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Applying RBT to Evaluate the 3D IC Strategies of CMOS Image Sensor IDMs

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Because of the ever increasing demand of the lower power consumption, lower cost and higher performance in consumer electronic industry, the Moore's Law almost came to its end. Most of the integrated device manufacturers (IDMs) of CMOS Image Sensor (CIS), such as Sony and OmniVision, had then already put 3D IC (Three Dimensioned Integrated Circuits) applying Through Silicon Via (TSV) technology in their roadmaps to resolve the upcoming challenges. Under such manner, for helping analyze the current situation of applying 3D IC concept in CIS industries, this research proposed a novel two-level evaluation model, where the long-term strategies were structured at the top level, and their corresponding short-term tactics were constructed at the bottom. Besides, Resource Based Theory (RBT) was also applied in the proposed model to help review and evaluate the resulted competitive advantage. In order to consolidate the proposed model, the data from the related market sections was retrieved and analyzed for modeling. For conducting the experiments, three significant IDMs were carefully selected for case studies in order to compare their current strategic competitiveness after introducing 3D IC related technologies in their roadmaps.

Keywords: 3D IC, TSV, Semiconductor Industry, Market Research, CMOS Image Sensor, Resource Base Theory

JEL Codes: F34, G21 and G24

1. Introduction

Current research and development (R&D) in semiconductor industry always follows the Moore's law, which depicted there will be a new generation innovation product every 18 months. This regulation was introduced based on the prediction of Gordon Moore, the founder of Intel, and, then regarded as a R&D guideline in semiconductor market for years.

For simplicity, the Moore's law implies either the numbers of transistors per unit area in the device would double, or the price would be halved every 18 months. Therefore, all the players in the semiconductor industry then tried hard to shrinkage the pitch of the transistors in order to increase the device densities. However, after the advent of 56nm technology node, the engineers started to feel tough to remain on the rail with the current mainstream packaging technology, System on Chip (SoC), which is a 2D approach. On top of that, driven by demanding more functionality, heterogeneous integrations in electronic devices have been another serious issue to aggravate the above problem. Under this circumstance, the packaging technology of integrated circuits (ICs) intended to utilize the third dimension to formulate Three-Dimensional Integrated Circuits (3D IC). The 3D IC concept intends to apply vertical stacking technology for wafer and chip packaging, and, the main purposes here are performance enhancement, miniaturization and cost- effectiveness. Among the relative technologies of 3D IC, Through Silicon Via (TSV), which is composed of drilling a vertical via through the silicon floor, filling conducting materials, bonding wafers/ chips for electronically

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interconnection, and thinning the stacked devices, is regarded as the most critical technology. Although there are some alternative technologies to formulate vertical stacking packaging, only those with TSV technology are regarded as pure 3D ICs. With this emerging technology, the density of interconnection would be improved and then the performance of devices could also be enhanced, such as the bandwidth between DRAM and CPU. Moreover, possessing the benefits of increasing signal density and shrinking packaging size, TSV is expected to be the next generation mainstream packaging technology. According to the market research, the first wave of applying TSV is primarily in CMOS Image Sensor (Complementary Metal-Oxide Semiconductor Image Sensor, CIS) market, where the core concerns of competition are all about high resolution, high sensitivity, low power consumption, and miniaturization of image sensor devices. Some integrated device manufacturers (IDMs) of CIS, such as SONY and OminiVision, had already arranged 3D IC concept in their technology roadmaps. Although there are many benefits of TSV, introducing a new technology would usually incur multiple impacts in current markets. A lot of experts believe the semiconductor value chain would be fully or partially restructured, no matter when and where this emerging technology would be employed. Organizing a consortium to coordinate the available resources for developing 3D IC infrastructures is the most viable way temporarily. That is partially because almost the consortiums are founded by IDMs, which will have valid roadmaps, the abilities to coordinate core technologies from member enterprises, and then have the power to impact the future 3D IC market. Since the IDMs will either forming consortiums to dominate the future 3D IC R&D direction or have the most powerful resources to cope with this emerging concept, this research intends to construct a hierarchical model with Resource Based Theory (RBT) for evaluating their strategies and competitive advantage in the future CIS market after employing 3D IC technology. With the review of their possessed resources, the proposed model could then deliver a reference for developing roadmaps before or after entering this emerging market.

2. Literature Review

While TSV grabbed the spotlight of CMOS image sensor market, Integrated Device Manufacturers (IDMs) now are trying to apply 3D IC to sustain their long- term competition advantage. Even though implementing TSV to vertically interconnect chips could be beneficial, it still requires the coordination among the partners of material, tool, equipment, process, etc. But it is tough and undetermined decision for these players since such an emerging strategy cannot immediately be foreseen its potential benefits on their sides. Therefore, this research started with the market analysis in order to propose a feasible model for those willing to enter this new era of technology.

2.1 CIS Market

The applications of CIS are currently diversified, and the relative products could include printer, fax machine, optical mouse, digital camera, smartphone, video recorder, etc. Especially, CIS employed in cameras of mobile phones was initiated in 2002, and became a standard device only in one year. Traditionally, the process technology of image sensors in Japan is Charge Coupled Device (CCD), but it inherits drawbacks of design complexity and high cost. On the other side, its competing technology, Complementary Metal-Oxide Semiconductor (CMOS) gradually grabs markets' spotlights, and is generally adopted in processing digital images. Compared with CCD, CMOS could offer more reasonable cost, higher integration abilities, and lower power consumption, which let CMOS have the potential to be a mainstream technology in image sensor industry sooner or later. Moreover, developing smart phones have focused on miniaturization, low power consumption, faster processing time, and plentiful functionalities, and, then the next generation of smart phones would continue applying CMOS to develop the required image sensors. Moreover, a France research group, Yole, predicted CIS could become high value-added intelligent sensors in the future as long as it could integrate the abilities of photography sensitization, image processing and identification. The potential applications here could include machine vision, fingerprint identification, motion detection, portable game console, etc. According to the above observations, clear market discrimination between CMOS and CCD then had been confirmed (Yole, 2010).

Since the evolutions of image sensors are almost towards higher resolutions and excellent qualities, applying TSV could just help fulfil the demand of multi-functionalities and miniaturization. Besides, applying TSV in CMOS image sensors could also have the benefits of facilitating integration, enhancing packaging abilities and shortening time-to-market. Therefore, a lot of CIS vendors had put TSV onto their roadmaps. According to Yole's forecast, TSV will soon become a leading-edge technology of CIS (Yole, 2010). Applying TSV for producing camera modules of CIS could shrink both the estate of print circuit board, and the total thickness of package.

2.2 Competition Advantage Evaluation of High Tech Industry

In the past few years, the leading edge technology evolves very fast and the advantage is harder to sustain. Strategic management is a tough task ever and needs more complicated methods to support and reinforce. The approaches used for leveraging enterprises' advantage are diversified than ever, and could not guarantee the corresponding effects. This issue is more significant in high tech industry, where the players usually intend to possess their own high value-added products, complicated technologies, intensive technology- oriented employees, and high R&D investment (Grant, 1996). In order to help evaluate the high tech industry, the following perspectives are selected as the common ways to identify the corresponding strategic advantage.

(1) Ability of R&D

From the perspective of market trend, the companies in high tech industry are always regarded as the most significant players to grab the market spotlight and behave as pioneers for developing the economy. The competition strength in such industry is determined by how fast they could incubate their R&D abilities. Moreover, since high tech industry usually exhibits the characteristics of higher R&D investment, faster technology evolvement, frequent environment change, higher industry complexity, shorter product life cycle, and higher added values, it is more trivial for its players to concentrate on developing R&D. Therefore, the speed of delivering new products or technologies is then regarded as the most critical indicator of whether they could sustain advantage or not.

There is a lot of literature studying the R&D abilities of high tech industry. Among them, Buckley selected 21 high-end technology enterprises in China, and collected the relative observatory data from 1997 to 2002. He claimed that the yearly sales of new products could be used for evaluating innovation performance, and for inspecting the results of innovation investment. The conclusions of his study implied that the more technology innovation the enterprise has, the more competitive it will be (Buckley et al., 2007). Moreover, global knowledge economy index (KEI) also gives highest priority to innovation and information infrastructure. That means technology innovation is indeed a critical issue while developing economy.

(2) Core Technology Development

Every enterprise should figure out their core competition in order to recognize the future directions. As for those high tech enterprises, technology advance is always the most critical factor in gaining core competition. Therefore, applying suitable technology strategies with finite core resources could then help create and sustain the core competition in the high tech industry. Based on the considerations of the most common technology strategies and the corresponding supporting product innovation abilities, the strategies of core technology development could have the following two types:

a. Technology Developer Strategy: usually possesses technology leadership, outstanding R&D resources, and superior innovation abilities.
b. Technology Follower Strategy: imitates or outsources to support and formulate core technology development.

As the high tech era advents plus the boundaries of enterprises blur, each enterprise would encounter a lot of challenges and pressures in the future. In order to leverage the entire competition advantage, enterprises should make the best of their core technologies in order to gain the first-mover advantage.

(3) Market Strategy

Since high tech enterprises have the abilities of offering high value-added products or services, their business models have been technology- intensity rather than labor-intensity. Nowadays, high tech enterprises usually possess a lot of intellectual patterns, and, they exhibit various co-existing business models, such as Intellectual Patent Providers, Outsourcing Providers, Foundry Service Providers, etc. No matter how they retrieve critical technologies, enterprises should eventually find their main applications in order to increase market share. In other words, if enterprises could have precise and successful application strategies, they would be able to enhance their advantage and sustain competition. Therefore, observing the strength of market applications could help evaluate the effectiveness of strategies.

2.3 Resource Based Theory

Well- diversified enterprises usually run business globally in multiple markets, where their competitive advantage depends on how well they could make use of all available resources (Prahalad & Hamel, 1990). There are a lot of methodologies addressing how to evaluate competition advantage, but Collis and Montgomery recommended Resource Based Theory (RBT) as one of the most powerful ones (Collis & Montgomery, 1995). Barney claimed that resources able to help sustain competitive advantage could be classified into the following four classes based on their contributions: (1)Valuable: be able to facilitate the efficiency and effectiveness of enterprises. (2)Rare: possess resources which are not easy to obtain or establish. (3) Inimitable: have historic dependence, causal ambiguity, social complexity, and is hard for the rivals to imitate. (4) non- Substitutable: the resources are unique and could be used for establishing entry barriers. As stated above, the contributions of resources are getting more from (1) to (4). Therefore, the competitive advantage could be evaluated through reviewing the available resources of enterprises. This concept is called RBT, and could be applied to evaluate the competition of various enterprises in many industries (Barney and Firm, 1991; Bharadwaj, 2000; Wu et al., 2006; Grant, 1996; Kuang & Xu, 2008; Rungtusanatham et al., 2003; Wernerfelt, 1998).

Nevertheless, Teece found the larger size an enterprise is, the more advantage of resources it possess, where the resources could be obtained from lands, factories, facilities, etc. Therefore, he claimed that if an enterprise possesses more tangible resources, it'll exhibit more abilities and possibilities to launch the new product development, and, then be easier to sustain the competitive advantage (Teece, 1994). However, these tangible resources are easier to be imitated, and could not always sustain the competitive advantage. On the flip side, the intangible resources which include human resources, innovation resources, innovation abilities, etc., usually require the rivals spend longer time and more cost to imitate, and, then are regarded as more critical than tangible resources. Therefore, intangible resources which are traditionally easier to be neglected, are now asserted to have more impacts on competitive advantage (Byrd & Turner, 2000; Hitt et al., 2001; Jean et al., 2008).

Mark and Adegoke applied RBT to review five different types of supply chains, and concluded both tangible and intangible resources could effectively sustain the entire advantage (Mark & Adegoke, 2007). Stavroula and Dionysis conducted a qualitative interview with managers in the exporting industry by employing the concept of RBT, in order to construct a model for studying the relationship between available resources and management performance. The results of their proposed model showed a strong positive relationship existed under the perspective of enterprise advantage (Stavroula & Dionysis, 2010). Wong and Noorliza also applied RBT to study the strategies of a logistic supplier, and the analysis model could help identify the contributions of human resource, capitals, and information to the competitive advantage (Wong & Noorliza, 2010). Ronan applied both cost economic review and RBT to conduct real case studies, and evaluate their outsourcing strategies. The result showed that taking into account both cost and resources is critical to leverage the performance of business operation construction, management enhancement and strategy making (Ronan, 2009).

3. The Methodology and Model

In order to serve the purpose of this research, a two-level hierarchical model was constructed, and RBT was applied to enhance the evaluating abilities of the proposed model. The indicators at the top level are to evaluate the adopted strategies, and then, those at the bottom level are to inspect the performance of tactics taken under the strategies. Therefore, the construction processes are top -down, and the evaluations would be conducted from the bottom up.

(1) Constructing the top level based on strategies

The top level of the proposed model is to evaluate the strategies of CIS companies. From the available literature, the main concerns of strategies might include strategic alliance, innovation technology, and market application. Based on these considerations, there would be three top-level strategic indicators employed in the proposed model, which are denoted as L1, L2, and L3.

L1. Establish Roadmap of Technology

The first perspective of evaluation is to observe whether the enterprise has a clear technology roadmap. A clear and feasible roadmap could be seen as an indicator of whether an enterprise could sustain its technology advantage, and what their future plan is for the next few years. This is very critical for introducing a new technology to the market, such as 3D IC and TSV. A technology roadmap usually could reflect an enterprise's core developing directions and future plans. Four of the main observatory factors are selected as follows:

1. Specifications of technologies: for CMOS image sensors, the most critical specification considered is usually about the resolution. Observing the specifications announcement of the major CIS players could offer a good picture of the future development.
2. Cost structure: cost is critical for enterprises' willingness to developing and adopting new technologies. A feasible cost structure can reflect the ability and intention of introducing a new technology.
3. Product performance: the performance of a CMOS image sensor is composed of Sensitivity, Auto Focus, Digital Zoom, Image Stabilization, etc. To compare and evaluate the performance can indicate how advanced the corresponding vendor has been.
4. Time to Market: shorten the time to market could grab more market share, and possess the first-mover's advantage. Observing the planned time to market of CIS vendors could help evaluate the intention of pursuing the technology advantage.

L2. Diversify Market Applications

The applications of consumer electronics have a considerable market, where the technology innovation and richness of integrated functions are critical to enlarge the market share, instead of forming entrance barriers. Since the requirements of function enrichment and miniaturization are increasingly demanded in consumer electronic markets, CMOS image sensors are forecasted as the first wave of applying 3D IC, according to Yole's report (Yole, 2010). Therefore, application diversification of CIS could help recognize whether CIS vendors have sound plans to enlarge their markets. Currently, two categories of CIS applications can be given as follows:

a. Low-end applications: mobile phones, digital cameras, webcams, portable game consoles, etc.
b. High-end applications: digital single lens reflex cameras (DSLR), digital cameras, healthcare devices, devises for industrial application and machine vision.

Since there are numerous kinds of CIS applications, to inspect an enterprise's current and future applications is a good indicator for understanding its abilities.

L3. Forming Superiority of Technology Innovation

CIS industry is technology- driven, so the advance of technology could leverage the competitive advantage. CIS vendors always pursue the state of the art technology to gain more market share. As we discussed above, 3D IC with TSV has been regarded an emerging leading- edge technology. Therefore, if CIS vendors have the intention to apply such technology, they would possess the advantage of lowering cost, enhancing heterogeneous integration, miniaturizing the devices, stabilizing technology innovation, and leveraging device specifications. In words, if a CIS company could invest and apply TSV, it would be considered having higher possibilities of sustaining competition advantage.

(2) Construct the bottom level with the corresponding tactics

The managers of an enterprise usually design the tactics with respect to their established strategies. A sound strategy should be implemented by the way of executing tactics and relative operations. Therefore, the bottom level was formulated according to the tactics that CIS vendors might have. The jth tactic of ith strategy is denoted as Li-j.

L1-1 Participating in Research Consortiums

Even though TSV had been confirmed to be the next generation mainstream technology, most CIS vendors still do not know how to launch the first step. To some extent, several technological issues should be solved beforehand. Parts of these issues include cost, reliability, heat dissipation, etc. In order to speed up time to market, several research consortiums are formed to offer pilot lines, construct standards, help deliver patents, etc. These consortiums are usually composed of the vendors of equipment, material, electronic data analysis tool (EDA), Fablite/Fabless, Foundry, Packaging house, Outsourced Assembly and Test (OSAT), etc. Therefore, participating in research consortiums is the most efficient way for implementing 3D IC in CIS industry at this moment.

After participating in consortiums, CIS vendors should then know how to make the best use of the resources from consortium members, and leverage their competition advantage. Afterwards, some of the potential benefits are as follows:

a. Better sense of market trends: historically, the time for flipchip became a mainstream technology of packaging is more than 10 years. Therefore, it is difficult for decision makers to formulate an accurate forecast to catch up the market trend. Since a consortium is usually composed of various kinds of players along the value chains, the members would absolutely possess better information and sense about the future trend. Currently, there are some research consortiums emerging for developing 3D IC, and their purposes are quite various, which might include the following:

    1. Offering the integration platform of 3D IC for members to enhance functionalities, performance, and lower power consumption in order to shorten time-to-market.

    2. Developing the TSV related technologies, materials, and tools for mass production.
    3. Constructing standards of 3D IC.

b. Coordinate the resources of members: a consortium usually could make the best of all the members’ contributions, such as the individual core technologies, equipment, tools, etc. Being able to Integrate and share all the available resource would appeal more members, and enhance consortiums’ roles. The criteria are given as follows:

1. A whole supply chain of semiconductor devices could be formed through the members, such as equipment, material, manufacturing, packaging, testing, etc.
2. Consortiums usually possess up-to-date pilot lines, such as 300mm fab, and could offer members to launch R&D of 3D IC.
3. The alternative TSV solutions from the sides of IDM, Fabless, Foundry, and packaging house could be compared with the performance within the consortiums.

c. Cut down the cost of developing new technology: whether to adopt an emerging technology, the cost issue is much more important than others. Consortiums possess members of various types, and, have the most qualification to develop the cost model. Therefore, joining a consortium would usually help lower risk and cost as well, which would have the following benefits:

1. Precise cost models could be obtained since consortiums could coordinate members to evaluate all the possible situations.
2. Consortiums could then offer cost-efficient solutions to help consolidate the infrastructures of 3D IC development.

L1-2 Forming Strategic Alliance

For facilitating the infrastructures of 3D IC market, a virtual integrated value chain is critical and mutual strategic alliance would be an efficient way. There are several types of strategic alliance, such as joint venture, outsourcing, acquisition, etc. The main points here are to evaluate whether the enterprises could have a sound strategic alliance to enhance their competitive advantage. The alliance strategies mainly have two opposite ways as follows:

1. Alliance with suppliers: although IDM could solely develop a new technology, it is more common for semiconductor enterprises to licence, purchase, or outsource the unfordable technology. Therefore, alliance with suppliers could be a more efficient way to serve that purpose.
2. Alliance with main customers: alliance with customers, such as packaging, testing, assembling companies, etc., could grab the market trend more easily, and have a shorter time-to-market.

L1-3 Leading- edge Technology appeared in Roadmap

A clear technology roadmap of an enterprise could reflect their strategic plan for the coming years. However, announcing to implement a new technology, like TSV of 3D IC, requires deep considerations. Therefore, as long as a CIS company put TSV into their roadmap, no matter of how far from now, it means they have recognized the market trend yet and are trying to get the first mover advantage. In other words, whether arranging TSV or 3D IC into the technology roadmap or not could be an indicator for considering the sustainability of enterprises' competitions.

L2-1 Find Applications in High Resolution Market

The future application trends of digital cameras and smartphones are almost towards enhancing resolutions, such as being able to produce clear photos in any condition of illumination. Since usually accompanied with higher price and more advanced integrated functionalities, the high end devices usually required to be equipped with higher resolutions of CIS. Therefore, major suppliers will have the following critical applications:

1. High-End Smartphones: the competitive resolution quality of CIS is now between 5M to 8M pixels, and the size of wafer has been already 300mm. Resolution enhancement of CIS is still the market trend for the camera modules equipped.
2. DSC/SLR applications: their applications of 300mm wafer have been around the corner.
3. Clinical Sensors: includes surgical laparoscopes, pill cameras, X-ray imaging etc. The applications of X-ray imaging also include teeth scanning, X-radiation inspections, disposable endoscopes, medical pills, etc.
4. Industrial and Machine Vision Applications: mainly include relative applications of high speed machine vision camera markets. Moreover, the applications of image sensors in the security are also a tremendous large market in the future.

L2-2 Find Applications in Low Resolution Market

Although the R&D trend of CIS is towards enhancing higher resolution, some of the developing countries, such as India and China, still have large markets of low end applications. The applications of this kind might include cameras of mobile phones, webcams of laptops, cameras of outdoor security and surveillance, cameras for vehicles, etc., which are listed as follows:

1. Low end mobile phones: the standard CIS resolutions of this kind are between 3M and 5M pixels. Their R&D trends include wafer level packaging (WLP), low thickness, low cost, auto-focus and digital- zoom etc.
2. Cameras for security and surveillance: the R&D of these applications is focused on low illumination environment applications.
3. Image detection in highly dynamic environment: devotes to improve the instability of traditional wide dynamic range (WDR), and be able to well function in extreme dark or bright environments.
4. Video cameras for game consoles and network applications: most of the portable game consoles and computers are still equipped with low resolution cameras.
5. Cameras for vehicles: potential applications could include parking assistance, driver monitoring, pedestrian detection, etc.

L3-1 Developing Intellectual Patents

In addition to launching R&D of process technology, developing critical intellectual patents (IPs) and having more licensing strategies could be an efficient way for gaining more advantages. Therefore, a lot of consortiums initiated to have more integrated plans, which would coordinate 3D system design, automatic design-to-manufacture system, 3D IC application platforms, and IP development. Currently, the main technology licensing of CIS includes:

1. Wafer-Level-Chip-Scale Packaging (WLCSP)
2. Vertical Staking Technology of TSV
3. Back-side Illumination (BSI)

L3-2 Consolidating Core Technologies

In order to leverage the performance of CIS, it is necessary to simultaneously take into account of resolution, size and cost. The CIS vendors are always trying to develop advanced technologies in order to consolidate their leading positions, and further formulate their core technologies. After observing the whole market, core technologies that CIS vendors possess could be found currently are as follows:

1. Back-side Illumination (BSI): the technical benefits for applying BSI in CIS are given as follows:

    a. Miniaturization: with the employment of BSI technology, the thickness of high end CIS applications in recorders, DSC and SLR are around 1.75-1.9μm. As for low-end applications in mobile phones, the thickness are then around 1.1~1.4μm. The resulted devices are relatively smaller than traditional technologies.
    b. Leading- edge Technology Advance: the new structure of BSI could support attaching lens on the backside of substrate, which would enhance the sensitivity of low illumination and total performance. That is because BSI could offer the shorter route for transmitting the light directly into Photodiodes.
    c. A lot of Potential Applications: include the applications of automobiles, healthcare, technology, machine visions, etc.

2. Wafer Level Packaging (WLP): WLP is one of the most popular packaging technologies, which could usually enlarge economies of scale. WLP could be applied in both the high-end and low-end CIS applications. The former one is employed in most of the smartphone markets, and the latter one could be applied in cameras, automobiles, and healthcare industries. Nowadays, WLP has been asserted to be an application trend in CIS for decreasing total cost.

3. Other Innovation Technologies: launching the technology innovations could sustain the competitive advantage of any enterprise. Therefore, observing whether an enterprise has adopted innovation strategies could help evaluate its future advantage as well. Some of the main innovation technologies in CIS are given as follows:

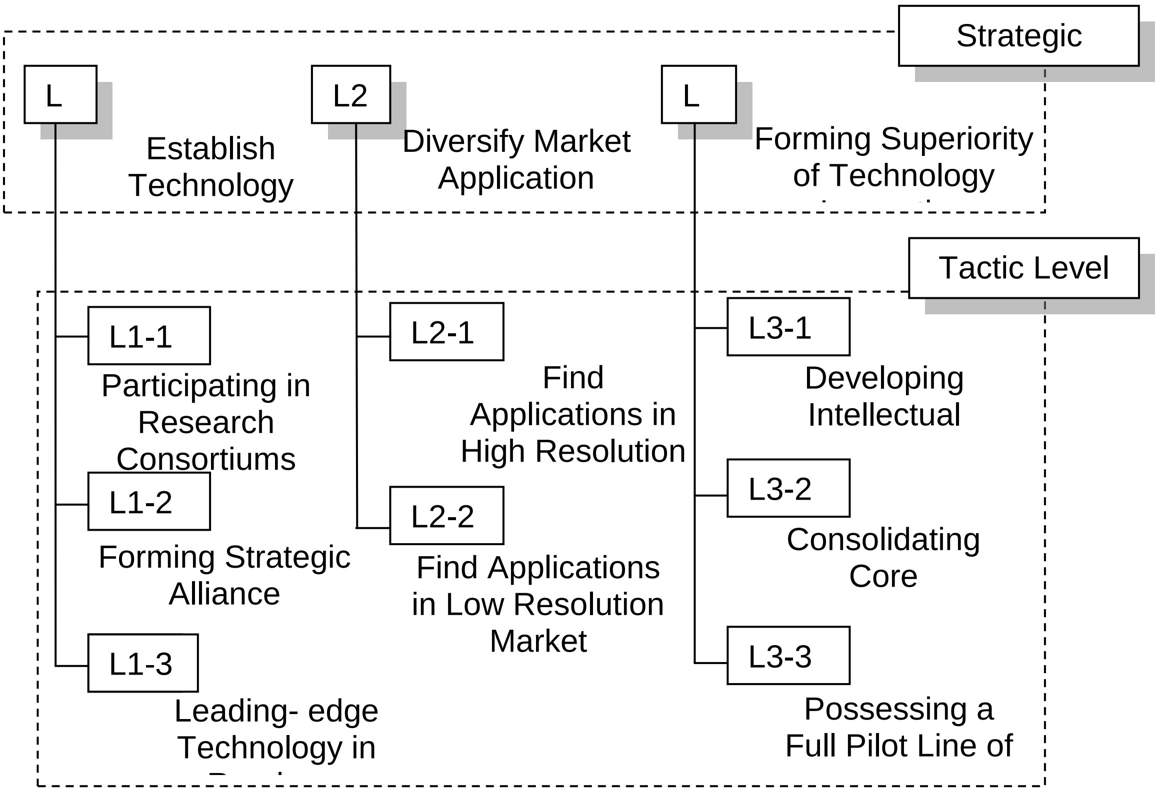
    a. Anti-Reflective Coating
    b. Colour Filter
    c. Micro-Lens Array
    d. Pixel Design Structure

L3-3 Possess a Full Pilot Line of 3D IC

Along with the advance of technology nodes, the main stream wafer size of a fab had been gradually shifted to 300mm. Although the 200mm fabs still possess the largest market share in Semiconductor industry, there are a lot of intentions for major enterprises to enter the era of 300mm. Under such manner, possessing or planning to have 300mm fabs could be regarded as having technology superiority. On the other hand, since 3D IC is still on the way, offering a full pilot line to integrate the resources in the supply chain could facilitate its time-to-market. Therefore, no matter the wafer size is 200mm or 300mm, having one full pilot line of 3D IC could also indicate the strong intentions and advantage of the enterprises. The evaluation criteria are as follows:

a. Availability of Pilot Lines
b. Plans of shifting to 300mm fabs

Figure 1: Hierarchical Structure of Evaluation Model Indicators



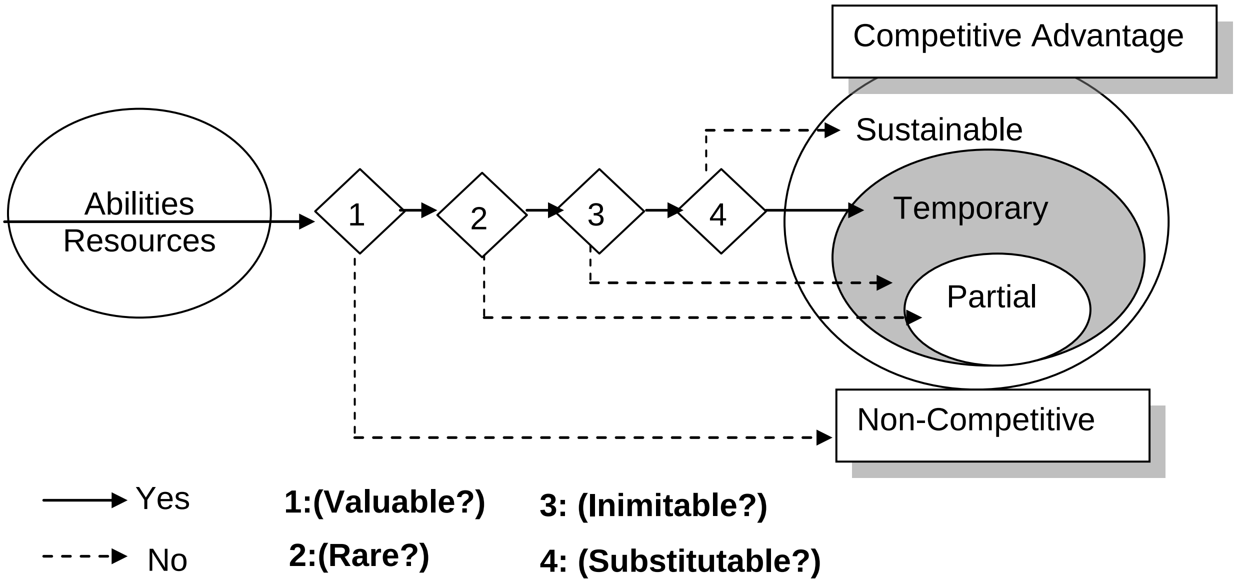
(3) Employ RBT to Evaluate Competitive Advantage

Resource Based Theory (RBT) is a methodology employed to review the available resources of an enterprise in order to evaluate whether the competitive advantage could be sustained. An enterprise usually possesses a lot of resources, and, enhances the performance through the use of those resources. Some of the resources are tangible, and easier to be evaluated, such as labours, equipment and tools, lands, Fabs, warehouses, etc. However, the others are intangible and harder to be physically evaluated, such as reputation of brands, business intelligence, management methodologies, etc. Therefore, while applying RBT, the resources are commonly separated into two clusters, which are denoted as resources and abilities. Resources usually refer to those tangible belongings, and abilities usually refer to intangible ones. In this study, each indicator was classified with respect to its tangibility, and redefined in table 1, accordingly. Moreover, the evaluation results of resources could be valuable, rare, inimitable, and non-substitutable with respect to their contributions, which are depicted in Figure 2. Each diamond box denotes an evaluation node. For example, the first one accompanied with valuable in parenthesis stands for the evaluation of whether the corresponding ability or resource is valuable or not. If it tends to be valuable, then it would go to the next node for the further evaluation. However, if the result is “no”, it would go along with the dotted line to the conclusion of non- competitive. With the evaluations conducted, the enterprise possessing a certain set of resources could be more easily understood its pros and cons.

Table 1: Classification of Indicators

Abilities	Resources
L2 Market Application	L1 Technology Roadmap
L3 Technology Innovation	L1-1 Research Consortiums
L2-1 Market Share of High Resolution	L1-2 Strategic Alliance
L2-2 Market Share of Low Resolution	L1-3 Leading- edge Technology
L3-1 Intellectual Patents	
L3-2 Core Technologies Consolidation	
L3-3 Full Pilot Line of 3D IC	

Figure 2. Evaluation Model of RBT



4. The Findings

In order to demonstrate the proposed model, three Integrated Device Manufacturers (IDMs) of CIS were selected, which are Toshiba, Samsung, and STMicroelectronics (STM). Although there are numerous CIS vendors in the current market, the main reasons for choosing the above three are because all of them possess well-known brands, participate in research consortiums, have technology roadmap announcements, and own leading- edge technologies.

4.1 Overview of Case Companies

In order to understand the fundamental information of the selected IDMs, their background data were collected from their websites and through the internet survey. First of all, the corresponding profile of each IDM was described as follows.

(1) Samsung

Samsung possesses a history of over 70 years, and has diverse businesses that span advanced technology, semiconductors, skyscraper and plant construction, petrochemicals, fashion, medicine, finance, etc. Through innovative, reliable products and services, talented people, a responsible approach to business and global citizenship, and collaboration with partners and customer, their business model seems feasible and could sustain for a couple of years.

(2) Toshiba

Toshiba is comprised of five business units: Digital Products Division, Visual Products Division, Imaging Systems Division, Storage Device Division, and Telecommunication Systems Division. Together, these divisions provide consumer electronics products and solutions, including industry leading laptops & netbooks, LCD and LED televisions, Blu-ray and DVD players, camcorders, imaging products for the security, medical and manufacturing markets, storage products for automotive, computer and consumer electronics applications, and telephony equipment and associated applications.

(3) STM

STM is a world leader in providing the semiconductor solutions, among the world's largest semiconductor companies, a leading IDM serving all electronics segments, and a leading technology innovator having around 12,000 researchers and more than 21,500 patents. In order to provide customers with an independent, secure and cost-effective manufacturing machine, STM operates a worldwide network of front-end (wafer fabrication) and back-end (assembly and test and packaging) plants and also has relationships with leading-edge foundries.

4.2 Evaluations based on RBT

By applying the indicators in Table 1 and the proposed model in Figure 2, the current strategies of the above companies were evaluated, and the results were shown in the following tables. As denoted above, the evaluation processes were manipulated from the tactic level to strategy level. The observations were analysed through the survey of each company beforehand, and, then the evaluations based on RBT were generated after reviewing the available resources and abilities.

Table 2: Evaluation Results of L1-1

	Observations	Evaluations
Samsung	Samsung has participated in: 1. EMC3D (USA)—devotes to implement cost effective TSV processes for 3D IC. 2. 3DASSM (USA, Germany, Korea)—devotes to develop leading- edge technologies of 3D IC. 3. SEMATECH (USA)—provides diversified and cost effective ways for integrating CMOS technologies. 4. IMEC (Belgium)—employ 3D integration technology for stacking DRAMs and Logic chips.	Since all consortiums were able to deliver leading- edge technologies, Samsung was evaluated as inimitable.
STM	STM has participated in: 1. Crolles2 (France)—devotes to develop CMOS, wafer testing and packaging technologies of sub 100nm technology nodes. 2. Collaborate with IBM to develop next generation technologies of Semiconductor, including CMOS technologies of 32nm and 22nm nodes. 3. IMEC (Belgium)—devotes to integrate DRAM and Logic chips with 3D technologies.	The consortiums of STM could just offer some temporary benefits for its innovation, so the evaluation was denoted as Valuable.
Toshiba	Toshiba has participated in: 1. ASET (Japan)—a government founded consortium for leading the 3D IC integration technologies in Japan. 2. SEMATECH (USA)—provides diversified cost-efficient processes for integrating CMOS technologies. 3. Team up with Sony and NEC for mutually sharing 45nm technologies in order to decrease the R&D cost. 4. Team up with IBM and Sony in order to launch fundamental researches for sub 32nm technology nodes.	Since all consortiums were able to deliver leading- edge technologies, Toshiba was evaluated as inimitable as well.

Indicator L1-1 concerns whether an IDM could take the advantage of participating in consortiums to catch the market trends, decrease total cost, and share resources with other members. According to the observations, Samsung seems to have all-aspect strategies, and then was evaluated as inimitable. Moreover, by participating in consortiums, Toshiba can easily integrate the resources of 3D IC, share CMOS technologies and facilities, and possess more technology innovations. Therefore, Toshiba was evaluated as inimitable as well. However, since the purposes of joining in consortiums are focused on the innovations of CMOS technologies and facilities, STM could have some values only after compared with the other two.

Table 3: Evaluation Results of L1-2

	Observations	Evaluations
Samsung	1. Coordinate with Qualcomm to offer advanced CMOS technology. 2. Alliance with IBM to jointly develop CMOS logic technology. 3. Licensing agreement with Microsoft to leverage R&D of CMOS technology. 4. Coordinate with NXP for mobile markets.	Samsung has excellent R&D, and is also willing to coordinate with other well-known enterprises. Therefore, it is evaluated as rareness.
STM	1. Coordinate with Soitec to jointly develop BSI technology for 300mm WLP. 2. Licensing Bosch with the most advanced technologies to develop highly integrated electronic devices of vehicles. 3. Coordinate with Nokia to develop mobile phones. 4. Coordinate with IBM for developing both the platforms of 28nm and 32nm technology nodes. 5. Outsourcing its packaging processes to Koycera in Japan.	STM had possessed a lot of IPs, and is also willing to strategically ally with others. It is evaluated as rareness.
Toshiba	1. Coordinate with Creative Sensor Inc. for licensing and marketing Contact Image Sensor. 2. Coordinate with IBM and NEC to develop 28nm CMOS process technology for low power consumption electronics. 3. Apply innovative CIS with Microsoft platform for entering smartphone markets. 4. Strategic alliance with Windond Inc. and license its 0.175μm and 0.15μm CMOS technologies. 5. Jointly develop technology innovations with Synopsys. 6. Outsourcing partial chip fabrication processes to Samsung.	Toshiba preferred to coordinate with other well-known enterprises, and mutually share resources with each other. It is evaluated as rareness.

Indicator L1-2 concerns whether IDMs could have appropriate strategic alliance plans in order to enhance processes, decrease cost, and shorten time-to-market. Among the three cases, with the strongest R&D abilities, Samsung was able to develop the critical components alone, and then assessed as rare. Toshiba possesses a 300mm fab for fabricating CIS, and have a lot of licence agreements with its partners. Therefore, Toshiba was also evaluated as rare. Although STM outsourced over 50% of the CIS fabrication, it is still regarded as a major vendor in CIS markets. Adding its emphasis on R&D and innovations, STM is also evaluated as rare for this indicator.

Table 4: Evaluation Results of L1-3

	Observations	Evaluations
Samsung	1. Two- year roadmap of CIS is available. 2. Clear roadmap about cellphones, digital cameras, video Recorders, etc. 3. TSV based CIS devices are in the roadmap.	TSV is in the roadmap, but the application roadmap is only restricted in 3C products, where the assessment is valuable.
STM	1. Clear roadmap of CIS for vehicle industry. 2. Fabs have clear process roadmaps. 3. Clear roadmaps for the applications of camera phones, portable devices, healthcare and industrial electronics, e- metrology, and security devices. 4. TSV based CIS devices are in the roadmap.	TSV is in the roadmap, and the application roadmaps of CIS are more diversified, where the evaluation is non-substitutable.
Toshiba	1. Clear product roadmaps of Webcams, Game Consoles, and Multimedia devices. 2. Fabs have clear process roadmaps. 3. Particular roadmaps for cellphones and camera modules. 4. TSV based CIS devices are in the roadmap.	TSV appears in the roadmap, but the focus of applications is limited, where the evaluation is valuable only.

Indicator L1-3 concerns whether IDMs could have well-established roadmap of CIS, including the leading- edge technology development, product applications, and market strategies. After conducting the assessments, with a more diversified roadmap of TSV based CIS, STM outperforms the other two, and then possess more powerful competitive advantage currently under this indicator.

Table 5: Evaluation Results of L2-1

	Observations	Evaluations
Samsung	1. High-end applications include video recorders, digital cameras, DSLR, smartphones, and High Resolution Monitors. 2. There are applications of webcams in high end laptops. 3. Small portion of products are offered in healthcare, and industrial usage.	The focus of high-end applications is restricted in cellphones, smartphones, and webcams, but the other market sections are comparatively weaker, which then is evaluated as valuable only.
STM	1. High-end applications include video recorders, digital cameras, DSLRs and extra- thin cellphones. 2. CIS devices are also deployed in endoscope, and machine vision. 3. Embedded cameras are offered in high-end laptops and PDAs.	STM’s applications are more manifold, which would have more potential benefits in the future. Therefore, it is currently assessed as inimitable.
Toshiba	1. High-end applications include video recorders, digital cameras, DSLRs and extra- thin cellphones. 2. Small portions of products are offered in healthcare, and industrial usage. 3. Embedded cameras are deployed in high-end laptops	Toshiba possess similar strategies as Samsung, which is also evaluated as valuable.

Indicator L2-1 concerns whether IDMs could have sound strategies in high-end application markets. Similarly, since STM possesses a more diversified market, it is the most potential player and evaluated as inimitable.

Table 6: Evaluation Results of L2-2

	Observations	Evaluations
Samsung	1. CIS modules are deployed in low-end cellphones and cameras 2. Small portions of CIS devices are employed in automobile and game console. 3. Possess network applications of laptops and PCs 4. Applications of Video conference and security are available.	Applications do not have discrepancy, and were evaluated as valuable only.
STM	1. CIS modules are deployed in low-end cellphones and cameras 2. WDR sensors and automobile CIS are available in their product lines. 3. Cameras for laptops, game consoles and machine visions are also available. 4. Markets in China have the trend of growth these years.	Being able to launch markets in China would help STM possess first-mover advantage to gain a big market share. Therefore, STM was evaluated as inimitable.
Toshiba	1. CIS modules are deployed in low-end cellphones and cameras 2. Cameras for laptops and game consoles are available. 3. Small portions of applications are in vehicle industry. 4. Applications of video conference and security are available. 5. Network applications are seen in laptops and PCs	Applications do not have discrepancy, and were evaluated as valuable only.

Indicator L2-2 concerns whether IDMs could possess good strategies of low-end applications. Based on the observations, STM seems like to have a different market plan in China. Therefore, it is temporarily inimitable among the cases.

Table 7: Evaluation Results of indicator, L3-1

	Observations	Evaluations
Samsung	1. The R&D of second generation BIS for 1.4μm is on the way. 2. License OptiML™ Focus image solution from Tessera to leverage EDoF. 3. R&D of employing TSV to interconnect CIS and substrate is on the way. 4. License OptiML™ wafer level camera technology from Tessera. 5. License 90nm CMOS logic process from IBM.	Possess all the critical technology of CIS, and then was evaluated as inimitable.
STM	1. First user of EDoF integration technology in the market. 2. Develop 5 million pixels of CIS with TSV and apply to wafer level cameras. 3. Apply Smart Stacking™ in BSI for 300mm wafers. 4. Develop wafer level packaging with TSV for EDoF. 5. STM will license patented technology BCD8 (Bipolar-CMS-DMOS) to Bosch for them to launch R&D of highly integrated vehicle devices.	First mover of EDoF, and possess commercial IPs for their customers. STM then has a market position unable to be substituted.
Toshiba	1. Reverse engineering technology of TSV, dubbed TCV. 2. Resolution reaches 1.4 million pixels with BSI technology. 3. Chip Scale Chip Module (CSCM), dubbed Dynastron is available. 4. License OptiML™ wafer level camera technology from Tessera.	For possessing first IP of TSV and most of the necessary technologies of CIS, Toshiba then has a market position unable to be substituted.

Generating Intellectual Property (IP) is an effective strategy to gain competitive advantage. Therefore, indicator L3-1 is to see whether IDMs could develop their own strategic IPs in order to sustain their competitive advantage. Based on the observations, the critical technologies of CIS consist of BSI, WLP, TSV, EDoF, etc. Generating IPs of these technologies could help improve resolutions and functionalities of CIS. Since Samsung has the strongest R&D abilities, it was then assessed as inimitable currently.

Table 8: Evaluation Results of L3-2

	Observations	Evaluations
Samsung	The core technologies of Samsung are composed of TSV, BSI, WLP, EDoF, Wafer Level Auto Focus, and Anti-reflective coating currently.	Core technologies of CIS are well developed, but relative innovation seems a little weaker. Therefore, Samsung was evaluated as valuable.
STM	STM possesses the core technologies of TSV, BSI, WLP, EDoF, Camera Module process, high temperature Anti-reflective coating, and process of manufacturing camera lens.	Core technology innovations are carefully arranged. STM was then evaluated as rare.
Toshiba	The core technologies of STM have TSV, BSI, WLP, EDoF, Camera Module process, Wafer Level Auto Focus, High resolution cameras, and μ-lens array of CIS.	Core technology innovations are carefully arranged. Toshiba was then evaluated as rare.

Indicator 3-2 is to evaluate whether each IDM possess necessary core technologies of CIS, and could have further relative innovations. Both STM and Toshiba devote to generate innovation technologies of CIS based on their current core technologies. However, although Samsung possesses sound roadmaps of innovations, but it did not address more innovations for CIS. Therefore, it was then evaluated as valuable only. In contrast with Samsung, STM and Toshiba could employ more core innovations in CIS applications, and then were evaluated as rare.

Table 9: Evaluation Results of L3-3

	Observations	Evaluations
Samsung	1. 200mm Fab devoted to manufacture CIS. 2. 300mm Fab devoted to fabricate memory and CIS. 3. Offer 300mm fab outsourcing service to Qualcomm and Xilinx.	With possessing 300mm Fab, Samsung was evaluated as Rare.
STM	1. 200mm Fab is at-hand. 2. Cooperate with IBM to develop CMOS process of 32nm and 22nm, and 300mm wafer fabrication processes. 3. Possess 300mm Fab with NXP and Freescale. 4. Cooperate with Soitec to develop 300mm wafer level BSI technology.	With necessary facilities are all available, STM was evaluated as valuable.
Toshiba	1. 200mm Fab is at-hand. 2. Possess a 300mm fab, and some of the capacity devotes for CIS. 3. 300mm Fab devotes for Front-end process of Power Supply devices. 4. Offer mass production service for Oita Operations from 2010.	With possessing 300mm Fab, Toshiba was evaluated as Rare.

Indicator L3-3 is to see whether each IDM could possess its own 200/300mm fab in order to have an entire pilot line for future R&D. Both Samsung and Toshiba possess their own 300mm Fabs, but STM has to form strategic alliance with partners in order to have pilot lines. Therefore, STM was evaluated as valuable, but the other two are assessed as rare.

Table 10: Evaluation Results of L1

	Observations	Evaluations
Samsung	1. TSV based CIS was started in 2007. 2. Mass production of TSV was started in 2008. 3. Mass production of cameras having the functionalities of auto-focus and image stabilization was started in 2008. 4. The size of TSV based camera module is smaller than traditional one by 55%. 5. The first shipment of products with BSI technology was at the end of 2010. 6. 300mm Fab was built in 2010. 7. Mass production of BSI CMOS image sensors was started in 2010. 8. The market share of CMOS mobile sensors reached 70% in 2012.	Samsung had established clear roadmaps, and was assessed as valuable for L1 indicator.
STM	1. R&D of applying TSV in CIS was initiated in 2006. 2. Mass production of TSV based products was started in 2007. 3. Applying TSV to connect CIS with substrate was started in 2008. 4. The market share of 200mm CIS wafers was at top three in 2009. 5. High- resolution auto- focus digital camera modules were taped out in 2009. 6. Mass production of BSI CMOS image sensors was initiated in 2010. 7. 300mm production line of digital camera sensor was launched from 2010.	STM was kind of earlier mover for launching TSV, and then was evaluated as valuable.
Toshiba	1. Applying TSV in CIS was initiated in 2008. 2. 3 Mega pixels Wide- Focus sensors were taped out in 2009. 3. Applying TSV to mass producing built-in autofocus CIS of 3 Mega pixels was announced in 2009. 4. WDR image sensors were taped out in 2009. 5. 300mm fab was launched in 2010.	Toshiba’s roadmaps were full aspect, and then were evaluated as valuable as well.

Indicator L1 concerns whether IDMs could have a clear roadmap of technology specification, cost, performance of devices, and time-to-market. According to the observations, all of them do not have any difference, and were assessed as valuable under the consideration of L1.

Table 11: Evaluation Results of L2

	Observations	Evaluations
Samsung	1. There are both products of high and low resolution recorders. 2. Apply embedded cameras in laptops and PCs. 3. Video conference applications of both high and low resolutions. 4. Digital cameras, DSLRs, mobile phones of both high and low resolutions. 5. Application markets include automobiles, security, healthcare, consumption electronics, etc.	Major applications are in mobile phones and digital cameras only, which were then evaluated as valuable.
STM	1. Digital cameras, DSLRs, mobile phones of both high and low resolutions are available. 2. CIS applications in dynamic environment, especially in automobile driver assistance are available as well. 3. STM's Profile of market applications is phone camera (31%), automobile (15%), digital camera (11%), computer (14%), industrial usage (8%), and others (21%). 4. Application in healthcare markets has been at the early stage already.	Almost all the possible CIS applications had been put in STM's roadmap, where the evaluation result was inimitable.
Toshiba	1. Digital cameras, DSLR, mobile phones of both high and low resolutions are available. 2. Integrated chips of high functional systems for cell processors in PS3 game consoles are available. 3. Future application markets in the roadmap will include automobile, industrial, healthcare, consumption electronics, etc.	Major applications are in mobile phones, digital cameras and game consoles only, where the evaluation was valuable.

Indicator L2 concerns whether the IDMs of CIS could have diversified application markets. The more diversified the application market is, the more potential market share they could obtain afterwards. From the observations, STM has most diversified application markets, and then is evaluated as inimitable currently.

Table 12: Evaluation Results of L3

	Observations	Evaluations
Samsung	1. BSI will become mainstream technology after the technology node of low end mobile camera modules shifts to under 1.1μm. 2. Extra thinned silicon material and wafer level optical technology employed in BSI could help decrease cost and size. 3. Mass production service with WLP and TSV is ready to offer. 4. Extended Depth of Focus (EDoF) or wafer level auto focus technology is available. 5. License OptiML™ Focus technology from Tessera.	The resolutions of CIS of Samsung are slightly lower than the other two, but solid R&D ability makes it to be evaluated as rare.
STM	1. First user of EDoF integration technology in the market. 2. Launch R&D of micro projector, including the functionalities of auto focus, image sharpen, etc. 3. Apply Smart Stacking bonding technology in processing BSI. 4. Smaller pitch and more complicated devices could be generated with its WLP technology. 5. TSV formation technology is available. 6. Wafer level camera module technology is available.	Possessing a lot of technology innovations make STM to be a technology pioneer. STM is then evaluated as inimitable.
Toshiba	1. EDoF, digital auto focus, and wafer level auto focus are available. By applying BSI technology, the resolutions could be more than 14.6 million pixels. 2. Toshiba has extra small CIS module which could result in less wiring packaging, smaller pitches, and thinner substrates. 3. First vendor to mass produce TSV technology, dubbed Through Chip Via (TCV). 4. Apply WLP to further decrease cost and size. 5. Wafer level camera module is available. 6. License OptiML™ Focus technology from Tessera.	Since there are a lot of technology innovation and critical technology of CIS, Toshiba is then evaluated as inimitable.

Indicator L3 is to see whether IDMs could apply the advantage of technology innovation to gain more competition. Under this indicator, the perspectives of miniaturization, heterogeneous integration, R&D of technology, cost, etc., are critical concerns. Moreover, both BSI and TSV are the most critical technology to leverage the performance of CIS. From the above table, it could be seen that all the case IDMs have such technologies to launch heterogeneous integration, and apply WLP to shrinkage the size of package. On the other hand, Toshiba also employed CSCM module technology to decrease the demand of wiring package, and its products currently have the highest resolutions in the market. Similarly, STM also emphasized the technology innovation, so it developed some leading edge technologies, such as autofocus. Therefore, STM and Toshiba were evaluated as inimitable. In this indicator, the performance of Samsung is a little bit restricted, but eventually it would be more competitive with its R&D abilities, which made it evaluated as rare.

In Table 13, all the evaluations are summarized. The results of evaluations showed that STM and Toshiba could sustain their competition advantage since both of them possess similar resource strength in this study. However, although Samsung has been a pioneer IDM in the world, it did not really arrange a lot of resource in CIS industry. Therefore, the evaluations of Samsung revealed it did possess competitive advantage, but still need more resources to sustain longer in CIS application markets of 3D IC.

Table 13: Evaluation Summary

	Summary of each indicator			
	Valuable	Rare	Inimitable	Un-substitutable
Samsung	5	3	3	0
STM	5	1	2	3
Toshiba	4	2	2	3

5. Summary and Conclusions

3D IC had been a hot topic these years, and CIS is the first wave of applications. However, due to some technical issues, such as thermal dissipation, lack of proper EDA tools, poor reliabilities, etc., it still needs more time to get into mainstream application. Although CIS vendors have witnessed the potential benefits brought by 3D stacking packaging technology, a comprehensive evaluation model should be offered for them to take into account whether to adopt this emerging technology. This research proposed a hierarchical evaluation model for helping CIS vendors figure out what adaptation they should launch in order to sustain competition advantage with 3D IC concept. Resource Based Theory was also employed to review both the tangible and intangible resource in IDMs of CIS, in order to analyse the corresponding advantage generated by each resource. With the bottom- up analysis of this proposed model, the following contributions could be obtained through this research:

1. Current market situations of CIS industry employing 3D IC was disclosed in this study.
2. A hierarchical reference model for entering or enhancing CIS industry could be obtained based on the proposed model of this study.
3. A set of evaluation indicators were set up with the concept of RBT in order to be more appropriate for evaluating competition advantage.
4. Insights of developing CIS application could be obtained through the analysis process in this research.

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