Semiconductor Manufacturing in Asia – The Changing Landscape

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Abstract

From its inception – well marked with the Bell Labs invention of the transistor in December 1947 – semiconductor industry manufacturing was US-centric for close to twenty-five years. This began changing in the early 1970s. US manufacturers built plants in Malaysia, the Philippines, Indonesia and Thailand to do labor-intensive assembly. But high value-added wafer manufacturing was kept mostly in the US. The only significant wafer manufacturing outside the US was in Japan and Europe; and it was Japan that bested the US in the 1980s, captured the global DRAM market, and took the #1 spot in semiconductor sales for seven years. This Japanese success spurred other Asian nations – notably Korea, Taiwan, Singapore and China– to accelerate their moves to wafer manufacturing and, at the same time, disrupted the business models of the US companies. From this tipping point began the restructuring of the semiconductor industry from broad-product-spectrum integrated companies (IDM's) to today's business models of highly focused specialty companies (e.g., Foundries and Fabless). In this transformation process, Asia's strengths have made the region into the world's factory for Memory and Logic semiconductors.

As we look to the future, we already see that the semiconductor market is being shaped by the economic development and increasing individual wealth of the five billion people at the bottom of the global pyramid. This is the future for the industry. Satisfaction of this huge and rapidly evolving market is accelerating the demand for high volumes of highly integrated semiconductors at appropriate price points and is reducing product life cycles. The successful Asian semiconductor manufacturers are among the few companies with the scale to meet this challenge. Wafer fabrication is their core strength built on manufacturing excellence, fabrication clusters and, now, the construction of Giga Fabs. However, fabrication can only be successful on a deep foundation of increasingly demanding R&D. Asian manufacturers are now R&D world leaders in lithography, device architectures, scaling, and in the creation of proven design platforms to accelerate product design cycle times. The semiconductor industry restructuring that started in the 1980s is still playing out, but it is clear that the shift of manufacturing to Asia is a great success and, most likely, irreversible.

1 Introduction

From its inception in the U.S. in the late 1940s, the semiconductor industry has fueled amazing innovations in electronics products. It has revolutionized business and personal productivity and delivered low cost global communications and entertainment to every rung on the economic ladder. The industry was one of the first to become truly global. It is now distributed across the globe with regional specialization based on local expertise and strengths. This eco-system operates with speed and efficiency, discovering and responding to customer needs and quickly delivering products in high volume and good prices.

The center of gravity of the manufacturing link in this eco-system has moved to Asia. Today, over 70% of wafer manufacturing is in the Asia Pacific region, including Japan. And the momentum continues to favor Asia.

In this paper, we will trace the migration of semiconductor manufacturing to Asia, highlight the factors that allowed this to first gain traction and then build momentum. We'll also look at evolving market changes, how these are driving the continued expansion and success of semi manufacturing in Asia.

2 The Global Electronics Market

The global electronics market has grown exponentially in the last six decades to a value of about US$1.6 trillion in 2008. Electronics products now reach into every corner of the world; many of the world's poorest people can buy a mobile phone and use it to improve their income and life prospects. In the early years, electronics products were bought almost exclusively by the rich, developed nations. By the mid-1980s, 80% of electronics went to the major developed countries (North America, Western Europe and Japan) and, even today, these countries consume over 60% of electronics. However, there has been a major change in the drivers of growth from the major developed countries to the developing countries. In the 1980s, 80% of growth came from developed countries. Today, more than 60% of growth comes from the newly industrialized and developing regions. Of this, 30% of growth comes from countries in the Asia-Pacific region.

Well before Asia became an important market for electronics, it became established as the prime region for electronics manufacturing. Drawn by plentiful, low-cost, semi-skilled labor, the shift of electronics manufacturing to Asia started with Japan in the 1960s and, as Japan moved up the value chain, spread to other developing countries in the region. Today, close to 90% of electronics products are manufactured in Asia with over 70% made in China.

3 The Semiconductor Market

The growth in the global electronics market has been fueled, in large part, by semiconductors and integrated circuits, which, enabled by Moore's Law, have fallen in price by many orders of magnitude. From its inception – well marked with the Bell Labs invention of the transistor in December 1947 – the semiconductor industry has grown to a value of about US$260 billion in 2008. The industry was predominantly US-centric for close to twenty-five years. Semiconductor companies developed process technology, designed products and manufactured them, often using equipment of their own making. Even by the mid-1970s, over 80% of semiconductors were made and sold by US companies. Early moves to Asia were by US manufacturers that built assembly plants in Malaysia, the Philippines, Indonesia and Thailand to do labor-intensive, low value-added work. The high value-added wafer manufacturing was kept mostly in the US.

By the late 1970s, Japanese systems companies, which had been buying chips from the US, started to vertically integrate and establish their own chip design and wafer fabrication. The Japanese, applying the quality principles learned from Deming and Juran, took wafer fabrication to levels of efficiency, quality, and yields which were much better than those of similar US wafer fabs. Due to geographical and language separation and focus on internal needs, the Japanese chip companies had difficulty selling their products outside Japan. This changed when some companies made the decision to focus on DRAM. With DRAM, the specifications were set by JEDEC (Joint Electron Device Engineering Council) and all vendors had to meet these specifications. This opened up a major global market to the Japanese and allowed them to fully capitalize on their wafer fabrication superiority. By the mid-1980s, about half of all semiconductors, by value, were being made in Japan.

The success of this DRAM-focused Japanese model was then emulated by the major Korean integrated systems companies and, by the mid-1990s, Korean companies were beginning to challenge the Japanese in the DRAM market. Following success in DRAM, Asia companies have repeated the success in Flash memory and, today, Asia companies make 75% of all memory chips. The leader is Korea with 49% followed by Japan with 17%; U.S. companies supply 15% and European companies 10%.

4 The Fabless/Foundry Model

In the 1980s several factors emerged that, together, created the opportunity for the innovation of the fabless chip company and the dedicated, or pure-play foundry. The success of the Japanese and then the Korean companies in the DRAM financially stressed many U.S. chip companies. This drove them to abandon DRAM and to focus on products in the microprocessor, logic or analog IC markets. Also, as Moore's Law advanced, the cost of building a wafer fabrication plant rose beyond the threshold considered acceptable by venture capitalists wanting to fund semiconductor entrepreneurs. However, in the U.S., there were still plenty of aspiring chip entrepreneurs with great ideas for innovative products. Luckily, around the same time, several smaller Japanese chip manufacturers, that had not made the move to DRAM, decided to offer spare capacity in their wafer fabs to other companies. The chip entrepreneurs and their venture capitalists realized they could build a successful company by investing in chip design and marketing and subcontracting the wafer fabrication to one of the Japanese companies with spare fab capacity. So came the genesis of the Fabless/Foundry chip model. However, this initial Fabless/Foundry structure had a fundamental flaw: the Japanese companies were interested in filling spare capacity; but when their internal demand was strong, their supply to the fabless customers was cut back; and the Japanese foundries had no business motivation to add capacity to meet the needs of its fabless customers. This made it difficult to grow the fabless business. To address this limitation, some fabless companies tried to source chips from a dozen or more foundries; this lead to major supply chain management issues and, ultimately, did not solve the fundamental problem of insufficient capacity when demand was good.

Earlier, in the mid 1970s, the Taiwan government wanted to nurture an indigenous chip industry and established a laboratory focused on semiconductors with a pilot wafer fab. It hired some of the country's best and brightest engineers to staff the organization and to seed startups in the new industry. By the mid-1980s, several Taiwan companies were established doing IC design, but were struggling in the global markets. Dr. Morris Chang, who earlier had managed the semiconductor group of Texas Instruments, observed the beginnings of the fabless chip companies and had the realization that these fabless companies had the potential to thrive and grow if they had a secure source of wafer fabrication capacity that stayed ahead of their needs. With this concept, Dr. Chang convinced the Taiwan government to convert their pilot wafer fab into a dedicated wafer foundry. The government did this as a joint venture with Philips of The Netherlands and other small investors and formed Taiwan Semiconductor Manufacturing Company. Even though the TSMC process technologies lagged the industry leaders by two generations, there were plenty of customers, mostly in the U.S., who developed market-winning products. The Taiwan government continued to support the industry with low priced land, an attractive Science Park environment, and tax credits on the purchase of capital equipment. And, as the foundry industry grew, it was able to draw upon a reservoir of U.S. educated Taiwanese engineers. Often, these engineers were working in the wafer fabs of U.S. chip companies and were attracted back to Taiwan to grow the industry and share in its success.

By the early 1990s, it was clear that the Fabless/Foundry model was a sustainable success and several new foundry companies were established in Taiwan, Singapore and, later, Malaysia and Mainland China. In each case, governments provided support to launch these companies. So, Asia continued to gain momentum in the foundry segment. By 2007, dedicated foundry revenues were close to US$20 billion and 95% of this was made in Asia – 69% in Taiwan, 14% in mainland China, 9% in Singapore and 3% in S. Korea and Malaysia. Although dedicated foundry process technology started two generations behind that of the leading integrated semiconductor makers, foundry companies aggressively invested in their own process R&D and, by about 2000 had essentially caught up with the leaders at the 0.18-micron node. Foundries are now driving advanced process development. They have increased their process R&D by 13% annually for the last five years and will invest over US$1.2 billion in 2008. At the same time, foundries have increased their wafer capacity by 17% annually. By 2007, dedicated foundries had over 20% of the world's wafer capacity. In 2008, foundries will invest over US$7 billion in additional wafer capacity.

Foundries now have the process technology and wafer capacity to support global leaders in the semiconductor industry. In 2007, the leading fabless company had revenues over US$5 billion and there were nine fabless companies with revenues over US$1 billion.

A parallel evolution has been the growth of wafer fabrication outsourcing by the traditional integrated semiconductor manufacturers (IDMs) that have always had their own wafer fabs. Initially IDMs began to outsource to foundries when their own fabs were full. Now, however, most U.S. and European IDMs have adopted a fablite or asset smart strategy in which they rely on foundries for a significant share of their wafer production. These IDMs have accepted that Asia foundries can supply leading technology, high yielding wafers at prices that are competitive with their internal wafer fabs. A further major change is now accelerating the shift of wafer fabrication to Asia foundries – this is the move from 200mm wafers to 300mm wafers. A 300mm wafer fab tooled to make 45nm technology can cost US$5 billion. Many IDMs have concluded that their core competitive advantage lies in their ability to understand their customers' needs and translate these into chip designs and not in manufacturing the chips. So, they have taken the decision to rely 100% on foundries for future advanced technology processes and wafer capacity. With the combination of fabless chips and outsourced IDM chips, foundries supplied about 23%, by value, of the world's semiconductors in 2007. Foundry-made chips are predominantly in the logic, microperipheral, microcontroller and DSP segments of ICs and, within these segments, dedicated foundries supplied about 70% of the total and 95% of these were made in Asia foundries.

5 The Coming Challenges

The semiconductor industry is maturing and this is evident in its revenue growth rate. In the early years of semiconductors, average annual growth in double digits was the norm; however, it is becoming evident, from the last few years, that growth is moderating to around mid-single digits. Although revenue growth has slowed, volume demand for chips is still increasing at double-digit rates. So, the demand is growing strongly but the markets require lower and lower prices. This divergence of volume growth from revenue growth is being driven by the increasing penetration of electronics into the developing, low-income countries. These countries, such as China and India, are now responsible for most of the growth in demand for major electronic products. For example, close to 80% of the growth in demand for PCs is coming from emerging markets. For mobile handsets the figure is closer to 90%.

In addition to pricing pressures, most products today have short life cycles either because new applications are quickly emerging and require more performance or because users have moved up the income scale and are ready for something new and better. In both cases, the chip company has to rapidly ramp new chip output to very high volume, be profitable immediately, and earn sufficient return over a short product life to sustain this model and provide a good return to its owners. At the same time, as pointed out already, the costs of designing and manufacturing chips have grown almost exponentially. So, the industry as a whole has to continually improve its efficiency. This need will, inevitably, drive further specialization such that each link in the chip chain contributes value that does not overlap with values from other links.

For wafer manufacturing, major Asian companies have already proven their superiority in the manufacture of memory products and foundry services. They are in a lead position to build on the scale they have already in place. Now Asia manufacturers are building Giga-fabs with capacities of 100 thousand 300mm wafers per month. One Giga-fab can manufacture up to US$12 billion of logic chips in a year – this is more than the annual revenue of all but the top three chip companies today. So, while the semiconductor industry will continue to restructure, to more efficiently meet market needs, the shift of manufacturing to Asia is already a great success and is, most likely, irreversible.