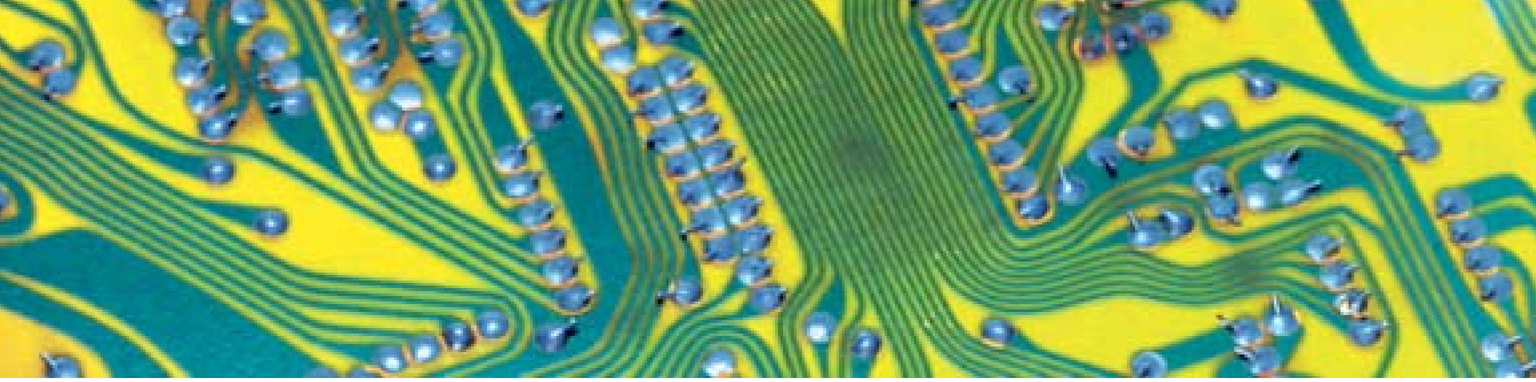


SIX SIGMA

Big Improvements For Small Parts

by **Lorena Dudman**

Headquartered in Silicon Valley, CA, National Semiconductor Corp. supplies several companies with microcircuits, also known as microchips, which process massive amounts of signals into digital information.

Microcircuits are inside all electronic devices, such as personal digital assistants, laptop computers and automotive controls. They are made by processing wafers consisting mostly of silicon through many fabrication steps, such as oxidation and photomasking to define the circuit layout, and ion implantation and diffusion to define the transistor. When the wafers have completed the fabrication steps, they are diced into "chips," assembled into the final package and shipped to customers, who use them in assembling their end products.

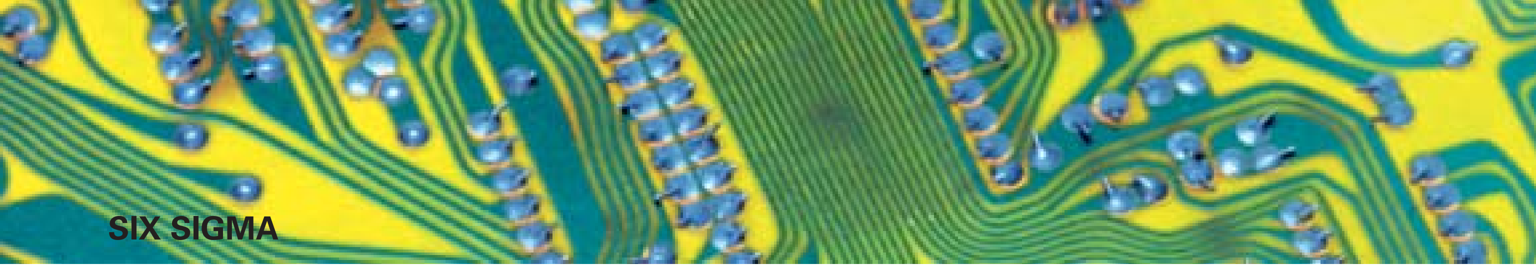
The fabrication process—from raw silicon to a packaged integrated circuit (IC)—involves more than 200 steps on 75 pieces of equipment. Processes involve epitaxial growth, ion implantation, photolithography, photomasking, diffusion, oxidation and chemical and physical vapor deposition. Many of these steps take place in class one clean rooms, meaning no more than one particle of dust greater than 0.5 micrometers is allowed per cubic foot of air.

In 50 Words Or Less

- **Semiconductor manufacturing is highly process driven and ripe for improvement through Six Sigma.**
- **National Semiconductor Corp. used the define, measure, analyze, improve, control methodology to save millions of dollars.**

Six Sigma—Integral to Success

Like most U.S. semiconductor companies, we at National perform all assembly and final testing offshore, where costs can be extremely low. But a few years ago, National began looking for ways to reduce cost even more. We wanted to work with our direct material suppliers to reduce cost and



benefit us all. The assembly process uses costly materials and many different kinds of tooling. What if we could consolidate tooling? What if we could cut material waste or use alternative materials to reduce cost while still meeting or exceeding quality levels? At National, our Singapore assembly and test facility did just that.

In 2000, the central technology and manufacturing group (CTMG), National's manufacturing arm at the time, began a continuous improvement initiative. After two years, CTMG senior management was still not satisfied with the improvement level. So in 2002, they invited representatives of Thomas A. Little Consulting to speak at the annual CTMG summit about their experience in high-tech disk drive processes that had a lot in common with semiconductor fabrication. They presented compelling arguments for Six Sigma when applied to the semiconductor industry's highly process driven manufacturing methods.

With fewer than 10 defective parts per million, National was satisfied with its track record and reputation but realized there's always room for improvement. It was apparent reducing costs while maintaining product quality was a goal ripe for a Six Sigma effort.

C.S. Liu, senior vice president of National's plant in Melaka, Malaysia, at the time, agreed to conduct a nine-month Six Sigma pilot program, which showed encouraging results. In June 2003, Kamal Aggarwal, then executive vice president of CTMG, mandated all CTMG units would deploy Six Sigma. National is now on wave three of its Six Sigma deployment.

Reducing Cost, Waste With DMAIC

National's Singapore plant was ideally situated for success with a material cost reduction project. It had a staff with plenty of Six Sigma experience plus access to software that could make Six Sigma projects run smoothly with less wasted time and manpower.

TABLE 1 Die Attach Paste Wastage Data Collection Plan

Define what to measure			Define how to measure			Who will do it?	Sample plan		
Measure	Type of measure	Operational definition	Measurement or test method	Data tags needed to stratify the data	Data collection method	Persons assigned	Where?	When?	How many?
1. Percentage waste of epoxy thrown	Y variable	Weight of epoxy thrown	Weighing scale	Device ID, machine number, epoxy tag, type, date/shift, volume of syringe, time from thaw to expiry, reason of change of syringe	Manual weighing	Die attach operator	Front of line	Daily	Length of project
2. Epoxy shelf life	X variable	Number of hours to expiry after thaw	Epoxy shelf life	Epoxy type, vendor	Material data sheet	Engineering	Vendor specs	Once	Once
3. Volume of units produced per syringe	X variable	Number of units produced per syringe	Number of unit die attach	Machine number, package type,lot details	Manual	Chris/Kuah	Front of line	Daily	Every syringe for a total of 80 syringes
4. Epoxy usage per device	X variable	Amount of epoxy use per device (die)	Usage per die calculations	Device die size,specific gravity	Data calculation	Die attach engineering	Engineering	Once	All devices involved
5. Machine stoppages	X variable	Machine downtime	Downtime	Machine number, downtime taken	Manual	Chris/Kuah	Overall equipment efficiency	Daily	Every syringe for 80 syringes

NATIONAL'S SINGAPORE FACILITY: About 2,000 employees work here.

National saw the importance of standardizing software organizationwide to support the Six Sigma initiative. For process mapping, National chose iGrafx Process for Six Sigma software. We used JMP statistical discovery software for design of experiments (DoE) to optimize the process for the new leadframe materials. To help Black Belts (BBs) effectively manage projects, collaborate with team members and provide status updates to upper management, we used ProjX Web based project tracking software.

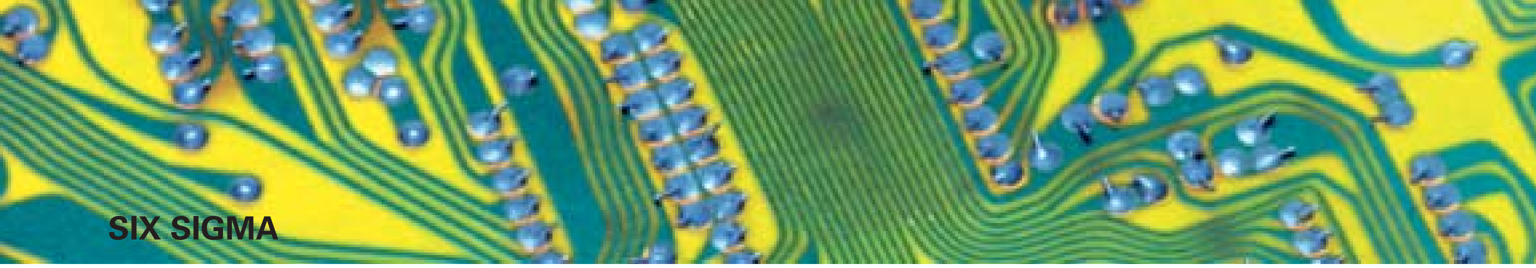
Over nine months, a six-member team in Singapore, led by Christina L.M. Lee and H.P. Kuah, developed a cost reduction plan, looking at product and workflow specifications, alternate sourcing, price negotiation, process simplification and change of material or design.

First, the team analyzed the direct material cost and usage trends, identifying opportunities and actions to achieve significant cost reduction. In the area of leadframes—the greatest material cost—they worked closely with the supplier to minimize tooling costs. A leadframe is the skeleton of the IC package, providing mechanical support to the die during its assembly into a finished product. A leadframe consists of two main components:

1. A die attach pad, to which the die is mounted using adhesive material such as epoxy or polyimide.
2. Leads, which are the means for external electrical connection to the outside world.

To minimize cost, National's Singapore assembly team converted from etch leadframes to stamp leadframes. Furthermore, it was able to consolidate stamp toolings for two die attach pad sizes and reduce die attach paste waste.

The team was successful because it followed the define, measure, analyze, improve, control (DMAIC)



roadmap. Throughout the project, the team measured the key product and process inputs to ensure it had enough information to make sound decisions. A rigorous financial analysis helped connect everyone, including staff outside the team, to see how they fit into the big picture and how their work contributed to the bottom line. The team actually quantified and evaluated during the analyze phase to ensure the cost of recommended improvements would be supported by the project's benefits.

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Here's how it worked:

Define. The problem was as follows: Total assembly material spending in fiscal 2003 was in the range of tens of millions of dollars. The largest component of that was around 27% in leadframe spending. The annual achievable savings from material cost reduction was not meeting the plant's 15% goal.

The team analyzed direct material expenditures, identified opportunities and executed actions to achieve savings. It set a target of no less than 2% in annualized cost reduction in materials and overhead spending by the end of the project. It also agreed actions to reduce cost should not affect characteristics critical to ensuring overall quality. The project's critical-to-quality components were to ensure:

- Process specifications for bond pull, die shear, coplanarity and form dimension C_{pk}s were above 1.5.
- Nonsticking on leads was no more than 300 parts per million.
- Wedge pull met minimum specification based on wire diameter.
- Reliability showed zero failures and met the package moisture sensitivity level.

Measure. In this phase, the team looked at leadframe price by gathering a list of 37 part numbers and reviewing in detail direct material usage for leadframes, die attach paste and mold compound. Through data collection and analysis, along with benchmarking, it was able to narrow its focus to areas that signaled maximum opportunity.

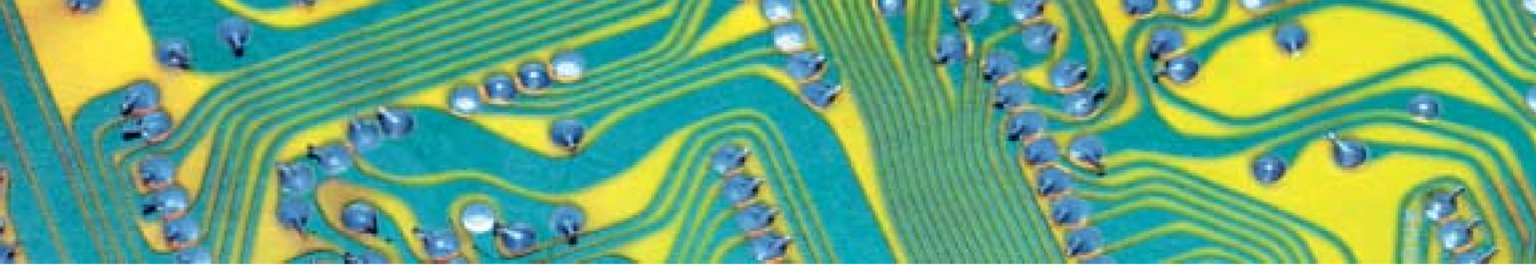
After going through a list of leadframes, the team narrowed the list to one etch frame that would yield the highest cost savings if converted to a stamp frame. Etch frame costs generally are higher than stamp frame costs because of the number of manufacturing steps involved. On the other hand, stamp framing involves initial tooling costs while etch framing requires none. This makes stamp framing only cost effective for high volume packaging.

The team began discussions with the selected leadframe vendor—the cheapest source identified through benchmarking largely due to its proximity to the Singapore plant—on the dimension and tolerance for stamp framing and the timeline for conversion from etch framing. It focused on the one specific low profile quad flat package identified as the best candidate for conversion. Working with the vendor, the team was able to reduce average per unit cost for that leadframe by 40%.

In those discussions, the team also identified a low profile quad flat package with two die attach pad sizes—6.1 millimeter and 8.0 millimeter—for consolidation of the stamp tool. By consolidating some tooling, the team was able to reduce initial startup costs.

Another measure for reducing costs was to reduce die attach paste waste. The measures that contribute to the cost of die attach paste include percentage waste of epoxy thrown, epoxy shelf life, volume of units produced per syringe, epoxy used per device and machine downtimes (see Table 1, p. 68). The team began taking steps toward reducing this waste and realized results in the improve stage.

Analyze. The team reviewed variables, such as competitive pricing, tooling price, tight specification and vendor packaging material, in its effort to reduce frame costs while ensuring continued quality (see Table 2). Competitive pricing and tooling price showed the greatest impact.



In its efforts to reduce costs associated with die attach paste waste, the team analyzed the variables that contribute to the cost of die attach paste, and visual analysis showed epoxy packaging per syringe had the biggest impact (see photo at right).

VISUAL ANALYSIS ON DIE ATTACH PASTE WASTE: These syringes were collected from the trash bin after each shift. About 80% of the die attach paste remains per syringe.

Improve. The team then designed an experiment to optimize the process for new leadframes. The first step was to identify which process would be most affected by the change in leadframe. The wire bonding process was identified as the most critical. The team asked the wire bond engineer to identify which factors needed to be optimized and which responses needed to be validated to ensure quality was not compromised.

The team used JMP software's custom (DoE) platform to reduce the number of runs needed. By identifying the critical factors and responses up front and using the custom design, the team saved time and effort over running a full factorial DoE matrix and eliminating factors that are not significant to the responses.

Power, force, ultrasonic compensation and profile were the critical process factors (X's) identified in the DoE. The critical responses (Y's) were nonsticking on leads (NSOL), open defects and wedge pull (mean and sigma). Factors kept constant were the wire bonder, operator and wire bonder capillary tool. The goal was to minimize the NSOL, open defects and wedge pull sigma while maximizing the wedge pull average. JMP's optimization engine, called prediction profiler (see Figure 1, p. 72), shows the response goals were met with a high power of 20%, force of around 609 millinewtons, maximum ultrasonic compensation of 0.6% and a ramp-up low ultrasonic compensation profile.

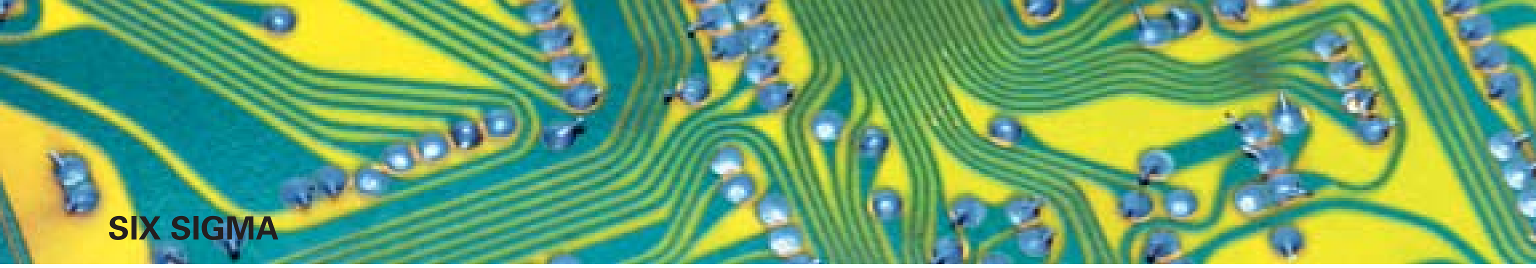
The team also designed an experiment that optimized paste shelf life and volume per syringe by taking into consideration process throughput and package unit usage. After the DoE, the team asked its vendor to provide a smaller amount of paste using the same syringe size. It wanted to keep one size syringe on the production line, but it wanted some syringes to hold less paste. The price per gram was not reduced because of the packaging cost of the larger syringe. Further, awareness of current waste encouraged the team to recalculate its paste usage rate and thereby order fewer syringes. In the end, die attach paste waste was reduced by 35 to 50%.

Control. The team worked with process owners to ensure proper training was provided to the line

TABLE 2 Root Cause Analysis Summary

Analysis method	Factors	Completed review date	Who?	Investigation method	Conclusion	Factor effect size	Units	Adjusted r^2	p-value	Effect
Process review (quad flat package frame spending—8.5% reduction)										
	Competitive pricing	10-26-03	Chris	Benchmarking	RC	5	$/KU	–	–	74%
	Tooling price (stamp frame)	10-26-03	Chris	Benchmarking	RC	1.6	$/KU	–	–	24%
	Tight specification	10-20-03	Chris	Review spec/tolerance	PC	0.2	$/KU	–	–	3%
	Vendor packaging material	10-20-03	Chris	Vendor discussion	NC	0	$/KU	–	–	0%

RC = root cause, PC = partial contributor, NC = noncontributor, KU = 1,000 units



technicians and that what was learned was documented. For example, the calculation of the die attach paste usage was documented in a material procurement specification for future new die attach paste introduction. That ensures paste waste is kept to a minimum as new materials are introduced into the line.

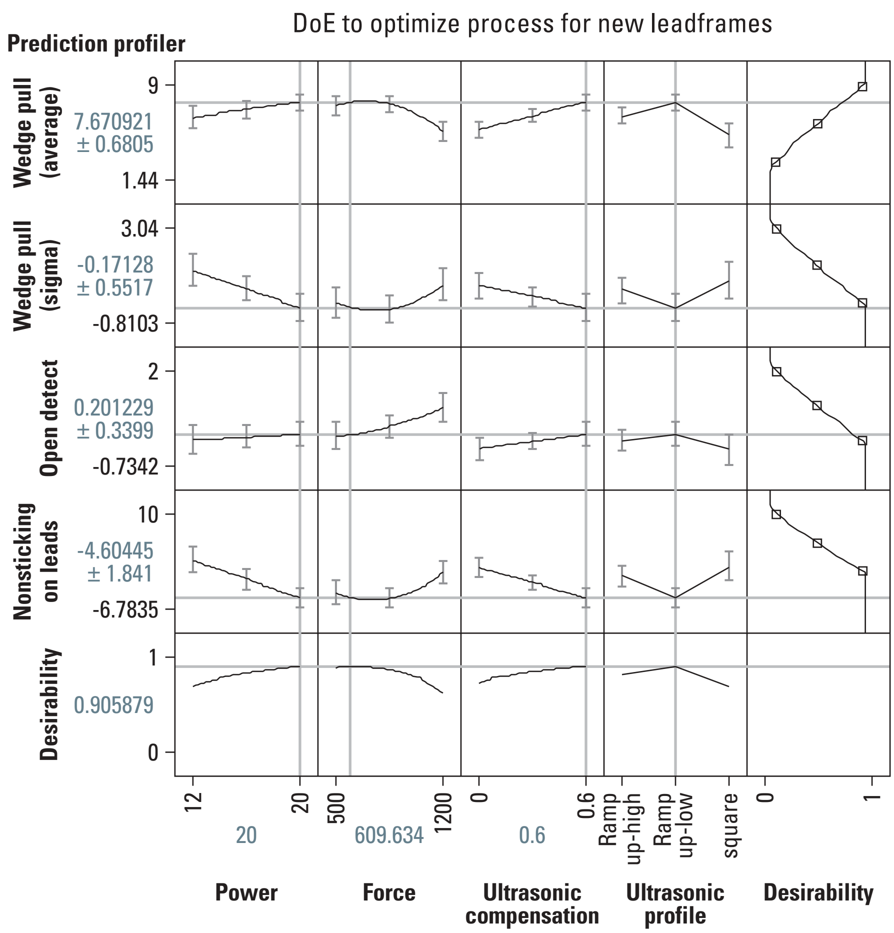
Riding the Wave

National has realized tens of millions of dollars in hard and soft savings from the work of various teams from our Singapore and Malaysia assembly and test facilities as well as our wafer fabrication sites in Texas, Maine and Scotland. We've shown how effectively our individual know-how, coupled with Six Sigma, adds a new level of value to our production capabilities.

The number of certified Green Belts and BBs at National is now rising. More than 30 DMAIC projects were initiated within manufacturing sites in wave two of our Six Sigma effort, and four cross site projects were initiated. Wave three deployment is now under way as National turns its attention to design for Six Sigma. Engineers from site to site are talking the same language and using the same analytical tools.

Six Sigma has enhanced National's problem solving expertise, giving us a logical path to follow to a wealth of business and strategic gains—as well as an edge to stay ahead of the competition.

FIGURE 1 Design of Experiments (DoE) Prediction Profiler



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