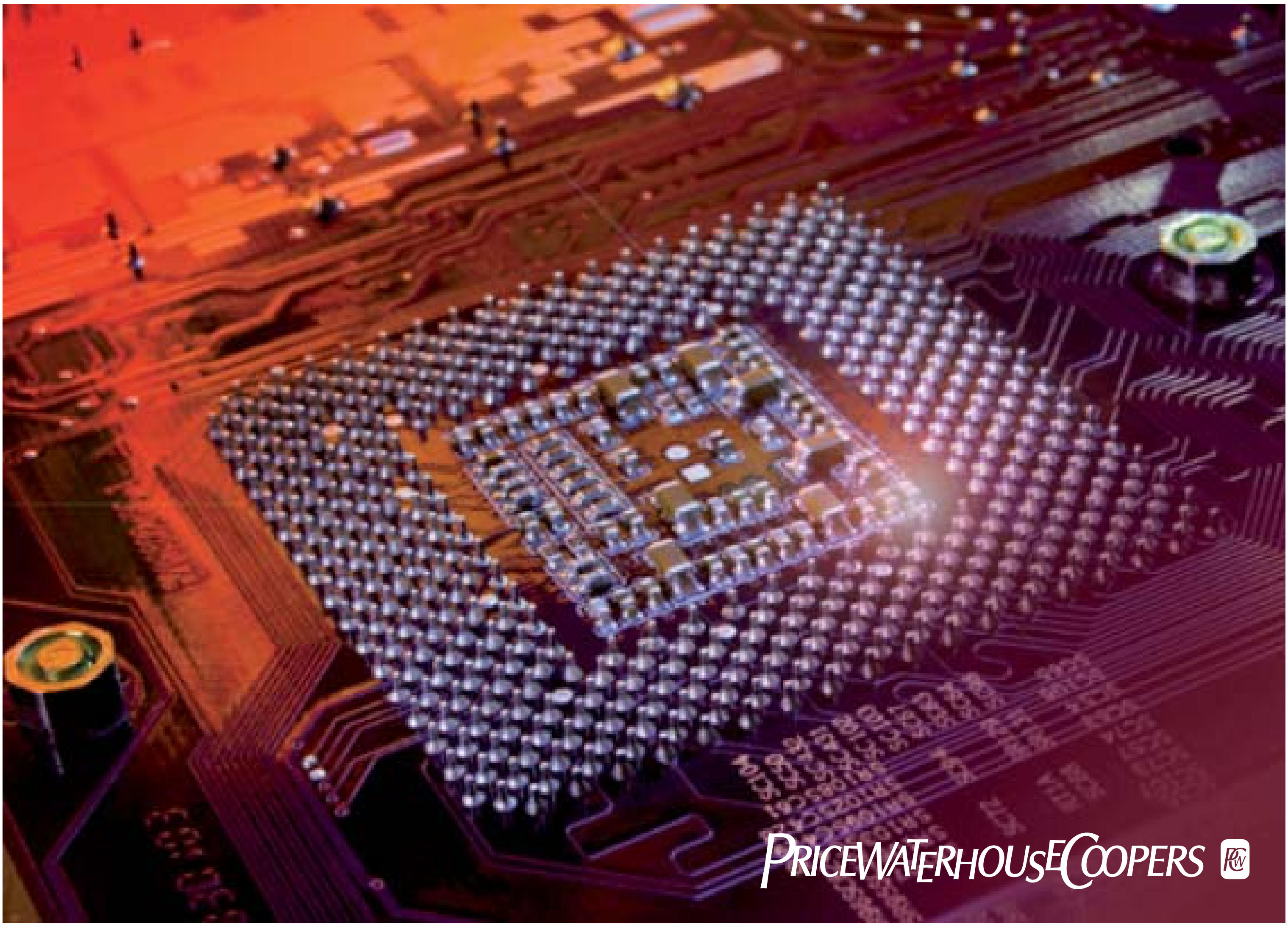
A change of pace for the semiconductor industry?



A change of pace for the semiconductor industry?

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Preface

Innovation drives the semiconductor industry, and in turn its chips form the heart of modern industrial societies. Chips are at the essential core of mobile telephones, computers, flat-screen monitors and television sets, a wide range of medical procedures including CT scans, ultrasound and X-rays, and they play an enormous role in today's sophisticated cars and aircraft. The number of installed semiconductor components expands constantly, so it would be easy to assume that the semiconductor industry is experiencing a golden era. However, despite the increasing demand for chips, hardly any other sector has been hit so hard by the current economic crisis.

How will the market for chips develop in the next few years? What business models will prove to be robust during the crisis and beyond? Where are the current opportunities? What are the critical factors of success? This study considers those and other essential questions.

Apart from an analysis of the production process and the subsequent value chain, this study comprises a benchmark analysis of the main segments of the semiconductor industry. Experts who offer their view of technological and economic developments in interviews include Professor Doris Schmitt-Landsiedel, Technische Universität München; Professor Jürgen Becker and Professor Michael Siegel, Karlsruher Institut für Technologie; Peter Wennink, ASML; Andrea Cuomo, STMicroelectronics; and Herbert Halamek, Continental. In addition to the interviews, we had fruitful discussions with Carla Sinanian, NXP Semiconductors; Dr Peter Hardt, Infineon Technologies; and Dr Helmut Lagger and Ulrich Schoen, Nokia Siemens Networks. We appreciate all these contributions and thank the participants for their cooperation and wisdom. We particularly thank Peter Bauer, Infineon Technologies, who has enhanced our study with a guest article.

The aim of this study is to identify issues which will be the driving force behind the market in the next few years and to use this analysis to recommend action for semiconductor companies (some of which have already acted and are now well poised to meet the challenges of the future). Which products, which components and which regions have to be considered is the subject of our sales forecast. Our study focuses particularly on the European perspective.

Are there indications of a change of pace for the semiconductor industry? Join our journey into the complex world of the semiconductor industry.

If you would like further information, or to discuss any of the findings in our report and how they might impact your business, please do not hesitate to contact either of us (raman.chitkara@us.pwc.com or werner.ballhaus@de.pwc.com) or any member of our technology team listed in the back of this document.

Düsseldorf, November 2009

Raman Chitkara
Global Technology Leader

Werner Ballhaus
German Technology, Media and Telecommunications Leader

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Abbreviations

ABS	Anti-lock braking system
AG	Aktiengesellschaft (joint stock company)
ASIC	Application-specific integrated circuit
ASSP	Application-specific standard product
CAGR	Compound annual growth rate
CFO	Chief financial officer
CMOS	Complementary metal-oxide semiconductor
CPU	Central processing unit
DDI	Display driver integrated circuit
DRAM	Dynamic random access memory
DSP	Digital signal processor
EBIT	Earnings before interest and taxes
EBITDA	Earnings before interest, taxes, depreciation and amortisation
EPROM	Erasable programmable read-only memory
EEPROM	Electrically erasable programmable read-only memory
ESP	Electronic Stability Programme
Fab	A production facility for semiconductors
FERAM	Ferroelectric random access memory
IC	Integrated circuit
IC IDM	Integrated device manufacturer, mainly manufacturing logic chips
IDM	Integrated device manufacturer
IP	Intellectual property
ITRS	International Technology Roadmap for Semiconductors
KIT	Karlsruher Institut für Technologie
LED	Light-emitting diode
LTE	Long Term Evolution
MCU	Microcontroller unit

Memory IDM	Integrated device manufacturer, manufacturing memory chips
mm	Millimetre
MPU	Microprocessor unit
MRAM	Magnetoresistive random access memory
nm	Nanometre
OEM	Original equipment manufacturer
OLED	Organic light-emitting diode
PC	Personal computer
R&D	Research and development
SG&A	Selling, general and administrative
SIA	Semiconductor Industry Association
SRAM	Static random access memory
SoC	System-on-a-chip
SiP	System-in-package

A Summary

1 The main results – an overview

The semiconductor industry reported constant growth from the time it came into being around 40 years ago until the current economic crisis began. The industry was able to cope well with short-term corrections, such as the bursting of the Internet bubble in 2001, but the current crisis brought major problems. For 2009, we expect to see a decline in revenue of about 20% from the previous year. But the industry will probably soon overcome these problems: for 2010, we anticipate considerable growth and expect that worldwide sales in 2011will roughly match the level of 2008, and grow further in 2012. Annual average growth is expected to be more than 10% between 2009 and 2012, in line with figures seen in the past.

In this growth, only minor shifts in sales distribution are expected. Applications of data processing will continue to account for the highest percentage of overall sales, followed by consumer electronics and mobile communications. Nor are major changes anticipated in the product mix: logic chips will remain the main segment. They will be followed by microprocessors and microcontrollers, with memory chips in third place.

The pace of innovation in the semiconductor industry is high. Moore's law postulates that the number of transistors that can be placed on a single computer chip doubles every 18 to 24 months, and over four decades the law has held up. And the process of reducing feature size will continue for years to come. However, the limits of the existing technology (CMOS, for complementary metal-oxide semiconductor) are already evident: in order to produce extremely small features in a cost-effective manner while avoiding functional restrictions, new materials and technologies must be brought into play. And the functionalities are becoming more and more important: previously independent modules are increasingly being integrated in individual chips. Moreover, larger wafer diameters promise to permit more efficient chip production in semiconductor manufacturing. The changeover to diameters of 450 mm awaits high levels of investment, and in view of the financial crisis, is probably several years off. We do not expect it before 2012.

The need for capital and the high pace of innovation mean that companies are increasingly specialising in individual elements in the value chain – such as fabless companies (those without production facilities) that design chips and foundries that specialise in semiconductor production. Integrated device manufacturers (IDM), which cover the entire value chain, are increasingly adopting a 'fab-light' strategy, in which some areas of production are outsourced to foundries.

Integrated device manufacturers generate the highest average sales in the sector; fabless companies, because they specialise in product development, report the highest spending on research and development as a percentage of overall sales. The lowest percentage spending on research and development is reported at the foundries, which do not have any chip development operations. Selling and administrative expenses follow a similar pattern: fabless companies report the highest percentage of costs, foundries the lowest.

The economic crisis has meant that most semiconductor companies were not able to generate positive results in 2008. This trend will also continue in 2009, despite cost savings and worldwide capacity reductions. We expect to see positive results in 2010 as a result of the growth in sales.

2 Structure of the study

This study consists of four parts. The first part (chapter B) starts with an article by Peter Bauer, CEO of Infineon Technologies AG, on prospects in the semiconductor industry. This is followed by a market overview, which analyses the value chain, the business models and the competitive environment. In the analysis of the competition, we use selected parameters to detail special features and mechanisms of the individual business models.

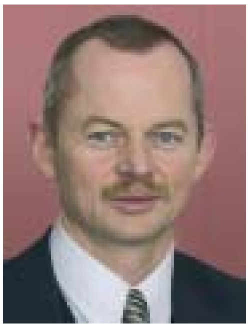
Chapter C deals with technology and technology trends. The technology drivers production, feature size, functionality and wafer diameter are used to examine the current state of technology and discuss expected developments.

Chapter D shows our market forecasts until 2012, broken down according to applications, components and regions.

Chapter E, the fourth and final part, offers our conclusion and provides an overview beyond the period covered by the study.

Guest article by Peter Bauer, CEO, Infineon Technologies AG

Peter Bauer
CEO
Infineon Technologies AG



Growing with energy efficiency, communications, and security

The year 2009 will enter the history of the semiconductor industry as a ‘black year’. Following many years of growth, the worldwide economic and financial crisis resulted in a huge downturn in sales in the industry. Although it will take some time for the market to return to the level of 2008, the semiconductor industry is and will continue to be a growth industry. In future, it will continue to be the case that many innovations will only be possible with the aid of semiconductor products. This is applicable particularly to three key challenges of our modern society: energy efficiency, communications and security.

Energy efficiency – green technologies on the advance

The increasing global demand for energy, the limited availability of natural resources, rising energy prices and the threat of climate change require solutions for enabling energy to be handled more efficiently. In order to meet the requirements of climate policy, for instance for reducing CO_2 emissions, it is necessary to increase efficiency throughout the entire chain of utilisable energy – that is, for the production, transmission and consumption of energy. Innovations from the semiconductor industry are playing a key role with regard to implementing these objectives. The requirement for more energy efficiency will have a positive impact particularly on demand for power semiconductors in the course of the next few years. This is applicable specifically to renewable energies, as well as for example to motor drives in industrial applications and in household products. With regard to power semiconductors for renewable energies, market researchers are assuming average annual growth rates of 18% in the course of the next years.[1] Solar and wind power will continue to be two of the main growth drivers. Power semiconductors are the core of rectifiers in photovoltaic and wind power installations, and are a key component for efficiently supplying power to the network.

In the automotive industry, the requirement for low-consumption and low-emission cars will also result in stronger demand for semiconductors in the long term, particularly for the drive train. With expected annual growth of around 9%, this is the area of application with the second highest growth rate for automotive semiconductors behind the safety segment.[2] This is due to the higher demand for powerful semiconductors for improved regulation of engines, and also the increased production of hybrid drives, which have a much higher semiconductor content than conventional drives. Additional opportunities are developing in the field of electric vehicles. In order to meet the requirements with regard to limiting pollutant emissions, carmakers around the globe are preparing for the mass production of hybrid and electric cars. Overall, despite the sales crisis affecting the car makers, the market for automotive semiconductors is expected to achieve annual average growth of 8% until the year 2013.[3] As the long-standing market leader for power semiconductors and the worldwide number two in the overall market for automotive semiconductors, Infineon will benefit from these trends.

Communications – transmission of data, everywhere and at all times

More and more people are wanting to have full access everywhere to the telephone, e-mails and the Internet at all times, with high transmission speeds. The mobile phone industry is working on setting up data networks with even higher speeds. Although mobile phone sales this year will decline for the first time since 2001, the manufacturers are developing new devices in order to be in a position to meet the expected long-term growth. Ultra-low-cost mobile phones and smartphones are two segments which are reporting considerable growth rates even this year despite the recession. With anticipated annual growth of approximately 20%, these fields will continue to be the segments which will report the strongest growth in the worldwide mobile phone market in the course of the next few years.[4]

[1] IMS Research, August 2009, CAGR 2008-13
[2] Strategy Analytics, July 2009. CAGR 2008-13
[3] Strategy Analytics, July 2009, CAGR 2008-13
[4] iSuppli, July 2009, CAGR 2008-13

The ultra-low-cost segment is being driven by the strong demand of first-time buyers in countries such as China and India. India alone is reporting around 10 million new users every month. This development is benefiting semiconductor manufacturers which are strong in the field of single-chip integration. This lowers the costs of manufacturing mobile phones by more than 30%. The market researchers are assuming that the revenues generated by single-chip products will achieve growth of more than 70% per annum until 2013.[5] Wireless high-speed data transfer is a key factor of success in the market for smartphones. Semiconductor manufacturers which provide a complete platform with a high-speed reliable modem are able to benefit in this respect.

Security – optimum protection of data, information and objects

The increasing extent to which our globalised world is networked requires solutions which take account of the more stringent security requirements – in communications, financial transactions, the identification of persons and objects as well as the protection of data and networks. This will have a positive impact on the demand for security controllers, security memory products and other system solutions. The identification of persons is one of the most rapidly expanding segments. The transition to electronic identity documents throughout the world – including passports, ID cards and driving licences – is the key growth driver in this respect. In the course of the next few years, the strongest growth rates are expected for electronic ID cards. This is a mandatory document in many countries, and the transition to an ID card in a chip card format will take place gradually. In Germany, the implementation process will commence in the year 2010 and all citizens of Germany are expected to have a chip-based ID card by no later than the year 2020. Secure payment using contactless cards is a further growth area for contactless security controllers. So-called micropayment is becoming rapidly established particularly in the major cities of the emerging economies of Asia.

Into the future with optimism

The semiconductor industry will benefit considerably from the growth potential resulting in the long term from the need for solutions for the efficient handling of energy, modern communication technologies and individual high-security solutions in a globalised world. Infineon will use its core skills in the fields of radio-frequency electronics, system integration, analogue or analogue-digital circuits as well as power semiconductors in order to participate in the future growth generated in these three key areas, and also to further expand its leading position in automotive and in industrial electronics, wireless communications and with chip cards and security solutions. Infineon has focused its activities on these four target markets and, for many years, has been one of the market leaders in these particular fields thanks to its high technological competence and innovative products.

[5] Strategy Analytics, December 2008, CAGR 2009-13

B The semiconductor industry

Semiconductors are extremely important in virtually all areas of life. They are vital for many consumer products.

The semiconductor industry has changed society in uncountable ways. Semiconductors are installed in virtually all technical equipment, ranging from dishwashers, microwave ovens and flat screens to machine tools. The use of semiconductors in cars, trains, aircraft and ships is constantly expanding. Mobile telephones consist mainly of chips. PCs, servers and pocket calculators owe their existence to the development of semiconductors. The world would be different without semiconductors and would surely be slower. And semiconductors have also laid the foundation for worldwide networking through the Internet. The development process continues to move ahead. Gordon Moore, a co-founder of Intel, formulated what came to be known as Moore's law in the late 1960s: the number of transistors that can be placed on a standard processor will double every 18 to 24 months. This law remains valid today and helps explain the tremendous pace of innovation.

However, progress is expensive, particularly in the semiconductor industry. Manufacturing processes and product development are based on the latest technologies, which require substantial levels of investment. Continuous research and development work is necessary, and the capital needs of the industry are accordingly high.

1 Market structure

Demand for semiconductors is driven mainly by the end markets in communications, data processing, consumer electronics, the automotive industry and the industrial sector.

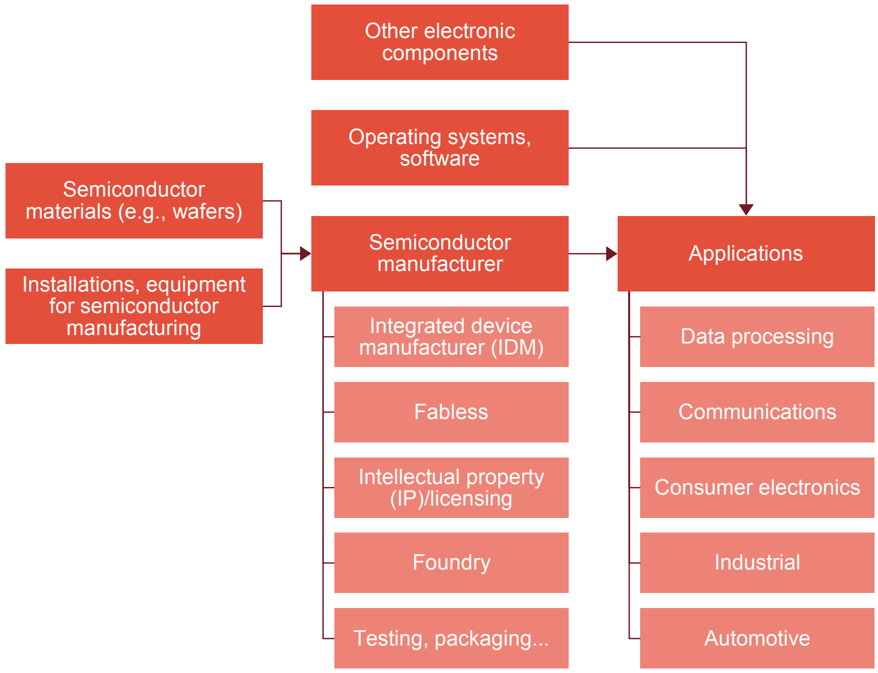
The semiconductor industry forms part of a complex interaction among various industrial sectors. In general, demand for semiconductors does not emanate directly from end users, but rather is determined by the related end-customer markets. Most sales (around 38%) are generated by data processing, followed by communications (26%), consumer electronics (18%), industrial accounts (approximately 10%) and the automotive industry (approximately 8%).[1]

Suppliers to the semiconductor manufacturers provide the raw silicon that is processed into wafers (see the related discussion) and develop installations for manufacturing semiconductors.

The semiconductor manufacturers can have various business models and can be classified as integrated device manufacturers (IDM), fabless, licensing, foundry and back-end processes (assembly and test, packaging). The business models differ in their value creation.

Figure 1 shows the way in which the various sectors interact.

[1] PwC analysis, figures for 2008



Source: Deutsche Bank, PwC presentation

Fig. 1 The semiconductor industry and its environment

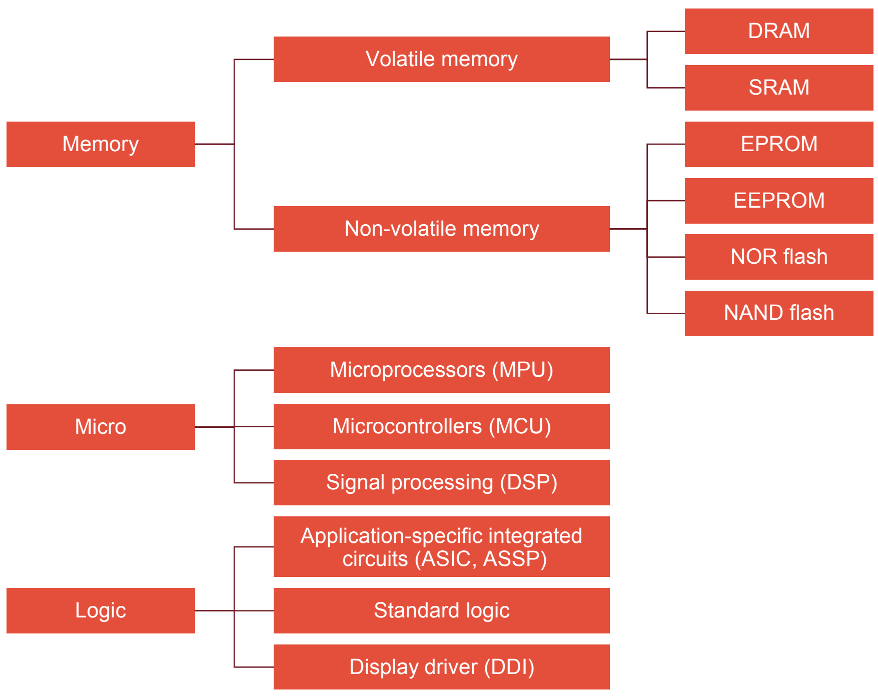
The main business models in the semiconductor industry are integrated device manufacturers, fabless, foundry, and assembly and test. Suppliers such as manufacturers of installations and equipment also have an important role to play.

- Integrated device manufacturers (IDM) are companies which operate along the entire value chain in semiconductor manufacturing. The considerable levels of investment for a new semiconductor production facility have resulted in many IDMs changing over to what is known as a fab-light strategy. This means that existing production capacities are retained and that newly developed semiconductors, which require more modern manufacturing procedures – for instance, as a result of very small feature sizes – are manufactured by partner companies.
- On the other hand, fabless companies focus exclusively on research and development, as well as sales of products. They do not have their own production facilities; they use semiconductors manufactured by other companies. Not only are no costs incurred for establishing production facilities, no fixed costs are incurred in conjunction with these factories.
- Some companies devote themselves exclusively to licensing (intellectual property or IP companies). They specialise in the design of certain modules and license the resulting intellectual property to their customers. Unlike fabless companies, IP companies do not have sales operations and license their design and development services exclusively to third parties. There are also companies which focus on electronic design automation (EDA). Compared with the other business models, the volume of sales generated by IP and EDA companies is a small part of the overall market.
- Foundries do not do product development; they manufacture semiconductors in their own facilities for other market participants, such as fabless companies. Foundries mostly operate large and modern production facilities, which they attempt always to operate at high levels of capacity utilisation, by managing commissioned production.

- The process of increasingly specialising on specific tasks has led to the emergence of companies which focus on back-end processes such as testing and packaging (assembly and test). Open-market assembly and test service providers are based mainly in South-East Asia, particularly in Taiwan, Singapore and Malaysia, drawn by the low labour costs. The degree of automation in these back-end processes is not as high as in other areas of semiconductor added value.

Semiconductors are broken down into discrete semiconductor elements, such as diodes, thyristors and transistors, and integrated circuits that connect numerous discrete semiconductors and thus provide a high degree of functionality.

Integrated circuits include memory, micro and logic families (see Figure 2). Most sales are attributable to memory modules (approximately 18% of the worldwide semiconductor market), microprocessors and microcontrollers (approximately 21%) and logic semiconductors (approximately 29%).[2] Digital integrated circuits accordingly account for virtually 70% of the worldwide market volume. The standard products consist mainly of memory products, which face fierce competitive and price pressure. With application and customer-specific products, price pressure is less pronounced because of the focus on specific application aspects or specific customers.



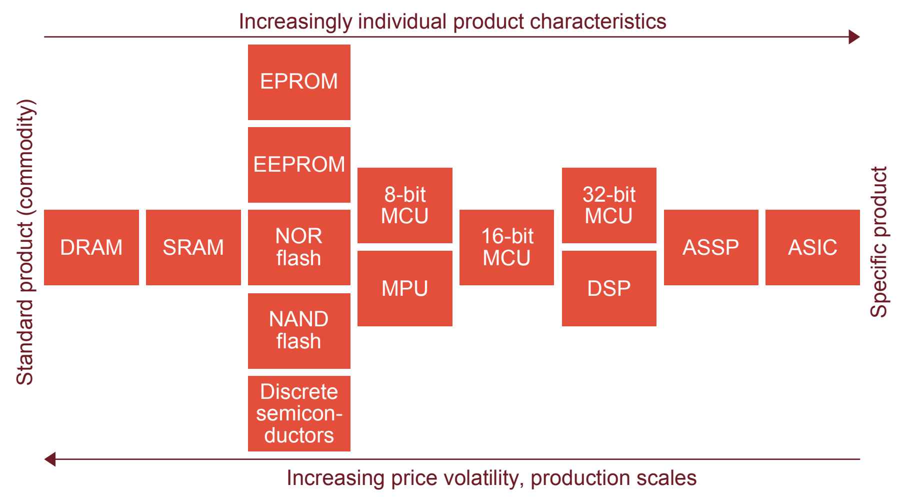
Source: Deutsche Bank, PwC presentation

Fig. 2 Product families of integrated circuits

Effective entry barriers to competitors are customer contracts, earned through a design tender procedure, and intellectual property rights for certain application characteristics. Product development and chip design in line with the needs of customers are extremely important to be successful in design tender procedures; they accordingly constitute factors of success.

[2] Source: PwC, figures for 2008

In the case of standard products, efficient mastery of the production process is a critical factor, in view of the typically high production scales. The 'yield', a parameter which provides information concerning the number of non-defective chips from each wafer processed, is a key metric. Moreover, effective capacity and its utilization are important for the production of standard products, because the modern production facilities used, for instance, in memory production have a very high capacity and require very high levels of investment to set up. Figure 3 compares products and certain characteristics, as well as factors of success of standard and specific products.



Factors of success for standard products:

- Production processes
- Capacity and capacity utilisation management

Factors of success for specific products:

- Product development, design
- Specific functional know-how in customer markets
- Customer access and customer management

Fig. 3 Comparison of standard and customer-specific products, as well as typical factors of success

Mr Cuomo, in the aftermath of the crisis, do you expect consolidation in the industry?
Consolidation in the industry is happening now. It happens in two ways: one is that companies go out of certain businesses; the other is through transactions. We have already seen some M&A, but now we see companies that are starting to lose substantial market shares in selected applications. And this trend is going to continue, especially on the platform side. Consolidation will happen whether through M&A or not. And we have seen M&A for the sake of M&A – at times the last step before collapse.

How do you think that business models within the industry will change? Are we going to see the fabless trend continue?
It depends very much on the winning chip architectures. We are at the crossroads: we either will see an evolution of today's business, or we will see processor-centric architectures in many applications, such as netbooks and smartphones. If the processor-centric business will expand to market segments beyond the PC, then we shall experience very important structural changes in the competitive scenario. Just to mention one, it is very difficult for semiconductor companies to keep the design function separate from the production process, because in the processor world the relation between chip design and manufacturing process is extremely tight. As a consequence, there will be reduced space for foundries, and the need to own a modern fab will trigger a very fast industry consolidation process. If, on the other side, this business model does not succeed and System-on-a-chip (SoC) prospers, then most companies will go fabless and we will have a longer time horizon for consolidation.

Andrea Cuomo, Executive Vice President, General Manager, Sales & Marketing, Europe, Middle East and Africa, STMicroelectronics

"We are at the crossroads: we either will see an evolution of today's business, or we will see processor-centric architectures in many applications such as netbooks and smartphones."

Which philosophy with respect to architecture will have an edge in the medium term?
It is going to be a battle between the SoC and the processor-centric view, and I am not sure who will win. For certain applications, processor-centric architecture may have advantages, such as faster time to market and software flexibility. But the negative aspects are higher costs, higher power consumption, the commoditisation of hardware and the consequent progressive reduction of the role of System OEMs. On the other hand, SoC architecture provides lower power consumption, higher efficiency and is a means of differentiation. A key aspect in this discussion is the software architecture on silicon. The amount of software running on our devices is huge, and people will not be able to redesign their software with each new device. Therefore, basic choices about software architecture will dictate the future of the industry. Which business model wins remains to be seen. And often life is about different shades of grey rather than a straight choice between black and white.

What do you view as the key growth areas for the semiconductor industry?
We see two major trends. First, data is going mobile. The movement toward netbooks will be as big as the run on mobile phones some years ago. We had voice going mobile years ago, and now we see data going mobile. We are going to see cheap wireless connections, and everything will be interconnected by wireless. The second big trend is the penetration of silicon into all aspects of daily life. The first examples that come to mind are silicon in medical devices, micropayment systems, food chain control and personal identification.

Do you expect that the e-mobility trend – the development of electronic cars – will have a big impact on the industry?
Of course. But I would not only say e-mobility. Rather, I see 'going green' at large as a major trend gaining more and more importance.

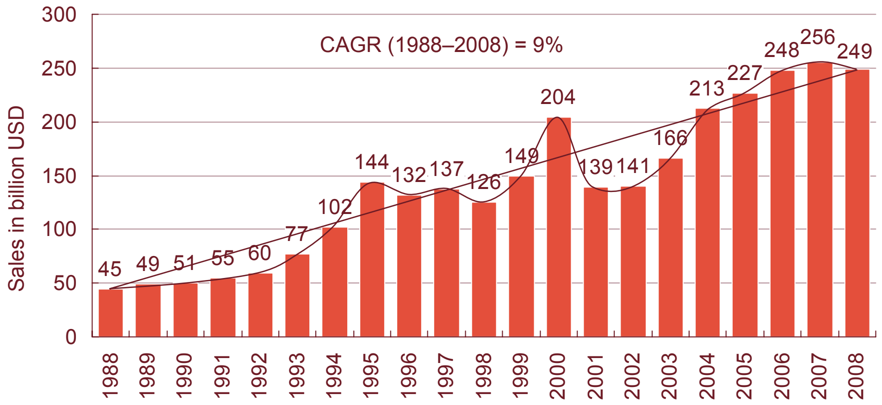
What are the key drivers for profitability in the industry?
First of all, of course, Moore's law and being on the leading edge of technology. Second, it is definitely the available production capacity and the usual overcapacity/shortage cycles. A third, and at times forgotten one, is product innovation. The first player in the market enjoys good margins, but for followers to attract customers they have to cut prices. When doing business forecasts, such events are often underestimated, as they tend to occur earlier than expected. Of course, as technology becomes increasingly complex and application lifetime is shortened, we may see more single source designs, and therefore some of these dynamics will change.

Do you think that Moore's law will remain the industry standard? And for how long?
A long time! Die shrinking is not always pushed by market needs. It is often driven by competitive behaviour. If you look at the foundry side, some players are willing to push the technology as much as they can just to make it harder for others to follow. We are coming to a point where the complexity, the cost of technology, market dimensions and market positioning are determining if consolidation will happen, simply because some players will not be able to compete on that level any more. In other words, as the game gets tougher, market leaders may be tempted to push their technology advantage to the point where they can marginalise their competitors.

2 Semiconductors in the crisis

The central role of semiconductors and the constantly rising demand for them are reflected in the continuous trend of growth in the sector. Industry sales have more than quadrupled over the past 20 years and have achieved annual average growth of 9% (CAGR) between 1988 and 2008.

Between 1988 and 2008, global semiconductor sales increased annually, on average, by 9%.



Source: SIA

Fig. 4 Semiconductor sales

However, this growth should not disguise the semiconductor industry's exposure to considerable volatility, with specific and defined cycles that closely correlate to economic cycles (see Figure 4, which shows the development of worldwide semiconductor sales between 1998 and 2008). In growth years, boosted by strong demand and profits, the semiconductor industry built up significant production capacities, because this was the only way to finance the high costs of setting up new installations. The surplus capacities which existed after the years of economic growth (e.g., in 1995, 2000 and 2007/8) exerted pressure on prices, with corresponding consequences for profitability and growth. Production capacity declined, semiconductors were affected by a shortage of supply, and prices stabilised. This, in turn, resulted in market growth, and the process started anew (e.g., in 1998 and 2002). The correlation between the cyclical nature, production capacities and supply and demand is not the only factor with a major impact on sales. Seasonality also influences supply and demand patterns. For instance, consumer electronic products (mobile telephones, MP3 players and computers) are mainly purchased in the run-up to Christmas, and demand for chips reflects that seasonality.

However, the current crisis is significantly different than previous cycles, with two factors that exacerbate each other. On the one hand, in mid-2008, the industry was in a market that was already declining, with excess capacities and falling prices, such as those affecting DRAM memory modules. On the other hand, demand dropped significantly in the industry's main markets. Automotive sales declined by 4% in 2008, a slowdown was reported by PC manufacturers, and demand for mobile devices and consumer electronic products has been declining since the end of 2008. This trend has continued in 2009.

The current crisis affecting the semiconductor industry is mainly attributable to lower sales on user markets. The situation is being exacerbated by global excess production capacities.

The DRAM manufacturers, which together with the processor manufacturers constitute the main market group in the semiconductor industry, are suffering the most from low sales prices and comparatively low sales volume. Indeed, even before the crisis, the prices for some DRAM memory modules were lower than their production costs. This was due not only to the excess capacities which had built up, but also to state subsidies, which, nowadays, are necessary to keep the manufacturers in business. Japan, for instance, has intervened at Elpida; Taiwan is assessing the possibility of consolidating several chip manufacturers into one large Taiwan Memory Corp.; South Korea has again provided considerable aid to Hynix, following its support at the beginning of the decade that enabled Hynix to grow into the second-largest DRAM manufacturer.

In these Asian countries, the semiconductor industry, with its high percentage of direct and indirect jobs, forms an important part of the economy. DRAMs also form a major element within the value chain of computers, sales of which will also increase. Accordingly, various governments are attempting to retain these key industries. However, these subsidies counteract the reduction of worldwide capacities that was initiated by market mechanisms through price erosion. Accordingly, the situation for DRAMs may not improve in the foreseeable future, and more and more state aid will be necessary to keep DRAM manufacturers in business.

Worldwide sales of computers and servers, the most important customers for microchips, have also declined appreciably amid the economic crisis. Moreover, particularly in consumer business, signs are evident of a considerable shift in sales in the direction of smaller, less expensive computers such as netbooks. This is reflected in lower average sales revenues and has had a negative impact on the market for microprocessors.

Logic semiconductors and analogue semiconductors also have to contend with lower sales volumes. However, this is less likely to produce lower prices than, for instance, as is the case with DRAMs, because the products are not traded on spot markets. Nevertheless, if customers are aware of their increased power in terms of prices, they are likely able to force through lower supplier prices.

The following chapter considers the positioning of the companies in the various semiconductor segments.

Peter Wennink, CFO
ASML Holding N.V.

“2010 will be a transition year for the semiconductor industry, while we might observe full recovery in 2011 and 2012. That is the kind of time period you have to think of.”

When do you expect the current crisis in the semiconductor industry to end?
Historically, the trend line in the semiconductor industry has been 8 to 9% unit growth over the last 20 years. Without doubt, we are currently lower than the trend line, but the industry is rebounding from the bottom. After stopping production and selling inventory, we have seen an increase in sales of some major electronic products, like PCs. Restocking of inventory is taking place, and semiconductor companies are able to report better than expected earnings. Additionally, the important and necessary investments in technology transitions which were on hold for about nine months are resuming again. But for demand to gain historical growth rates, we need to see some economic recovery. The year 2010 will be a transition year for the semiconductor industry, while we might observe full recovery in 2011 or 2012. That is the kind of time period you have to think of.

You mentioned the important investments in technology transitions. When do you think the technological transition to 45 nanometres is going to happen?
It is happening this year. The transition to the advanced 45 nm will come first in logic. At this stage, the leading foundries are ramping up production of the 45 nm process, and the others will follow next year. In DRAM, the full transition to 50 nm started in the second half of 2009 and is continuing. The technological leaders in the DRAM industry are even going to pilot production of 40 nm by the end of the year.

And will there also be a transition to 450 mm wafers?

The transition to a bigger wafer is driven by cost. The most effective way to reduce cost is by applying Moore's law, which describes the regular trend to shrink the size of transistor on a chip. There are discussions about increasing the size of wafers, but a major issue is the big investment required by the equipment industry for the development of 450 mm tools. Without the commitment from the customer base, the equipment makers will not foster the transition to 450 mm wafers.

Do you think market consolidation will play a bigger role in the future? To what extent will this have an impact on your business?

We are already seeing market consolidation. For example, in the flash business there are effectively only four players left, with two of them having close to 80% market share. Market consolidation in the semiconductor industry is an inevitable trend which actually started at the end of the last decade and will continue. The main driver for consolidation is the need for economies of scale. R&D costs are ever-increasing, and only by achieving production economies of scale can firms cover their R&D expenses. We saw a lot of logic producers that admitted they did not have enough market share to fill one of the huge 300 mm fabs, and eventually they consolidated. The need for economies of scale also explains the emergence of many joint-venture structures. The impact on our business is in principle the same. We see that the technology requirements and R&D expenses are continually increasing and that the drive for scale gains in importance. I think we will see more consolidation in the future.

We talked about the developments in the market, but these days, many companies are concerned about access to capital markets as well. What are your medium- to long-term expectations concerning access to capital, especially for risky businesses like semiconductors?

In recent years, money has never been that cheap and I think clearly that will not be the case in the future. Access to capital will still be there. In fact, profitable companies will always have access to capital and will be able to refinance. Consequently, all elements which drive profitability, such as achieving economies of scale, are of major importance for the semiconductor industry. In the second quarter of 2009 the capital markets opened up a bit, and our customers were able to finance transactions. So I think access to capital will be there, but it will be for a selective group and it will more expensive than in the past.

Are companies currently more focused on liquidity management than they were in the recent years? How does that affect you when your customers are focusing more on liquidity and working capital management?

Without doubt, liquidity management has become an important issue. In times of the credit crises when credit lines are limited, companies focus on cash and usually find it in their working capital and in their fixed assets. The semiconductor business is very capital intensive, and liquidity is everything. Capital markets opened up a bit, which eased the situation, but liquidity management is still of great concern. Our customers are demanding more favourable payment terms and are tightening their capital expenditures. That will remain the case until there is a more relaxed financial situation in the industry.

Do you expect that financial investors such as private equity firms will play an increasing role in the future, because they have access to capital and might find relatively cheap companies in the market?

Companies might be relatively cheap, but you always have to ask yourself why they are cheap. But, in general, I think the current appetite of private equity firms is not as high as it used to be. Money was very cheap, which it isn't today. Banks and investors are not willing to lend their money at the same cost as one or two years ago. Consequently, private equity firms have to put more of their own stake into the venture. We all know that the semiconductor industry is a very cyclical business, and I think that an element of conservative financing is strongly required.

What about R&D spending in the current crisis? Do you expect that R&D spending will be cut in the next few years?

R&D is absolutely essential in the semiconductor industry. Every transition drives down costs eventually. It is just a matter of time until companies which are not improving their technology are driven out of the market. In this sense, R&D is almost a prerequisite for existence. I don't think that the willingness to spend on R&D is going down, but R&D spending will be limited to those companies which can actually afford it. R&D spending is not going to be lower as a result of less access to capital. Instead, the industry will use the R&D budgets more efficiently by consolidating and cooperating.

In the past we have seen a lot of state aid for manufacturers. Will it be necessary for governments in Europe to support local industry, especially in the face of state interventions in Asia?
Every government has fields which are critical to their economic strategy and economic policy. In some countries, the financial system is recognised as the main value driver and governments will invest in that, as happened in the United States. In Asia, where the electronics industry has created so much value and wealth over the last 25 to 30 years, government intervention is quite reasonable. But here a critical issue emerges. We will have governments opposing each other, saying that the intervention is not fair and demanding a level playing field. This is a big political question.

Herbert Halamek, Business Unit Connectivity, Vice President Sales and Portfolio, Continental AG

"The electric car will revolutionise the automotive industry. And electronics will be the new heart of the car."

Mr Halamek, what will the automotive industry require of semiconductor manufacturers in the future?
The percentage of semiconductors installed in modern cars will continue to increase, for two main reasons: first, more and more functions with a high semiconductor content are being installed in cars, involving safety, infotainment, comfort and engine control. I expect that within a few years, incandescent bulbs will no longer be installed in cars, and LEDs will be installed instead. This will provide designers much more freedom in terms of the colour of the lighting and the atmosphere. They also have a much longer life and consume less energy than conventional lighting solutions. The second main driver, albeit more long term, will be the development of the electric car, which will revolutionise the automotive industry. And electronics will be the new heart of cars! Semiconductors will play an extremely important role, particularly in the field of energy electronics for controlling power.

What will the electric car of the future look like?
At present, we have only initial indications of the general direction. I believe the automotive industry will undergo a fundamental change. I believe that electric motors will be housed in the wheels, together with an electromagnetic brake and the control unit. The battery will sit on the vehicle floor as a plate, for reasons of weight distribution and for cooling purposes. There will be a considerable quantity of control and regulating electronics, but hardly any mechanical drive parts will remain. The content of mechanical parts will decline by up to 90%, as the vehicle control unit to a large extent functions electronically. Cars in the future will also have an entirely different appearance. In the final analysis, we do not need a large space for an engine. However, this development will take place in many stages. A lot of development work is necessary, and petrol and diesel engines will continue to dominate the mass market in the short to medium term.

What developments in car making can we expect to see in the short to medium term?
The issues of information processing, lighting and displays, as well as drive-by-wire, will continue to be important. The further development of displays is a particularly interesting aspect: OLEDs, that is, organic semiconductors, offer new opportunities for cockpit design. We will probably soon see a central OLED screen in the car instead of a large number of individual displays and indicators. The displays could be configured in a customised manner – similar to an iPhone or an iPod, where I combine my desired applications according to my own preferences. The most attractive aspect of this is not only that it is fashionable, but inexpensive in the long term, because the cockpit elements can be configured by software and because production complexity can be reduced considerably. In the medium term, it is conceivable that current heads-up displays will be improved by means of OLED technology. And as I mentioned, the electronic control unit of the car, drive-by-wire, will continue to be a very interesting area of development: it simply offers a large number of advantages, and mechanical parts in the car which are much less prone to breakdown. It also offers much more design scope. However, safety issues remain to be clarified.

What are the specific requirements of the automotive industry for the semiconductor manufacturers?
In principle, the same that are already applicable – only everything has to be quicker and less expensive! Most semiconductors which are produced nowadays are not suitable for automotive purposes, and instead have to be specially developed. This is because in the automotive field aspects other than pure computing power are of crucial importance: resistance to mechanical strain and temperature change, for example, as well as an extremely high delivery quality. These are absolutely essential, particularly for safety-relevant functions.

Is the pursuit of smaller and smaller feature sizes relevant in the automotive field?
It is indeed relevant, simply as a result of the costs, albeit not quite as crucial as with other applications. The automotive chips always lag behind state-of-the-art technology, for the reasons mentioned previously but also because of the relatively small volumes involved. As soon as the volumes assume dimensions which are attractive for a particular application, there will be manufacturers to make such volumes.

Related discussion: the semiconductor value chain

The value chain is broken down into primary and support activities. Primary activities consist of silicon extraction, raw wafer production, semiconductor design, mask production, front-end and back-end production processes, logistics, marketing and sales. Support activities include the infrastructure, human resources, technology, financing, management and administration, purchasing and procurement. Figure 5 illustrates the correlation among these various factors.

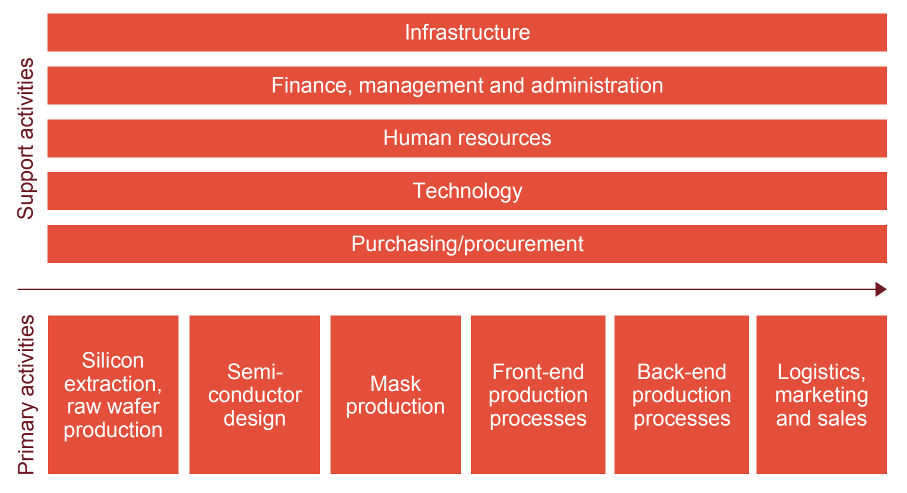


Fig. 5 Value chain according to Porter

Silicon extraction

The value chain in the semiconductor industry starts with the extraction of silicon dioxide from rock or sand, particularly from quartz sand. Silicon is the basic raw material for the semiconductor industry, and in nature occurs only in bound form as silicon dioxide. The oxygen is split off from the silicon in an energy-intensive process. The processes of mining rock and separating the silicon from oxygen are generally performed in countries with relatively low energy costs.

Semiconductor design, as well as development and manufacturing, achieves the highest added value.

Ultra-pure monocrystalline semiconductor silicon is required for applications in microelectronics. For this reason, a smelting process is used to lower the level of impurities in the silicon below a critical value.

Raw wafer production

The silicon used for microelectronics requires a purity level of 10^{-9}. This means that only one foreign atom can be contained in one billion silicon atoms. Microelectronics differs in this respect from the solar industry, which requires a purity level of only 10^{-7}. In addition to the extremely high purity level, the silicon has to meet a further requirement for chip production: it must be present in mono-crystalline form. This is the only atom arrangement that enables the effects of quantum physics used in semiconductors to be realised.

A wafer blank is drawn from liquid silicon at a temperature of approximately 1,400°C. In order to ensure that the blank is not contaminated with foreign atoms, which would result in impurities and changes in the crystal structure, this process takes place in a clean room. After cooling, the blank is cut into wafers. These wafers are processed and polished to maximum smoothness. Several wafers are packaged to form an air-tight packaging unit and are then delivered to the chip manufacturers.

Semiconductor design

The chip design is a major part of added value in the semiconductor manufacturing process. It reflects either general market expectations and market developments or a specific customer request. The chip design is then used as the basis for the corresponding chip layout.

Mask production

In the production of semiconductors, masks are glass plates with an opaque layer of chrome. The masks are used for copying the chip layout, at the beginning of the production process, onto a previously applied photosensitive layer of the silicon wafer by means of exposure. This essentially defines the structure and thus the function of the chip. Depending on the complexity involved, 15 to 40 different masks are required for one chip. A complete set of masks for a complex chip costs several million US dollars.

Front-end production processes

The front-end production processes contain most of the added value in semiconductor production. They are also the most capital-intensive production processes.

A microchip is developed and manufactured in several stages. The production process can be roughly broken down into front-end processes and back-end processes.

In the front-end processes, chips are made from the raw material for semiconductor production, the so-called wafers, through processing and specific changes to the material properties. Figure 6 provides an overview of the individual front-end process stages.

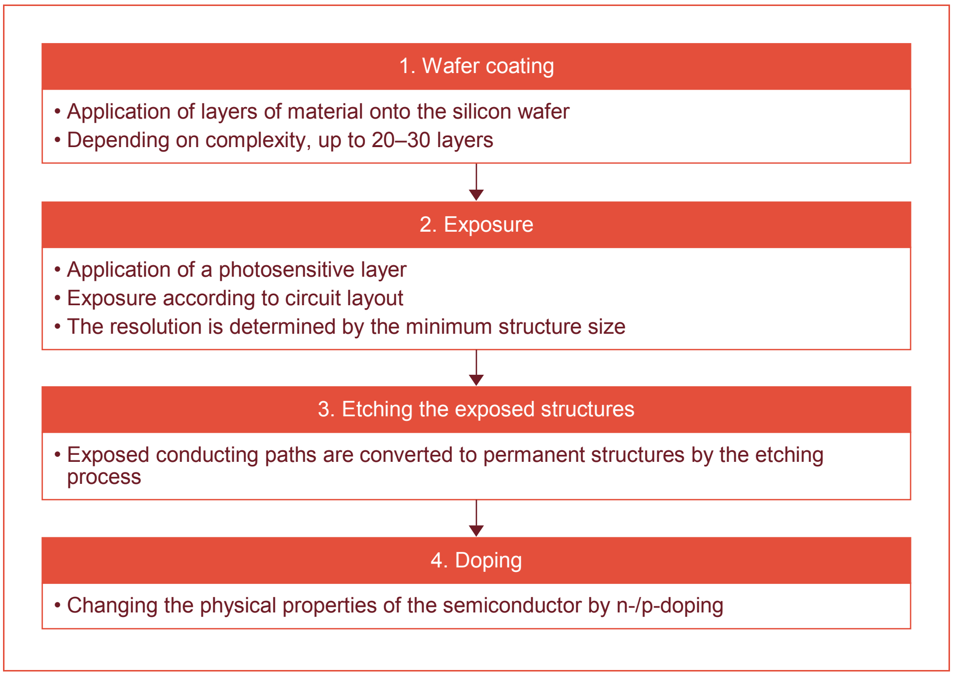


Fig. 6 Front-end production processes

In the first process, wafer coating, many material layers such as insulators and conductors are applied to the wafer, depending on the complexity of the semiconductor to be produced. A photosensitive layer is then applied; this is subsequently exposed by means of various masks using a lithographic process. The exposure process depends on the structures defined by the chip design. The resolution of the exposure mask determines the minimum feature size possible on the chip. The exposed conducting paths are then converted to permanent structures by an etching process. By means of doping with foreign atoms, the physical properties of the semiconductor are changed. This process stage marks the end of front-end production.

Compared with the other value creation phases, wafer processing has the highest capital requirement. The highest value creation phases are to be found in wafer processing and in chip development.

Back-end production processes

In the back-end process stages, the chips which are made in the front-end production process and which are still on the wafers are sawn individually from the wafer, fitted into the protective housing, tested, packaged and sent to the customer. Figure 7 shows the individual stages in back-end processing.

Back-end production processes are increasingly being outsourced to external specialists.

If the chips are to be processed into modules, they are soldered onto the module in a process which follows the actual back-end stages. The module is then tested again.

The complexity of the process stages, the applicable requirements for personnel and the costs of the machines are higher in the front-end fabs than in back-end processes. Back-end processes are thus frequently carried out in low-wage countries.

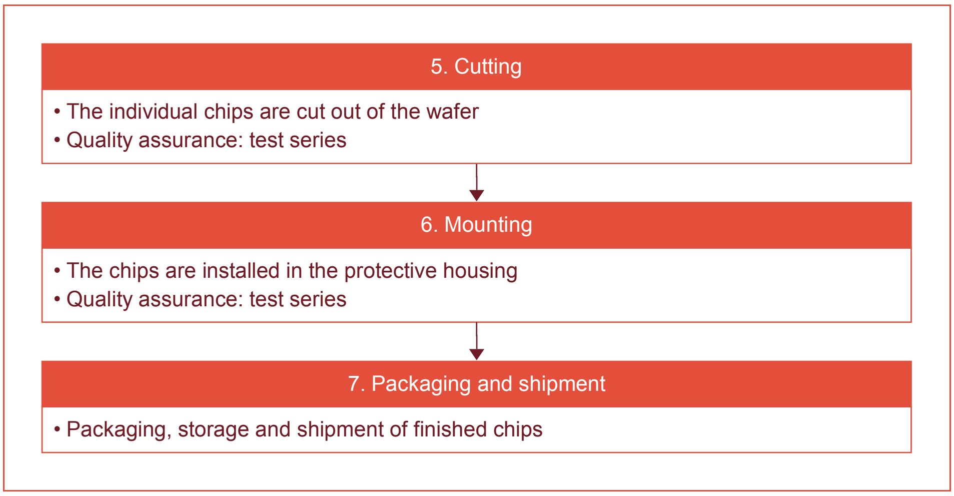


Fig. 7 Back-end production processes

Support activities

Design and complicated front-end production require highly qualified and experienced employees.

The actual value chain of semiconductors requires numerous support activities. These include logistic requirements, infrastructure conditions or the corresponding production facilities, financing, management and administration, know-how, production technologies and purchasing and procurement conditions.

Storage and inventory management play an important role. Logistics service providers frequently handle the entire supply chain, including storage under clean room conditions. And the production facilities are also of crucial importance. Indeed, the costs of an installation with 300 mm process technology and corresponding production scales amount to around 4 billion US dollars. In order not to incur these costs, some companies decide that they will entirely or partially do without their own production facilities and outsource production to external companies. In particular, fabless companies operate entirely without production facilities.

Know-how and the skills of employees are vital to the success of semiconductor companies. In particular, the design and the front-end production of chips require highly qualified employees with relevant experience. Because of the complex nature of the physical background, the workforce accordingly has a particularly high percentage of graduates.

In the innovation-driven semiconductor industry, the technologies in the chip production processes, the materials used and the chip design are of vital importance. The functionality of the semiconductors, feature sizes and production efficiency, which is also reflected in the processing of large wafer diameters, have important roles to play in this respect.

Key components in semiconductor production, and in particular wafers, frequently require individual purchasing and procurement conditions and are purchased in accordance with supplier-specific specifications. For instance, to ensure the required purity level of the silicon, wafers have to be tailored specifically to meet the requirements of the individual production process of the fab. Financing and control are also extremely important as a result of the capital intensity, the high pace of innovation and the cyclical nature.

3 Analysis of the competition

The semiconductor industry is increasingly specialising in individual elements of semiconductor value creation. Whereas IDMs cover the entire value chain from the initial chip design through to production, foundries concentrate exclusively on manufacturing. Fabless manufacturers are responsible for design and sales. The companies with the lowest content in the value chain are open market assembly and test service providers.

In the following analysis of the competition, we discuss key parameters for the selected business models: integrated device manufacturer (IDM), broken down according to logic (IC IDM) and memory manufacturers (memory IDM), foundries, fabless, assembly and test, as well as equipment manufacturers.

Sales and margins

Semiconductor companies differ considerably in terms of their size and sales. Intel, an IC IDM, is the company with the highest sales, more than 35 billion US dollars in 2008, whereas Trident Microsystems, a fabless company, generated sales of around 78 million US dollars, and was accordingly the smallest of the companies we measured against overall sales for the sector.

The highest average sales are generated by IC IDM and memory IDM (2008).

We found that companies with the strongest sales are in the IC IDM and memory IDM segments, followed by fabless, foundries and equipment manu-facturers. This is scarcely surprising. In the final analysis, the IDMs cover the entire value chain and thus generate higher sales, compared with companies which concentrate on individual elements of the value chain.

Figure 8 shows the minimum, average, median and maximum figures of the semiconductor companies considered in this study, broken down according to business model.

With regard to the assessment of sales for 2004 and 2008, it is apparent that IDMs and equipment manufacturers suffered a downturn. On the other hand, fabless, as well as assembly and test companies in particular, were able to achieve a relatively high increase in sales. The downturn in sales at the equipment manufacturers is indicative of lower corporate investment. The growth in sales at fabless and assembly and test companies is an indication of the increasing specialisation in individual elements of the value chain. In the final analysis, each element in the chain requires specific knowledge and skills that justify specialisation. In addition to specialising in core competences, the strategy of focusing on chip production permits better management of fab utilisation, with orders from several customers. Some IDMs adopt a fab-light strategy, with parts of production outsourced to external companies. From the point of view of the IDM, the fact that the fabs are no longer necessary results in a considerable reduction in fixed costs, which means that more homogeneous operational results can be achieved. For example, AMD and the Advanced Technology Investment Company established global foundries in March 2009 and outsourced the former AMD fabs to the new company. Intel adopted a different strategy, considering semiconductor production to be a core competence which it intends to retain and develop further.

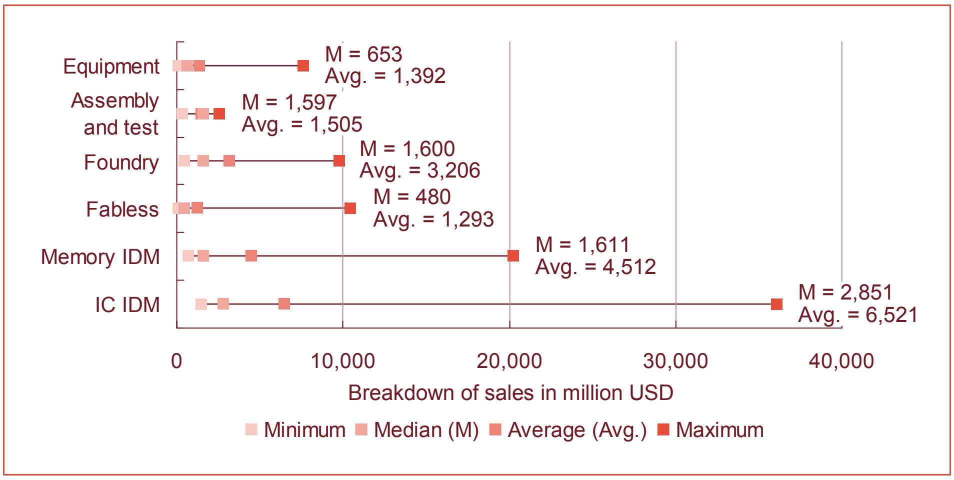


Fig. 8 Breakdown of sales according to semiconductor business models

In 2008, foundries, assembly and test and IC IDMs generated on average the highest EBITDA margins, namely 38%, 21% and 20% respectively (see Figure 9). Fabless companies achieved approximately 11%. Equipment manufacturers attained approximately 7%, while memory IDMs in 2008 achieved on average a negative EBITDA margin of around 3%. This reflected the difficult climate for DRAM and flash memories, with sales prices in 2008 that were on occasion lower than production costs. Since 2004, the EBITDA margin has been declining for the group of memory IDMs considered in this study. In 2007, the average EBITDA margin was still more than 20%.

Note that a considerable fluctuation in the range is common, particularly for equipment manufacturers.

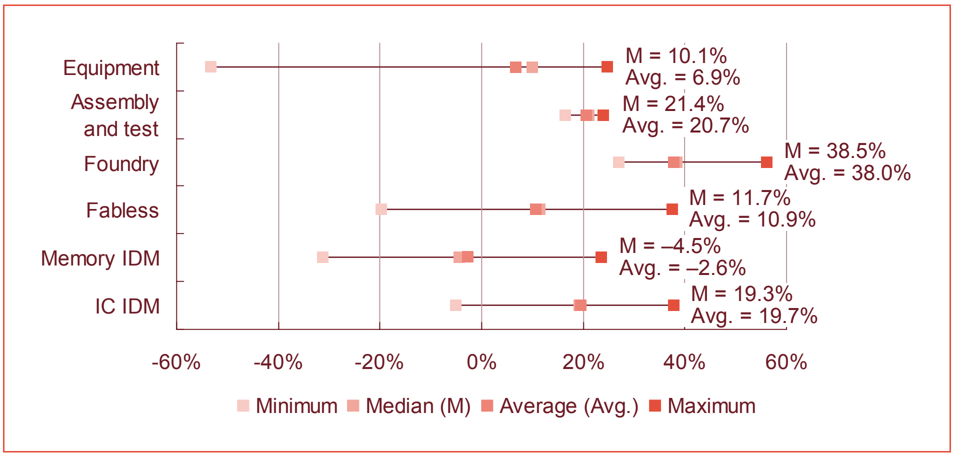


Fig. 9 EBITDA margin broken down according to business models

A similar scenario is applicable to the EBIT margins (see Figure 10). Striking aspects in this respect are the considerable capital requirements and fixed cost content of IDMs and foundries; this is reflected in higher levels of depreciation than is the case at fabless companies, which have no production facilities.

The highest average EBIT margin (approximately 9%) was achieved at IC IDMs in 2008, followed by assembly and test (approximately 7%), foundries (around 3%) and equipment manufacturers (approximately 2%). The EBIT margin at fabless companies was virtually zero. This was due mainly to the sharp downturn in sales in the last two quarters, whereas the EBIT margins at memory IDMs were extremely negative (an average of −47%).

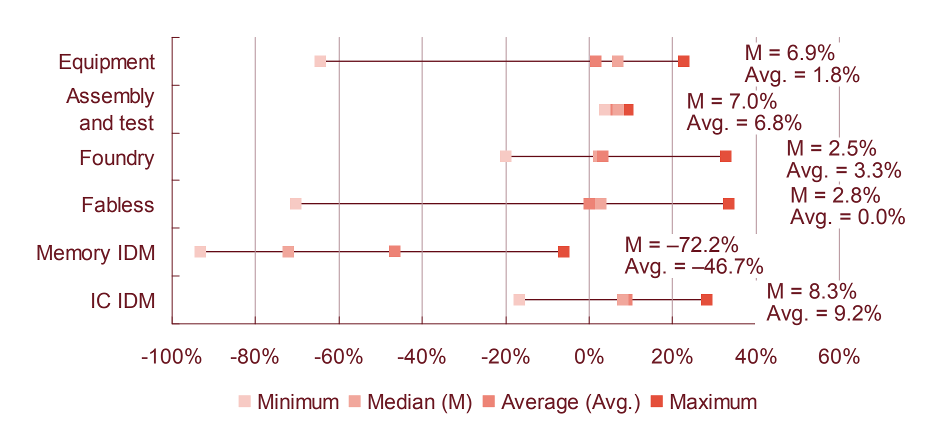


Fig. 10 EBIT margin broken down according to business models

Research and development spending

Research and development spending is of vital importance in the semiconductor industry because of the level of innovation. Again, there are significant differences depending on the business model. Fabless companies concentrate on that part of the value chain which deals with the design and development of semiconductors and which is subject directly to Moore's law. Accordingly, they account for the highest percentage of research and development costs, with approximately 26% on average. IC IDMs also design and develop chips, so their research and development spending is also high. Such spending is on average 16%, and roughly equivalent to the figure at the equipment manufacturers (17%). The miniaturisation process, as well as transitions to larger wafer diameters, require appropriate installations and production tools so that production may keep up with innovation. Memory IDMs spend approximately 11% of their overall sales for research and development. At the bottom end of the scale, are foundries with an average of 8%, and assembly and test companies with approximately 2%. For IC IDM, fabless and equipment manufacturers, research and development spending has been constantly rising in recent years. Memory IDMs, foundries and assembly and test companies, on the other hand, have been able to keep their research and development spending constant or to reduce it.

Fabless companies have the highest levels of R&D spending; assembly and test have the lowest levels of R&D spending.

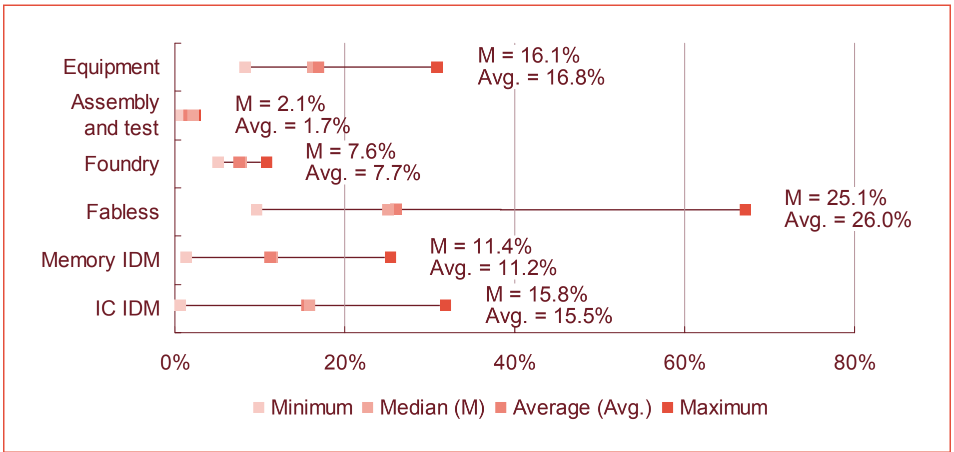


Fig. 11 Research and development spending broken down according to business models

Selling and administrative expenses

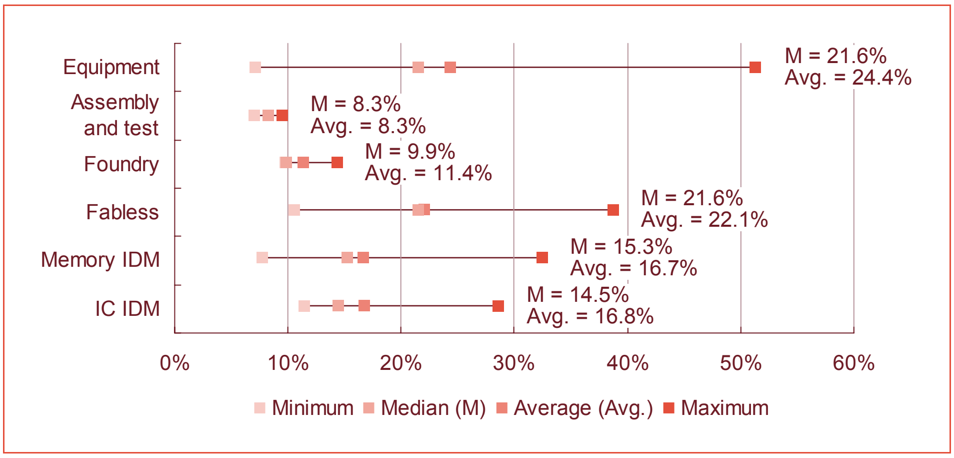


Fig. 12 Selling and administrative expenses broken down according to business models

The lowest selling and administrative costs on average are encountered at foundries.

Figure 12 shows the breakdown of selling and administrative costs over the various business models. On average, equipment manufacturers have the highest percentage of selling and administrative costs, with an average of 24% of sales. However, the distribution range of the figures is again very wide. Equipment manufacturers are followed by fabless companies with an average of 22%. IC IDMs are to be found in midfield (approximately 17%). With a similar range, memory IDMs spend an average of approximately 17% of sales on selling and administrative activities. Foundries and assembly and test have the lowest selling and administrative costs, approximately 8 to 11%, and a very low variance within the range. Compared with 2004, and with the exception of assembly and test, all business models considered in this study reported a proportionate increase in selling and administrative costs.

Net income/net loss

The effects of the financial crisis in the last two quarters of 2008 had a negative impact on all business models, as illustrated in Table 1. Memory IDMs and fabless, which had come under pressure in 2007, were particularly affected. On the other hand, all other segments were able to achieve very positive profit margins in 2007. Foundries and equipment manufacturers reported the highest margins, followed by assembly and test. IC IDMs also achieved a positive result in our average assessment. However, there are indications of a downward shift in the overall picture for 2008, and all average figures are now negative. The worst performance in 2008 was reported by Memory IDMs.

Profit margin	Minimum	Average (Avg.	Median (M)	Maximum
2008				
IC IDM	–67.9%	–6.0%	–2.0%	30.4%
Memory IDM	–117.7%	–68.5%	–65.3%	–5.8%
Fabless	–144.4%	–15.5%	–0.1%	28.4%
Foundry	–32.5%	–4.9%	–5.6%	31.1%
Assembly and test	–17.2%	–4.7%	1.6%	1.6%
Equipment	–97.7%	–8.4%	4.1%	17.8%
2007				
IC IDM	–57.7%	1.9%	3.4%	20.2%
Memory IDM	–23.6%	0.6%	–1.8%	48.0%
Fabless	–218.3%	–7.8%	6.5%	44.9%
Foundry	–1.3%	16.8%	15.9%	34.8%
Assembly and test	5.4%	8.5%	8.0%	12.2%
Equipment	–0.9%	12.5%	12.1%	26.7%

Tab. 1 Comparison of profit margins in 2007 and 2008 for different business models

4 Summary of results and outlook

	Sales	Trend 2004–2008	EBITDA/ EBIT margins	Trend 2004–2008	R&D spend- ing	Trend 2004–2008	Selling and adminis- trative costs	Trend 2004–2008
IC IDM	●	↘	●	→	◕	↗	◑	↗
Memory IDM	◕	↘	○	↓	◔	→	◑	↗
Fabless	◑	↑	◑	↘	●	↗	●	↗
Foundry	◑	↗	◔	↓	○	→	○	↗
Assembly and test	○	↑	◕	Clear trend not evident	○	→	○	↘
Semi equipment	◑	↘	◑	↘	◕	↗	●	↗

Fully shaded circles indicate that the values of the particular parameter are relatively high compared with the other business models. A reduction in the extent of the shaded area indicates a decline in the relative importance compared with the other business models. A horizontal arrow indicates a constant trend between 2004 and 2008. The extent of any rising or falling trend is indicated by the rising or falling slope of the arrow.

Fig. 13 Consolidation of the results of the analysis of competition

Figure 13 shows the consolidated results of the analysis of competition. Research and development spending accounts for the relatively highest percentage of overall sales at fabless companies, followed by IC IDMs. Assembly and test and foundries have only a very low level of R&D spending in relation to overall sales. R&D spending has increased in recent years at IC IDMs, fabless and equipment. With the exception of assembly and test, selling and administrative costs have increased for all business models considered in this study. These costs expressed as a percentage of overall sales are the highest at fabless companies and semiconductor equipment manufacturers. Very low selling and administrative costs are reported for assembly and test and foundries. This result is scarcely surprising, as the costs are explained by the different emphasis of the business models.

IDMs cover the entire value chain, and this group contains the companies with the highest sales. Fabless and foundries specialise in those elements of the value chain which feature the highest individual added value within semi-conductor production. Accordingly, the strongest sales are reported for IDMs for these two business models. Assembly and test reports the proportionately lowest sales. Since 2004, sales have increased for all business models up to and including 2008, with the exception of IC IDMs and semiconductor equipment, where a slight downturn in sales was reported in 2008 from 2007.

Particularly strong sales growth has been reported for fabless and assembly and test. Considerable capacities have been established in recent years, and this is reflected in a proportionately higher percentage of fixed costs, in higher costs and in profits particularly at IDMs and foundries. Since the beginning of the crisis, sales and capacity utilisation at the production facilities have fallen considerably. All business models have been affected by the impact of the crisis.

For 2009, sales are expected to decline by around 19%, and this will be reflected in the margins and results of all business models. A further increase in research and development spending will be essential in order to keep up with the rapid pace of innovation. The specialisation process, and in particular the segregation between production and chip design, will continue to make progress. Outsourcing will enable fixed costs to be converted into variable costs in certain cases. Accordingly, the companies will be less affected by economic cycles with a sharp downturn in sales.

C Technology and trends

The semiconductor industry is characterised by a high pace of innovation. This was recognised and described by Gordon Moore in 1965 in what came to be called Moore's law. In 1968, with two other engineers, he established the Intel Corporation, which today is the largest semiconductor manufacturer in the world.

Moore's law is not only useful for describing the strong pace of innovation in the semiconductor industry: it can be used to predict resulting consequences and trends. The law postulates that the smallest features are reduced by a further 20% approximately every three years, and the number of transistors per chip increases by a factor of three to four. In addition, the clock frequency of the processors increases by a factor of 1.5, while the costs of a production facility more than double, by a factor of 2.3.

In addition to miniaturisation, the ability to affect the physical characteristics of semiconductors by specific technical means is significant. The electrical conductance of semiconductors is between conductors (for instance, copper or iron) and isolators (such as glass). The conductance of semiconductors can be influenced in a specific manner by way of doping with foreign atoms, so that numerous electronic elements can be produced in an extremely small space by means of chemical, optical and mechanical processes.

The production of semiconductors, as well as the trends and developments in the sector, can be described essentially in terms of production capacity, structure sizes, enhanced functionality and wafer sizes. The following sections analyse these four technology drivers and the underlying technological challenges within the context of the current economic crisis. They also examine development prospects for the future.

1 Production capacity

Excess capacities exist due to declining capacity utilization and increasing production capacity.

In the first quarter of 2009, the worldwide production capacity of semiconductors declined by more than 8% from the fourth quarter of 2008, to around 2.2 million wafer starts per week (measured in 200 mm-equivalent wafers).[3] This is roughly equivalent to the capacity level of the second quarter of 2007. At the same time, capacity utilisation of production facilities declined to around 56%, while the decline in utilisation for discrete semiconductor elements (to about 43%) was more significant than the decline for integrated circuits (which account for approximately 91% of overall capacity). Capacity utilisation for integrated circuits was around 57%. In the previous quarter, the sector reported a sharp decline in semiconductor production capacity utilisation from 87 to 68% as a result of the current economic crisis. In the previous 10 quarters, this capacity utilisation amounted to approximately 89% on average.

In the second quarter of 2009, installed worldwide production capacity again declined by approximately 4% from the first quarter of 2009 to approximately 2.1 million wafer starts per week. On the other hand, capacity utilisation increased to almost 76%. For discrete semiconductors, capacity utilisation was approximately 65%, and capacity utilisation for integrated circuits climbed to 78%. The increase in capacity utilisation reflected cuts in production capacity and also the fact that, in recent months, destocking has taken place and the

[3] SIA (2009).

industry has placed virtually no orders. Because inventories have fallen to zero and now have to be replenished, semiconductor production is rising. However, this naturally positive effect is not in itself a clear indication of a definite end to the crisis. The current restocking might be followed by further declines in utilisation if the economy continues to be weak.

Nevertheless, we expect to see a further increase in production utilisation in the remainder of 2009. At the same time, production capacities will probably be reduced further, particularly at older fabs, and this will have a positive impact on utilisation figures.

In the semiconductor industry, the economic crisis is reflected as a sales crisis, and further exacerbates the already difficult situation. Before the crisis, installed production capacity was continuously rising. At present, production capacity is being cut, as a result of much lower demand compared with the time before the crisis. When demand recovers, this process will be reversed and, as has been the case following previous downturns, capacity will be built up again.

Related discussion: complementary metal-oxide semiconductors (CMOS)

The term 'CMOS technology' is used to define the technology which is currently commonly applied in semiconductors of the logic family. CMOS combines two complementary field effect transistors in order to represent the statuses '0' and '1' with one control voltage and thus to carry out logical operations by means of a combination of large numbers of these statuses.

The term 'metal oxide' indicates the physical structure of the field effect transistors. They consist of a metal gate electrode that is applied to the semi-conductor material. Aluminium was frequently used for this purpose in the past, but silicon dioxide is mostly used nowadays. However, with the increasing miniaturisation of features, high leakage currents occur with gate electrodes based on silicon dioxide; these leakage currents drive up power consumption. For this reason, development is going in the direction of materials with a high dielectric constant (the dielectric conductance of a material is a parameter used for the permeability of magnetic fields), known as high-κ dielectrics. The process of changing over to these materials has consequences for the production process, making it even more complex.

Up to certain feature sizes, the advantages of CMOS technology are relatively low power consumption and high noise tolerance.

2 Feature sizes

According to Moore's law, progress in the semiconductor industry is reflected in a continuous reduction in the size of the smallest structures which can be achieved in the production of integrated circuits. Every semiconductor product family, ranging from processors and memory chips to microcontrollers, has a different characteristic feature size. According to the International Technology Roadmap for Semiconductors (ITRS), the so-called half-pitch spacing is the characteristic feature size for DRAM memories.

Approximately half of the current worldwide production capacity is suitable for feature sizes of less than 80 nm. In particular, commodity products such as

DRAMs and central processing units for PCs are manufactured with the smallest possible feature sizes.

Structure size	Percentage of CMOS production capacity
x ≥ 700 nm	5.7%
700 nm > x ≥ 400 nm	6.0%
400 nm > x ≥ 300 nm	6.9%
300 nm > x ≥ 200 nm	4.3%
200 nm > x ≥ 160 nm	7.1%
160 nm > x ≥ 120 nm	11.9%
120 nm > x ≥ 80 nm	9.7%
x < 80 nm	48.4%
Source: SIA, figures for the second quarter of 2009	

Tab. 2 Distribution of the installed worldwide CMOS production capacity according to smallest possible feature size

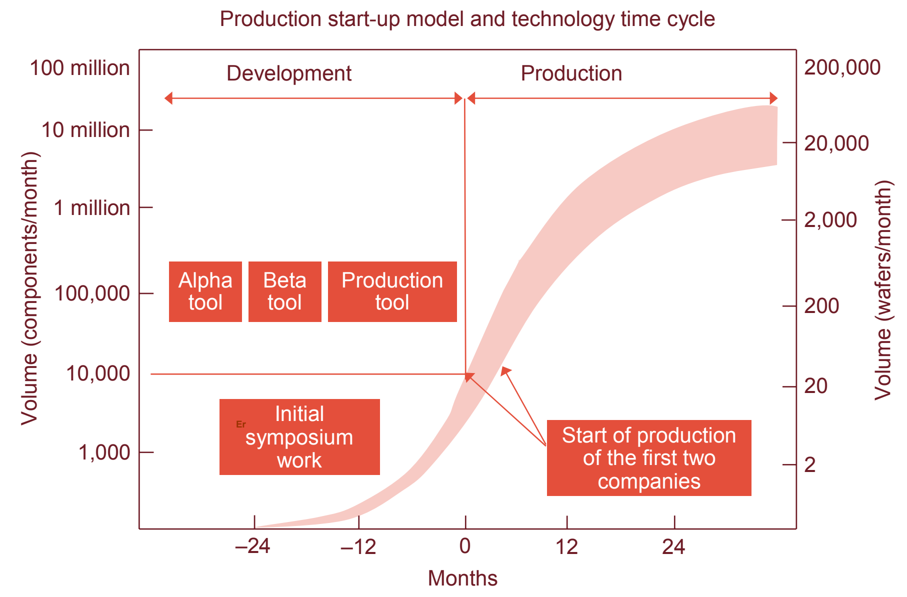
With regard to the reduction of feature sizes, note the difference between geometric and equivalent scaling. Geometric scaling is the physical reduction of feature sizes. Equivalent scaling describes an increase in the number of transistors for a given geometric scale size. This is achieved particularly by using three-dimensional structures for integrated circuits, the application of new materials and innovative design and technologies, such as the multi-core central processor units in PCs and servers that have been in use for quite some time.

According to Moore, the development of geometric feature sizes follows a linear pattern.[4] The technology cycle is defined by the ITRS as the period between the first development work and the point at which two manufacturers use the new production technology for production purposes. This period is between two and a half years, for instance in reducing the half-pitch spacing for DRAM memory modules, microprocessors and application-specific integrated circuits, and 3.8 years for reducing the physical gate length in a microprocessor.

Geometric feature sizes are reduced in a period of 2.5 to 3.8 years.

These periods contain the development and production of tools for the prototypes, the so-called alpha and beta tools, as well as series production. Production of the alpha and beta tools takes up to two years. Series production tools require a lead time of one to two years. The technology cycle also covers the qualification of the semiconductors at the specific customers and can also take up to one year. Figure 14 shows an example of the technology cycle and the subsequent ramping up of series production.

[4] Linear relationship for development of the geometric structure size $\mu_t + \theta = s \cdot \mu_t$, with the scaling factor s = 0.7 and the structure size μ_t (in nanometres) at time t. θ defines the duration of the technology cycle for individual semiconductors in years.



Source: ITRS, PwC presentation

Fig. 14 Example of technology cycle for the changeover to new technologies in semiconductor production

CMOS technology covers around 89% of the installed worldwide production capacity for semiconductors.

The most common technology now in use for creating integrated circuits is based on metal-oxide technology (CMOS, or complementary metal-oxide semiconductor) and covers approximately 89% of the installed worldwide production capacity for semiconductors.[5] In its projection of technology development, the ITRS shows the reduction of the smallest feature sizes. This forecast is shown in Table 3. The feature sizes shown for the specific years describe the point at which production commences in accordance with Figure 14.

Product	Relevant scale	2009	2010	2011	2012	2013	2014	2015	2020
DRAM	Stagger-contacted metal 1 (M1) 1/2 pitch (nm)	52	45	40	36	32	28	25	14.2
MPU/ ASIC	Stagger-contacted metal 1 (M1) 1/2 pitch (nm)	52	45	40	36	32	28	25	14.2
Flash	Uncontacted poly Si 1/2 pitch (nm)	40	36	32	28	25	23	20	11
MPU	Printed gate length GLpr (nm)	41	35	31	28	25	22	20	11.1
MPU	Physical gate length GLph (nm)	27	24	22	20	18	17	15	9.7
Source: ITRS, 2008 update									

Tab. 3 Development of feature sizes attainable by lithography broken down according to product

The continuous process of reducing feature size will bring CMOS technology up against its limits in an area of around 9 nm (according to state-of-the-art technology). To achieve smaller sizes, new materials and technologies will have to be developed. This is considered to be a major challenge. As shown in Table 3, this limit in production will probably not be attained before the year 2020.

[5] SIA (2009)

Professor Schmitt-Landsiedel, the future of semiconductors is currently the subject of much discussion. Where is the journey going? Will we see even smaller circuits?
The technological trends of the continuous process of reducing feature size in accordance with Moore's law are essentially defined in the International Technology Roadmap for Semiconductors. With conventional CMOS circuits, the feature sizes of 9 nm defined in the roadmap will certainly be attained one day, however, only in conjunction with considerable spending on development. Only a handful of integrated device manufacturers and some silicon foundries worldwide will probably be able to keep up in this respect. Many IDMs have decided that they will no longer take part in the technological arms race. It is to be hoped that at least two foundries which invest in these small feature sizes will be able to survive.

Will there be shortages in terms of production because only a very limited capacity will be set up?
These small feature sizes are not really needed for many products. What do we want to do with these high integration densities? The designs are also very sensitive and difficult because there will be more and more production fluctuations. We will have to wait and see how the equipment manufacturers will be able to cope.

Why do the large manufacturers still have in-house production facilities? Where is the competitive advantage of having their own production?
The processor manufacturers produce, for instance, very high-performance high-frequency chips with corresponding losses. In this field, extremely intensive cooperation between design and production is required, as this is the only solution which will function. The same is applicable to the memories. In view of the tremendous volumes involved, these manufacturers can afford their own production. There is, of course, also fear of foundries being able to exert tremendous price pressure.

Will the quality requirements for production continue to become more demanding?
Yes, because new materials will appear. Particularly in the field of dielectrics, there is a tremendous amount of innovation at present, although there are still considerable problems. It remains to be seen whether the research is worthwhile and whether all products genuinely improve as a result. A further important issue is the connections to the housing, as the new chips with the sensitive nanostructures also have to have contacts. However, particularly in the field of the memory chips and processors, the development in the direction of smaller and smaller feature sizes (we speak of 'more Moore') will continue for the foreseeable future – and the requirements applicable to production will thus become more stringent. However, a key driver in research and development at present is the aim to achieve less power loss, particularly for the chips used in portable applications. With modern chips, the power loss does not decline with the feature size; leakage currents are a problem in this respect. In the final analysis, the supply voltage can thus no longer be reduced in line with the feature size, so it is becoming more complicated. I believe that development overall will move even more in the direction of additional functions of the chip, in other words in the direction of 'more than Moore'.

Which areas are the growth fields for the European semiconductor industry?
The advantage of Europe is that the semiconductor industry in the region works together very intensively with the users, for instance in the automotive and engineering sectors. Interdisciplinary knowledge is necessary, and the overall environment in Europe is very good for this purpose. We also have good opportunities in the growth areas of energy and environmental technology, for instance in power electronics. Commodity chips will probably be manufactured in Asia for the foreseeable future.

When 9 nm production arrives, will we be able to expect yields similar to those seen in the past?
Yes, but the design philosophy will have to be changed and will have to become even more robust, not only with redundancies but also with error tolerance, for instance with monitoring circuits. Many functions will then be included in the software. The boundary between hardware and software will become increasingly fuzzy.

Professor Doris Schmitt-Landsiedel, Institute for Technical Electronics at the Technische Universität München

"The opportunities in the fields in which not only zeros and ones are processed are huge!"

What are the limits of CMOS technology?
It is not possible for the dimensions to be reduced ad infinitum, because there are so-called tunnel currents and short channel effects, and the circuits no longer function properly. On the other hand, lithography also limits feature size. The other question is whether it will eventually no longer make commercial sense to manufacture even smaller structures. However, the semiconductor companies live from technical progress, and thus there will continue to be further innovations.

Many years ago, Gordon Moore calculated at a conference that, in the near future, one million transistors would be needed for every person; that was a gigantic figure at that time. It is hardly conceivable that the inventor of Moore's law will no longer have any further ideas concerning the further use of transistors.
We have now arrived at my favourite subject. Who needs increasingly powerful computer performance? What we need are functions for which nature provided very elegant solutions, such as image and voice recognition, intelligent regulation, data compression, etc. We therefore need to research new architectures in accordance with bio-analogue principles. We can use entirely new elements which are not merely switches for generating zeros and ones. We are currently carrying out research into systems with nanomagnets. CMOS is not replaced, but rather enhanced in this respect. A further example: a ferroelectric associative memory was proposed some time ago. This would enable patterns to be recognised many times more quickly than would be the case with traditional processors and with a power loss which is several times lower. This is impressive and is what is known as 'beyond Moore'.

Is it also problematic in various respects that, in the industry, past experience (i.e., developments in CMOS technology) are simply extrapolated for the future?
The companies should not only look at the roadmap and instead should ask: what do we really need? The hope is that we will be able to co-influence this future in Europe. The opportunities with systems in which not only zeros and ones are processed are huge. Indeed, biology does not operate in digital form, and instead tends to operate by semi-analogue means. There is also more tolerance of errors and faults. However, we need courage in Europe for this purpose!

3 Enhanced functionality

In addition to the further development of production processes and feature sizes, the innovation potential in the semiconductor industry is boosted significantly by enhancing functionalities through integrating analogue functionalities in integrated circuits. Such modules are described as system-on-a-chip (SoC) or system-in-package (SiP). The aim is to migrate as many analogue functions as possible from the circuit board to the individual chip as part of a continuing process of miniaturisation. For instance, in mobile communications, it is possible for transmitters and receivers of radio frequencies, passive components, sensors and actuators to be combined on a single chip.

Enhanced functionality encourages miniaturisation and demands technological complexity.

This enhanced functionality is accurately described by the ITRS as 'more than Moore', because it constitutes a further dimension of technological progress. The enhanced functionality means that module sizes can be reduced further, power consumption can be reduced and production costs can be lowered.

The ITRS expects that enhanced functionality will become even more important in the future. The resulting chip designs impose stringent requirements on the manufacturing process. In the final analysis, additional process stages are necessary, and they result in production becoming more expensive. In addition, the sharp distinction between analogue and digital signals poses a technological challenge. It is essential for the two signals to be isolated to avoid noise interference that might have a negative impact on the functionality of the component. This becomes more and more difficult with very small feature sizes.

What technological developments may we expect in the semiconductor industry in the next few years? Will CMOS technology and Moore's law come up against technical limits?
Becker: There are two reasons why Moore's law will only be applicable for approximately five more years: firstly, we will come up against a cost limit – the immense and necessary research and development costs will no longer be amortised as quickly. Secondly, we will probably require new materials. Leakage currents will be simply too high on silicon-based circuits. We are already starting to use special alloys to achieve high-performance clock frequencies with acceptable energy and power losses. However, we have been constantly, positively surprised by materials scientists in the past …

Siegel: We must not discuss the industry roadmap merely from the point of view of technology; instead, we have to ask: what functions do I intend to achieve with the chip? Moore's law essentially describes the development of memory chips and processors – however, the semiconductor world comprises much more than this! We will also be able to further reduce the feature size of the chips in the course of the next few years by means of new dielectrics – 8 nm is certainly technologically feasible. But this is not the crucial question: on the contrary, we should consider what requirements will be posed in relation to chips in future. And there I consider that the focus will be not only on computing power but on low access times, low power losses, constant availability of information and additional functions.

Becker: I can only agree. There will be additional functionalities on the chips, and the trend is probably going in the direction of 'more than Moore'. It is unbelievable that Mr Moore set up such a rule in 1965, and it is still applicable today! In my opinion, however, interest is now focusing more on the multi-core chips. The main problem in this respect is parallelisation, high-level programming. Multi-core technologies will be the predominant technology for the foreseeable future. I believe that there will be heterogeneous multi-core systems with different chips and different functions. However, it is still necessary to consider whether we can program these multi-core systems appropriately.

Siegel: With very small circuits, there are also additional problems, for instance the wiring, that is, the drivers which supply the power to the transistors: how do I achieve sensible wiring which is adequate for the clock frequency and which also permits low-loss switching? We must also not forget that high clock frequency high-performance chips are frequently affected by heat problems. I consider that, with regard to the feature sizes, the large semiconductor manufacturers are engaged in a fight for ultimate survival with the other manufacturers. The first-mover advantage counts and keeps innovations high in this particular field. On the other hand, the situation is different with regard to analogue chips, where the feature sizes are not such a dominant factor, and many, including small, companies are achieving very attractive profits in this respect.

Becker: We are coming up against limits. The technologies will no longer be so stable and will become more prone to errors and faults. We will then require new circuit designs and architectures which provide a facility for adapting to low switch reliability, in other words, self-healing, self-correcting circuits. With very small feature sizes, the yields will also be considerably smaller, so that we will have to build systems and architectures which will switch properly despite individual defects affecting these very complicated chips. And this is also the direction in which research is going: how can we develop such adaptive circuits and architecture structures which will cope with the changeover to the latest technologies? However, I am not yet able to say where we will eventually land.

In addition to the functionalities of the semiconductor industry, the subject of power consumption and 'green' information and communication technologies (green ICT) is becoming much more important. What trends do you expect in this particular field?
Becker: There is huge demand for green ICT solutions, and not only because this is a fashionable subject at present. Instead, there are entirely practical reasons: at present, 30% of energy in large developed cities is used for IT, and the electricity bills in our data centres are also enormous. This means that green ICT provides specific savings in terms of costs for companies. However, intelligent IT systems can also be used for reducing CO_2 emissions in traffic by optimising traffic flows. There is still tremendous potential for improvements in this respect. We will therefore set up an increased number of research projects backed by industry for this particular field, also within the Karlsruher Institut für Technologie centres for energy and for climate and the environment.

Professor Jürgen Becker, Institut für Technik der Informationsverarbeitung, Karlsruher Institut für Technologie (KIT)

"We need new circuit designs and architectures which provide a facility for adapting to low switch reliability; in other words, self-healing, self-correcting circuits."

Professor Michael Siegel, Institut für Mikro- und Nanoelektronische Systeme, Karlsruher Institut für Technologie (KIT)

"The focus is not only on computing power; instead, the focus is also on low access times, low power losses, constant availability of information and additional functions."

There will probably be relatively few problems with regard to funding programmes in the green ICT field; however, what is the situation at present regarding funding for research in the field of semiconductor technology in Europe?
Siegel: The decision-makers are responsible for using this state funding in a forward-looking manner. It is necessary to consider whether the technologies which are the subject of research promise to be successful in the short, medium or long term. At present, in the field of green ICT, a lot of work is being carried out only for the sake of showing that something is being done, but there is a lack of a medium- to long-term research strategy. On the other hand, other high-tech research projects are of such a long-term nature that we will probably not see the results in our lifetime. A more balanced and more considered approach would be desirable in this respect. Nevertheless, I believe that the European research world is in a very good position and together in the ecosystem with the manufacturers.

What will the world look like after CMOS technology?
Siegel: Another forward-looking issue beyond conventional CMOS technology will be computers using new methods based on quantum principles. These will be able to solve specific mathematical tasks, for instance the solving of codes, very quickly. However, they will not be a product for the mass market, but will be required wherever it is necessary for high-security data to be transferred via high-security channels. For the mass market, I consider that the focus will probably be on modified memory technologies such as FERAMs and MRAMs, that is, non-volatile memory techniques.

Becker: The boundary between the present-day silicon-based semiconductor technology and nanotechnology is also becoming very exciting: I believe that we will see a considerable number of innovations in the fields of medical technology, robotics, car making and in the field of energy in the foreseeable future.

How will the business models of the semiconductor manufacturers be affected as a result of the changing technological conditions?
Siegel: Foundries will continue to be extremely important, simply due to the fact that the production technology is extremely expensive and is becoming even more so. The organisational form of the business alliance, which we are currently seeing more frequently, will become more frequent. However, the trend at the foundries will be to expand their range of products even further – in the future, they intend to be able to offer all production technologies from a single source. Wait for another two years, and then they will also be making MRAMs. However, from the point of view of the fabless companies, the risk of a monopoly position being established by a very small number of foundries is very high.

4 Wafer sizes

The highest production capacity in the world is for 300 mm wafers.

Around half of the installed worldwide production capacity of the different wafer sizes consists of facilities for 300 mm wafers (see Figure 15). Compared with the previous quarter, the capacities at fabs with 200 mm wafers and smaller diameters have declined to a greater extent than has been the case at fabs with 300 mm wafers. This indicates that older production capacities with lower efficiency have been withdrawn from the market to a greater extent.

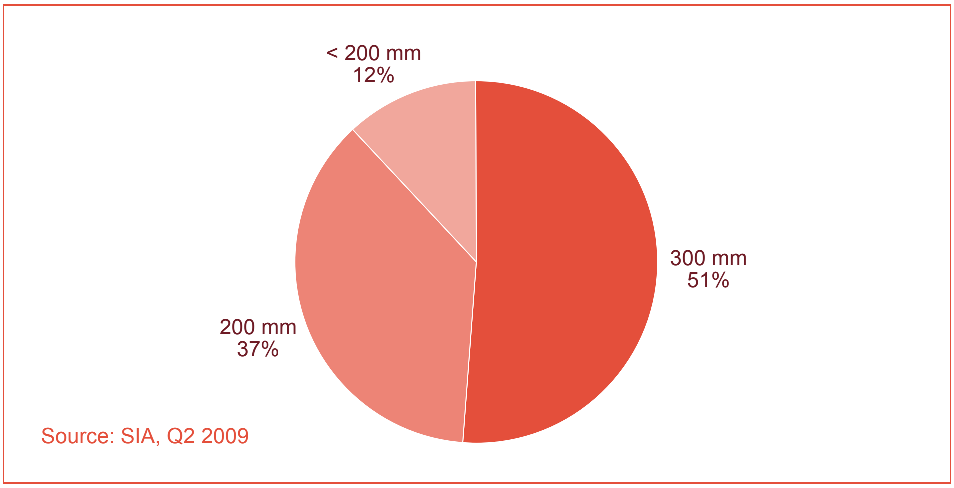


Fig. 15 Breakdown of the installed worldwide production capacity by wafer size

The number of integrated circuits on a wafer can be significantly increased by changing production facilities for wafers from a diameter of 300 mm to 450 mm. Compared with a wafer with a diameter of 300 mm, this results in a 2.25-fold increase in the surface area, allowing for more than double the number of integrated circuits per wafer. The increased effectiveness in production is offset by very high costs for construction: a modern facility for 300 mm wafers requires an investment of 4 billion US dollars, while current estimates for a production facility for 450 mm wafers are up to 10 billion US dollars. But the changeover to 450 mm and corresponding production sizes will reduce costs per chip by up to 30% and will enable production throughput times to be accelerated by up to 50%.[6] ITRS expects the changeover to production of 450 mm wafers to take place between 2012 and 2016 (estimate as of 2008, see Figure 14). As a result of the economic crisis, further delays may arise if investment spending continues to be somewhat sluggish and in view of current surplus capacities.

[6] ITRS

D Sales forecasts

1 The semiconductor market according to applications

We expect to see the market decline by 19% in 2009.

The year 2009 is one of the most difficult in the history of the semiconductor industry: the overall market was unable to grow in 2008, and the financial and economic crisis had a particularly severe impact on the semiconductor industry. Sales volume has fallen as a result of weaker consumer demand and destocking at customers of the semiconductor industry. Adding to concerns is that highly volatile commodities prices are still at a very low level.

Investments in new production facilities declined appreciably in 2009.

Investments in production have declined dramatically. In 2007, total investment in the sector amounted to 61.2 billion US dollars; only 26.7 billion US dollars is expected for 2009.[7] Until signs emerge of a substantial market recovery and as long as the financing situation on the capital markets remains difficult, it is unlikely that investments will return to their former level.

A further aspect is that only three companies will invest 1 billion US dollars or more in 2009,[8] compared with 2007, when 16 did. The leader in this respect is Intel, investing 4.7 billion US dollars, followed by the memory chip manufacturer Samsung at 4.5 billion US dollars and the Taiwanese foundry TSMC at 2.3 billion US dollars. These three players intend to focus on reducing feature sizes and developing production facilities for 450 mm wafers.

While record sales of 255 billion US dollars were reported in 2007, and declined by only 2.8% in 2008, we expect that market volume will contract by 19% to 201 billion US dollars in 2009. The sales markets have been affected to varying degrees. Automotive semiconductors are expected to decline by 38% from 2008, but we anticipate a decline of only 16% for industrial applications. The major market segments of data processing and communications will probably have declines of 16% and 23%, respectively. By components, we expect to see a 27% downturn for analogue semiconductors in 2009, while memory chips and processors will drop by 11% each.

In 2011, worldwide semiconductor sales are expected to return to the level of 2008.

We expect to see a return to high rates of growth starting in 2010

The sector will report double-digit percentage growth again in 2010 and 2011. In the year 2011, sales will rise to 248 billion US dollars, roughly the level before the crisis. The average compound annual growth rate (CAGR) between 2009 and 2012 is expected to be 10.6%. On the one hand, investment intentions in the industry will remain weak, and consumers' appetite for durable goods will also continue to be weak. On the other hand, structural trends such as wireless networking of applications and the increasing role of semiconductor products in the added value of end products will boost growth.

In our opinion, semiconductor prices will remain under pressure because the high capacities of the semiconductor fabs are not yet fully utilised. Even if difficult financing conditions mean that only a very small number of new fabs are being built or that not many old production facilities are being replaced, demand can be satisfied by the existing production capacities. We do not expect to see initial capacity problems, and more stable prices, before 2012.

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7 Source: IC insights, PwC analyses
8 Source: IC insights, PwC analyses

We do not expect that there will be any major change in the sales mix in the next few years, while automotive, communications and consumer electronics will probably achieve stronger growth. In the final analysis, these markets will benefit from the increasing number of installed semiconductor components and their increasing contribution to the quality of the end product.

Application	2006	2007	2008	2009	2010	2011	2012	2009–2012 CAGR
Data processing	96.6	99.4	95.0	79.6	84.6	92.8	99.8	7.8%
Communications	64.6	64.9	63.4	48.6	54.5	62.7	68.0	11.8%
Consumer electronics	42.9	45.8	45.2	39.4	44.5	50.4	56.1	12.5%
Automotive	17.6	18.9	19.2	11.9	14.9	17.0	19.9	19.0%
Industrial	26.0	26.6	25.8	21.6	23.2	25.6	27.8	8.8%
Total	247.7	255.6	248.6	201.1	221.7	248.5	271.6	10.6%
Growth	8.9%	3.2%	–2.8%	–19.1%	10.3%	12.1%	9.3%	
Source: SIA, PwC analyses								

Tab. 4 Semiconductor sales, according to applications for 2006–2012 (in billion USD)

Application	2006	2007	2008	2009	2010	2011	2012
Data processing	39.0%	38.9%	38.2%	39.6%	38.1%	37.3%	36.7%
Communications	26.1%	25.4%	25.5%	24.2%	24.4%	24.0%	23.6%
Consumer electronics	17.3%	17.9%	18.2%	19.6%	20.1%	20.3%	20.7%
Automotive	7.1%	7.4%	7.7%	5.4%	6.5%	7.7%	8.4%
Industrial	10.5%	10.4%	10.4%	11.2%	10.9%	10.7%	10.6%
Source: SIA, PwC analyses							

Tab. 5 Percentage of applications in relation to the total semiconductor market for 2006–2012

Under data processing, we include products for PCs, notebooks and servers, as well as peripheral devices such as printers and monitors. While semiconductor components continue to become much more efficient and sales volume will increase as a result of strong demand from the emerging markets, prices will weaken. The market in the industrialised countries remains largely saturated, and the scene is dominated by replacement investments. Although the introduction of new operating systems has a positive impact on the rate at which computers are upgraded, end customers are increasingly questioning the need for more and more powerful computers. We anticipate that end customer prices will come under pressure.

For PCs, the predominant demand is for inexpensive products.

We do not expect to see any revolutionary product innovations in the next few years. On the contrary, the market will be rounded off by the development of further product derivatives, such as the recently very successful netbooks. The product mix will continue to shift in the direction of mobile devices, as is indicated by the increasing flexibility and mobility of workers, the increasing efficiency and lower prices of mobile devices and Internet access conditions as a result of WLAN and mobile technologies.

In 2008, the server market accounted for approximately 11% of the overall market volume for computers. Servers are available with an extremely wide range of features and capacities. On the one hand, the operating system is a distinguishing competitive feature; on the other, so are process architecture and the number of processors.

Microprocessors, the heart of the computer, as well as DRAM and SRAM memory elements, are the main products to be installed in data processing. Additional components control the hard disks and peripheral devices. It will be interesting to see to what extent semiconductor memories, such as NAND flash memories that operate without mechanical components, will replace the traditional hard disk. With regard to the displays, we expect that mobile terminals will in the long term see the installation of OLED (organic light-emitting diode) semiconductor displays, which provide very high contrast and have low power consumption. As a consequence of increasing mobility, we expect that semiconductor manufacturers will concentrate to an even greater extent on energy efficiency to increase battery service life.

We expect that the market for data processing will expand with a CAGR of 7.8% until the year 2012, when market volume will reach 99.8 billion US dollars.

Smartphones and low-cost mobile phones will continue to be the driving forces behind growth in mobile telephony.

Demand for telecommunication products has increased considerably as a result of the opening of telecommunication markets that had formerly been run as monopolies, as well as by the spread of mobile telephony. The telecommunication groups invested in new mobile networks and in expanding the landline telephony network into a data infrastructure network.

The increasing market saturation, fierce competition and considerable regulation produced sluggish levels of investment by telecommunication groups in recent years; this also had a negative impact on the sales of telecommunication equipment manufacturers, which are major customers for semiconductor components. Even if it is likely that IP-based networks and fibre-optic lines will be introduced in large cities, sales volume is not likely to increase significantly in the landline equipment market. In part, this is because developing countries are leapfrogging over landline infrastructure and frequently concentrating on expanding the infrastructure for mobile telephony.

On the other hand, with the introduction of new generations of mobile networks such as LTE (Long Term Evolution), we expect additional demand for mobile infrastructure components. Semiconductor components are required, particularly in the field of the access networks, for data concentration in the backbone and for processing data in the core network. The increasing spread of mobile data applications is expected to lead to a considerable increase in data volume and will result in a high volume of investment at mobile network operators throughout the world.

While mobile telephone manufacturers have reported strong growth in sales volumes in recent years, there has hardly been any increase in revenues. Moreover, growth in emerging countries is flattening, so that OEM business is increasingly becoming replacement business. Growth is expected to be achieved primarily by means of smartphones such as Apple's iPhone, for which the advanced semiconductor components provide the promise of higher revenues, as well as simple low-cost mobile telephones in the emerging markets. Now that voice telephony has become mobile, we are expecting a considerable increase in the volume of mobile data. New devices such as netbooks will also boost sales. However, it is likely that the price per component will come under pressure as a result of high production figures.

The main products installed in mobile telephones are memory elements, digital-analogue converters, digital signal processors (DSPs), MCUs and optical semiconductors for the displays. Energy efficiency is a particularly important criterion for these components, in order to guarantee long battery life. We expect a greater emphasis will be placed on integrating several semiconductor components on one chip set, particularly in this segment.

We expect that the market for communications will attain a volume of 68 billion US dollars in 2012, with a CAGR of 11.8%.

The introduction of digital TV is a major driver in the field of consumer electronics.

Various semiconductor products are used in the field of consumer electronics. Game consoles such as Microsoft's Xbox 360, Sony's Playstation 3 or Nintendo's Wii contain powerful processors and graphic chips, as well as memory modules and analogue semiconductors. The market is characterised by a high concentration of suppliers and dominated by a small number of players, including IBM and Toshiba. The product cycles of Microsoft, Nintendo and Sony are very important, because the installed components only undergo major changes with new generations of consoles.

Set-top boxes for digital TV are a rapidly expanding segment within consumer electronics. In the next few years, many countries will change from analogue to digital for broadcasting TV signals. High-resolution TV and pay TV are expected to grow. Digital set-top boxes are required for decrypting pay-TV signals and for converting digital TV signals.

Among the other consumer electronics products with a high content of semiconductors are MP3 players, DVD recorders and photo and video cameras. Non-volatile flash memories are mainly used as the memory medium in MP3 players such as Apple's iPod or in digital cameras. Memory elements, as well as MCUs and DSPs, are also installed in DVD recorders.

Overall, we expect that the market volume will increase strongly to 56.1 billion US dollars in the year 2012; this is equivalent to an annual average growth rate of 12.5%.

Electronic components will increasingly substitute mechanical components in the car making industry.

The subjects of safety, consumption, environmental efficiency, driving dynamics and comfort are important distinguishing features for car makers – and these are all areas in which electronic systems and thus semiconductor components play a crucial role. Semiconductor elements installed by car makers are used in engine control, the instrument panel and comfort components, safety and driving dynamics systems (for instance ABS and ESP) and navigation and entertainment elements. The main components to be installed are sensors, MCUs, DSPs, power electronics and analogue components.

At present, semiconductor elements with an average value of approximately 250 US dollars are used in each car. The main drivers behind the growth in the automotive industry are the greater extent to which electronic components are being installed, even in low-price models, and the increasing substitution of electronics for mechanical components and sensors.

The market for automotive semiconductors is characterised by long product cycles. If a semiconductor manufacturer is successful in a design tender process, the corresponding components are typically installed throughout the entire model cycle. In contrast to other semiconductor applications, the design has to take account of reliability, service life, supply quality and temperature resistance. Accordingly, the performance characteristics of automotive semiconductors typically lag behind those encountered in other segments by two to three generations.

The number of new worldwide registrations is expected to fall appreciably in 2009, but the situation is likely to recover in the medium term. However, there will only be moderate growth in worldwide volume car sales until 2012.

Market volume is expected to increase to 19.9 billion US dollars in 2012, with a CAGR of 19% between 2009 and 2012. Bear in mind, however, that the decline in 2009 was particularly severe. Major growth impetus as a result of the introduction of hybrid or electric cars will occur only after 2012.

Energy efficiency and environment-friendly technologies are becoming growth drivers in the semiconductor industry.

Modern engineering and plant construction, transport and infrastructure technology and other industrial applications (all compiled under industrial) require complex control systems. We expect that electronics will generate an increasing percentage of overall added value and that demand will increase relative to other areas of application for semiconductors. Similar to the situation in automotive, the focus in this case will be on the possibilities of energy saving and environmental compatibility. Particularly in the field of transport technology and traffic management, intelligent electronic organisation forms provide considerable scope for energy savings, with corresponding growth potential for specialist semiconductor designs.

In industrial, demand focuses mainly on semiconductors for control and power electronics. The most installed components are therefore MCUs, DSPs and logic. We are expecting a CAGR of 8.8% until the year 2012, equivalent to a market volume of 27.8 billion US dollars in 2012.

The next section will analyse the worldwide sales market according to installed components. It will consider the development of recent years and will provide an outlook for 2012.

2 The semiconductor market according to installed components

The breakdown of sales volume by installed components shows the pre-dominance of digital semiconductors (digital integrated circuits, ICs). These account for the highest percentage of overall sales throughout the entire period covered by the forecast (67.6% in 2008). Sensors and actuators account for the lowest percentage of sales. Table 6 shows worldwide semiconductor revenues broken down by components. Table 7 provides an overview of the percentage distribution of sales in the product mix and the development over a period of time.

Components	2006	2007	2008	2009	2010	2011	2012	CAGR 2009–2012
Memories	56.4	54.0	43.4	38.6	41.5	46.2	50.1	9.1%
MPUs and MCUs	51.8	52.5	53.3	47.5	51.3	56.9	61.8	9.2%
Logic	63.2	69.3	71.4	57.7	63.5	71.4	78.5	10.8%
Digital ICs, total	171.4	175.8	168.1	143.8	156.3	174.5	190.4	9.8%
Analog ICs	40.2	41.1	41.0	29.7	32.4	36.0	39.6	10.0%
ICs, total	211.6	216.9	209.1	173.5	188.7	210.5	230.0	10.3%
Discrete semi-conductors	16.2	17.0	16.5	10.5	11.9	13.5	15.1	12.9%
Optical semi-conductors	16.3	17.7	18.9	14.1	16.8	19.8	22.4	16.7%
Sensors and actuators	3.6	4.0	4.1	3.0	3.3	3.7	4.1	11.4%
Total	247.7	255.6	248.6	201.1	221.7	248.5	271.6	10.6%
Growth	8.9%	3.2%	–2.8%	–19.1%	10.3%	12.1%	9.3%	
Source: SIA, PwC analyses								

Tab. 6 Semiconductor sales according to components (in billion US dollars)

Components	2006	2007	2008	2009	2010	2011	2012
Memories	22.8%	21.2%	17.5%	19.2%	18.8%	18.7%	18.4%
MPUs and MCUs	20.9%	20.5%	21.4%	23.6%	23.3%	23.0%	22.7%
Logic	25.5%	27.1%	28.7%	28.7%	28.7%	28.9%	28.9%
Digital ICs, total	69.2%	68.8%	67.6%	71.5%	70.8%	70.5%	70.1%
Analog ICs	16.2%	16.1%	16.5%	14.8%	14.7%	14.6%	14.6%
ICs, total	85.4%	84.9%	84.1%	86.3%	85.5%	85.1%	84.7%
Discrete semiconductors	6.6%	6.7%	6.6%	5.2%	5.4%	5.4%	5.6%
Optical semiconductors	6.6%	6.9%	7.6%	7.0%	7.6%	8.0%	8.3%
Sensors and actuators	1.4%	1.5%	1.7%	1.5%	1.5%	1.5%	1.5%
Source: SIA, PwC analyses							

Tab. 7 Percentage of components in relation to the total semiconductor market for 2006–2012

Digital integrated circuits

Digital integrated circuits include memory chips, microprocessors, micro-controllers and logic chips.

The segment of logic chips will achieve above-average growth.

A characteristic aspect of the market for memory chips is considerable price volatility combined with a capital-intensive business. The associated fixed depreciation and the lack of possibilities for differentiating the end product mean that price is the main criterion for differentiating the products of one company from those of the competition. As a result, hardly any company has been able to generate profits in recent years.

With prices low and refinancing difficult, some plans for new fabs were broken off or postponed in 2008 and at the beginning of 2009. The next few years are unlikely to see any considerable expansion of production capacity. Prices might rise slightly with a foreseeable recovery in demand. The strategy adopted by the dominant manufacturers of DRAMs (Samsung, Hynix Semiconductor and Elpida) should be followed closely. In addition, growth prospects are very good for non-volatile memory (flash memory, FERAMs, MRAMs). After several difficult years, we expect to see a recovery in the memory chip market. In 2012, sales volume will probably be 50.1 billion US dollars.

The market for microprocessors is dominated by the giants Intel and AMD. The main customers for these products are the computer manufacturers. We expect that this segment will recover, but we do not expect to see any significant growth beyond recovery. Growth will be driven by the introduction of operating systems which require more powerful processors, as well as new products such as netbooks. Energy efficiency will become an even more significant distinguishing feature of the manufacturers.

Microcontrollers provide all key elements of a computer (microprocessor, memory chips and connections to peripheral devices) on a chip. These can be manufactured inexpensively and are used in numerous domestic products, in cars and industrial applications.

We expect that the market for microprocessors and controllers will achieve an annual average growth rate of 9.2% until the year 2012.

The market for logic chips comprises the standard components (ASSPs, or application-specific standard products) and customer-specific modified chips (ASICs, or application-specific integrated circuits). Logic chips process certain input signals, originally analogue signals, in accordance with specific requirements. They are installed in various ways, particularly in mobile telephones, in cars and industrial applications. For logic chips, we expect increasingly stronger demand for comparatively inexpensive standard components. Overall, the logic chips segment will slightly outperform the overall market. We expect to see overall sales of 78.5 billion US dollars in 2012.

Analogue integrated circuits

Analogue integrated circuits process analogue signals and can be found in any area where those signals are in use, be they sound, light or electrical. They can be used whenever analogue signals have to be converted into digital signals for further processing. Typical components are analogue-digital converters, digital-analogue converters, operational amplifiers, voltage references, oscillators and linear components.

There is a wide range of sales markets for these products. Analogue integrated circuits are installed particularly in mobile telephones, in signal processing and telecommunications, in the automotive industry and in industrial applications. As the economy recovers, we expect to see the market volume increase to 39.6 billion US dollars in 2012, equivalent to annual average growth of 10%.

Other semiconductors

The segment of other semiconductors (discrete and optical semiconductors, sensors and actuators) is comparatively small. Discrete and optical semiconductors are virtually identical in terms of revenues, although growth in the next few years is expected to be achieved only by optical semiconductor elements. In particular, light-emitting diodes (LEDs) will increasingly complement and replace conventional lighting such as incandescent bulbs and fluorescent tubes. Further innovations will also open up new application opportunities in screen technology. We expect a significant increase in demand for optical semiconductors, particularly from OLED-based (organic light-emitting diodes) screens, which operate without background lighting and are thus extremely efficient in terms of power consumption. Such displays can be used in the future in mobile telephones and e-books. The first steps have already been made here.

3 The semiconductor market: a regional comparison

The semiconductor industry traces its origins to Silicon Valley in California. The development of the region as an economic centre began in 1951 with the establishment of a research and industrial park, the Stanford Industrial Park, next to Stanford University. Contributing to its success were investors prepared to take on risk and researchers with a positive attitude about innovation, as well as the proximity of Stanford University and the University of California, Berkeley. A successful technology cluster also requires a critical mass of relevant companies and employees, and that is what emerged in Silicon Valley. For years, nothing comparable existed, but recently such clusters have emerged, first in Japan and then in Taiwan, South Korea and China. Not only has much production migrated to Asia, but it is there that demand is strongest.

In 2008, the Asian countries excluding Japan accounted for around 50% of overall sales. America and Europe each accounted for 15%, and Japan for 20%. Asia will continue to become more important in the course of the next few years, but we are anticipating growth in America and Europe. In Japan, however, we anticipate a decline in relation to worldwide demand. For 2012, we expect that demand in Japan will account for only 16% of worldwide demand.

Region	2006	2007	2008	2009	2010	2011	2012	CAGR 2009–2012
America	44.9	42.3	37.9	33.4	37.1	40.7	43.7	9.4%
Europe	39.9	41.0	38.2	30.8	32.7	37.7	41.8	10.7%
Japan	46.4	48.8	48.5	35.4	37.5	40.9	42.2	6.1%
Asia (excl. Japan)	116.5	123.5	124.0	101.5	114.4	129.3	143.9	12.3%
Total	247.7	255.6	248.6	201.1	221.7	248.5	271.6	10.6%
Growth	8.9%	3.2%	–2.8%	–19.1%	10.3%	12.1%	9.3%	
Source: SIA, PwC analyses								

Tab. 8 Semiconductor sales broken down according to regions for 2006–2012

Region	2006	2007	2008	2009	2010	2011	2012
America	10.3%	–5.7%	–10.5%	–11.9%	11.3%	9.6%	7.5%
Europe	1.6%	2.7%	–6.6%	–19.4%	6.3%	15.0%	10.9%
Japan	5.3%	5.2%	–0.7%	–27.1%	6.1%	8.9%	3.3%
Asia (excl. Japan)	12.7%	6.0%	–0.4%	–18.1%	12.6%	13.1%	11.3%
Total	8.9%	3.2%	–2.8%	–19.1%	10.3%	12.1%	9.3%
Source: SIA, PwC analyses							

Tab. 9 Sales growth broken down according to regions for 2006–2012

America

Sales of semiconductor products are concentrated in North America, in particular the United States. Following a decline of 11.9% amid the recession of 2009, the market will expand to 43.7 billion US dollars by 2012. Many industrial products in which semiconductors are installed are no longer being manufactured in North America, and that production has migrated to Asia.

Silicon Valley will continue to be a creative centre.

As a production location, Silicon Valley will continue to be a key innovation engine and driver for the worldwide semiconductor industry. However, fewer and fewer standardised commodity products are being manufactured in America, and production of these semiconductors is increasingly being outsourced to Asia.

Europe

Demand in Europe focuses primarily on semiconductors with a customer-specific profile, for such sectors as car making, engineering and infrastructure providers. Since the 1980s, PCs and consumer electronics have increasingly been manufactured outside Europe, mainly in Asia. We expect that the market in Europe will achieve growth primarily as a result of stronger demand for innovative special solutions, particularly for the automotive industry, engineering for energy and environmental technology companies.

The manufacturers in Europe focus mainly on customer-specific developments. Proximity to and interaction with the development teams of the client industries is a crucial factor for success.

Whether this competitive advantage can be maintained or even expanded in the long term also depends on the innovative ability of the semiconductor companies and the client industries, as well as the support they receive from research institutions and government. If cooperation in research were expanded at the European level, manufacturers would clearly benefit. It is doubtful that significant volumes of production, apart from design, will be retained in Europe in the long term.

We are assuming that demand between 2009 and 2012 will expand at an average annual rate of 10.7%.

Japan

Historically, the electronics industry has played a major role in the Japanese economy and has been an important customer for semiconductor elements. However, Japan has suffered severely during the economic crisis, and recovery will not be very rapid in the next few years. Japan’s situation is complicated by a structural change: the production of high-value electronic products, in which most semiconductor components are installed, is migrating to other Asian countries, particularly to China. This means that the market volume of 2008 will not be repeated for the foreseeable future.

Asia excluding Japan

China will become a major semiconductor manufacturer.

The world market for semiconductor products will continue to shift towards Asia in future, with several factors playing a major role. These include the continuing shift of sales markets to Asia, the increase of research at Asian universities, the improvement in technical know-how and, not least, state funding. This market will achieve the strongest growth and will account for 53% of total demand in 2012.

Most chips for computers and consumer electronics that are designed in Europe and the United States are already manufactured in Asia, and this will continue. Initially only labour-intensive processes such as testing and packaging were outsourced to Asia, but now many production facilities are being set up to satisfy local sales markets. Numerous projects have been postponed as a result of the economic crisis, but this will not continue in the medium term. On the contrary, China will become a major semiconductor manufacturer, as Taiwan already is. That growth is likely to come at the expense of the country’s Asian neighbours. The difference between demand and production widened constantly until 2007, but we expect production in China to increase as a result of state interest in setting up this key technology for the electronics industry.

Increasingly high-value cars and industrial products are also being manufactured in China and will stimulate demand for semiconductor products. And the large capital-intensive foundries are already mainly to be found in Asian countries.

In the field of chip design, Asia lags behind Europe and America. Copyright is one reason why there is great reluctance to move production processes away from their home countries. However, some fabless companies that have the potential to operate successfully are now emerging from Asian universities. This process is being supported by the constantly increasing technological expertise of the developers and manufacturers.

Significant government support for setting up production capacity in some Asian countries is a factor not to be underestimated. In South Korea and Taiwan, funding of the semiconductor industry is part of industrial policy, encouraging the establishment of a large and independent branch of industry with national champions. Other countries, such as Malaysia and Singapore, also consider their domestic semiconductor industries strategically and economically important.

We do not expect India to play a crucial role in the production of semiconductors in the short to medium term, because it specialises in other products and services. In the long term, a semiconductor industry will probably develop, not least as a result of the large population and the associated sales market.

E Conclusion and outlook

The current economic crisis has had a major impact on the semiconductor industry. This traditionally cyclical industry has been affected worldwide by destocking processes at its customers, the decisions by industrial customers to hold back on new investments and consumers' reduced propensity to purchase durable products. For 2009, we predict that sales in the industry will decline by around 19% from the previous year.

However, even during these times, the companies continue to carry out research and development, focusing on even smaller feature sizes, more functionality per chip, lower power consumption and less expensive production. These developments and the continuing increase in demand for high-value and powerful electronic components will make a major contribution towards a gradual recovery in the next few years. We expect that the market volume of 2008 will be repeated in 2011 and will be considerably exceeded in the year 2012.

What issues will concern management in the next few years? What should companies take into consideration to be able to stand up to the competition and set trends?

The experts we interviewed are assuming that Moore's law will continue to be valid for the next few years. Although discussions at present are focusing on when the technical and physical limits of CMOS technology will be reached, the experts agree that the number of transistors on a standard processor is likely to continue to double every 18 to 24 months for four to five years.

A further trend of recent years will also continue. Enhanced functionalities on the chips (System-on-a-chip) and innovative chip designs with several applications – summarised as 'more than Moore' – will gain importance as a distinguishing competitive feature. This is particularly true for those industry segments that manufacture logic chips, analogue chips and processors, rather than such standard components as memory chips.

'Going green', the creation of an environmentally sound value chain and the development of energy-saving components will also continue to be relevant. This goes beyond the increased environmental awareness of consumers; the costs of energy and disposal would become excessive if manufacturers do not to provide appropriate products. The development of products which make efficient use of resources can thus generate a genuine competitive advantage.

The business models within the semiconductor industry will undergo change, and this will continue to occupy management at semiconductor manufacturers. Every manufacturer has to consider where its strengths within the value chain are to be found and which components can be handled better by other companies. The trend is going in the direction of concentrating on a small number of components in the value chain and on selected application products. Production is particularly affected in this respect. The main drivers are the considerable amounts of investment in modern production installations. In order to be able to manufacture products inexpensively, the capacity of the large semiconductor plants will have to be utilised. Accordingly, we expect that chip production will increasingly be outsourced to the major foundries. This makes the significance of capacity management extremely important to all companies. The key question is how the necessary production capacity can be assured without incurring high costs and how that might be possible while remaining flexible enough to respond to fluctuations in demand. Companies will need to ensure that the know-how in production built up over many years is not surrendered exclusively to the foundries. Strategic alliances can help spread the cost of necessary investments, cover the required production scales and maintain and expand important expertise in front-end production. In the long term, the winners in the sector will be those companies which are able to organise processes in such a way that the new chip designs are integrated quickly and smoothly in production.

F Methodology

1 Sales forecast

Calculation of sales forecasts

The sales forecasts are based on the analyses of the technological trends, the main value drivers and the competition. This is followed by analyses of macroeconomic factors, changes in consumer behaviour and demographic developments. Mathematical forecast models are used as the basis for investigating the impact of individual value drivers and for forecasting the developments of the semiconductor market. The data obtained are then critically assessed by our industry experts and are checked for consistency and adjusted where necessary.

Currency used for the sales forecasts

The currency used for the sales forecasts is the US dollar because it is the 'base currency' of the semiconductor industry, at least in the main commodity markets. Exchange rate fluctuations have not been assumed. The figures are reported in nominal terms, and thus include inflation effects. The historical data are taken from the Semiconductor Industry Association. The sales are shown as 'billing revenues'.

2 Interviews with experts

Interviews were held with selected experts and representatives of companies in the semiconductor industry in July and August 2009.

3 Analysis of the competition

The analysis is based on the data of more than 80 companies, provided by the financial information services of Bloomberg. Unless otherwise specified, the data and results presented relate to 2008. Developments and trends taken from an analysis of the past up to the year 2004 are also selectively specified. The analysis results are used as the basis for interpreting results and possible consequences. The companies included in our analysis by no means constitute the entire semiconductor industry. For this reason, this study does not claim to be a complete and comprehensive benchmark assessment of the market.

4 Peers in the analysis of competition

The following companies have been included:

IC IDM	Fabless	Equipment
• AMD • Analog Devices • Atmel Corp • Avago Technologies Ltd • Fairchild Semiconductor International • IDT Corp • Infineon Technologies • Intel • National Semiconductor Corp • NEC Electronics • ON Semiconductor Corp • Rohm • STMicroelectronics • Texas Instruments	• Altera • Applied Microcircuit • Atheros Communications • Broadcom • Cavium Networks Inc • CSR • Elan Microelectronics • Exar Corp • Ikanos Communications Inc • Lattice Semiconductor • LSI Corp • Marvell Technology Group • MediaTek • Mellanox Technologies Ltd • Netlogic Microsystems Inc • Novatel • NVIDIA • OmniVision Technologies • PMC-Sierra • QUALCOMM • RF Micro Devices • Sandisk Corp • Sierra • Sunplus • Trident Microsystems Inc • TriQuint Semiconductor • VIA Technologies • Wolfson Microelectronics • Xilinx • Zoran	• Advanced Energy Industries • Advantest • Aixtron • Applied Materials • ASM International • ASML • Brooks Automation Inc • Cabot Microelectronics • Cymer • Disco • Jusung Engineering • KLA-Tencor • LAM Research • Mattson Technology • MKS Instruments • Novellus • Teradyne Inc • Ultratech • Varian Semiconductor Equipment Associates • Verigy • Yokogawa
Memory IDM	**Foundries**	**Assembly and test**
• Cypress Semiconductor • Elpida Memory • Hynix Semiconductor • Inotera Memories • Micron Technology • Nanya Tech • Powerchip Semiconductor Corp • ProMos Technologies • Samsung Electronics	• CHRT • SMIC • TSMC • UMC • Vanguard International Semiconductor Corp.	• Amkor • ASE Test Limited • STATS Chip PAC • Unisem

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