industry. Continual improvement of products, processes and information management systems will be required as these environmental factors continue to change. The International Technology Roadmap for Semiconductors and the iNEMI Technology Roadmap are both including chapters focusing on environmental issues,[10,12] and organizations such as IEC, IPC and RosettaNet are working on supporting standards for the electronics industry. Continued efforts by these organizations and companies and individuals within the industry will ensure that electronics products continue to improve and meet the requirements of both customers and governments.

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# Sustainability: Good for Business

**Julia Bussey** – AMEC Geomatrix, Inc.

*Dear Editor – I am a facilities manager trying to do my job. I have huge demands on my time managing a bunch of building engineers and fabs, and plenty of customer, global supplier and transportation challenges. I don't need more headaches. I keep hearing "green this" and "sustainability that" and it all just sounds like talk to me. But now my company has some interest in this and wants to add it into my job. What's a working stiff to do?*

*Dear Manager – It might just be time to jump on board this bandwagon. In this demanding environment with global pressures, resource constraints and shrinking employee pools, taking the time to analyze your current environmental footprint and adopting some sustainable business practices can actually reduce your headaches and save you time and money. Sustainability does not have to be a daunting prospect. Read on for a practical, systematic guide to developing sustainable business practices. This is where the talk stops and the change begins.*

Sustainability and green business practices have become the new mantra in today's business world. But what does sustainability actually mean? Can it really improve your bottom line? And if so, how can you approach it without exhausting your internal and financial resources?

## *Sustainability Demystified*

Sustainability is often defined as using the resources of today in a way that does not compromise the needs of the future. Another common definition is running your business to the triple bottom line: maximizing environmental, economic and societal aspects. Basically, when applied to a facility's business model, sustainability is about identifying and minimizing the potential environmental impacts of your business so that you can use your resources as efficiently as possible. Although it requires time and energy to develop, it ultimately does not add to your workload so much as reshape it and reduce the costs to your company for resources and outside services.

That is not to say that becoming a sustainable business is as simple as recycling paper products and switching out a few lightbulbs. While these changes may be a part of a sustainable business model, this is a much oversimplified view of green business practices. To reap the true rewards of sustainable business practices, you need to take a systematic approach to evaluating the unique characteristics of the operation, identify and rank potential changes, and then develop a quantifiable plan for implementing those that will be most effective.

Many people are searching for the "magic" checklist from which they can select a few items to implement. Indeed, it would be nice if there *were* such a simple checklist, but the reality is that companies must develop unique sustainability plans based on their own unique operations. In other words, every company will need to do this differently, according to its capabilities and circumstances.

## *The Bottom Line*

Why go through the time and expense of making any changes in your practices? Why not wait until government regulation or societal pressures demand it? True, developing and implementing a sustainability plan for your business may require a substantial financial investment, but recent data has shown that companies that take a systematic approach to implementing sustainable business practices save money, attract new customers, enjoy improved brand value and have better employee productivity – all of which contribute to an improved bottom line. In the meantime, new regulations and standards are in the works and it is just a matter of time before they are implemented. During this "voluntary" period, businesses can use their experiences to help shape the developing rules, and at the same time, refine their own programs without the shadow of regulatory enforcement. In addition, while many of the current reductions are voluntary, credits and rebates are available to those with new approaches. The Hypothetical Case Study sidebar illustrates the impacts sustainable changes can have on a company.

OK, so how to begin? Following are some steps to a greener, more profitable future.

### *Hypothetical Case Study*

*Company A ("It's All Right Now") and Company B ("Better Change") both had a great year. They were equally positioned and had the same amount of revenue, stock and employees. At the end of the year, Company A decided to disperse its bonus, have a big holiday party and continue with business as usual; Company B met with internal stakeholders and announced that it was pursuing sustainability initiatives based on internal values, which would have some short-term costs. After three years, Company B created a sustainability report to announce its results transparently. The results are shown below.*

| | Company A | Company B |
|---|---|---|
| Profit | $100M | $100M |
| Stock Price | $50/share | $50/share |
| Energy Costs | $100K | $100K |
| Employee Productivity | Same | Same |
| **Year 1** | | |
| Profit | $100M | $99M[1] |
| Stock Price | $50/share | $50/share |
| Energy Costs | $100K | $100K |
| Employee Productivity | Same | Same |
| **Year 3** | | |
| Profit | $100M | $104M[2] |
| Stock Price | $50/share | $62.5/share[3] |
| Energy Costs | $115K[4] | $80K[5] |
| Employee Productivity | Same | +6%[6] |
| **Year 5** | | |
| Profit | $100M | $140M |
| Stock Price | $50/share | $72.5/share |
| Energy Costs | $136K | $50K |
| Employee Productivity | Same | +12% |

## A Step-by-Step Approach to Sustainability

### *1. Assemble a team*

Building a team representing multiple disciplines from all parts of your operation (facilities, procurement, contracting, environmental, finance and human relations) not only helps you gather the data and understand the impacts of various aspects of the business, it also is a first step to ensuring that the program has buy-in and can be continuously improved. Similarly, top management support is vital to encourage the process of developing a systematic evaluation and to communicate the results upward.

You may have the staff and expertise to manage this process internally. But even so, it may actually be more cost-effective to hire an external consultant to guide your team than to try to determine exactly what you should do as you go along in the process. Data analysis, systems analysis, strategic planning, environmental regulations, financial analysis and writing are all critical for the development of an effective plan. Sustainability consultants obviously add additional expense to the project, but their expertise can help you quickly and objectively define, measure and achieve your goals. In addition, they can provide credibility to the process in the face of public scrutiny.

### *2. Identify your objectives*

It is important to document what you hope to accomplish through your sustainability efforts and to set up a time frame for achieving those objectives. Being able to quantify and document success is critical to the continued viability of a sustainability program.

### *3. Understand the footprint of your operation*

Your business footprint is the sum of the economic, environmental and societal impacts that result from your operations. Operations and product areas are the place to start in evaluating your footprint since you are already measuring the costs and often the inputs into them. By understanding the actual footprint of your operation and targeting the areas with the largest impact, money can be spent where it will make the most difference.

What you choose to measure and how you define the operations are key to how much savings you can find and who you need on the team. For example, by including tools and processes, you may identify significant potential reductions, and the team would include research and product designers. Operations and product data generally exist in overall cost categories such as energy use, water use, waste produced and chemicals used. Monitoring, auditing or measuring the specific tool or product in real time both ensures that the most significant impacts are recognized and allows you to gather the necessary data for transparency later to show concrete results.

Water and energy producers may offer free audits and checklists of areas for improvement and may have tool lending libraries that will help reduce the cost of the process. Solid-waste agencies can provide information on available recycling and businesses that use waste materials as feedstock for products.

### *4. Develop an implementation plan to reduce your footprint*

After identifying the impacts of your operations, the next step is to develop a plan for reducing these impacts. Do not become overwhelmed by all the possible actions that emerge. The best approach is to establish some objectives and develop a phased approach. The plan you develop can be better managed if you view sustainability as a journey of ongoing improvement, not a final end. Therefore, you can select the largest and most direct areas of impact to target first, and then expand from there either by initially phasing in actions with early paybacks so that savings can be used to finance more-costly actions, or by making large improvements so that the larger reductions will become effective sooner.

Even though every business is different, each has common potential impacts to consider (see Figure 1). Businesses can use

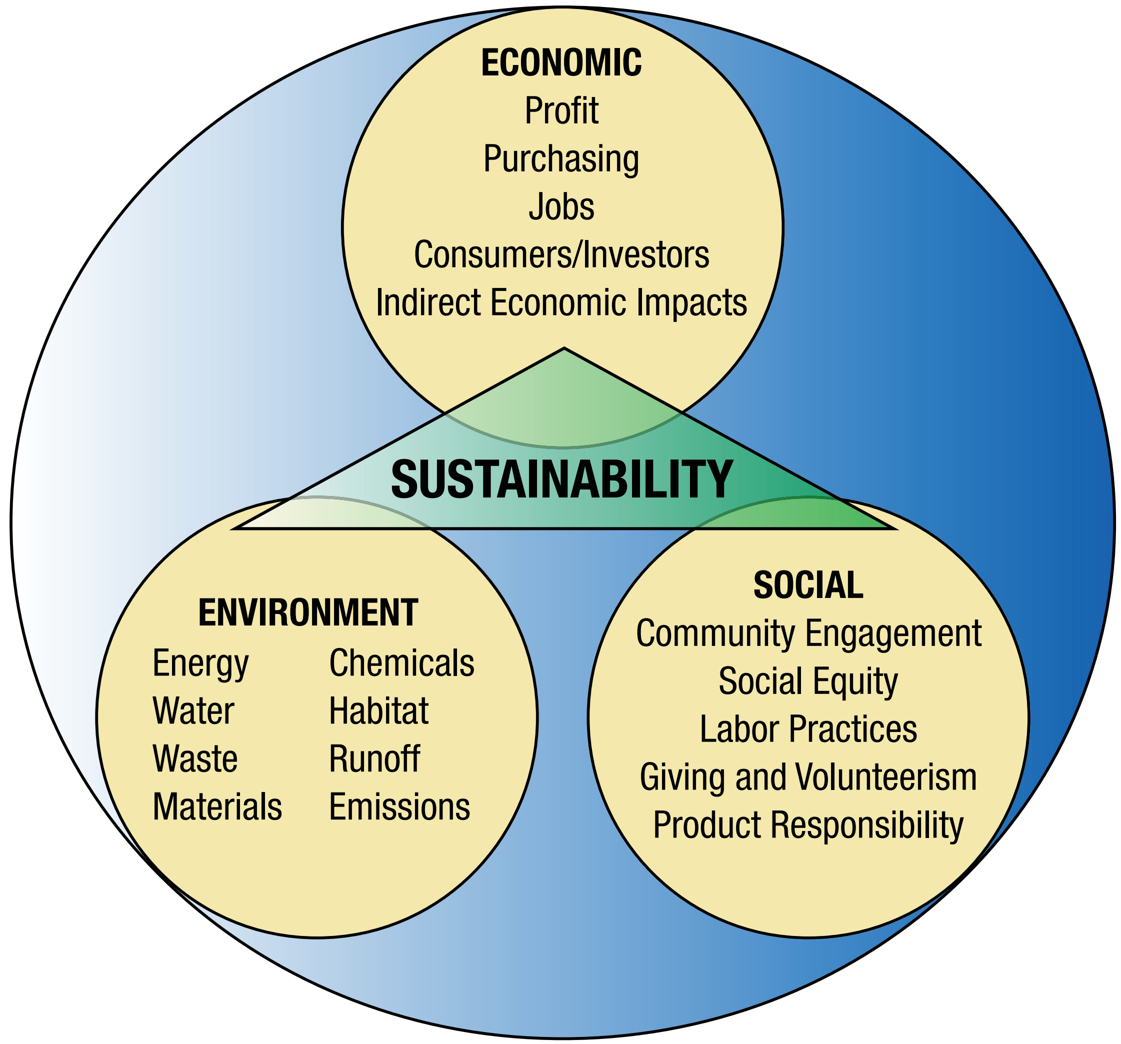


Figure 1. Sustainable Business Practice – Triple Bottom Line

systems analysis approaches such that a potential single action can affect several parameters; for example, targeting over-spraying and over-irrigation can save water and energy (both in irrigating and in pumping water to the site) and reduce runoff of potential harmful materials into the environment. An example of multiple benefits from a product change is the development of concentrated detergent, which has reduced packaging needed for shipping, the amount of plastic for the bottles, warehouse and transportation vehicle space, number of truck trips, and energy.

As you evaluate each area, consider subsidies and industry group programs that can reduce your costs. Many utilities provide subsidies on energy-efficient equipment, and industry groups such as ISMI have developed energy evaluation programs for tools. In addition, environmental leadership can be realized through independent standards, such as Energy Star for products, and Leadership in Energy and Environmental Design for Existing Buildings: Operations and Maintenance (LEED™ EB O&M) for building operations. These independent standards provide third-party review while increasing public confidence. They can be helpful for establishing credibility or brand recognition.

Some specific areas to address in your plan:

***Energy usage***. Reducing energy usage or changing your type of energy usage can save money quickly. Places to look include chilled water, IT servers, lighting, process equipment, fab or lab size, and control systems.

***Water usage***. Minimizing water use reduces both water consumption and energy usage. For example, 19 percent of greenhouse gases are estimated to come from electricity spent for water in California. Offices and ultrapure water are two areas where savings may be found. Typical office sinks can be adapted with aerators that shift the flow rate from 1.5 gallons per minute to 0.5 gallons per minute.

***Packaging and printed materials***. Double-siding printed materials uses half the amount of paper, which ultimately will need to be managed by employees, and recycled, or it will make its way to the solid waste landfill.

***Hazardous waste***. Effective waste management both affects bottom-line costs and reduces the regulatory and liability burden.

***Chemical***. Reducing chemical toxicity in janitorial, landscaping and maintenance areas may reduce the need for protective equipment as well as improve working conditions for contractors and employees. The downstream impacts are also reduced on wastewater treatment plants and storm drain runoff.

***Waste***. Minimizing waste saves labor, can reduce regulatory burdens, directly reduces costs of landfills, and has downstream impacts by reducing landfill space and greenhouse gas emissions.

***LEED EB O&M***. Using LEED EB O&M as a framework is a great way to evaluate sustainability for a facilities operations program because it is systematic and based on existing standards. Although it was designed for buildings, each category can be applied to an operation. For example, "sustainable sites," which encompass storm water, landscaping and commuter solutions, can be applied to comprehensive facilities operations rather than a building. As stated previously, as an independent standard, LEED EB O&M acts as a credible sustainability measuring stick because it is a third-party reference that was developed by content experts in energy, water and green chemistry. This establishes the credibility of the facility and minimizes the potential accusation of "greenwashing."

***5. Develop a company vision and goals***

- Developing the vision with a mixed employee and management team engages the organization in the program and increases the likelihood of success. Now that you understand your footprint and target impacts, you can envision the value proposition for your company.
- Specific measurable goals for reductions can reduce costs and show the value proposition for your company.
- A written plan stating the vision, the goals and implementation plan provides both the internal roadmap as well as the transparent assurance of the company's public commitment to sustainability.

***6. Implement the sustainability plan and share results to ensure the durability of the plan and the success of the vision***

- Build a team to manage the process and make sure that someone with financial knowledge can be tapped to help quantify impacts and results.
- Consider bringing in an outside consultant to guide your process.
- Top management mentoring is critical during implementation of the sustainability program to champion successes, bridge gaps between organizations and ensure that learning, not blame, is gained from failures.
- Recognize that even though your issues are specific, some areas are common to many businesses. Borrow good ideas and templates. One sustainable business does not a sustainable Earth make.
- Quantify and document everything – capital costs, environmental impacts, return on investment, cost of ownership, subsidies and rebates.
- Use free outside resources – energy, waste and water agencies will help you.
- Look for quick and visible wins and reward all who participate to jump-start your plan and raise awareness at your company while setting medium- and long-term goals.
- Stay focused over time and make continuous improvements. Semiconductor, nano-technology and biotechnology applications are emerging to reduce costs for energy, water and transportation.

Sustainability is not without cost, but the benefits are numerous. Whether your objective is to reduce the impact of your operations on the environment, operate your business more efficiently, reduce labor costs or improve your image in the community, implementing a plan for developing sustainable business practices will have a positive impact on your business. The key to implementing an effective sustainable business plan is not to view your efforts as a quick fix or one-time project, but to incorporate ongoing evaluation, monitoring and modifications into your business practices. Done properly, being sustainable does not add responsiblity to your workload so much as redefine how you do what you do.

## Endnotes

1. Hypothetical Company B shows a reduction in profit from its investment in sustainability due to capital improvements and expenses from implementing a robust sustainability program with investments in energy, water and changes to its buildings and vehicles.

2. Companies with effective sustainability programs are 16 percent more profitable. February 2008 survey of international business executives, "Doing Good: Business and the Sustainability Challenge," *The Economist Intelligence Unit Report.*
3. Goldman Sachs reported that the stock of companies that were sustainability leaders outperformed their peers by 25 percent over a three-year period. *GS Sustain*, June 2008, Goldman Sachs.
4. Hypothetical energy costs are estimated to rise for each company by 5 percent a year.
5. Energy savings programs are estimated to save 35 percent per year, according to the Energy Star website.
6. Employee productivity is estimated to improve 2 to 18 percent in a green building. U.S. Green Building Council LEED Existing Buildings brochure, 2005.

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# Third-Party Considerations

## Compliance: Standards vs. Certification

**Gary Alexander**
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**L. T. Guttadauro**
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*President, FOA Purchasing Partners, Inc.*

"Going it alone" in the wild and wooly semiconductor heydays have long passed. Today even the largest integrated device manufacturers (IDMs) are forced to collaborate to stay ahead of the curve(s), taking advantage of partnerships to access the best in global innovation.

The Third-Party Considerations section in this issue of Fab Engineering & Operations offers OEMs and suppliers to our industry an opportunity to tell it like it is, helping to bring awareness, opportunities, information, education, appreciation and value that third parties with their unique perspective can provide.

In this issue, Gary Alexander of AMC Intl. LLC helps us to contemplate compliance regarding standards and certification in the secondary semiconductor used equipment market.

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# Compliance: Standards vs. Certification

**Gary Alexander** – AMC Intl. LLC

One of the primary objectives in the founding of SEC/N was an expressed desire by semiconductor device manufacturers for secondhand equipment standards. Today there are few device manufacturers who show a proactive interest in the future of the secondary market, and their support has all but disappeared for establishing secondhand equipment standards.

A recent reply from an international device manufacturer, responding to a request that it participate in an SEC/N-sponsored seminar, stated *"… The goal appears to be mainly focused on driving standards and integrity into the used tool market. … I don't believe we want to drive standards."*

To be fair, it is not just the device manufacturers that are reluctant to embrace standards for secondhand equipment. Most refurbishers (OEMs and independents), brokers, dealers and other service-related providers are not crazy about the idea either.

Why? Because unlike with new goods, secondhand goods are unique in that there exists a little of the "caveat emptor" ("let the buyer beware") mentality that buyers and sellers actually seem to enjoy, unless of course you are the unfortunate loser in the deal. Unloading a piece of junk on an unsuspecting buyer, being overpaid by an inexperienced buyer, or taking advantage of a naive seller seems to have more to do with the thrill of victory and a company's bottom line than any need to adhere to standards.

Several years ago, SEC/N developed an Equipment Condition Index (ECI) in an attempt to add objectivity and standardization to the condition of secondhand equipment. The assumption was that sellers would adopt it to help justify the difference in value between secondhand equipment offerings and that buyers would require the ECI when they purchased secondhand equipment. Some companies did adopt and are still using the ECI, but the concept of a condition standard for used equipment never caught on.

However, where this lack of concern for standards crosses the line is when self-serving interests compromise the health and safety of others and/or could potentially have a negative impact on the Earth's environment. Using chemicals to clean PC boards in rivers and side streams, and having secondhand equipment leaking hazardous chemicals through their crates are both examples of why governments and third-party organizations around the world are now pursuing initiatives regarding the cross-border commerce of secondhand goods. No company in its right mind would publicly endorse such actions, yet these hazards still continue to happen.

The topic of secondhand goods has been a part of the World Trade Organization Doha Talks for the past several years. Most recently, the ISO Project Committee on Cross-border Trade of Secondhand Goods, in conjunction with ANSI, has established global VTAG task forces, with China volunteering to be the Secretariat/Chair and Canada the Co-Chair. I have been participating as a member of both task forces and as the sole representative from the semiconductor industry. While the bureaucracy and politics of such efforts grind slowly, it does not take much imagination to see where all this is heading.

**The topic of secondhand goods has been a part of the World Trade Organization Doha Talks for the past several years.**

## A Case for Compliance

The ISO 9000 definition of compliance is, *"Certification or confirmation that the doer of an action (such as the writer of an audit report), or the manufacturer or supplier of a product, meets the requirements of accepted practices, legislation, prescribed rules and regulations, specified standards, or the terms of a contract."*

Interestingly enough, many device manufacturers and other semiconductor companies are in favor of some form of compliance, especially with regard to compliance on the part of others, but they stop short of endorsing secondhand equipment standards. In other words, the idea of a softer term like "certification" appears to be more palatable, as long as the requirements to be met do not encroach upon certain transactional rights that companies perceive to be indigenous.

Going back to our ISO 9000 benchmark of terminology, *"Certification to an ISO 9000 standard does not guarantee the compliance (and therefore the quality) of end products and services; rather, it certifies that consistent business processes are being applied."* ISO does not itself certify organizations. *"Certification refers to the issuing of written assurance (the certificate) by an independent external body that it has audited a management system and verified that it conforms to the requirements specified in the ISO 9000 standard."*

So, if we are to assume that certification is the semiconductor industry's preferred road to compliance, the questions become: *"What form of certification?"* and *"Administered by whom?"*

The ISO model and other creditable forms of certification stipulate that objectivity in certification requires the authentication of an independent third party. While it is true that some refurbishers (OEMs and independents) offer their own certification programs, consensus is that such certifications are just another way of stating what that company provides in the way of a warranty for its refurbished products. To be effective, objective and acceptable, certification needs to include the involvement of a third party.

International governments and other regulatory bodies are no doubt going to continue to pursue global standards for secondhand goods. The degree to which they will be successful in developing secondhand goods standards that effectively cross all industries and borders is questionable. And, they are not going to be ratified anytime soon. Providing leadership in this effort is, however, an opportunity for those industries that have their secondhand goods' "acts together."

## *Summary*

The easiest and most acceptable approach to the semiconductor industry's pursuit of secondhand equipment compliance lies with the development of a third-party certification program. And the two most knowledgeable third-party organizations with benchmark experience in the semiconductor industry to initiate and lead such a coordinated and cooperative effort are SEC/N and SEMI. ■

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