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Second Generation Product Development at Zylex Corporation[1]

Continuous vs. Discontinuous Innovation in Rapidly Changing Environment

Zylex Corporation developed its highly successful FutureEtch product in 1987 when it was a relatively small company with annual revenue of $20M. The product was targeted for the thin-film etch segment of the semiconductor process equipment market. Semiconductor manufacturing process is briefly described in Appendix A and the design and operation of an Etcher is described in Appendix B.

By 1992, FutureEtch (Exhibit 1) had penetrated the market worldwide and could be found in most IC production fabs. Zylex had successfully developed and commercialized its second generation product past its startup stage and had grown into a major player in the industry with annual revenue of $175 million. The company's impressive growth rate continued over the next two years and Zylex became the number one etch equipment supplier in 1994.

By early 1995, however, the company's fortune was about to overturn by the way the company had managed new software product development. Mike Hsu, Director of Software Engineering Department was contemplating what had gone wrong and how to recover from the serious problems that the company's new software was facing in the field.

State of Software Technology at Zylex

The software real-time operating system (OS) and graphical user interface (GUI) for FutureEtch were developed internally (home grown) at Zylex; as it was the common practice of the time due to the lack of a mature commercial solution. The product's process capability had been continuously improved based on the original software platform and the company had managed to keep up with customers' increasing demand for higher productivity and tighter etch performance.

On the other hand, software technology in the industry had advanced significantly since the inception of FutureEtch and the software engineering managers at Zylex sensed

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[1] *Dr. Dariush Rafinejad prepared this case based on an excerpt from his book: "Innovation, Development and Commercialization of New Products", 2005, and as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.*

that their product had become archaic. Their sense was reaffirmed by competitive pressure and input from the company's sales force conveying customers' concerns about the limitations of FutureEtch software. Zylex software managers were also dismayed by competitors' superior software exhibited at *semicon* trade shows around the world.

The design of the legacy software (or Classic, as it was later called) was limiting the life cycle evolution of FutureEtch capabilities, and its GUI was not user friendly and did not look appealing. The legacy code was not designed in Object Oriented (OO) structure and most of it was written in assembly language. The continuous improvement projects (CIP), for adding new features and capabilities or fixing bugs, were very difficult and time-consuming to implement. It was hard to partition work, and to do simultaneous development by several developers for rapid execution. Furthermore, the engineering pool with the right skill to maintain the legacy software was getting increasingly small. Most of the original designers and developers of the Classic product had left the company by 1992 and it was hard to hire anyone who knew the legacy methods or was willing to learn the antiquated technologies that would not enhance their resume! It was time to overhaul the FutureEtch software.

Upgrading Software With Modern Methods and Technologies

In 1991, Zylex hired a new software engineering director, Mike Hsu, a graduate of Carnegie Mellon University who was trained in modern software technologies and development methods. He immediately initiated a major project to replace the FutureEtch legacy operating system with a new OO-design and to write the code in C-language. Mike alerted the electrical engineering department that the system controls had to be upgraded as well in order to take advantage of the new software capabilities. The best software engineers in the department were assigned to the new project and it was code-named Enable. Hardware engineers, in turn, initiated their own parallel project.

Enable project plan called for beta testing of the product by autumn of 1992, six months after the project start, and for product release by January 1993. The Enable software design that adopted the latest advances in software technology was also planned for use in the company's new Symphony product line, which was based on a new multi-chamber cluster platform (Exhibit 2).

Symphony's development had begun in March of 1992 and was planned for market introduction by early 1994. Symphony was a radical departure from the past platform architectures. Traditionally, process equipment such as FutureEtch, had one process chamber and performed a single process step. New market requirements necessitated an equipment platform that was constructed with several reactors and performed multiple process steps on the wafer (serial processing). The multi-chamber (or cluster) platform was also used to perform a single process step on multiple wafers concurrently (parallel processing) to enhance productivity of the tool.

Following intensive research, the Enable product development team selected NeXT Corporation as the supplier of several major components of the new software, including the operating system, GUI framework and a few utilities. NeXT Corporation in 1992 was shifting its product strategy from a hardware computer company (that competed with Apple

Corporation) to a software product company. Zylex's Enable project was an attractive opportunity for NeXT enabling it to penetrate the real-time operating system market. NeXT Corporation was founded by the Silicon Valley icon Steve Jobs and Zylex engineers were excited to work with his company and to integrate leading edge innovative technologies into their second generation products.

Mike and his team promoted their new strategy heavily inside the company and won support of Alan Kingsley, vice president of engineering, and Ray Brown, the Company CEO. Ray Brown was impressed by the sleek GUI demo that Mike and his team were able to put together after only a couple of weeks of effort. Mike was off to a great start at Zylex.

The Zylex team was so impressed with the GUI capabilities of NeXT products that they did not adequately assess the suitability of the NeXT operating system (OS) for real-time control applications. The etcher's real-time control required a very small signal latency and very robust performance under a wide range of operating conditions. Also, as the team found out later, NeXT Corporation's initial commitment to real-time OS technology diminished over time as the company's product strategy shifted to other markets.

Enable project was completed on schedule and the Enable version of FutureEtch was introduced to the market as planned by December of 1992. At this time, Enable did not have all the features and capabilities that had been built in the Classic software over its long life. The marketing team argued that they had to introduce the new product to fend-off competitive pressure and to position Zylex as a leader in software technology. The lacking features were deemed non-critical to etch performance and could be tolerated for a short while. The engineering team, on the other hand, committed to develop the lacking capabilities in a few months and to upgrade customers' tools at no charge. Enable FutureEtch was positioned as the next generation etcher that could deliver substantial added benefits.

By January of 1995 Enable's installed base had grown to more than 200 machines.

Market Reality Fades the Initial Euphoria

While Enable's software was being developed, Zylex continued to sell etchers with the legacy Classic software and grew its large installed base. Meanwhile, Zylex customers, to keep up with their product needs, demanded continuous improvement of the legacy software (in their fabs) with new features and capabilities and with improved reliability and usability. Although the software department's engineering pool to staff the Classic software projects had diminished to a critical few in 1992, Classic's continuous improvement projects (CIP) continued with the help of old employees turned consultants and part-time contractors.

The Classic product, with continuously enhanced capability, shipped concurrently with the Enable FutureEtch. Customers who had an installed base of Classic and wanted to increase fab capacity were reluctant to change process tool fearing loss of operational efficiency and quality in manufacturing process. On the other hand, when they built a new fab to manufacture the next generation IC design, they preferred to use the most advanced process tool and many switched to Enable. Most customers owned both Enable and Classic products and could compare their performance.

In spite of its great initial promise and future potential, Enable software proved to be unreliable in the field and its features and capabilities remained below the level of Classic performance even by 1995. Because Classic capabilities and features were continuously enhanced, Enable could not catch up, particularly because most of Enable engineering resources were tied up in resolving numerous critical reliability problems with the NeXT Operating System soon after the product was shipped to customers in early 1993.

The problems with Enable were twofold: first: the poor quality (reliability) of NeXT software and its shortcomings as a real-time operating system, and second: competition with Classic, a (continuously improving) legacy product.

Exhibit 3 illustrates the first problem by demonstrating the growth paths of features and capabilities for both Enable and Classic products. The Classic software development followed a typical new product s-shaped profile: a slow start followed by a steady rise that finally leveled off as the old technology of Classic software became the limiting factor in keeping up with the market demand for more capabilities.

In contrast, Enable's development and capability growth started very rapidly (Exhibit 3) for the following reasons: many of Classic capabilities could be directly ported to the new Enable-NeXT platform; management assigned high priority to the project; the development environment for Enable's new technology was efficient; the overall system performance requirements (such as the reactor parameters and characteristics of the robots) were well understood when the Enable project started; and finally, FutureEtch hardware was mature (except for the new controller). Hardware maturity was an important factor. When hardware and embedded-software of a new product are designed concurrently, software development is often hindered by hardware problems (as it was in the case of Classic during its early development phase.)

Nevertheless in early 1995, Enable capabilities were at best on a par with the Classic, except for the GUI look and feel, where Enable was clearly superior. Software reliability problems had disappointed the customers and were Enable's most critical challenge.

The software engineering director, FutureEtch product manager and the company sales personnel had told customers that Enable would be a lot "better" than Classic. To the customers, "better" meant more capabilities and enhanced reliability from the day that the first Enable was received!

Software Problems Turn into a Major Business Challenge

In January 1995, the future prospect of Enable was in jeopardy as it faced two major challenges. First, the customers' and Zylex Management's patience with the product's numerous reliability problems was running thin. Customers were so unhappy with Enable that they were threatening to convert the software in their machines to Classic and Sales did not want to sell any more Enable. Second, NeXT Corporation, the supplier of the OS and GUI software, appeared non-committal to fixing the shortcomings of the OS and was hinting that it might discontinue the OS product in the not so distant future.

The latter was a huge problem because Zylex's new Symphony platform was also using the NeXT OS, with the same reliability problems. The situation with Symphony had not yet reached an acute state since the product's installed base in 1995 was still less than 50 tools, which were mostly in the customers' R&D lines and not in production where product reliability was a major requirement. Yet, Symphony's situation was a time bomb and potentially a more severe problem than FutureEtch Enable because Symphony was the product of the future for the company and was estimated to have at least a 10 year life, extending to 2005.

The company management was facing a major decision in January of 1995. Conversion of all or a large number of the Enable tools in the field to Classic, as some customers had demanded, was a very unattractive option for Zylex. The Enable software accompanied a new hardware module for the control system that had to be replaced in any Enable-to-Classic conversion. Furthermore, Zylex had sold Enable at a premium price compared to Classic and potentially had to refund the customers if the tools were converted! The total conversion cost was estimated to exceed 50 million dollars, accounting for incidental costs of market share loss and customer dissatisfaction in addition to the hardware and software retrofit cost and the refund. Furthermore, all converted equipment in customer fabs had to be re-qualified for production at a huge downtime disruption, production risk and cost to the customers.

This had become a make-or-break scale problem for Zylex Corporation, which had grown its business to $750 million in 1995, thanks to successful development and commercialization of several FutureEtch derivative and CIP products.

New Product Strategy

Mike Hsu received a rare phone call from Ray Brown late at night from Korea. Ray had just finished a key meeting with the top executives of his number one customer whose fab operation had been seriously impacted by Enable. Ray Brown asked Mike to recommend a comprehensive product strategy that would get the company out of its conundrum and encompassed new direction for Classic, Enable and Symphony product lines.

Contemplating what course of action to recommend at the upcoming strategy session with Ray Brown, Mike Hsu summarized the issues with NeXT Corporation and its OS software as follows:

1. Future business viability of NeXT Corporation and its ability to support Zylex.
2. NeXT Operating System's technical and reliability limitations and NeXT Corporation commitment to the operating system (OS) and to fixing its problems.
3. Symphony software and controls architecture and GUI framework were based on NeXT.

4. Zylex, being only a small customer of NeXT, had very little leverage and was not strategically important to NeXT.
5. Contractually, Zylex managers had done a poor job of negotiating an agreement that committed NeXT to a tight performance spec and to provisions for default. Hence, NeXT was not willing to license their software source code to Zylex to fix the problems!

Mike and product managers considered many options going forward including changing the operating systems from NeXT to Microsoft NT, for both Enable and Symphony products lines. In 1995, NT was rapidly gaining market acceptance as an operating system for many professional PC applications, but field data about its appropriateness as a real-time operating system was limited. The experience with Enable had taught Zylex managers a lesson in product development: “Replacing the software of an existing product with a radically different one was not so easy”, said Mike to his department staff. Nevertheless, Zylex engineers and managers spent many weeks exploring the NT option. For Symphony, the team considered writing whole new software based on the NT OS.

Questions:

1. What course of action should Mike Hsu recommend to Ray Brown at the strategy session: for Classic and Enable versions of FutureEtch and for the Symphony product line? Why?
2. What were the characteristics of Zylex products, markets and lifecycle that made it susceptible to its problems?
3. What do you think were the root causes of Enable product problems?
4. What could Mike and his team have done differently for Symphony?
5. What correct turns and wrong turns did the team make in project execution, market penetration and market positioning of the Enable FutureEtch?

Exhibit 1

FutureEtch System Layout

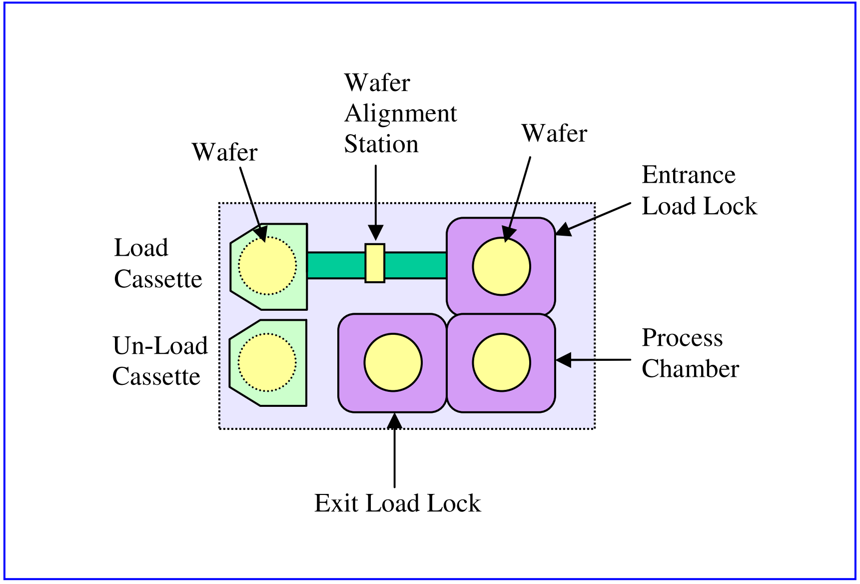


Exhibit 2

Symphony System Layout

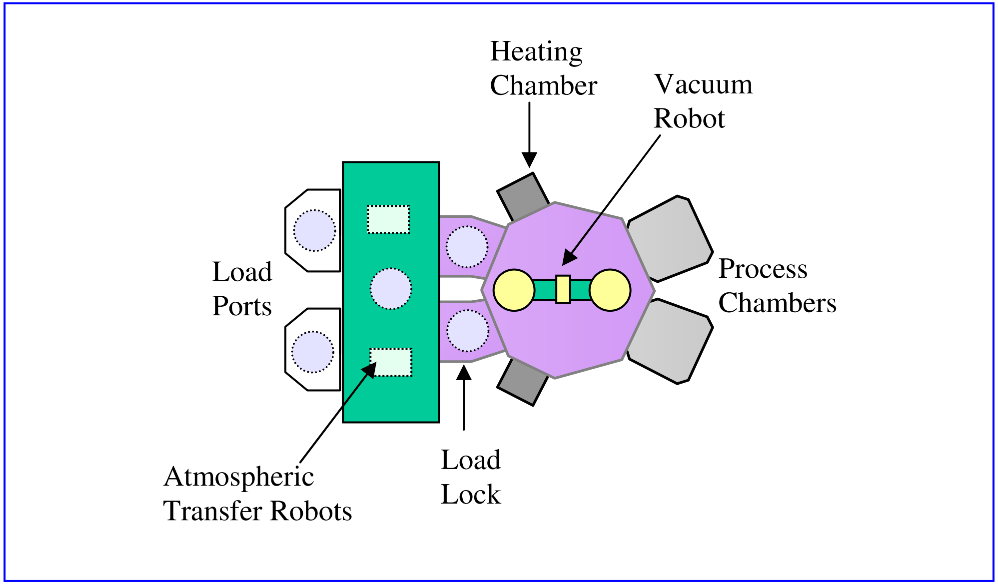
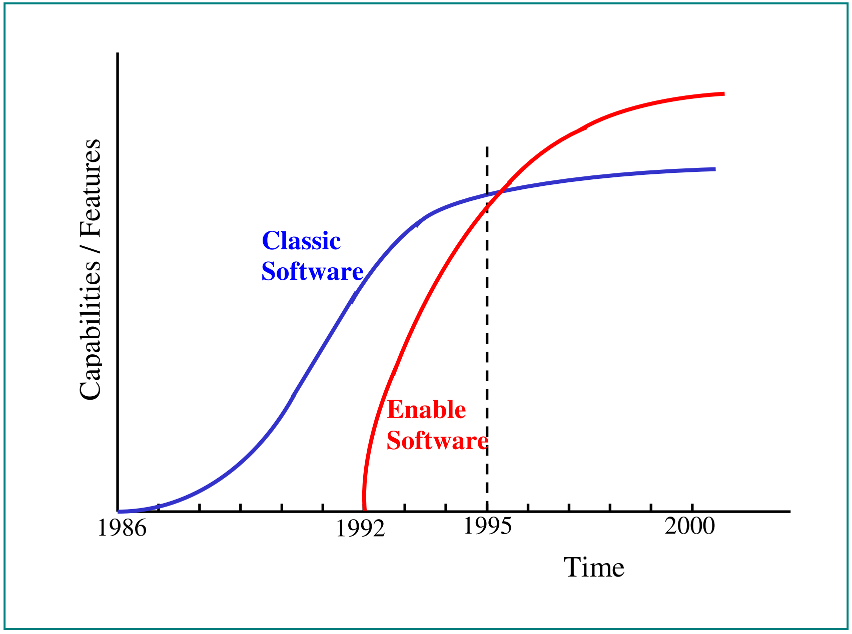


Exhibit 3

Capability / Feature Growth of Classic vs. Enable Software



Appendix A
Semiconductor Manufacturing

Over the past few decades, advances in the semiconductor industry have been rapid through ubiquitous application of electronic technology in consumer and industrial products, worldwide. Application of integrated-circuit (IC) chips is widespread even in places that are neither visible nor suspected. For example, in 2001, 40% of the cost of building a car was in electronics and software.

End-user products in consumer and industrial markets drive the entire supply-chain of the semiconductor business, in technology and production demand. As shown in Exhibit 4, the chain starts with consumer electronics products that create demand for IC chips and drive their design. The chip design sets requirements for the fabrication process technology that in turn influence the design and manufacturing of wafer process equipment. IC manufacturing plants, or fabs are furnished with process equipment and produce a variety of semiconductor devices such as microprocessors and memory chips.

Semiconductor devices are fabricated on single-crystalline silicon wafers through a series of steps performed by multitude of process equipment. The process steps comprise successive deposition of thin films, photolithography (for pattern-generation) and etching of the patterns to build transistors and other microstructures such as interconnect wiring. Multiple inspection and metrology steps are also performed along the way to ensure high yield manufacturing. To fabricate a high-performance microprocessor that is designed with 90 nm transistors, over 300 process and inspection steps are required. Several hundred IC devices are typically built onto a single 300 mm wafer that is subsequently diced and packaged as individual IC chips for integration onto end user electronics products.

The market for consumer and industrial electronics products and services drives the demand for semiconductors that in turn is fulfilled through building IC fabrication (fab) capacity. Because of the high cost of process equipment in building IC manufacturing capacity (~ $2 billion for a typical 300mm fab), equipment is designed for a long production life and for use over two or three generations of IC technology cycles (or design rules.) To meet the evolving performance requirements over successive IC generations, process equipment is modified through continuous improvement programs that are performed by equipment suppliers according to IC manufacturers' specification. Process equipment platform architecture (in hardware and software) has a typical life span of 10 years which is the half-life in wafer size evolution. The wafer size in IC production has steadily grown from 100 mm and 150mm in the 1980s, to 200 mm in 1990s, and to 300mm in the current production fabs.

Semiconductor and wafer fabrication equipment industries have both grown at a compound annual rate of 15% over the 1975 to 2000 period. This has been faster than the growth rate of the overall U.S. economy and most other industries over the same time period.

The impressive growth in the semiconductor industry has been enabled by technological achievements (following the Moore's Law and doubling IC performance every two years) and by cost reduction through productivity and yield enhancement. The pace of IC production ramp to design-yield has also increased concurrent with technological progress over multiple generations of Moore's Law. The industry's best performance in going from equipment installation to full production yield in manufacturing of 250 nm microprocessors (on 200mm wafers) was seven quarters. Ten years later in 2002, the duration of an equivalent ramp for 90-nanometer microprocessors and on 300mm wafers, was only four quarters. This is in the face of much increased complexity in the manufacturing technology at 90 nm device generation vs. the 250 nm device.

Relentless improvement in functionality per unit cost over the last four decades has been truly phenomenal and has made semiconductor devices so ubiquitous that it is hard to imagine life without them.

Enabling or even keeping up with these impressive accomplishments has, as expected, presented tremendous challenge for the players in the semiconductor value-chain throughout its the history.

Appendix B
Design and Operation of an Etcher

The intricate circuitry of an IC requires deposition and patterning of many different thin-film materials and in several layers. As a result, many etch steps must be performed in an IC fab, making the etch equipment market the largest segment of the wafer process equipment market.

Exhibit 1 illustrates the layout of Zylex FutureEtch product. Wafers are transported around an IC fab in a 25-wafer holder or cassette that is loaded onto the etcher at a loadport. Modern etch processes are performed under vacuum in the reaction chamber that is isolated from the loadport by a vacuum-loadlock. Upon completion of the desired etching process on a wafer, it exits from the reactor, passes through an exit-loadlock and moves into the unload-cassette. Wafers, one by one, move around the etch equipment automatically and without human intervention to minimize contamination and maximize productivity. In order to achieve the desired etch results, pressure, temperature and flow of reactive gases inside the vacuum reactor are controlled in real-time to a very high degree of precision. Furthermore, wafer transport around the etcher is carried out by advanced robotics that enable maximum productivity (speed) and accurate positioning of the wafer at every station on the etcher.

Real-time process-control electronics and software represent two of the most critical subsystems of the etch equipment. The software that manages the equipment input/output and the interfaces to the operator (GUI) and to the fab is also critical to material-handling and fab-wide process control.

At Zylex, like other fab-equipment suppliers, software engineers learn to be very good system engineers because they need to understand the function of every component as well the operation of the entire system.

The reactor design and process formulation (recipe) of an etcher are generally deemed the core technology of the product and the basis of competitive advantage in the equipment market. Software subsystem, on the other hand, is considered an “infrastructure” capability of the equipment and not a differentiator. Nevertheless, software performance is critical to achieving the desired etch-performance and high productivity of the etcher and, as this case illustrates, can become the choke-point of success for an equipment supplier.

Exhibit 4

Electronics Products and Semiconductor Manufacturing Supply-Chain