The underlying reason for high profitability in semiconductor industry

Seiichi Kondo
Showa Denko Materials Co., Ltd., kondo.seiichi.xihrf@showadenko.com

INTRODUCTION

The operating profit in semiconductor industry is well known to be very high not only for device manufacturers but also for those equipment or consumable manufacturers. Especially, the manufacturers or business sectors in wafer process usually yield operating profit margin of more than 20%, and it often achieves 40 - 60% in good times. On the other hand, operating profit margin in automotive industry is generally less than 10%, which is common from automobile to automotive components manufacturers. Although profit margin depends on each company or period of time, but the main reason of such difference lies in the structure of the industry.

BACKGROUND

An example of profit margin comparison is Samsung Electronics as one of the top manufacturers in semiconductor industry to Toyota as one of the top in automobile industry. The revenue of Samsung is about $240 B (2019) and number of employees is 310,000, while those of Toyota are $300 B (2019) and 380,000, respectively. The company sizes are comparable, but operating profit margin of Samsung is more than doubled to that of Toyota ($54 B vs $25 B). The operating profit margin of semiconductor sector of Samsung exceeded 50% (2018); in contrast, that of Toyota was at most 10%, even in good shape, for the last 10 years. Toyota sells 10 million cars of $30,000 - 50,000 annually, while Samsung sells 18 million wafers with $3 - 5 memory chips. How does this affect the profit margin difference? The sales price of a car does not change except a few % discount, however, memory chip price changes drastically, which can be doubled in a year. Why does this happen?

Understanding this difference is the first priority we should consider for yielding high profit margin in our business sector, which is more important than raw materials or labor cost reduction. While showing good examples of other industries yielding high profit margin with the same method, in this paper, I would like to re-acknowledge the source of profit in semiconductor industry, and discuss the important challenges to be faced in proceeding our business. All the financial data used here is derived from the open sources via internet. The simple exchange rate of $1 = 100 JPY = 1000 KRW is often used to compare the sales between different countries and years.

PROFITAVILITY OF SEMICONDUCTOR INDUSTRY

The reason why Samsung shows high profitability is not because Samsung is special, other device manufacturers such as Intel (30%), SKhynix (29%), Micron (23%), TSMC (42%), Kioxia (20%, 1H2022), and Renesas (30%) also show high operating profit margins (2020 - 2021) as shown in Table 1. Especially, in 2018, the operating profit margins of memory manufacturers reached 50% such as 51.6% of Samsung, 51.5% of SKhynix and 49.3% of Micron. The high profitability is not limited to memory manufacturers, but also to many other device manufacturers such as logic device manufacturers, foundry and MCU manufacturers, which are around 20 - 50%.

In fact, this high profitability of semiconductor industry is not limited to device manufacturers, but also includes semiconductor equipment and consumable manufacturers. For example, operating profit margins of Applied Materials and Tokyo Electron (top semiconductor equipment manufacturers), ASML (lithography machine), KLA (defect inspection apparatus), Lam Research (dry etcher) and SCREEN (cleaning machine) are 30%, 30%, 36%, 38%, 31% and 20%, respectively (2021); all are higher than 20%. According to the announcement of Tokyo Electron (Toshiki Kawai CEO, 2022), their target profit margin is more than 35% in five years. Moreover, operating profit margins of semiconductor consumable manufacturers are also higher than 20%. For example, those of CMC and Fujimi (CMP slurry), Shin-Etsu Handotai and SUMCO (Si wafer), TOK, JSR and Shin-Etsu (photoresist) are 19% (27% in 2018), 23%, 39%, 23%, 15%, 23% and 30%, respectively (2020 - 2021).

On the other hand, low profitability of automobile manufacturers is not limited to Toyota, but it is common among the whole automotive industry. The operating profit margins of Honda and Nissan are 5.4% and 4.8%, respectively, and that of Toyota (8.3%) is much higher. The operating profit margins of Bosch (No.1

automotive parts), Denso (No.2 in automotive parts), Aisin Seiki (No.5 in automotive parts), NSK (No.3 in bearing), MinebeaMitsumi (No.1 in extra-miniature bearing), Avics (No.2 in brake), Akebono (No.7 in brake) and GS Yuasa (No.2 in lead-acid batteries) are 6.8%, 8.1%, 6.5%, 8.0%, 7.7%, - 0.1% (red), 0.1% and 6.4%, respectively (data derived before COVID-19, 2017 - 2019). The manufacturer whose profit margin higher than 10% is tire manufacturer, such as Michelin (12.5%, No.1) and Bridgestone (11.6%, No.2). This is because they can control their product price due to their business style as B to C, namely periodical tire exchange by general consumers as consumables.

Then how about the profitability of luxury car manufacturers, whose product prices are very expensive? Even Ferrari, Lamborghini and Porsche which sell sports car of higher than $100,000 show operating profit margin of 24.4%, 20.2% and 17.6%, respectively. Those of BMW, Bentley, Mercedes-Benz and Audi are 14.0%, 13.4%, 11.0% and 10.7%, respectively. Surprisingly, Tesla was in the red from 2012 to 2019, but got out of the red in 2020, became 12.1% in 2021, and reached 19.2% in Q1 of 2022, which is terrific improvement. It is true that profitability of luxury car manufacturers are high, but in other words, even automobile manufacturers which sell cars more expensive than $100,000 show profit margin of less than 25%.

As a result, this discrepancy of profitability is attributed to the difference between semiconductor industry and automotive industry as a whole, not to the difference of each manufacturer or individual products. As I pointed out in the background, each memory chip is sold with a price of $3 to $5, and about 1,000 chips are mounted on a 300 mm-diameter silicon wafer and produced at the same time. In this case, the device wafer's price become $3,000 to $5,000, indicating a 30 - 50 times of values added up by manufacturing semiconductor devices on a silicon wafer surface compared to a simple $100 bare silicon wafer. Top semiconductor manufacturers produce 1 million device wafers per month (for example, 1.5 million wafers production per month by Samsung), so their sales become $3 - 5 B/month which corresponds to $36 - 60 B/year. The actual semiconductor sales of Samsung is $75 B/year (2021), thus this simple estimation (sales of $36 - 60 B/year) seems to be roughly correct when we consider the assumption of memory price, number of wafer production, number of chips on a wafer and additional package process. Furthermore, more expensive logic device wafers are not taken into account in this estimation.

The semiconductor manufacturers can have high capital investments considering their high profitability. For example, the semiconductor sales of $3 B/month corresponds to the sales of $100 M/day. If operating profit margin of 40% is achieved, a cash of $40 M/day is obtained (to be precise, cash flows from operating activities) and they can recover the capital investment of a EUV lithography machine with a price of $200 M in a week.

Next, let us consider CMP slurry as an example for semiconductor consumables. Suppose an amount of $3 CMP slurry is used for one layer of device wafer fabrication, which includes all slurries used in two or three steps such as copper bulk step and copper barrier step. If 10 times of CMP process is performed for one device fabrication process, the cost of slurry usage is $30 per device wafer, corresponding to 1% of device wafer sales of $3,000. As explained above, if device wafer production was 1 million wafers/month, the slurry cost would become $30 M/month, and it corresponds to $360 M/year, which is 1% of device wafer sales ($36 B/year). When we consider global slurry market is about $2B/year, this value is roughly correct.

VOLUME EFFICIENCY OF MASS PRODUCTION

As explained above, device manufacturers do not make memory chips one by one, but fabricate about 1,000 chips simultaneously on a wafer as batch production. Twenty five wafers are stored in a cassette (FOUP) and processed with the same specification by lot production. The lot flows through the production line of about 1,000 processes consisting of FEOL, MOL and BEOL for two or three months. And finally, the line production of the same product continues for two or three years with a production speed of 1 million wafers per month in a big memory manufacturer. As a result, production efficiency can be improved to the utmost limit. In other words, the source of high profit margin in semiconductor industry is the line production of huge quantity of the same specification chips in combination with batch production (1,000 chips on a wafer) and lot production (25 wafers in a cassette) as shown in Fig. 1.

In contrast, automobile manufacturing is a typical line production where automobile is produced one by one, so it is not batch production. Besides, the same model of automobile can have individually different body color, interior design, engine size, transmission type and other option. This difference in production efficiency is thought to be a root cause of the difference in profitability between semiconductor industry and

automobile industry. If automobile manufacturer fixed only one color and one engine type with the same option, consumer's purchasing intension would decrease. Thus, in order to not further decrease the profitability, customizable options are also minimized during line production, such as body color is limited to five or six colors and engine size and transmission to two types.

It is well known that silicon wafer size was enlarged in order to improve production efficiency of semiconductor industry, from 0.75 inch (after 1960) to 2 inch (after 1970), 4 inch (after 1975), 6 inch (after 1980), 8 inch (after 1991) and finally to 12 inch (300 mm, after 2001). For example, comparing an 8 inch and a 12 inch wafer, 580 chips of 7x7 mm square size is obtained from an 8 inch, while 1,360 chips of the same size is obtained from a 12 inch wafer, which indicates number of chips increases 2.3 times (1,360/580) by enlarging wafer size of 1.5 times (12/8). Even though equipment cost increases by 1.3 times, chip sales becomes more than twice (with 90% chip yield), so the wafer size is continuously enlarged for the past 50 years to improve production efficiency.

In the same semiconductor industry, semiconductor equipment manufacturing is individual production while consumable manufacturing is mainly batch production, and their production efficiency is not so superior compared with other industries. However, their profitability is also maintained at high margin by adding high values in their products owing to device manufacturer's high profitability. The high reliability of machines (short down time or low failure frequency), and the high quality of materials (low metal contamination or low particles), are required for fabricating high performance devices. This kind of highly reliable machines or high quality consumables would not be needed from other industries because of over-specification; additionally the product does not meet price target for other industry customers.

In fact, even in the same semiconductor industry, profitability of packaging process is incomparable to the wafer process. For example, operating profit margin of Shinkawa (Yamaha, No.2 in wire bonder) is -28% (deficit), TOWA (No.1 in molding equipment) is 11.1%, Apic Yamada (Yamaha, No.2 in molding equipment) is 1.3%, Toray Engineering (No.1 in flip chip bonder) is 1.4% (company as a whole), Fuji (No.2 in mounting equipment) is 16.1%, ASM Pacific (No.1 in die bonder) is 18.0%, Shinko (lead frame and flip chip package) is 12.4%, Ibiden (printed wiring board and interposer) is 11.9%, and that of ASE (No.1 in OSAT) is 7.3%. Although those of Disco (No.1 in grinder) and Accretech (No.2 in grinder) are 25.6% and 21.4%, respectively, but others are lower than 20%. Actually, most of packaging process fabs are located in China or Southeast Asia apart from wafer process fabs to suppress cost.

In packaging process, wafer thinning process is first carried out by grinding the backside of wafer. Yet, most of the total packaging process is simple line production of chip level, and the portion of batch production is low. Since each equipment and consumables are used for a $3 memory chip, not for a $3,000 device wafer, the cost should be suppressed. This is the root cause of lower profitability of packaging process compared to wafer process. Even so, a huge quantity of 1 billion chips can be produced per month from 1 million wafers supplied from wafer fabs, thus the operating profit margin of higher than 10% is accomplished by several packaging manufacturers.

Although logic devices are produced by MTO (make to order), the MTS (make to stock) of memory device often cause price fluctuation. When we see the memory price change of the first half of 2019, both DRAM and NAND prices suddenly fell by about 30% for a half year (DRAM DDR4 type, 4Gbit: from $3.6 to $2.5, NAND TLC 128 Gbit: from $2.7 to $1.9), and many device manufacturers went into the red. Because the prices of equipment and consumables are fixed, the risk of device manufacturer is very high. In order to survive in the semiconductor business, device manufacturers have to develop new products with a 70% device shrinkage every two years (following Moore's law) and continue capital investments for maintaining high profitability. They need to improve production efficiency by increasing the number of wafers to a maximum degree and always keep high operation rate (Economies of scale). Finally, oligopoly have proceeded in the semiconductor market. Actually, number of logic players with leading-edge manufacturing have gradually decreased with a speed of one company a year for the past 20 years (26 players in 2002 for 130 nm node, 2 or 3 players in 2022 for 5 nm node).

HIGH PROFITABILITY IN OTHER INDUSTRIES

There are some business examples which shows high profitability in the same way as semiconductor industry does. To take an example close to home, baking several croissants on a pan in a bakery oven is a simple batch production. However, when we bake many loafs of white breads in a large oven, it is thought to be a high profit method with a combination of batch production and lot production since a loaf of bread is

sliced into six to twenty pieces before consumption, which corresponds to 1,000-chip making from a wafer (batch) or 25 wafers in a cassette (lot). At least, they can sell it cheaper than croissants with the price per unit of weight.

Another example is cake prices. Making of small cakes such as Mont Blanc cake (chestnut cream cake) one by one is an individual production. Making a big whole cake and slicing it into 25 pieces is more productive and more profitable. At least, its price competitive power is higher.

There is an interesting example in railway industry in Japan. Of the 40 railway companies in Japan, but only JR Central (JR Tokai in Japanese) shows by far the highest operating profit margin of about 40% (consolidated sales before COVID-19). Others are less than 17% and some local companies are in the red. JR Central covers the center of Japan around Nagoya city and it is easy to understand that they are getting high profit from Shinkansen (bullet train) which runs between Tokyo and Osaka (Nagoya as a center stop point). In comparison, JR East (Tokyo area) and JR West (Osaka area) all have Shinkansen trains, so running Shinkansen is not special to JR Central. However, when we see the sales and profits in details, it was found that 32% of 2019 sales in JR East ($21 B, non-consolidated) is obtained from Shinkansen business and others are from local train. On the other hand, Shinkansen business of JR Central achieves 92% of their total sales ($15 B, non-consolidated) and high operating profit margin of 46% is obtained (that of JR East is 19%, non-consolidated).

A total of 205 trips of Shinkansen depart from Tokyo for Osaka every day. The round-trip fare between Tokyo and Osaka is about $300, thus the sales is $60 M/day assuming 1,000 passengers (boarding rate of 76% for full capacity of 1,323 seats in 16-car train) and 205 round trips. It corresponds to $22 B/year, so the simple calculation meets the actual sales of JR Central ($15 B in 2019) considering rough assumption of boarding rate.

Although the price of a Shinkansen 16-car train is $40 M, which is comparable with that of immersion ArF lithography machine (about $60 M) in semiconductor process, this cost is recovered for a few days by the high profit margin from Shinkansen ticket sales (roughly $60 M/day). As I described above, semiconductor manufacturer can buy a EUV lithography machine worth $200 M by their high profitability because the sales of semiconductor manufacturer is $100 M/day ($3 B/month when 1 M wafers/month production). From the view point of their capital investment method, they have similar industrial structure (Table 2).

It is interesting to note that number of cars of Shinkansen have become longer from an 8-car train to a 12-car train and finally to a 16-car train with an increase in boarding rate. This tendency is similar to the increase in silicon wafer size from 4 inch to 8 inch and finally to 12 inch. It is the same volume efficiency both in manufacturing industry and service industry.

In conclusion, the reason why we can buy a memory chip of advanced technology node by $3 - 5 is thought to be very high volume efficiency of the semiconductor production (Fig. 2), and their product is not a $3 - 5 chip, but a $3,000 - 5,000 worth of device wafer.

CONCLUSIONS

In order to get high profit margin in our business, increasing mass-production efficiency is more important rather than cost reduction of raw materials or labor. The source of high profit margin in semiconductor industry, especially in wafer process is the line production of huge quantity of same specification chips in combination with batch production (1,000 chips on a wafer) and lot production (25 wafers in a cassette). On the other hand, packaging process (as well as automobile industry) is a simple line production in chip level, not in wafer level. This causes a difference in profit margin. The same volume efficiency can be observed in other familiar industries such as bakery, cake making, and railway business.

Corresponding Author:
Seiichi Kondo
Tel: +81-80-1300-9518
E-mail: kondo.seiichi.xihrf@showadenko.com
Showa Denko Materials Co., Ltd.
GranTokyo South Tower, 1-9-2 Marunouch,
Chiyoda-ku, Tokyo 100-6606, Japan

Table 1 Comparison of operating profit margin between semiconductor industry and automotive industry. The data of semiconductor industry is 2020 or 2021 (*additional data is 2018), while that of automotive industry is mainly before COVID-19 (2017 – 2019) or after recovered (1H 2021).

Semiconductor industry		Automotive industry	
TSMC	42.3%	Ferrari	24.4%
Shin-Etsu (Si wafer)	38.5%	Lamborghini	20.2%
KLA	37.9%	Porsche	17.6%
ASML	36.3%	BMW	14.0%
Lam Research	31.2%	Michelin	12.5%
Samsung	31.0%, 51.6%*	Tesla	12.1%
TEL	29.9%	Bridgestone	11.6%
Intel	30.4%	Mercedes-Benz	11.0%
AMAT	29.8%	Audi	10.7%
Shin-Etsu (SEMI)	29.9%	GM	8.4%
Renesas	29.8%	Toyota	8.3%
SKhynix	28.8%, 51.5%*	Denso	8.1%
Disco	25.6%	NSK	8.0%
SUMCO	23.3%	MinebeaMitsumi	7.7%
Fujimi	23.3%	Bosch	6.8%
JSR (SEMI)	22.9%	GS Yuasa	6.4%
Micron	22.7%, 49.3%*	Hyundai	6.2%
SCREEN	19.7%	Aisin Seiki	6.5%
Kioxia (2Q2022)	19.5%	Honda	5.4%
CMC	19.4%	Nissan	4.8%
Ebara (SEMI)	14.5%	VW	4.4%

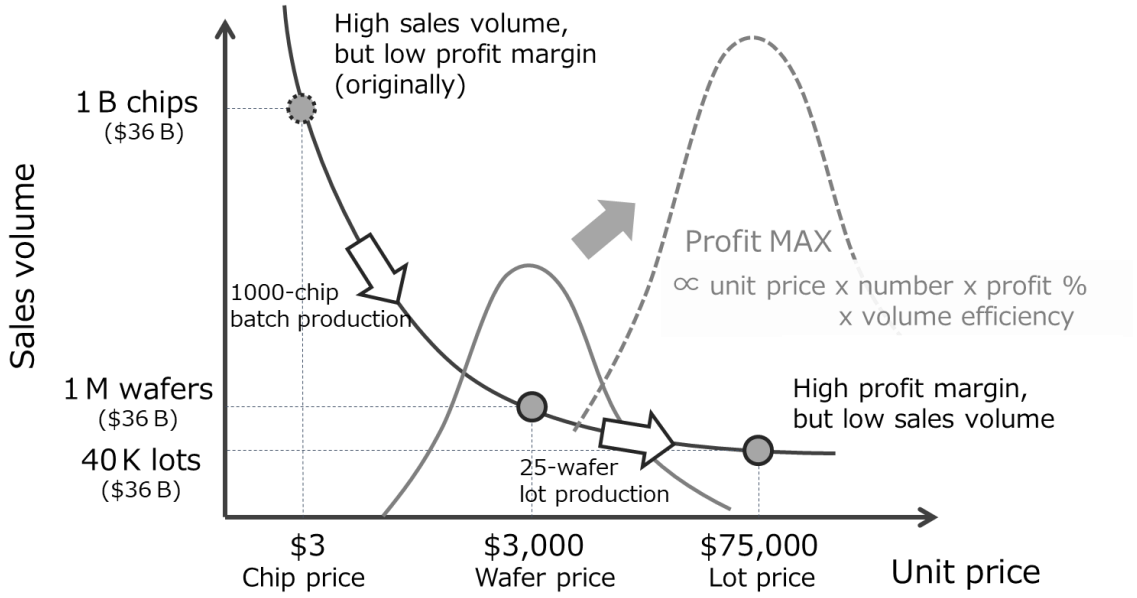

Fig. 1 Sales volume of memory chips and unit price.
Although unit price of memory chip is cheap, it is mass-produced by 1,000 x 25 units, so its volume efficiency is higher than that of automobile industry.

Table 2 Similarities between semiconductor industry and railway industry.

The sales of semiconductor manufacturer is estimated by the memory chip price of $3, batch production of 1,000 chips/wafer and production amount of 1 M wafers/month. The sales of railway company is estimated by the round-trip fare of $300, 1,000 passengers/train and 200 trains/day.

	Semiconductor industry (Memory chip business)	Railway industry (Shinkansen business)
Estimated sales	$36 B/year	$22 B/year
Product price	about $3/chip (Memory)	about $300/ticket (Tokyo ⇄ Osaka)
Batch production	1,000 chips/wafer	1,000 passengers/train
Output	1 M wafers/month	6 M passengers/month
Operating profit	20 – 60%	40 – 50%
Volume efficiency	4 → 8 → 12 inch wafer	8 → 12 → 16 cars
Capital investment	$60 M for ArF immersion	$40 M for Shinkansen train

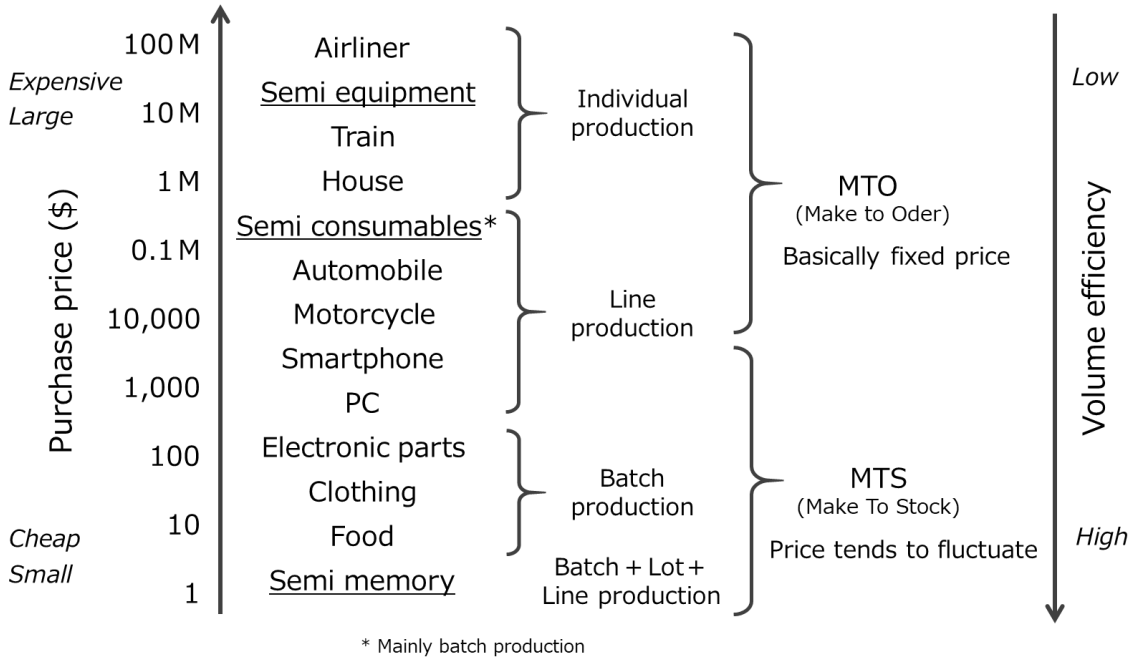

Fig. 2 Classification by purchase price and production method.

The reason why we can buy a memory chip of advanced technology node by $3 - 5 is very high volume efficiency of the semiconductor production which is the line production of huge quantity of the same specification chips in combination with batch production and lot production.