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Inside

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The Impact of Yield Variation on Cost of Ownership

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ABSTRACT

Increasingly, Cost Of Ownership (COO) is being used not only for equipment purchase decisions, but also as a metric for continuous improvement of machine operations. There are many things to consider for COO; reliability, consumables, gases and liquids, maintenance cost, cleanroom floor space, etc. Though product yield is one of the largest leverage points for COO, and is one of the least understood inputs, understanding the impact that product yield has on COO is an important part of continuous improvement. Using machine particle counts for predictive yield modeling has been discussed before and is part an on-going effort supporting the International Technical Roadmap for Semiconductors (ITRS). Utilizing the modeling methods previously published and validated in the SEMATECH effort, the yield impacts of machine to machine particle variation on product yield and excursions can be studied. This paper looks at the impact of particle variation on product yield and the resulting impact on COO. Trending these on a real-time basis provides an overall operational success metric for driving continuous improvement in semiconductor manufacturing.

BACKGROUND

One of the roles of the 1999 International Technology Roadmap for Semiconductors (ITRS) and its U. S. predecessors, the 1994-1998 National Technology Roadmap for Semiconductors (NTRS), has been to quantify many of the requirements for keeping the semiconductor industry on Moore's Law of productivity. The random defect targets recently released in the ITRS are based on predefined technology nodes using data collected by SEMATECH member companies on 164 machines, which are divided into 30 generic equipment categories (Wilson 1999). The ITRS identifies a consensus of conditions for the semiconductor industry

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2001 Calendar of Events

July

13-14 SEMI-sponsored seminar
"How to Successfully Manage New Product Introductions"
Moscone Hall
San Francisco, California

16-20 SEMICON West 2001
San Francisco/San Jose, California

16-18 Visit WWK's Booth at SEMICON West
Moscone Hall North • Booth 6574
San Francisco, California

17 SEMI-sponsored seminar
"Understanding and Using Cost of Ownership for Wafer Fab"
Moscone Hall
San Francisco, California

19 SEMI-sponsored seminar
"Understanding and Using Cost of Ownership for Assembly & Packaging"
Fairmont Hotel
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maintaining its historical 25%-30% increase in productivity each year. One key to maintaining this high level of increasing productivity is by not losing ground in areas of historical accomplishment, such as yield improvement.

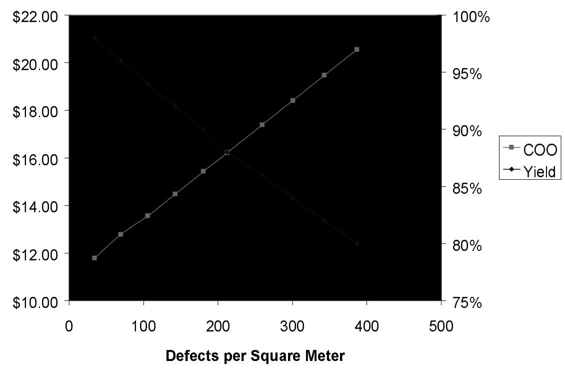

Figure 1: Lithography Defects vs. COO and Yield

There is a strong relationship between integrated circuit yield and cost of ownership (COO). This is illustrated in Figure 1, which shows both yield and COO as a function of defect target for a 180-nm (line width) lithography cell. The 1999 ITRS defect target for this tool is 112 defects per square meter. This results in a yield of almost 94% and a COO for a single process step of about $13.50. The 1999 ITRS defect target for the lithography cell at 210-nm line width is 152 defects per square meter, which also would result in a 94% yield for the wider line width. However, attempting to manufacture the 180-nm line width at 152 defects per square meter lowers the expected yield to 92% and increases the COO to $14.50. Thus, to maintain the same economic productivity requires reducing the defect target from 152 at 210-nm to 112 at 180-nm. The ITRS roadmap defect target progression for the lithography cell is shown in Figure 2. Just maintaining the current equipment defect reduction pace to meet the requirements of Moore's Law is a very difficult challenge.

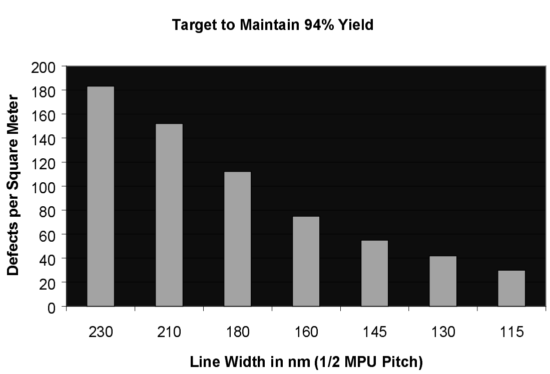

Figure 2: ITRS Defect Targets

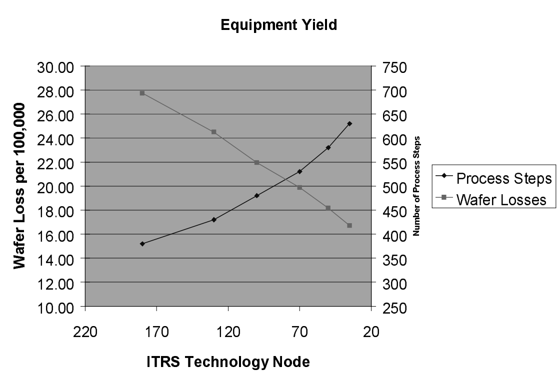

Figure 3: Per Step Equipment Yield required for 90% Production Yield

Thus far, we have focused on maintaining the pace of Moore's Law for random defect-limited yield. Maintaining equipment yield in wafer fabrication is also a challenge. As is shown in Figure 3, the number of process steps in the roadmap is expected to increase from 380 in 1999 (180-nm) to more than 600 in 2014 (35-nm). At this rate, per step equipment yield loss must be cut almost in half, from 28 wafers per 100,000 moves to 17 wafers per 100,000 moves just to maintain 90% production yield.

Thus, maintaining the semiconductor industry's significant yield accomplishments in the face of finer line widths, larger chips, and more complex processes will be a significant challenge. Cost of ownership can be used as an important metric in measuring progress meeting these challenges.

USING COST OF OWNERSHIP

The basic cost of ownership algorithm is described by the following equation (SEMI E35):

$$COO = \frac{F\$ + O\$ + S\$}{L \times TPT \times Y \times U}$$

Where:

COO = Cost per good unit or wafer
F$ = Fixed Costs
O$ = Variable cost
S$ = Cost due to yield loss
L = Life of Machine
TPT = Throughput
Y = Mechanical throughput yield
U = Utilization

Fixed costs include purchase, installation, and facilities costs that are normally amortized over the life of the equipment. Variable costs such as material, labor, repair, utility and overhead expenses are costs incurred during equipment operation. Throughput is based on the time to meet a process requirement such as depositing or etching a nominal film thickness. Mechanical throughput yield is the operational yield of the machine and may include breakage and misprocessing.

Utilization is the ratio of production time compared to total available time. Non-production down time is the time lost due to scheduled maintenance, engineering usage, standby, and repair. Repair time is estimated from mean time between failures (MTBF) and mean time to repair (MTTR).

Yield loss cost is a measure of the value of wafers lost through operational losses and defects. Yield models are used in COO models for estimating the relationship between contamination and yield loss or scrap. These models relate integrated circuit yield to circuit and process parameters such as device geometry and particle density.   For purposes of this discussion, we will use the negative binomial model described by:

$$Y = \left(1 + \frac{AD}{\alpha}\right)^{-\alpha}$$

Where:

Y = Yield
A = Chip Active Area
D = Defect Density
α = A parameter related to the coefficient of variation of the gamma distribution – often called the clustering coefficient

(Stapper 1989)

This yield model has the advantage of approximating several common yield models by adjusting α.

CONTINUOUS IMPROVEMENT WITH COO

Frequently COO is only used for initial machine purchase comparisons. Such use would include the following sequence of events:

1. Identify proposed machines
2. Request information
3. Estimate COO
4. Select and purchase machine
5. Install and qualify machine
6. Verify COO (Optional)
7. Identify multiple production metrics
8. Monitor production metrics
9. Address failures
10. Plan and implement corrective actions

Unfortunately in many cases, multiple performance metrics results in multiple corrective actions with no single clear picture of machine performance relationships. Many times, metrics do not include all the variables that were used to purchase the tool, like yield and operating costs. Corrective actions focus on symptoms rather than root cause analysis and correction.

Using yield modeling feedback as part of a continuous improvement cycle is well established (Dance and Jarvis 1992). Adding cost of ownership analysis to that feedback provides an important financial metric for determining improvement priorities and return on investment. A proposed machine purchase could include the following sequence of events:

1. Identify proposed machines
2. Request information
3. Estimate COO
4. Select and purchase machine
5. Install and qualify machine
6. Verify COO
7. Identify multiple production metrics using elements of COO
8. Monitor COO and production metrics
9. Prioritize failures by COO impact
10. Address failures
11. Plan and implement corrective actions
12. Verify corrective actions with change in COO trends

While most of these steps are similar to normal production monitoring, several steps should be discussed in more detail. The COO verification in Step 6 is performed to compare actual COO with expected COO. (I.e. Did you get what you paid for?) Verification also establishes a baseline for the machine COO performance monitor. This should also be compared with the production COO of other similar machines with which may be already in operation. Step 7 helps you understand the relationship of common performance metrics to COO. Step 9 quantifies the impact of performance variance on COO and helps prioritize corrective actions. Step 12 is a continuation of the actions of COO verification in Step 6.

As was shown in Figure 1, yield has a strong impact on COO. However, that impact must be compared with the cost of the yield improvements to determine a return on investment for corrective actions. For example, a major process change that requires requalification of products by several customers may not recover the requalification investment over the life cycle of the product. That yield learning however will be useful as future processes and machines are considered.

EXAMPLE

We illustrate the use of COO monitoring as part of continuous improvement by looking at the impact of particle per measurements and COO trends for a semiconductor processing machine.

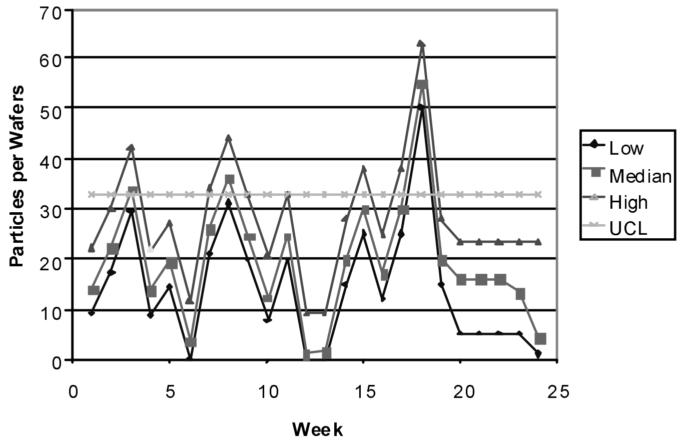

Figure 4 Particle per Wafer Control Chart

Figure 4 is a Poisson control chart of weekly particle per wafer pass (PWP) measurements. For each weekly set of measurements the low, median, and high values are plotted against an upper control limit estimate (Wheeler and Chambers 1986). This chart flags out-of-control events in Weeks 3, 8, and 18. Figure 5 trends COO for this same period.

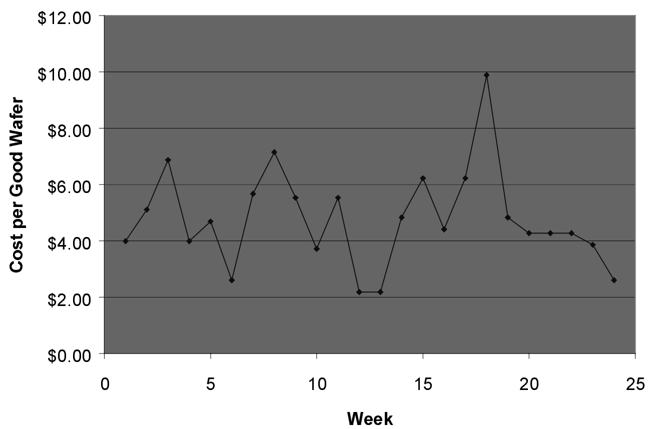

Figure 5: COO Trend for Machine 11

In this example, cost per good wafer varies from $2.18 to $9.89. COO for the average PWP of 20 is $4.83. In Weeks 3, 8, and 18 the COO value also includes the cost impacts of additional downtime for cleaning, repair, and testing. In an average week Machine 11 can process about 5,536 wafers but in Week 18 no more than 5,093 wafers could be processed due to the downtime impact of out-of-control PWP.

The improved PWP performance following repairs in Week 18 suggest a new average PWP for Machine 11 of 14 particles per wafer, with an upper control limit of 25 particles per wafer. This leads to a new average COO of $3.99 for a savings due to reduced scrap loss of $0.84 per wafer and a more than $232,500 per year increase in profit before taxes[1]. If this machine is used more than once in the process, as many machines are, the benefits would be even greater.

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[1] All cost estimates assume that the value of a completed wafer is $750.00.

SUMMARY

Increasingly COO is being used as a process control metric. By reflecting the impacts of traditional process control metrics in financial terms, COO provides a way to prioritize failures in terms of their impact on wafer costs. Some of the traditional process control metrics that are included in COO are material consumption rates, production testing, scheduled and unscheduled maintenance, production output, and yields. Each of these must be tightly controlled and improved to maintain the industry's historical 25% - 30% per year productivity improvement.

Using previously published modeling methods, the yield impacts of machine particle variation on product yield and excursions can be studied. This paper has focused on the impact of tool particle variation on product yield and the resulting impact on COO. Trending these on a real-time basis provides an overall tool operational success metric for driving continuous improvement in semiconductor manufacturing.

Key monitoring steps for using COO as a performance metric include validation of COO during equipment characterization to establish a COO baseline, prioritizing failures based on COO impact, and verifying corrective actions by observing changes in COO trends. We have illustrated the benefit that can be obtained for a single process step. Understanding the impacts of yield variation on COO and implementing COO monitoring as part of a continuous improvement system for all processing machines can expand that benefit to the complete process.

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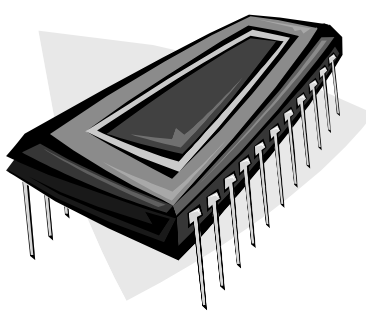


Supply Chain Analysis White Paper Available from Wright Williams & Kelly

Wright Williams & Kelly (WWK) has announced the availability of its Critical Path Supply Chain Analysis™ white paper. The white paper is available at no charge from WWK's web site at http://www.wwk.com under the "What's New" section.

"Managers often view supply chain management as an effort to 'pin the blame' for supply chain issues on someone else. They are looking to fix the problem with their suppliers," reports Daren L. Dance, WWK's VP of Technology. "However, they may be looking in the wrong direction. The problem may be inaccurate demand forecasts from their customers."

"External events have internal consequences. Our Critical Path Supply Chain Analysis™ helps management understand the risks and other internal consequences of supply chain issues, even if those issues are outside their control. With a clear understanding of internal risks and consequences, management is in a much better position to structure effective supply chain solutions and validate customers' demand forecasts."

Effective control of the flow of components and materials to the manufacturing or assembly line is a key to cost effective manufacturing. In an optimal supply chain, materials and components are received just-in-time to enable lean manufacturing, i.e., the right product, in the right place, at the right time, at the lowest possible cost. Critical Path Supply Chain Analysis™ is a methodology that identifies the supply chains with the highest potential to interrupt manufacturing and explores the risks of interruption. This methodology becomes the foundation for a corrective supply chain solution.

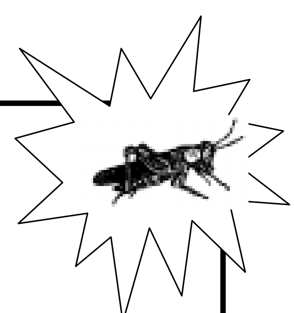
In the white paper, WWK analyzes a semiconductor supply chain from wafer fabrication through final assembled board test. For each stage in the supply chain WWK considers cost, yield, variability, and cycle time. Each stage also includes transportation and handling to the next stage. Some of the management questions that can be answered from this type of analysis include:

- How much lead-time must be provided to insure sufficient supplies of tested boards?
- How many wafers should be started to provide sufficient supplies of tested boards?
- How much time could alternate sources save?
- At which stages would alternate sources be most beneficial?
- How much time could accelerated transportation methods save?
- What is the average cost per good board shipped (Cost of Ownership)?

A comment on today's business environment . . .

"Business cycles are about as easy to nail down as a grasshopper on amphetamines."

Anonymous



WWK to Celebrate Its 10th Anniversary

On the eve of our tenth anniversary, I thought it would be interesting to look back at a brief history of the company and answer the famous question, "so who are Williams and Kelly?" The founding date for WWK is a little bit vague in that WWK really represents the merger of two different organizations in the summer of 1991. For lack of a better date, SEMICON West has always been a good benchmark.

In 1991, Wright Williams & Kelly was founded by Michael Wright as a marketing consulting company focused on assisting semiconductor capital equipment organizations. At the same time, I had formed my own company focused on building cost of ownership software for non-SEMATECH/SEMI-SEMATECH members.

Mike Wright and I go back to the late 80's where we laid out the marketing strategy for Ultratech Stepper (mix and match, thin film record head, scanner replacement…). So, when I found out Mike was back on the west coast running his own business after his stint with GCA, as part of the Ultratech Stepper/GCA on again off again merger, I touched base to see how things were going. It turned out that while we were doing different things, our potential client bases were the same. It made sense to see how working together could leverage our limited resources. What came out of that conversation was a strategy that pulled together a group of independent consultants operating under the WWK banner, sharing resources and looking bigger than we really were. Why the name Wright Williams & Kelly and not a new name? It was very simple; Mike had already printed up brochures with that name and no one had any spare cash to get them reprinted with a new name.

What evolved over the next three years was closer ties between the business relationships and, in 1994, WWK was incorporated. During that time, we had constructed the first semiconductor industry-wide equipment specification database framework and definitions guide under contract to SEMATECH and had just received the contract to commercialize cost of ownership software, training, and support. This latter contract would ultimately change the face of WWK from primarily a market based consulting company to the world leaders in operational cost modeling and consulting.

In 1995, WWK was acquired by Industrial Design Corporation (now Industrial Design & Construction), one of the world's largest architectural and engineering firms focused on fab construction and sustaining engineering. Later that year WWK formed an alliance with CIS to add discrete event simulation (Factory Explorer®) to our cost of ownership product line. The IP licensing continued in 1996 when WWK acquired the exclusive rights to what became Factory Commander® from Sandia National Labs. In 1997, WWK filled out the remaining spot in its operational cost modeling product line with the development of PRO COOL® for process sequences. As with most software, nothing has stood still and all the products in our product line have continued to be updated and upgraded based on our customers' suggestions and requirements.

2000 saw the beginnings of what would eventually become WWK's Software Consulting Services group; a team of senior software designers and programmers focused on providing turnkey, custom software development services to industries as diverse as oil refining, market research, semiconductors, and restaurants. This exposure to a new group of clients has allowed WWK to expand its skill set in the area of software development and is directly responsible for the 2001 introduction of COOL FUSION™, a sales force automation and product configuration tool.

It has also prepared us for the introduction later this year of a new version of TWO COOL® that will leverage the web to provide our clients with a lower cost to distribute, coordinate, and publish their COO results. Without this last development, WWK would not have been in a position to sign a 2001 IP licensing agreement with Electroglas for the embedding of TWO COOL® in their SortNet and Statware software products, another first in the history of WWK.

That brings us back to the question I started this history with, "so who are Williams and Kelly?" Actually, they are Mike Wright, or at least family names from his genealogy. When you are a one-man marketing show, a couple of extra names on the shingle never hurts.

David Jimenez

Electroglas, Wright Williams & Kelly To Develop the IC Industry's First Real-Time System for Monitoring Equipment Cost and Utilization

Constant monitoring of equipment performance will lead to immediate gains in productivity and enable fabs to more accurately model future manufacturing processes

SAN JOSE, CALIF.—May 23, 2001—Electroglas, Inc. (NASDAQ: EGLS), a leading supplier of process management tools for the semiconductor industry, announced today that it has signed a definitive agreement with Wright Williams & Kelly (WWK) to jointly develop a real-time system for monitoring equipment performance utilizing the Statware tool set Electroglas acquired in January. The resulting system will help fabs effectively manage and model manufacturing processes by identifying cost drivers and the cost impact of capital equipment purchases, alternative processes, and overall equipment efficiency (OEE) improvements. WWK is the developer of the semiconductor industry's standard for cost of ownership (COO) and OEE software, TWO COOL®. Development plans call for the integration of WWK's TWO COOL product with Electroglas' SORT*net*® products for probers and the Statware Web-based tool for process optimization analysis and reporting.

"We are very excited about this partnership with Electroglas," said David W. Jimenez, WWK's president. "COO and OEE have had significant impacts on the semiconductor and other high tech industries for the past decade. However, the focus has been on early analysis and not constant monitoring of performance. This new approach will provide real-time feedback of cost and utilization parameters just like any other statistical process control area of interest. The long term benefit to the industry in cost reduction and productivity optimization will be huge."

According to Electroglas' director of strategic software marketing, Howard Ignatius, "The Electroglas vision of a data-centric approach to process management is characterized by this breakthrough improvement in equipment performance monitoring. Through the integration of WWK's COO and OEE capabilities and our toolset – wafer probers, optical wafer inspection products, networking software and yield management solutions – we can offer access to and analysis of the information generated at each process step to allow IC manufacturers to pinpoint what is possible in terms of cost containment, efficiency and yield."

Tom Simas, Electroglas' strategic business manager for the Statware products, added, "A state-of-the-art fab has a denser capital per square foot than any industry. The ability to effectively identify cost drivers and manage cost reductions in real-time, will separate the 'haves' from the 'have-nots'. WWK's comprehensive set of COO and OEE analysis tools, together with Electroglas' Web-based business intelligence tools provide unparalleled functionality and benefit to the IC manufacturer. We are extremely pleased with our exclusive arrangement with WWK. Together, we believe our impact on the industry will be tremendous."

About the Technology

TWO COOL is the first software to comply with Semiconductor Equipment and Materials International's (SEMI) Standards E35, E79, and E10. These standards are the semiconductor industry's guidelines on the construction and use of COO, OEE, and equipment reliability metrics. COO is a key metric in the semiconductor industry because it provides a means to model future semiconductor manufacturing processes before companies invest in new fabs, fab refurbishment, or technology migration. The International Technology Roadmap for Semiconductors (ITRS), additionally, has called for increasing OEE as a primary factor in improving the cost of semiconductors and maintaining the impact of Moore's Law on the growth of the industry.

SORT*net* is a Web-based data acquisition, analysis, reporting, and process control system for the sort floor. SORT*net* automates process control, yield enhancement and equipment utilization to maximize the return from existing equipment and resources.

Statware products combine statistical quality analysis and reporting capabilities with Web technology to deliver a process optimization system that enables enterprise-wide participation in monitoring, analysis, and improvement of critical processes.

About Electroglas, Inc.

Electroglas delivers essential tools for process management to enhance the profitability of semiconductor manufacturers. The company's wafer probers, inspection systems and software solutions serve as data collection, management and analysis tools that semiconductor manufacturers depend upon to improve their productivity and process control by optimizing sort-floor efficiency. Electroglas has been a leading supplier of wafer probers for over 35 years and has an installed base of more than 15,000 systems. The company's stock trades on the NASDAQ National Market under the symbol "EGLS". The company's World Wide Web site is located at www.electroglas.com.

About Statware

Electroglas, Inc. acquired Statware, Inc., in 2001. Originally founded in 1983, Statware is the leading developer of process optimization software technologies for manufacturing industries. Statware provides products that assist users in understanding and managing processes and their outcomes for optimal quality, consumer satisfaction, and cost containment. In 1997, Statware transformed its vision for developing process optimization software applications by focusing on Internet technologies. Building on a decade of development in statistical quality control, Statware has created a new model for empowering the enterprise through its web-based applications for total and continuous quality improvement. For more information, visit www.statware.com.

SORT*net* is a registered trademark of Electroglas, Inc. TWO COOL is a registered trademark of Wright Williams & Kelly. Other trademarks are property of their respective holders.
