Vertical Integration and the Portability of Skill Sets in High Tech Industries

by

Benjamin D. Siebach

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Signature of Author_____

Benjamin D. Siebach
Department of Material Science and Engineering
Sloan School of Management
May 8, 1998

Certified by_____

Thomas W. Eagar
Head, Department of Materials Science and Engineering
POSCO Professor of Materials Engineering

Certified by_____

Donald B. Rosenfield
Senior Lecturer, Sloan School of Management

Accepted by_____

Linn W. Hobbs
John F. Elliott Professor of Materials
Chair, DMSE Committee on Graduate Students

Accepted by_____

Lawrence S. Ablen
Director Master's Program
Sloan School of Management

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Abstract

Some companies use vertical integration to enter higher growth businesses and gain higher margins. Attractive business opportunities often appear just beyond one's stage in a value chain, leading companies to grasp for another stage's profits. However, the skill set one builds in a particular stage of a high tech value chain is often not portable to another stage in the same chain, offering a potential pitfall to those who seek to vertically integrate. This thesis explores the experience of one company's efforts to integrate vertically to capture profits enjoyed by their customers. Through a lack of appreciation for the complexity of the downstream manufacturing operations and a lack of portable competence, the firm failed to gain the hoped for revenues. Additionally, by focusing on new businesses, this company also lost some of the competence they had in their traditional business.

Thesis Advisors:

Professor Thomas W. Eagar, POSCO Professor of Materials Engineering

Professor Donald Rosenfield, Senior Lecturer

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I am grateful to my parents for their unwavering support and advice in pursuing these degrees and writing this thesis. Without them, the process would have been much more daunting.

The people who have sacrificed most through this educational process are my wife, Natasha, and my children Spencer, Sterling, and Grace. They put smiles back on my face at the end of arduous days, helping me keep perspective and balance in my life.

The company, technology and products described in this thesis are loosely based on fact.

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The Crystal Growth Allegory

Chapter 1 Technology development

Crystal Growth Company (CG) was a small division of a very large high tech materials company. CG specialized in the manufacture of silicon panels for the growing solar cell industry. With the invention and patenting of a new solar panel production technology, CG hoped to become the dominant producer in an industry with high predicted growth.

Crystal Growth had developed a proprietary technology which enabled them to cast large panels of silicon in a relatively continuous fashion. The process, called Edge-defined Film-fed Growth (EFG), was a method to produce a thin cross-section ribbon of polycrystalline silicon.

The process began by melting raw materials, mostly high purity silicon, in a crucible. The ribbon was produced through a drawing process. A mandrel would be dipped into the molten pool of silicon. The mandrel and silicon melt would fuse together and then the mandrel would be drawn vertically, pulling behind it a thin cross-section ribbon of silicon.

The geometry of the mandrel was the determining element of the final shape of the ribbon. For example, a hexagonally-shaped mandrel hoop would draw a thin-walled hexagonal tube. Such a tube could then be cut apart at the corners, with the subsequent side panels used in solar arrays. With EFG, Crystal Growth could produce panels of standard thickness up to several inches wide and up to 3 feet in length.

The patent CG received for their process was the realization of a revolutionary concept which had been proposed decades earlier. Crystal Growth had assembled a group of expert scientists and technicians. The group had

doggedly pursued the idea and were the first to successfully produce the panels in this fashion.

The EFG production process offered many advantages over other types of panel production. First, the EFG process had much higher yields than other panel fabrication methods. The cutting process produced some narrow trimmings, but over 90% of the drawn material could be used in final applications. Second, because of the almost continuous drawing of panels, CG was able to produce high-quality panels in larger quantities than other methods. Third, the solidification rate of the silicon could be closely controlled with the EFG process. This affected the grain size of the silicon, enabling the tailoring of material properties to specific applications. Fourth, based on the mandrel, many different geometries could be produced for specific customers and applications. Lastly, larger panels could be produced than possible with other production methods. This reduced customers' waste and costs as they fabricated panels into solar arrays.

Crystal Growth was enthusiastic about the potential the EFG process had to revolutionize the solar panel industry. They could produce a tailored, high quality product at a lower cost than other producers. CG's next efforts went towards the industrialization of their casting processes and the development of markets.

Chapter 2 Evolution of the EFG process

Over several years, Crystal Growth scaled up their production processes. The first generation furnace and drawing equipment had been used in the Research and Development laboratories for process development. Every two or three years, as market growth demanded, CG would introduce a larger and more advanced generation of their casting equipment. The latest version stepped from batch to continuous production by constantly replenishing the melt bath from a preheating furnace. The older equipment stayed in service and gave CG development capacity and small order flexibility.

Other enhancements were introduced to the casting process. Improved computer control over critical process variables enabled CG to more accurately influence solidification rates and grain sizes. This enabled CG to satisfy customers who were increasingly interested in large grains because of improved electrical properties. Also, improvements were made in raw material inputs, mandrel materials, and crucible design. CG continued to invest heavily in the development of all elements of casting technology.

A continuing and rewarding challenge for Crystal Growth was the development of applications for customers. The older, small-scale casting lines gave CG flexibility and capacity to support innovation. Among the innovations were novel methods of doping silicon panels, specialized coatings and films, and variations in product thickness. With their flexibility and expertise, CG was able to expand beyond their core solar panel business and garner a large number of customers in diverse industries.

Chapter 3 Revenue and cost pressures

Crystal Growth had profitable relationships with several small panel material consumers. Small customers were usually outside the solar energy industry and used CG's material as a small component in some larger, high value-added products. These customers generally purchased customized material developed by CG for them or for a specific application. In these cases, CG was producing and supplying as a job shop using their small batch casters. The costs of production were higher, but CG's highest margins made the business very attractive.

Crystal Growth also had a single large customer, Solen, with high demand for less specialized solar panel material. The U.S. market for solar energy was small, but foreign governments avoiding large infrastructure investments often turned to solar energy for remote locations. Solen was the leader in these foreign markets.

Because of their large size and market dominance, Solen was able to negotiate very low prices for panel material. CG's margins were barely sufficient to keep the business attractive, but the high volumes kept the largest casting line mostly loaded. CG tried to keep the product volume high, as much like a continuous process industry as possible, to gain economies of scale and to help cover most of the overhead costs of their factory.

Crystal Growth's parent company had made a significant investment to invent and industrialize the EFG process. These initial investments had not yet been recovered. In fact, more capital was flowing into CG to improve equipment and pursue other markets through tailoring material properties. The business was not making a satisfactory rate of return and pressure was placed on CG to improve their growth and margins.

Along with corporate profitability pressures came a reduction in Solen's demand for CG-supplied panels as foreign investment in solar energy slowed. This reduction in demand led to a reduced workweek for many of CG's caster operators and some uncertainty about the future of the business.

To satisfy corporate's goals of growth and higher margins, Crystal Growth needed to change their business. CG had several options, one of which was to close the casting lines, sell the technology and equipment to another company and gain licensing fees. The scientists, technicians and business managers were committed to the technology and did not want to see the business, or their jobs, go to another company. Another more attractive option was to fill the capacity vacated by Solen with higher margin products. Crystal Growth set out to discover new markets and applications which promised higher growth and higher margins.

Chapter 4 New products and markets

Crystal Growth entered a market search phase with urgency and enthusiasm. With significant casting expertise and in-depth product and application experience, CG was confident that large revenue-generating opportunities were yet to be discovered.

The largest consumer of electronics grade silicon was the computer industry. Silicon wafers, a material very similar to CG's panel material, are the foundation of all integrated circuits. The computer industry was growing rapidly and no slow down was predicted. Crystal Growth knew that high-end chip producers were seeking superior materials that could enhance chip performance or reduce production costs.

Further, the industry changed so quickly that a constant turnover of suppliers and producers was the norm. The cultural barriers to market entry were nearly non-existent in the computer industry. With a superior technology and product, CG could easily gain market share.

Lastly, IC producers were accustomed to high prices for silicon wafers. If CG could provide a material superior to traditional wafers, the market and margins could be better than any other market for panel material. With CG's history of successful innovation, the chip industry appeared to be a promising and untapped market.

Traditionally, silicon wafers for computer chips were made in a very expensive drawing process in which a seed crystal is placed in a bath of molten silicon. The silicon melt immediately contacting the seed crystal takes on the same atomic structure as the seed. The seed crystal is then drawn from the melt, creating a solid, single-crystal cylinder called an ingot.

The ingot is three to eight inches in diameter and reaches lengths of more than two feet. After cooling, the cylinder can be ground perfectly round and sliced into

thin wafers with a diamond saw. However, sixty to seventy percent of the silicon is lost in the grinding and slicing operations. The high losses and costs associated with post cast operations make this process a very expensive step in the chip industry.

Crystal Growth's idea was to use EFG to draw silicon ribbons, but to cool the ribbons extremely slowly. Through slow cooling, the grains would grow to a large size, perhaps an inch in diameter. From these large grains, a single chip-sized wafer of silicon could be inexpensively cut out. This small wafer, cut carefully from one grain, would have no detrimental grain boundaries. A single microchip could then be made from the wafer instead of the one to two hundred integrated circuits on traditional large wafers.

Crystal Growth's material offered chip producers many improvements over traditional silicon wafers. First, chip manufacturers could more economically produce low volumes of prototypes or of a particular design. Second, if quality problems occurred in production, with a lot size of one chip, only one chip would be lost. Though the contamination and loss of an entire eight inch wafer was rare, a quality problem could potentially ruin all 200 chips, an enormous cost and loss of revenue to the chip producer. Lastly, tooling required for microchip production could be made smaller and less complex, resulting in start-up cost savings. Reduced start-up costs would let new chip producers enter the market and introduce new chip designs, spurring a whole new wave of innovation in electronics.

The market opportunity for small wafers was appealing to Crystal Growth. The chip business would require high volumes, perhaps fully loading CG's largest casting line, and would offer very high margins. The match between market needs and CG's growth and revenue requirements appeared to a good one.

Chapter 5 The decision to integrate vertically

The integrated circuit chip market represented a tremendous market and profit potential for Crystal Growth. The margins in this business promised to be more than ten times higher than the margins CG received in the solar panel business. Where CG sold several square feet of material for tens of dollars to Solen, they could sell a single wafer, maybe a square inch, for the same price to chip makers. Some salesmen predicted even higher margins in niche markets, particularly if Crystal Growth's wafer material had some tailored properties.

Crystal Growth felt they needed these high margins to save the struggling EFG technology-related business. The decision was made to pursue the computer chip market with all available resources. Research and development produced a rudimentary production process to make small wafers. Many other hurdles had also been crossed. For example, some test material had already been produced with suitable large grains. This material had been used by a chipmaker to evaluate the concept. Preliminary results were very promising. Crystal Growth trademarked the Uniwafer name for this application and began showing the product to potential customers.

After further development and market research, Crystal Growth had to decide how they would participate in the market. Several options were present, though two seemed most likely. First, Crystal Growth could be a material supplier to the wafer production companies. CG's superior materials could be purchased by wafer makers, processed further by them, and then sold through the standard industry channels to chip makers. A drawback of this plan was that some of the potential margin would be ceded to wafer companies. CG worried that they would be relegated to a commodity supplier role and their profits would disappear as they had with Solen.

Another possibility was for Crystal Growth to produce IC-ready Uniwafers. This option required CG to become a more integrated producer of electronic

materials. After casting, additional steps would be added to the manufacturing process to turn raw cast panels into wafers salable to chip producers. CG would need to build supply channels by establishing relationships with wafer distributors as well as chip producers. This option had the added advantage of getting CG closer to their end consumer. With face to face contact, CG hoped to identify additional high margin market opportunities for their products.

Crystal Growth made the decision to become an integrated producer of chip wafers. Several reasons brought CG to this conclusion, but foremost, revenues would be much higher if all value-adding steps of the wafer production process were done by one company. CG wanted the margins to insure they would be able to keep the business going.

Chapter 6 Production process development

Crystal Growth Research and Development group had produced small quantities of test wafers for chip manufacturers. These test wafers were made by technicians and scientists, largely by hand. In order to produce large volumes for the computer industry, the method of production had to be industrialized. CG pursued industrialization in several different ways.

In some instances, laboratory equipment, or time on the equipment, was dedicated to the production process. For other process steps, a scaled-up version of their lab equipment was purchased. For example, a heating jacket used in the production process to maintain panel temperature for grain growth was simply a larger model of the heating jacket used in R&D. In all of these cases, the staff was comfortable with the technology and its capabilities, knew suppliers, and could get off-the-shelf equipment quickly.

Crystal Growth also bought some state-of-the-art, numerically-controlled machinery available in the market. Especially in the case of panel cutters, this equipment was identical to the machines that any outside wafer production

company would have. CG had used this type of equipment in the past in the customization of panel material for other customers.

Other specialized equipment was available in the market, but CG felt they could build something in-house with greater capability than the commercially available equipment. This was the case with the grain boundary locators. This machine would find the edges of the silicon grains and mark them. The later cutting process would then cut out the material within these marks. CG felt they had requirements nothing in the market could adequately fill. They designed their own equipment, had the parts produced by local machine shops, and assembled the machines themselves. These machines worked well, but were very expensive, having been designed and built by highly paid lab researchers and technicians.

With equipment gathered from R&D and vendors, installed in warehouse space next to the R&D center, and with the addition of a temporary labor force, Crystal Growth began producing Uniwafers for the IC chip industry. Initially, scientists and technicians were the primary production workers, training the temporary work force during the course of normal production.

Chapter 7 The production process falters

With the development of a production process, Crystal Growth began to produce low volume Uniwafers for a small number of chipmakers. Word quickly spread about the advantages of Uniwafers and a subsequent ramp-up in demand was dramatic, far more than marketing predicted. Almost immediately, CG was thrown into a crisis order-fill role with processes not fully proven.

Several factors handicapped Crystal Growth's production process. First, operators needed to become familiar with the equipment they were running. Either machinery was new to operators or new operators were running older machines. In both cases, operators were incapable of producing consistent

volumes with high quality. In other cases, machine vendors had not installed equipment properly. Operators slowly learned to run the machines, but significant downtime was spent troubleshooting.

Second, process parameters had never been fully defined. In research and development, scientists found a simple production process that worked. However, the additional efforts of process optimization and stabilization had never taken place. Yields were low through many process steps. In some production steps, equipment was not capable of consistent production. In other stages, the equipment was fine but procedures and methods were lacking. Much of this process optimization and stabilization was now taking place as the factory struggled to ramp up.

Also, management had difficulty scheduling the factory effectively. Production was very erratic. One day a particular process step may produce up to expectations, then the machine may be down for a few days with mechanical problems. Process bottlenecks shifted often and unpredictably. Order lead times were difficult to forecast.

Management had the additional challenge of controlling a process with which no one was comfortable. Scientists and technicians, functioning as part of the workforce, had little expertise but significant responsibility for training others in production methods. The process engineering group was expert with panel casting processes, but had very little experience with discrete part manufacture. They had difficulty making improvements in the process. Management was no more familiar with the process than others. All employees were being challenged with new and different issues.

Crystal Growth's management focused their attention on the many problems at hand. Machine vendors were brought in to fix equipment. Engineering and maintenance resources were dedicated to Uniwafer production problems. Consultants were called in to identify problems and suggest improvements. Familiarity brought some stability to the production environment and CG

managed to service many of their new Uniwafer accounts. The general feeling, however, was that production was on the edge of either significant success or disaster.

Chapter 8 Loss of focus

Crystal Growth's management made an excellent first pass at stabilizing the process and making the Uniwafer production process more capable. With both the casting operations and Uniwafer production stable, management confidence grew. However, when problems developed in either casting or Uniwafers, management had difficulty bringing processes back into control.

Focus was difficult to maintain in the very different businesses that a single team of employees was running. Management's attention was now spread over very different types of production, different types of customers, and different production workforces. Maintenance had a casting operation to maintain as well as becoming familiar with and maintaining new Uniwafer production equipment. Supervision had the traditional CG employees in casting to oversee as well as a largely temporary workforce producing Uniwafers. Each type of business presented significant and very different challenges.

For many months, the primary problems were with Uniwafer production. All efforts were made in improving the productivity and quality of this process. However, by neglecting the casting operations, problems began to surface. In the absence of most support people, the productivity and quality of cast material deteriorated. Now that many in the plant had spent most of their time in and grown comfortable with Uniwafers, their old specialty, casting, became the Achilles heel of the operation.

A cycle developed. There were not enough resources to have dedicated teams focused on both casting and Uniwafers production. In fact, upper level management was reluctant to dedicate resources to either side, fearful that silos

of responsibility would develop within the factory. Instead, a single team would flow from problem to problem. While focused on that solution, other areas would be neglected. Frequently, progress made in one area would disappear once the team left to face another problem. Thus, a complete and permanent solution to nagging production problems was rarely found and instituted.

Also, customers for other materials cast by CG began complaining about slow order fulfillment. Lead times for typical stock material, usually filled within a couple weeks, were stretching out several months. Casting's priority was to support Uniwafer production at the expense of other markets. In some cases, delivery date promises were not even offered to customers.

Chapter 9 Skill sets diminish

The Uniwafer business started stronger and with greater potential than anyone predicted. Initial successes overwhelmed Crystal Growth's ability to supply the demand. Variation in quality and a lengthening delivery time eventually drove customers to substitute materials and competitors. The Uniwafer concept was widely accepted, but the industry could not afford CG's unreliable supply. The business continued to grow but at drastically reduced rates.

Eventually, Crystal Growth turned to a joint venture partner, Bhata Industries, to produce some of the Uniwafers. CG supplied cut out wafers and left some final product preparation steps for Bhata. The partner's advantages were low labor rates, high productivity, and substantial experience with discrete manufacturing. Bhata proved to be an effective supplier for the Asian chip producers. Crystal Growth came to rely more and more on Bhata's productivity and capacity for a more stable supply. However, with increased reliance, CG was becoming increasingly uncomfortable with the partnership and resented losing revenues.

With the focus on product, process, and market development for Uniwafers, the quality and delivery reliability of the core cast materials business declined.

Important quality gains won at great expense in prior years evaporated. Productivity fell as supervision and management became absorbed in other issues and lost touch with the casting operations.

Because of Crystal Growth's inability to supply on a timely basis, many of the low volume / high margin panel customers turned to alternative materials or suppliers. Crystal Growth maintained some market leadership because they were the only supplier capable of filling the volume requirements of the larger, low margin relationships like Solen. These customers remained and continued to hammer CG for price reductions and improved quality.

Chapter 10 Learnings

Several factors combined to lead Crystal Growth to evolve from an advanced material developer and supplier to a computer parts manufacturer. Additional factors led them to underperform when both businesses were combined. Several of the salient points are presented with commentary.

Vertical Integration Promoters

Crystal Growth was led by competent managers with first-rate scientists leading the technological innovations. These rational people were led by a series of logical decisions into a business in which they could not perform. Some of the good reasons for entering the wafer business are presented.

The most important reason for Crystal Growth's entrance into the wafer market was the need for growth markets and higher margins. The wafer business offered both of these. Without the promise of significant growth sources, CG's cash lifeline may have been pulled by their mother corporation. CG and the EFG process needed new and lucrative markets with new applications to stay in business.

Second, Crystal Growth needed a more powerful position in the marketplace. In prior supply chain relationships, CG lost power as they were relegated to a material supplier role while their partners gained profits and market position as the users and suppliers of CG's innovative material. By controlling the whole value-adding chain, from materials to finish parts for the end user, CG hoped to prevent anyone from stealing their profit margins.

Third, by supplying the end user of their products, Crystal Growth hoped to find a seedbed of new ideas. The ideas would become new businesses and markets for their products. Instead of supplying a fabricator, a market middleman, CG would supply the chip makers, known as the industry innovators. With effective partnering, CG would become a valued supplier in a very high tech industry. This reputation would serve CG well in future markets. Also, CG's parent company liked to be associated with high growth, high tech industries as a vehicle for profitability. A business plan presented by CG which included a growing portion of business in the computer industry would be much easier to sell to corporate management.

Fourth, Crystal Growth already had a small scale production operation. CG felt the scale up to full production would be straightforward, perhaps more so than sharing the methods of production with a partner. CG considered the post cast operations to be relatively simple and felt they could do it as well as anyone else.

Fifth, Crystal Growth protected their casting operation with a fortress of patents. In the early casting development process, they had lost some critical technology rights and were determined to not let that happen again. By sharing the post cast fabrication steps with an outside partner, some fear existed that other competitors, or their partner, could learn too much about their material and the casting operation. That knowledge could be used to duplicate the EFG process.

Lastly, Crystal Growth had developed technology and expertise that was superior to any of their competitors. After having invested an enormous amount of money into the development of this expertise, CG wanted to protect their product's

inherent value by moving down the value chain. Of the steps in the value chain, the casting process was the most critical link for producing a high quality and highly differentiated product. Other processes were relatively standard, whether the chipmaker was using CG's material or a competitor's. CG felt they deserved the high margins because they made the unique, high value-adding material.

Vertical Integration Inhibitors

Many pitfalls, however, prevented Crystal Growth from being successful in the Uniwafer business. First, Crystal Growth had assembled a portfolio of low technology post-cast operations. These operations were the methods used in the research and development process. Many could be done by hand. They were simple and straightforward and could be easily done by the scientists and technicians who performed them. CG needed to minimize additional capital required to industrialize their production process. Therefore, CG's vision was to add the same types of machinery and more labor to serve a large and demanding electronics market. However, the market demanded much more.

The wafer volume of the electronics market required mass production techniques with a significant amount of automation. The quality achievable in a labor intensive process was not high enough for the electronics industry. Also, even the relatively automated processes were not robust enough to provide consistent throughput and quality.

CG failed to recognize that their methods of production were not sufficient or sophisticated enough to service their markets. They were using what had worked in an R&D environment with R&D style equipment: highly flexible machinery, significant handwork, and low yields. Sufficient capacity and a capable process were never developed. In some cases, additional capacity in bottleneck resources was relatively inexpensive and had very rapid payback periods. Yet because of cash flow constraints, the investment necessary to remove the bottleneck was slow to be committed. Additional resources were

eventually purchased to enable CG to produce to peak demand, but the machines were not installed until demand levels had fallen precipitously.

Second, Crystal Growth's prior markets, the solar panel and other specialty applications markets, were very stable in comparison to the electronics industry. The solar panel business was relatively lethargic, with demand growing at a predictable rate. Significant changes in order quantities were often contracted months in advance of delivery. CG had a number of response options and time to consider them carefully.

The computer industry was much faster moving, and potentially explosive. For example, if CG's Uniwafers were designed into a new chip set for the latest microprocessor, demand could shoot up by hundreds of thousands of units per month, likely to begin the following month. While this would not strain the casting operations, the post cast operations would suddenly need to produce significantly more wafers. CG had very few options. Capacity needed to be available immediately.

CG was never able to keep pace with rapid ramp-ups. It is common in the electronics industry for a company to win a contract and then immediately subcontract that production out to others in the industry, even competitors. CG, without excess capacity or a willingness to partner, handicapped their ability to supply the market.

Third, Crystal Growth's managers felt they could manage whatever was thrown at them. In this case, the two types of business, and their accompanying mindset, were too diverse for management to be successful.

The panel casting business was a high tech, semi-continuous casting process. Management needed to concern themselves with machine utilization, the administration of cost and quality control systems, incremental technological advancements in a stable process, management of a stable and skilled workforce, preventative maintenance, customer relationships, and product

development. Casting was a relatively stable, older business with an enormous amount of process knowledge and experience supporting it. Customers were also very stable. A typical process improvement effort lasting months might yield a 1% improvement in machine utilization.

In the wafer business, management needed to oversee fundamental process development, the purchase and installation of new machinery, factory layout, the development of a supply chain, resource scheduling, and the management and training of a temporary workforce. Wafer production was a completely different business, lower tech but in its absolute infancy, and with much more demanding customers. There was no foundation of experience, let alone expertise, with a discrete part manufacturing operation. Here a typical process improvement effort, which may be completed in a week, doubled the yield in a process step.

Some progress was made in these fundamental areas of wafer process development at CG, but significant long-lasting improvements were not realized. For example, production resources were initially laid out in functional groups. Large waves of inventory would slowly pass from resource to resource, often sitting for days in front of various process stages. Later, efforts were made to shorten cycle times and improve quality by implementing work cells. However, management attention was not available to fully implement the work cell ideas and the potential positive impact of workflow improvements on productivity and quality was never realized.

With two disparate businesses, management and the rest of the local resources were never able to gain control of both casting and wafer production. Two separate management teams, with very different skill sets focused on each of the businesses, were required in order to be successful in supporting both businesses.

Fourth, Crystal Growth did not manage the intersection of their skills and goals very well. CG had expertise in the development of a new silicon casting process, the production of silicon panels, the adaptation of their products for new

applications, and in supplying their material to many different customers. They were flexible and innovative. Growth and higher margins were their goal. CG sought markets which would help them cover their investments and earn high profits.

Crystal Growth did not realize that their skills did not necessarily extend beyond those of an advanced material supply company. They had gotten close to material applications in the past, through partnerships and business development, but had always wisely returned to their core skills of casting and material supply. These experiences had deepened their expertise in casting, but had not extended their skills into other areas.

Presented with the Uniwafer opportunity, Crystal Growth did not appreciate the kinds of challenges that this business would present and the skills, which were necessary to be successful in the business. The opportunity was attractive, but it was not an opportunity that CG could capitalize on. Looking intently at the profit upside and minimizing the downside production failure risks led them to embrace the opportunity.

Other Options

CG was right in trying to discover and exploit new applications for their material. However, based on the superiority of their material, it is possible that CG could have developed a much stronger market position without entering the wafer supply business.

One scenario for the development of the wafer business is for CG to prove the superiority of their material to end users in the electronics industry. Then, based on the demand these end users create, CG could supply ALL wafer production companies with their material. By sharing margins with the wafer producers, perhaps something above what they can get with other competing materials, the wafer companies immediately would have huge incentive to push the product in the market. Demand for the material would skyrocket.

As a sole supplier of the material because of their patent positions, CG could have reaped close to monopoly profits in the industry. When demand outstripped their capacity, CG could have licensed the technology to other silicon material producers.

The next step would be for CG to join chip producers in designing the next generations of chips, with CG tailoring materials to the specific chip types being made. This customization adds complexity to the production process, but CG is still only in the casting business, something which they do well. CG could wield enormous market power by creating demand and controlling the raw material supply, which they were uniquely qualified to do. Such a strategy would enable them to grow and profit from their core competence without straying into other stages of the value chain through vertical integration.

This strategy is similar to what Intel did in the computer market. Intel convinced the consuming public that the maker of the computer is really unimportant in comparison to the chip set inside. If it contains an Intel chip set, the computer is good. CG could pursue the same strategy by convincing chipmakers that the wafer maker is relatively unimportant in comparison to the material that goes into the chip. As long as you use CG Uniwafers, you are assured of quality.

Crystal Growth had many other options available to them as they sought market growth and improved profitability. First, If CG believed the Uniwafer production technology were critical to keep within the business, a possibility would have simply been to create a different division within the parent company that did Uniwafer production. This is much like the path they took. Technology and scale up would still be a significant problem. Yet, the necessary resources would have been available to focus on the two disparate businesses.

CG could have formed a joint venture with a wafer production house. CG would bring the superior material while the partner would bring wafer fabrication, market and management experience. Tight secrecy agreements would need to be forged between the partners. This option would be similar to the joint venture

CG entered into to overcome some of their production troubles. An important difference would be a preference to partner with an existing strong player in the wafers market to gain their market advantage. CG had partnered with a relatively obscure labor provider who gave them capacity but little else in the development of markets and customers.

The advantage of a partnership between two industry players is that each partner gets to focus on their strengths while sharing contacts and markets with each other. Both should be able to profit handsomely with a superior material being fabricated into a superior wafer by a market leader. A disadvantage to each may be exclusivity. CG may not be able to fully capitalize on their intended market unless they supply several wafer-producing partners serving many different market segments.

Another option for Crystal Growth would have been to simply serve the wafer market as they had every other business, as a material supplier expert in innovation and partnering. Margins may have been somewhat lower in this sort of market structure. The hope would be that growing demand would get revenues and profits up.

Conclusion

Crystal Growth had led a concerted research and development effort to create a technology and a line of cast products that were revolutionary. They spent tens of millions of dollars and years of efforts to develop a significant and marketable skill set. When they applied their skill set in their niche, they did well. However, dissatisfaction with market growth and profitability led them to migrate to other parts of a high tech value chain.

CG turned to the development of a product and chose to build and market the product itself, a departure from earlier market development efforts where they returned to a supplier role after developing an application. In this new value chain niche, their skills were no longer applicable.

After many years of struggle and underperformance, Crystal Growth never realized extraordinary profits from their new business. The skill set CG brought with them from their casting experience was not applicable in the new business, and a new skill set did not develop to a sufficient degree to enable them to capitalize on the new business. Additionally, while focused on new skill set development, they lost much of their expertise with their casting business. Their ability to service any market was severely hampered by their years of thin attention to many diverse markets.

From the outside, Crystal Growth did not accurately assess the skills necessary to run the Uniwafer business. What looked like a relatively simple extension of CG's business with a modest amount of post cast processing turned out to be a very complex set of problems fundamentally different than CG's casting expertise. Their core business suffered as they struggled to master the skills of another business.

These conclusions are consistent with the body of literature which deals with the complexity of product/process development and the complexity of vertical integration. Abernathy and Utterback (1975) decribe a period of product innovation coupled with little process innovation. This is analogous to Crystal Growth's efforts to develop Uniwafers, using R&D resources as production resources. At some time, product innovation declines with standardization while the focus of development turns to the production process.

The allure and danger of vertical integration are discussed by Hayes and Wheelwright (1984) and Stuckey and White (1993). Both sources suggest frameworks for the evaluation of vertical integration opportunities as well as caveats regarding potential pitfalls.

Selected References

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