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STEVENS ALLIANCE FOR TECHNOLOGY MANAGEMENT

Getting to Breakthroughs:
Approaches and Organizational Structures, *or* How to make the Impossible Possible

by Peter Koen

Disproportionate wealth creation comes from breakthrough products. A study done by Kim and Mauborgne[1] of 30 companies in 30 different industries, highlighted in exhibit 1, indicated that breakthrough products are responsible for a substantial amount of the profit in these companies. While breakthroughs comprised 14% of the product launches, they contributed 61% of the profit.

What do we mean by a breakthrough? Perhaps the best definition comes from the book by Leifer[2] et. al. on Radical Innovation, which classifies a breakthrough as being one that offers a 5-10 times (or greater) performance improvement or a 30-50% (or greater) reduction in cost. A classic example of a breakthrough product is Tagamet, a new class of drug, called H2 antagonists, for healing ulcers more quickly and painlessly than previous drugs. It was the first billion dollar drug in the pharmaceutical industry. Similar breakthrough products include 3M Post-It notepads and the Polaroid camera.

Why don't more companies focus more of their resources on breakthrough products if disproportionate wealth creation comes from them? This dilemma is best explained by Christensen in his classic book, "The Innovator's Dilemma[3]." He indicates that leaders do not embrace disruptive technologies because:

- Disruptive technologies at first have worse performance for mainstream customers. A classic example is the hard disk drive market. Initially mainframe computers utilized 14 inch Winchester drives which had 200 MB of capacity. New competitors were developing smaller drives – such as the 8 inch drive. However, IBM and other companies in the mainframe market saw little use for this niche product and failed to take it seriously. As most companies do, they continued to focus on the current technology in order to improve its performance and decrease its cost. The 14 inch drive market had margins and certainty that appeared superior to the lower margin and uncertain technology of the 8 inch drive market. However, the 8 inch drive fueled the minicomputer market which – over time – proved disruptive to the mainframe market to the extent that the 14 inch drive became obsolete. It was too late for IBM and other companies to take advantage of the new trend since the 8 inch drive developers already had established a foot-hold based upon their skills and manufacturing capacity.

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DIRECTOR'S NOTE

During the past fifteen months the Alliance has devoted four Roundtable meetings and a symposium to the general theme of stimulating creativity and achieving breakthrough products. Our colleague Peter Koen, Associate Professor at the Howe School, has been a prominent contributor during these meetings, providing us with much insight and stimulation. In this issue Dr. Koen summarizes the key conclusions and recommendations from his extensive research on breakthroughs.

We are also pleased to feature in this issue an article by Murrae Bowden on the technology S-Curve. Dr. Bowden is Director of the Executive Master's program in Technology Management at Stevens, and his extensive experience as a technology manager in industry makes him eminently qualified to address this important topic.

Larry Gastwirt

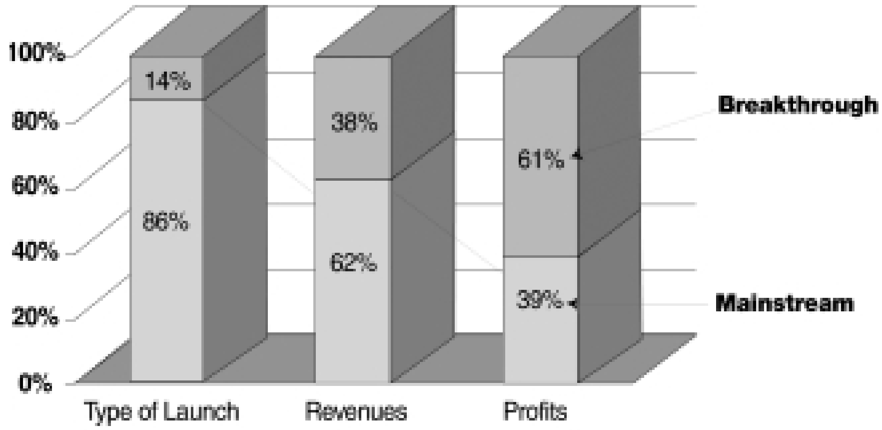
STEVENS Institute of Technology

Breakthroughs...

Continued from cover

Interestingly, the pattern repeated itself in the 5.25 and 3.5 inch drive markets, where each of the preceding companies failed to take advantage of the new market until it was too late. To quote Bower and Christensen[4], great companies "…fail – not because they make the wrong decisions, but because they make the right decisions…." by listening to their mainstream customers who typically demand enhanced performance with deceased price from the existing technology.

• It is difficult to see the long term potential of the new technology. When the 8 inch drive was first introduced it was difficult to see how a lower performing product could be of value to mainframe companies. It was difficult for these companies to envision the rapid rate at which the technology of 8 inch drives would improve in terms of storage capacity. Similarly, it was difficult for vacuum tube makers to take seriously the poor fidelity that was being introduced in the early transistor radios. Today's radios are all made from transistors (i.e. integrated circuits). Just as IBM missed the 8 inch drive technology, so did vacuum tube manufacturers fail to make the leap to the new technology.



Kim and Mauborgne. "Value Innovation: The Strategic Logic of High Growth." HBR, Jan-Feb, 1997

Exhibit 1. *Study done by Kim and Mauborgne of 30 companies in 30 industries showing that while Breakthroughs made up only 14% of the product launches, they accounted for 61% of the profit.*

To quote Bower and Christensen , great companies "…fail – not because they make the wrong decisions, but because they make the right decisions…." by listening to their mainstream customers who typically demand enhanced performance with deceased price from the existing technology.

Bower and Christensen advocate that the organization that is developing the disruptive technology be isolated from the mainstream until the new technology becomes commercially viable in the new market. They indicate that a separate organization is necessary since the new stream business cannot attain the same profit margin or focus on technologies that are distractive to the main stream business. Based on this challenge I have been investigating the ways in which companies organize around breakthroughs.

Separated Business Development Group

A well documented example is Proctor and Gamble's separated corporate business development group (Whitney and Amiable[5]), which put aside $250 million of seed money to develop at least one major business per year. The team consisted of full time people from brand management, R&D, finance and market research. While they handed off 5 projects to the business sectors, they have yet to develop a profitable business since the divisions have had difficulty allocating people to the new projects. In fact the director of the unit wondered if many would "…survive…" (Whitney, 1997, pg 13), since many of the concepts were several years from the market.

This transition from the internal corporate venture group to the existing businesses is a classic problem of separated business development units which are funded by the corporation. Thus it appears that separated business development, while successful in pursuing new opportunities, has difficulty transitioning the new business or technology to the main stream business. In fact the director of the venture unit indicated that if he "…started over today, he would have the heads of all the business units involved as an advisory council" (Whitney, 1997, pg. 13) to ensure better transition.

The Changing Role of the Corporate Research Laboratory

The Corporate Research Laboratory's (CRL) traditional mission has been to develop and prove the feasibility of high risk exploratory research which would have significant benefit to the corporation. Traditionally these units were relatively independent of the business units – being funded through a corporate tax and free to pursue high risk technologies. However, considerable reorganization in most CRL's occurred during the latter part of the 1990's when firms placed more emphasis on CRL's to produce bottom line results. Most companies "…increased the business-focused level of funding from between 30-50 % to up to 70-80%…" (Glass[6], et. al. 2003, pg 25). This has resulted in much stronger

To quote Deming,

"The quantity and quality of results you get depend on the processes and systems you use to produce the results." Processes are essential for high impact innovation.

alignment of the CRL with the SBU. The new model that appears to be emerging in successful CRL's is a more integrated approach to breakthroughs that employs the following nine principles:

- **Business Technology Interspersing**. Basic research can provide the fundamental underpinning for a disruptive technology, but often delivers little value to the corporation. In contrast, applied research, which is tightly focused on application and incremental improvement, provides value, but rarely becomes the platform for high impact projects. The new role of the CRL is to effectively link them. This is done through corporate oversight and business stewardship, by assuring that the basic science goals are business-driven rather than science-driven, by integrating corporate and functional research planning, and by executing projects with a cross-functional team made up of both corporate and applied research people.
- **Market and Technology Trend Analysis**. Companies that first ask, "What sand box should they be playing in?" before focusing on specific products have a consistent track record of high impact innovation. This is a hallmark of successful Venture Capitalists, who first ask what market areas they should be looking at for new businesses, rather than by starting their search with specific new businesses. The new sand boxes are typically identified by evaluating market and technology trends.
- **Science-Based Core Competencies**. Competitive advantage is often derived from the unique core competencies and capabilities of an organization. These reside in the skill of people within the organization. Thus one of the prime imperatives, to achieve a continuous flow of breakthroughs, is to ensure that the organization possesses a skill base that is superior to its competitors and ensures continued retention of the people who posses the competencies. In addition, science-based core competencies typically lead to an intellectual property position which better assures long term competitive advantage and profitability.
- **Aggressive Goals**. Setting aggressive goals with a clear vision is often necessary to achieve success in breakthroughs. An example of this is the way in which Corning senior management set forth a clear aggressive goal to develop the next generation of catalytic converters when they realized the huge potential of the forthcoming reduced emission requirement of the Clean Air Act. Corning, in 1970, directed hundreds of scientists and engineers to focus on this single challenge, and now dominates the marketplace in catalytic converters.
- **Scientific Peer Review**. Review by scientific peers during a project helps evaluate the scientific aspirations of the project and better assures that the science involved meets the necessary standards of excellence and rigor. Many technology projects in companies are not accomplished with the correct scientific rigor. Peer review forces the project team to address the hard scientific issues that in turn will typically result in sounder scientific plans and execution than without such review. Scientific peer review represents a fundamental characteristic for assuring technical rigor in "best in class" companies.

While scientific peers may exist within the company, I recommend that companies utilize external scientific peers. External peers are more likely to provide a fresh view and opinion of the project, and typically are more forthright in their evaluation of the technical risks associated with the project. The external peers invited to participate are required to sign confidentiality agreements that include non-compete clauses and assign any inventions that occur as a result of the engagement to the company.

- **Constancy of Purpose (Focusing)**. In order to get to the next breakthrough the overall vision should be stable over time. For example, Corning stated the goal of developing the next generation catalyst which would be able to meet the new regulatory standards. This vision was communicated so that the organization clearly knew where they were heading, and that it was unlikely for this vision to change.
- **Process Optimization**. To quote Deming, "The quantity and quality of results you get depend on the processes

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What leads to success?

Business-Technology Interspersing

Project Selection based on Market and Technology Trend Analysis

Competitive Advantage, often derived from Science-Based Core Competencies

Aggressive Goals

(External) Scientific Peer Review

Constancy of Purpose

Process Optimization

Very early Prototyping and Field Trials

Full-time Project Team, populated with inventors with demonstrated track records

Moore's Law and the Technology S-Curve

by Murrae J. Bowden

The birth of the modern electronics industry can be traced to two seminal inventions - the invention of the transistor in 1948 at AT&T's Bell Telephone Laboratories in New Jersey in 1948, and the invention of the integrated circuit in 1959 by Robert Noyce at Fairchild and (independently) Jack Kilby at Texas Instruments.

The transistor enabled the electronic functions of modulation and amplification to be performed in a tiny piece of silicon, which consumed a fraction of the power used by vacuum tube based electronics, and ushered in the era of solid-state electronics exemplified by the popular transistor radio of the 1950s.

The integrated circuit derived from the development of the planar silicon process, which permitted simultaneous fabrication of multiple transistors and other electronic components in the surface of a silicon wafer. The individual components could then be interconnected on the surface of the chip to produce functional semiconductor devices, such as memories and microprocessors. These devices enabled the personal computer revolution, along with the plethora of electronic equipment exemplified by cell phones, digital cameras and such like that today constitute a near trillion dollar electronics market, sustained by a $150B market for semiconductors.

Since its inception circa 1960, the modern semiconductor industry has been driven for reasons of economics, speed and reliability to build more and more functionality into the integrated circuit or 'chip'. The principal means to accomplish this has been to shrink the size of the individual circuit elements. By reducing the feature size associated with the circuit elements of the transistors in a memory cell, for example, smaller and smaller transistors can be fabricated enabling more of them to be packed into a given area of silicon real estate, thereby increasing functionality while lowering the

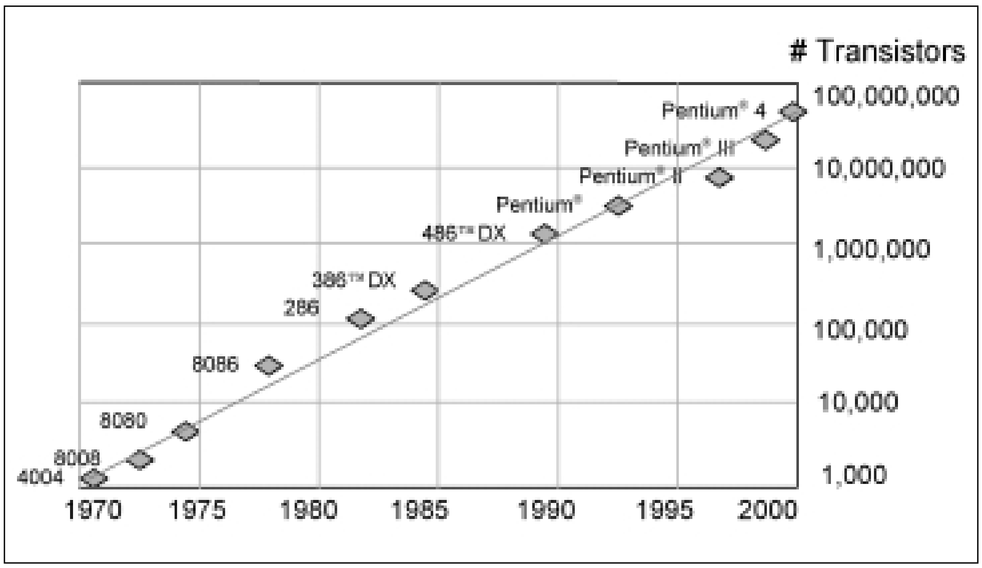

FIGURE 1. Moore's Law

cost of a memory 'bit'. Since 1960, the cost of a transistor has fallen by a factor of 107, which is a triumph of technology matched by few other advances.

Shrinking the size of circuit elements, e.g., the gate feature of a transistor, also enables the transistor to operate at faster speed, thereby reducing the time required to perform certain operations. The 2.2 GHz speed of a Pentium 4 processor, for example, compared with 66 MHz of the earlier generation Pentium 1 derives primarily from the much smaller gate dimensions of the former. The third advantage attending shrinkage of the device is reliability. Being able to cram 1GByte of memory, for example, into a single chip results in a more reliable package than having to interconnect and package 4 separate 256MByte chips.

These advantages provide a clear incentive to chip manufacturers to shrink the feature size as quickly as possible to gain competitive advantage by bringing the latest generation in chip design to market before their competitors. But how quickly?

Historically, the industry has been able to double the number of transistors on a chip approximately every 18 months. This trend was actually first reported by Gordon Moore in 1965 in a review article published in Electronics. Moore who, subsequently cofounded Intel along with Robert Noyce, noted that the number of transistors on a silicon chip, plotted as a semi log plot against time, had increased linearly over the preceding 5 years, doubling approximately every 18 months. Moore reasoned that continued improvements in manufacturing technology, innovation (device design) and chip size should enable that trend to continue for several more years. Just how well Moore predicted the industry trend can be seen in Figure 1, which shows a semilog plot of the number of transistors in the various generations of microprocessor chips against time through 2000 indicating continuation of the linear trend for the past 35 years!

So accurate was Moore's prediction, it has become enshrined in the industry lore as Moore's Law, and subsequently codified as the International Road Map for Semiconductors. For forty years, Moore's Law has been the yardstick driving innovation as semiconductor manufacturers continually strove to gain competitive advantage by being first to market at the next technology node within the time frame 'specified' by Moore's Law, or even earlier. Indeed, 'beat Moore's Law' has become the competitive mantra for leading-edge firms.

Moore's Law is an example of a classic S-curve whereby performance as measured by some convenient metric, e.g., speed, plotted on a linear scale follows the shape of an S over time, ultimately reaching a limit determined by some fundamental physical constraint associated with the underlying technology, such as a basic law of physics (Figure 2). At this point, the technology is mature with no potential for further improvement.

To understand how the industry has been able to adhere to the trajectory of Moore's Law, it will be helpful to have an understanding of the underlying technologies used to manufacture integrated circuits. Principal among these is optical lithography, shown schematically in Figure 3.

A silicon wafer is first oxidized to create a thin film of silicon dioxide on the surface of the wafer. The wafer is then coated with a thin film of a photosensitive material called a photoresist, and exposed to a patterned source of radiation (by means of a photomask) to form a latent image of the mask pattern in the photoresist. Development of that latent image creates a three-dimensional replica of the two-dimensional mask pattern in the photoresist. The process is analogous to photography with the exposure tool equivalent to the camera, and the photoresist equivalent to the photographic film. Etching the oxide layer bares the silicon substrate, enabling subsequent modification of the electrical properties in these precisely patterned areas.

As seen in Figure 3, there are two critical requirements associated with the lithographic process - tools to translate the circuit image into a spatially modulated aerial image, and resist materials to record that image as a latent image, which can subsequently be developed to form a three-dimensional pattern in the resist film. Both are highly interdependent. Development of a suitable resist requires tailoring the photochemistry of the resist to the wavelength associated with the exposure tool, and development of the tool requires availability of a suitable photoresist. Both exposure tool and resist must be commercially available to the chip manufacturer in the timeframe "dictated" by Moore's Law.

The problem is that the development of viable lithographic tools and process technologies takes a considerable period of time - typically10 years and more, which means that technology choices must be made long before the extant technology has matured. Why should this be a problem?

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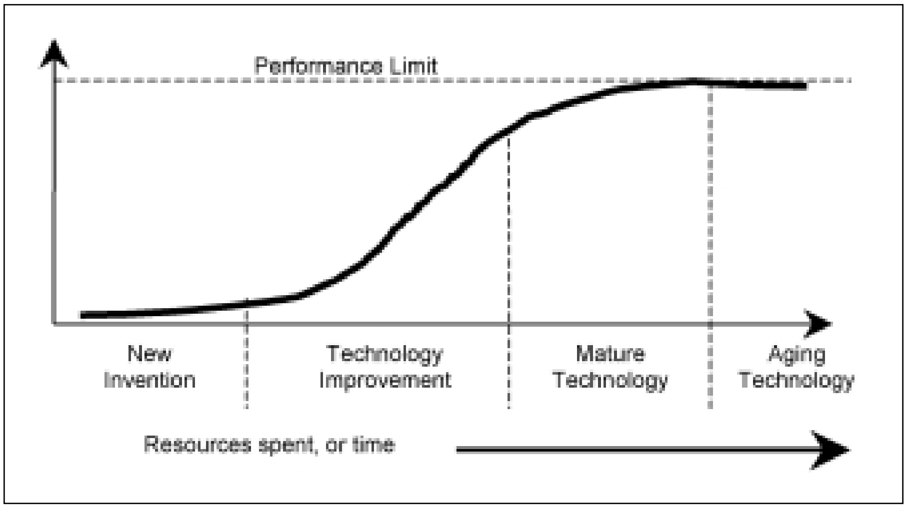

FIGURE 2. Technology S-curve

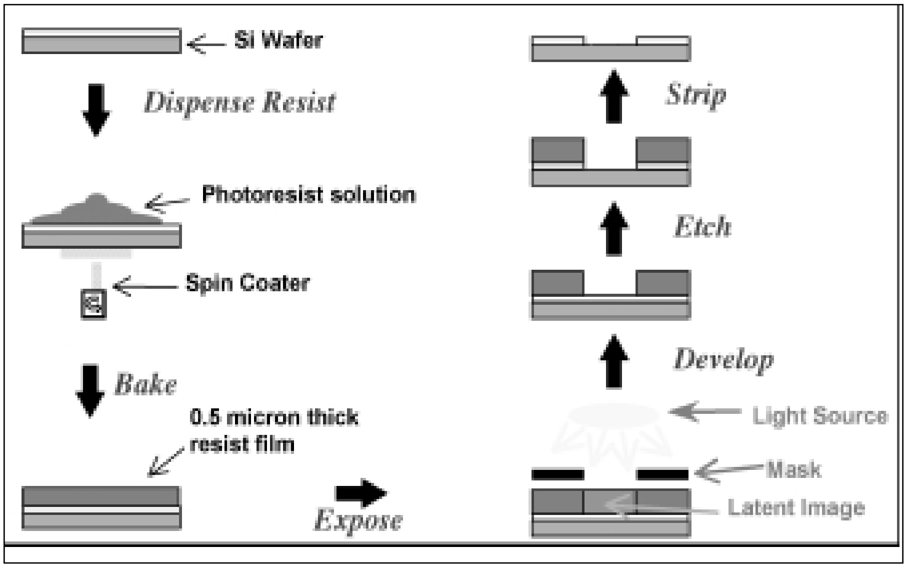

FIGURE 3. Lithographic Fabrication Scheme

Moore's Law...

Continued from page 5

In the early 1970s, technologists believed, based on prevailing knowledge of physics and materials science, that diffraction/engineering constraints would limit the resolution of optical lithography to around 2.0 micro meters (µm). Hence, practical realization of Moore's Law beyond feature sizes of 2.0µm would require development of an alternative exposure technology offering higher resolution. Although the optical performance "limit" was not anticipated for several more years, early choice and development of a substitute technology was needed in order to assure timely availability of the next generation of manufacturing technology. In response, advanced R&D organizations, such as Bell Labs, IBM, Texas Instruments, Hitachi, and others began around 1970 to pour millions of dollars into the development of electron beam lithography, which was seen as the logical successor to optical lithography.

Committing to a successor technology and development timeframe long before the extant technology has matured carries enormous risk. Factors include:

- The correctness of the assessment of the performance limit associated with the prevailing technology
- Potential for development of sustaining technologies enabling further progression along the technology S-curve, i.e., the predicted performance limit derives from engineering limitations of the prevailing technology, not with the larger optical lithography paradigm
- The technical and economic viability of the substitute technology

Failure to adequately consider these risks may result in flawed technology strategies and business decisions that can threaten the viability of the business.

In the case of optical lithography, the prediction of 2.0µm as the performance limit proved completely wrong. Subsequent improvements in sustaining technologies associated with optical lithography, especially the development of reduction step-and-repeat printing tools employing shorter and shorter wavelengths, enabled printing of circuit features well below 2.0µm. However, this was not before millions and millions of dollars had been spent on developing scanning electron beam exposure tools, that subsequently came to be viewed as impractical for chip manufacture, not for reasons of resolution, but of throughput limitations, which made manufacturability uneconomical.

Moore ... noted that the number of transistors on a silicon chip, plotted as a semi log plot against time, had increased linearly over the preceding 5 years, doubling approximately every 18 months. Moore reasoned that continued improvements in manufacturing technology, innovation (device design) and chip size should enable that trend to continue for several more years.

Fortuitously, the investment in e-beam lithography was not entirely wasted. Bell Labs recognized that this technique was ideal for making the masks used in photolithography, and subsequently commercialized their electron beam exposure system known as EBES, together with the associated resist technology also developed at Bell Labs. The EBES system, commercialized by the ETEC corporation as MEBES, has been the industry standard for e-beam mask making since its introduction in the mid 1970s.

As the 1980s approached, the industry again faced a critical decision. Recognizing that the diffraction limitations of optical lithography were wavelength dependent (the limit was now thought to be around 1.0um), technologists recognized that diffraction effects could be all but eliminated by making a two to three- order of magnitude reduction in wavelength by moving to the X-ray region. Again, millions and millions of dollars were committed to the development of X-ray lithography by Bell Labs, IBM and others. Again, these decisions proved to be highly flawed. Continued advances in the technologies sustaining optical lithography enabled fabrication of devices in the sub-micron regime. Further, as with direct write e-beam lithography, X-ray lithography also proved to be impractical for commercial implementation because of engineering constraints associated with source and mask. Those constraints proved insurmountable, and those who embraced the X-ray lithography paradigm ended up writing off the hundreds of millions of dollars in investment, and in a number of cases, claiming bankruptcy.

It is interesting to speculate whether these mistakes could have been avoided, or at least the investment losses minimized. The quest for an alternative to optical lithography was driven by inaccurate predictions of the performance limit of the technology. It had been recognized in the 1970s that resolution, defined by the Rayleigh equation as $W = k_1\lambda/2NA$ where λ is the exposing wavelength, NA the numerical aperture of the lens in the exposure tool, and k a processing constant, was theoretically much less than 2.0µm. There was no evidence to suggest, however, that the wavelengths and numerical apertures could be realized that would enable such improvements. The incorporation of short wavelength lasers, for example, used in today's advanced steppers could not have even been conceived back in 1970. In other words, the predictions of the demise of optical lithography were limited by assumptions regarding the prevailing engineering technology not fundamental physical limitations.

In reality, the S-curve encompassing Moore's Law is a composite of multiple

S-curves associated with the underlying sustaining technologies, which include

- Mask
- Light Source
  - Wavelength, bandwidth
- Image Projection
- Optics
  - Materials (Chemistry)
  - Aberration, Distortion (Physics)
- Tools
  - Engineering
- Resists

As the history of optical lithography has shown, claiming the demise of a technology based on the development status of some subset of sustaining technologies can be highly flawed. Improvements in lens technology (materials and engineering) have subsequently enabled fabrication of lenses with close to theoretical numerical apertures. Improvements in laser technology have enabled practical light sources at wavelengths down to 157nm. Improvements in mask technology have enabled implementation of wavelength engineering techniques and k-factors permitting fabrication of devices with minimum feature size less than half the exposing wavelength. Continued improvements in materials technology enabled development of resists matched to the shorter and shorter wavelengths of evolving stepper tools.

Over time, the development path of each of these technologies continued to evolve along their individual S-curves (See Figure 4 which illustrates the evolution of resist technology by wavelength with different platforms emerging as the previous platform reached its limit of performance). Convolution of these individual S-curves has enabled continued progression along the composite S-curve for optical lithography.

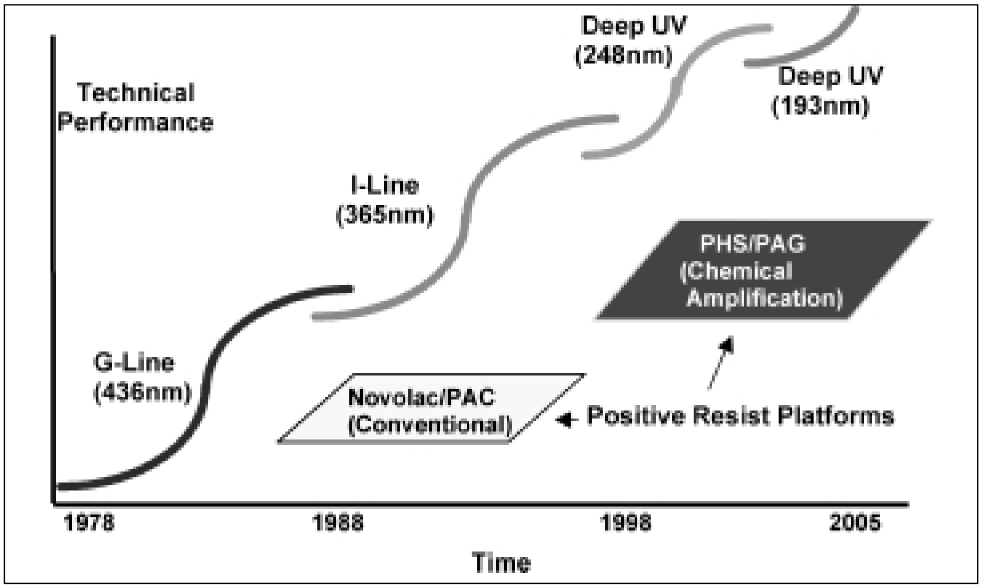

FIGURE 4. Resist Evolution showing material platform transitions required by changes in wavelength of the exposure tools

The problem faced by the industry over the years has been in accurately assessing just where the technology in question lies on the S-curve, and the difficulty of the technical challenge limiting the attainment of optimum performance. Had the developments in the technologies supporting optical lithography been foreseen, the millions of dollars in R&D costs invested by the industry in alternative technologies might have been forestalled.

So accurate was Moore's prediction, it has become enshrined in the industry lore as Moore's Law, and subsequently codified as the International Road Map for Semiconductors.

Perhaps, but herein lies the tyranny of Moore's Law and the pressure it creates for the semiconductor industry. Moore's Law says nothing about the manufacturing technology associated with a given technology node, only the timeframe in which it will be available, i.e., it defines the time frame for technology evolution, without specifying what that technology should or will be. In this context, Moore's law is simply an expression of faith in the engineering community's ability to have a manufacturing solution available in the required timeframe.

Given the long lead-time for technology development in the semiconductor industry, management must make a rational assessment of practical performance "limits" of the prevailing technology and decide whether they reflect a true performance limitation caused by some underlying physical principle, or an engineering limitation in one or more of the sustaining technologies. S-curve methodology tells us that if we are at the physical limit of performance of a prevailing technology, we have no choice but to opt for the discontinuity, provided a viable technology and business model can be implemented.

The choice is more difficult when the limitations are perceived as engineering in nature. The industry's commitment to Moore's Law precludes the luxury of waiting to see if developments in the prevailing technology prove capable of meeting manufacturing needs several years hence. The risks of adopting such a technology strategy are simply too great. Hence the strategy of the industry has been to do both, viz., attempting to solve the engineering problems thereby moving further up the S-curve

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Roundtable Meeting Take-Aways

KEYS TO DEVELOPING "BLOCKBUSTER" NEW PRODUCTS

The fiftieth SATM Roundtable meeting was held at Unilever Bestfoods North American Headquarters in Englewood Cliffs on July 17, 2003. This was a follow-up to the January Roundtable, which was devoted to tools and techniques for achieving breakthroughs. The facilitators were Prof. Gary Lynn (glynn@stevens-tech.edu) of the Howe School of Technology Management at Stevens, and Dr. Brad Allenby (ballenby@att.com), Vice President for Environment, Health and Safety at AT&T.

Gary Lynn began by summarizing the major findings from the eight-year study of more than 700 new product launches conducted with his colleague Prof. Dick Reilly, which culminated in their 2002 book "Blockbusters: The Five Keys to Developing Great New Products". The term "blockbusters", as used by Lynn and Reilly, refers to those rare new products and services that alter the future of a company, lead to entirely new families of products, or possibly even usher in a whole new industry.

Examples include Motorola's cellular telephone, the Iomega Zip Drive computer storage device, General Electric's Cat Scanners, the Xerox 914 plain paper copier, Corning's optical fibers, the Apple IIe, and the Handspring Visor personal digital assistant. In this sense the findings apply to a different class of products than the breakthrough new products studied by Peter Koen, in that the latter, as important as they are to a company's results, do not necessarily transform a company, a market, or an industry.

Gary and Dick found five critical practices -- within the control of the company -- that determined success in coming up with a blockbuster. They can be summarized under the headings of: Senior Management Commitment, Clear and Stable Project Pillars, "Lickety Stick" Improvisation, Effective Information Exchange, and Collaboration Under Pressure (See inset, page 9, for elaboration.)

Gary emphasized that doing all five practices well was critical to successfully creating a blockbuster. The five essential practices were present at high levels on the blockbuster teams, and at relatively low levels on the teams that were unsuccessful or only moderately successful. The differences were illustrated quantitatively in Gary's slides, one of which is reproduced here as Exhibit 1.

This exhibit, for example, illustrates the importance of senior management involvement. Of the blockbusters studied, over 70% reported high levels of management involvement. By contrast, high levels of management involvement was reported in a little more than 50% of the successful projects, and in only some 15% of the failures.

Similarly, clear and stable project pillars was some three times more prevalent in the block-

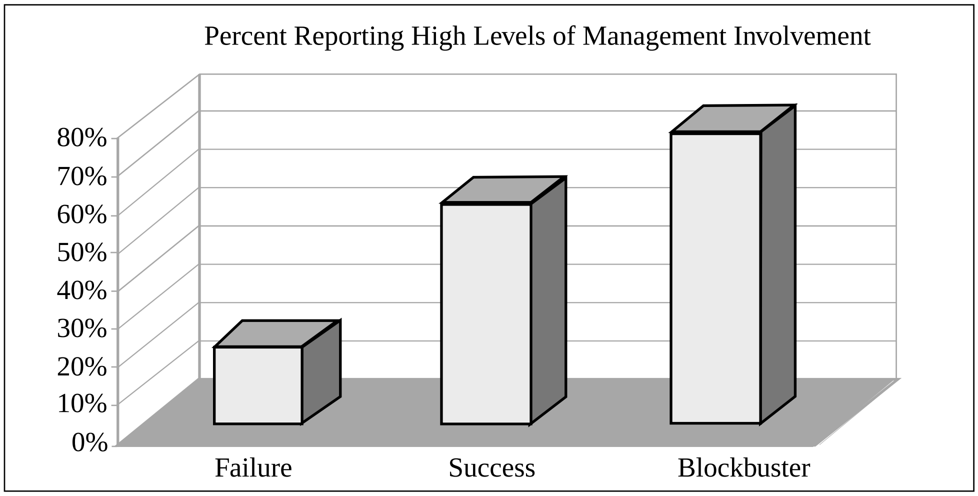

EXHIBIT 1. Senior Management Involvement

buster projects than in the failures, and "Lickety Stick" improvisation was used proficiently in twice as many blockbuster projects as in failures. Similar differentiation was found with respect to the other factors.

Following Gary's presentation, we heard from Brad Allenby of AT&T, who led a discussion of teleworking and the virtual office. Implementation of the virtual office concept would certainly represent a "blockbuster" innovation, in that it clearly has the potential to transform a company or an industry. AT&T is moving aggressively to the virtual office scenario, and Brad and his team have been very active in assessing, resolving and implementing this concept on all fronts: technology, process, policy and the soft side of career, environment and psychological impacts. Brad thus presented his discussion as a case study of a blockbuster work-in-progress.

Already 17% of AT&T managers work from virtual offices without provisioning, either from home, on the road, or in "hotel space" furnished with telecommunications equipment when they need to visit an AT&T facility. An additional 33% telework at least two days per week. The higher the management level, the higher is the percentage of teleworking. AT&T is experiencing savings of $35M/yr. in real estate costs, and over $100M/yr. in increased productivity, from implementation of the virtual office concept.

Achieving and sustaining the virtual office requires developing a communications foundation and a truly "net-centric" organization with ubiquitous access to company databases and information. It also requires a change in the culture of the organization. It will fail if treated as the "flavor of the day". While there is a feeling of discomfort initially, Brad said that people get used to working that way. Indeed, he raised the question of whether it makes any sense to bring knowledge workers into a central location.

This led to a spirited discussion, with several participants questioning how it could be effective in developing complex products requiring the integration of inputs from many functional groups, where wisdom has it that direct face-to-face collaboration is essential. Brad claimed that at AT&T, teams are working as well as, and perhaps better than, they were before.

The loss of spontaneous, unstructured interaction between team members was also raised as a possible downside effect. Brad responded that there could be a loss among functions of differing cultures, but that emails and chat rooms could help this interaction take place.

Don Gulliksen commented that at ARDEC, the virtual office concept is already operative to a large degree. Elements of the virtual office were employed by the Army in developing some of the weapons used in the Iraq war. People aren't necessarily working with their distant colleagues from home, but from their individual, separate offices. There is usually an initial kick-off meeting on a project, followed by teleworking through emails and mutual use of websites. Physical co-location of project teams is becoming less and less an issue with ARDEC. Getting to the virtual office is an evolutionary process, not achieved "cold turkey".

Brad concluded with some other words of caution. Teleworking is very hard to do right. It is daunting in terms of the support organization, such as IT services to keep the remote network running. Network security is a major issue that must be addressed, as is managing the people side. As further background, Brad distributed a working paper, "Implementing the Knowledge Economy: The Theory and Practice of Telework", and a recent white paper that provides updated information on the AT&T virtual office program. Copies of these papers are available by contacting the Alliance office.

It was clear that we only managed to scratch the surface of this topic. There was much interest in continuing, so we returned to this topic at the November 2003 meeting. Takeaways from the November meeting will be published in a coming issue. ■

The term "blockbusters", as used by Lynn and Reilly, refers to those rare new products and services that alter the future of a company, lead to entirely new families of products, or possibly even usher in a whole new industry.

Five Critical Practices

- **Senior management commitment** (not contribution): The project team had the full cooperation of the highest level of management. Senior managers were involved intimately with every aspect of the project, or they made it clear by their actions and their "management by walking around" that they were fully behind the project, and then empowered the team with the authority it needed.
- **Clear and stable "Project Pillars"**: Blockbuster teams stayed on course by following a clear vision of the product attributes -- specific goals for the product, including time targets -- which the team had to deliver. These were defined early on by senior executives and/or team members. The desired attributes often came from their hobbies and interests, and from past exposure to things that had failed.
- **"Lickety Stick" improvisation**: Blockbuster teams did not follow a structured path to market, such as a stage-gate process. Instead, they were flexible, trying many different ideas, getting prototypes out to customers quickly, and iterating to reflect their comments until they developed a version that "stuck" with their customers. While they did not follow a rigid process, the teams did work to hard and urgent deadlines.
- **Effective information exchange**: Teams used many formal and informal methods to exchange information, including frequent video conferencing and use of "war rooms" papered with Post-it notes.
- **Collaboration under pressure**: Blockbuster teams focused on goals and objectives, as opposed to interpersonal differences. They were not especially concerned about building friendships, but they built coherent teams.

Breakthroughs...

Continued from page 3

and systems you use to produce the results." Processes are essential for high impact innovation. These include a process for interspersing business and technology planning, managing high risk technology projects – such as Technology Stage Gate[7] – linking basic and applied research and intellectual property management. It also involves developing a series of value creation metrics which are linked back to the planning process.

- **Early Prototyping and Field Trials.** The author found that all of the 11 breakthrough products on which he performed case studies took significantly longer to get to market because the team failed to identify key constraints in how the product would actually be used. For example, new process analytics equipment developed to measure octane level in the refinery was found to meet the required specifications in the central laboratory. However, the same equipment failed to work when placed near the refinery in a high humidity environment – even when the humidly was controlled. (The humidity needed to be controlled under very tight requirements, which could not be met in a field environment). This unexpected field requirement could have been uncovered had the team done prototyping with an earlier version, and would have saved several years in the product development cycle.

  Similar events have occurred in each of the breakthrough products studied by the investigator. There seems to be an inherent desire by the technology team to complete the design before releasing it for tests in the actual environment so as to not be subjected to criticism for design elements which have not been completed. While this sounds logical, it is actually counter-productive. The actual field requirements will often require additional design changes to what was already perceived as a completed design. Allowing the team to identify many of the unknown constraints earlier, which will be facilitated by early prototyping, helps accelerate breakthrough product development.

- **Full-time Project Team** populated with inventors with demonstrated track records. Numerous studies have demonstrated that people begin to become unproductive once they are juggling more than two projects. Recent work by Amiable[8] indicated that people become more creative when they are focused on a single activity for a significant part of the day and feel that they are doing important work. This is in contrast to having a highly fragmented day with multiple activities and discussions.

  Numerous studies have also shown that a relatively small percentage of all inventors do most of the discovery. It is therefore critical for a company to identify, nurture and retain these leading producers and insure that they are part of the breakthrough discovery teams. Thus this body of work tends to indicate that full-time focused teams composed of inventors with demonstrated track records have higher probability of success than similar teams not organized in the same way.

Conclusions

Breakthroughs will continue to be a challenge for all organizations. Christensen and Bower, in their ground-breaking work, provide a cogent explanation of why companies reject breakthroughs as a result of their relentless focus on their current customers. However, this relentless focus allows them to become blind-sided to new technology developments which often have perceived problems. They advocate developing the breakthrough in a completely separate organization – though these have been problematic since the new concepts have difficulty transitioning to the mainstream. A new organization is emerging, that is only partially separated from the main stream business. Organizations that appear to be having success in breakthrough projects are partially separated organizations which adhere to business and technology interspersing, perform market and technology trend analysis, develop their breakthroughs based on science based core competencies, set aggressive goals, subject the work to scientific peer review, demonstrate constancy of purpose, constantly foster process optimization, utilize early prototyping and use full time project teams populated with inventors with demonstrated track records. ■

Footnotes:

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[3] Christensen, C. M., "The Innovator's Dilemma: When New Technologies Cause Great Companies to Fail, " Harvard Business School, Boston, 1997.

[4] Bower, Joseph and Christensen, Clayton, " Disruptive Technologies: Catching the Wave," *Harvard Business Review*, Jan – Feb, 1995.

[5] Whitney and Amiable, "Corporate New Ventures at Proctor and Gamble," *Harvard Business Review*, Case 9-897-088, June 1997.

[6] Glass, J. T., Ensing, I. M. and DeSanctis, G., "Managing the Ties Between Central R&D and the Business Units," *Research Technology Management*, 46(1), 24 - 31 (2003).

[7] Ajamian, G. and Koen, P.A., "Technology Stage Gate: A Structured Process for Managing High Risk, New Technology Projects," In P. Belliveau, A Griffin and S. Sorermeyer, eds. *PDMA Toolbook for New Product Development*. New York: John Wiley and Sons, 267 - 295, 2002.

[8] Amiable, T., Hadley, C. and Kramer, S., T., "Creativity Under the Gun," HBR, August 2002.

About the Author

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2003 in Review

2003 was a productive period for the Alliance, with eight major meetings held. Our annual conference, in May, dealt with the topic of Business Process Redesign. In June we co-sponsored a symposium on Creativity under Time Pressure together with the Consortium for Corporate Entrepreneurship, and in October we co-sponsored a seminar on Increasing Shareholder Value using Technological Value Drivers, in collaboration with the Columbia University School of Engineering.

Five Roundtable meetings were conducted:

- Tools and Techniques for Achieving Breakthroughs
- Review of Faculty Research Receiving Alliance Support
- Keys to Developing "Blockbuster" New Products
- Application of Learnings from Creativity Symposium
- Workplace Transformation for the Knowledge Economy

The third of the year's Roundtables marked the 50th such forum since the series began eleven years ago.
Our re-designed newsletter appeared on a quarterly basis, and we supported the research of the Center for Technology Management Research with a significant contribution. ■

Moore's Law...

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of the prevailing optical technology, while evaluating alternative approaches aimed at creating technological discontinuity. Had the industry realized back in 1970 just how far it was from the true physical limitation of optical lithography, it may not have committed the level of funds that it did to the alternative technologies of e-beam and X-ray. The fact is it did not know, which drove the leading edge companies to hedge their bets by pursuing e-beam and X-ray lithography in addition to efforts aimed at continuing the optical paradigm.

The optical lithography example demonstrates another tenet of S-curve thinking, viz., the extant technology will continue to prevail as long as it provides an economic solution to the problems it confronts. The ultimate resolution capability of e-beam lithography is higher than that of optical lithography, but given the continued evolution of optical technology to meet industry's needs over the past 40 years, there has been no economic incentive to switch to e-beam. As a general rule, the investment in the prevailing technology is so great that industry will extract every last measure of performance before switching to an alternative. This tenet also holds true within the technologies sustaining optical lithography. Taking wavelength as an example, the switch by the industry to the next (lower) wavelength has invariably taken place only when the diffraction limit of the preceding wavelength has been reached. This has important implications for resist developers who must anticipate resolution needs encompassed by a particular exposure technology, in order to optimize their R&D investment profile.

How much further will optical lithography extend? And what lies beyond? As was the case in 1970, massive investments continue to be made in alternative next generation lithographic technogies (NGL) in anticipation of the death of optical lithography, which is now expected around 50nm. The front-runners are extreme ultraviolet (EUV) and projection e-beam, but both have engineering limitations that remain to be overcome. Today, there is even talk of the death of Moore's Law itself which, like the Concorde airplane, will likely be driven by economic constraints rather than technology capability. ■

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UPCOMING EVENTS

Five Roundtable meetings are scheduled for 2004:
February 3, April 20, July 12th, September 20th, and November 15th
(in conjunction with the annual Advisory Board Meeting).

The February Roundtable meeting will be held from 2:00-5:00 PM at ARDEC, Picatinny Arsenal. It begins a new umbrella theme, sustaining innovation in a pervasive cost reduction environment. The specific topic is "Issues in Managing the Outsourcing Relationship." Facilitating speakers will be Geza Pap, Chief of Portfolio and Knowledge Management at ARDEC, and Doug Ogino, Director of Vendor Management at Lucent Technologies.

The 2004 Conference, dealing with the issue of retaining and motivating technical managers, will be held on Tuesday, May 11.
The location and speakers will be announced shortly.

For further information on these and other Alliance activities, contact Dr. Lawrence Gastwirt: **212-794-3637 • lgastwirt@aol.com**

INFORMATION

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