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ORIGINAL ARTICLE

The implementation of SCM concepts and information technology to the photomask supply management of IC companies

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Abstract Outsourcing has been the main business operation model in the semiconductor industry worldwide. The process of ensuring the overall performance of the subcontractor is essential to a successful operation. Photomask is a major outsourcing item in the semiconductor manufacturing. Its complexity, precision, and quality requirements have become crucial for 90-nm technology node and beyond. However, the photomask outsourcing management is currently inadequate. The purpose of this paper is to propose a framework to resolve the inadequacies and enhance the photomask supply management in terms of quality, delivery, manufacturing management, and lower the risks and cost of photomask purchasing. The literature review of outsourcing, supply chain management, and information technology application has been conducted and obtained the most concerned management topics. In-depth interviews have also been performed with the experts in Taiwan's semiconductor industry to analyze the imperfection of current practice and fine-tune our proposed Internet-based supply management framework and system. Furthermore, this research has employed a real case study of a Taiwanese semiconductor manufacturing company, which is the top 5 worldwide photomask buyer, to demonstrate the procedure, cost, and benefits. The estimated benefits of the proposed framework include overall performance improvement, significant cost reductions, and timely responses between suppliers and customers. This solution can be a general framework that is able to be tailored and applied in other supply domains in the semiconductor industry or other industries.

Keyword Semiconductor · Photomask · SCM · Information Technology

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1 Introduction

In the intense business competition today, outsourcing has been a main stream in global business operation [1]. Outsourcing allows companies to pursue quality, costs, flexibility, and dependability objectives from suppliers [2]. The semiconductor industry has also evolved along with the trend and transformed the manufacturing strategy, which released many of the manufacturing steps to outsourcing subcontractors including integrated circuit (IC) design, wafer manufacturing, wafer test, and IC package. Photomask is an essential tool in IC fabrication because it reflects the circuit diagrams designed by IC designers [3]. In IC manufacturing, optical photolithography technology is used to print circuit patterns in photomask onto wafers. Therefore, the quality of photomasks directly affects the IC pattern formation on wafers. Defects or irregularities cause wafer yield loss and may even require scrapping wafers.

The circuit width in ICs has shrunk by 30% every 2 to 3 years [4]. Photomask suppliers must, therefore, meet the challenge of constantly increasing photomask precision. The photomask cost for general logic ICs increases from 1 million to 3 million US dollars when 90-nm IC fabrication technology is enhanced to 45-nm technology [5]. Prohibitive photomask cost is becoming a critical portion of the IC manufacturing cost. IC fabrication generally involves more than 30 photomasks and 300 to 400 process steps. A single defective photomask can affect all of the wafers that have gone through the IC fabrication processes. Because defect-free and on-time-delivered photomasks are critical to IC fabrication success, both IC designers and foundry operators are serious in ensuring the quality, on-time delivery, and cost of photomasks.

The merchant photomask vendors (e.g., Dai Nippon Printing Co., Ltd. (DNP), Toppan Photomasks Inc., and Photronics) supplied 68% of worldwide photomask demand in 2006 [6]. This demonstrates that most of the Integrated Device Manufacturer (IDM) (e.g., TI, Freescale, and Infineon), fabless IC design companies (e.g., Broadcom, Qualcomm, and Nvidia), wafer fabrication foundries (e.g., United Microelectronics Corp. (UMC) and Charter), and Dynamic Random Access Memory (DRAM) manufacturing companies (e.g., Powerchip and ProMos) purchase photomasks from merchant photomask vendors that cover a wide geometric range from 28 nm to 1 um. If the vendor fails to meet any requirement, quality, or delivery, the customer will suffer a tremendous loss from the time-to-market delay and affect the customer's end market in products such as PCs, cell phones, or other electronic devices.

Current practice for ensuring the quality of delivered photomasks is incoming quality inspection, which requires investment in expensive defect inspection equipment. The costs range from 10 to 30 million US dollars for each unit of equipment from our survey. If any defect is detected during the incoming inspection, the disqualified photomask must be returned to the mask manufacturer for reproduction, which delays the IC foundry manufacturing and delivery schedules and product's time-to-market. For delivery management, customers have no early information from the photomask vendors and can only wait for the final delivery result passively. These phenomena reflect that there is not a solid, real-time, and completely reliable photomask outsourcing supply management framework and system exist.

The research framework of this paper is based on literature review, interview with the experts in this industry, and a case study. This framework was utilized by Hwang, Chang, Yu, and Chang [7] in analyzing and constructing a seamless supply chain management model between wafer testing vendors and a wafer fabrication foundry (Taiwan Semiconductor Manufacturing Corp.). Therefore, this framework is suitable for our research topic. We interviewed experts of Taiwan's IC design houses and wafer foundries to analyze the issues and imperfection of current practice procedure. Then, we reviewed related literatures to create the concepts of improvement making. Through linking and integrating the academic researches and current practice in the industry, this paper proposes a seamless solution for photomask outsourcing supply management by combining current practice issues, supply chain management concepts, and information technology (IT). And we exploit a tier one semiconductor manufacturing company worldwide as a case study to demonstrate our proposal including the cost and benefit analysis.

2 Current practices and issues in photomask outsourcing management

We summarized the issues of current practices based on interviews with experts in Taiwan's semiconductor industry including fabless IC design houses, wafer fabrication foundries (e.g., UMC), and photomask vendors (e.g., DNP and Photronics). We obtained the comments from the experts and concluded that quality management and delivery management are the two most critical issues that photomask buyers are encountering.

2.1 Quality management in current practice

According to the interviews, most of the photomask buyers manage mask quality by performing incoming inspection on the delivered photomasks. This is the so-called check-based methodology. The buyers decide whether to accept or reject the photomask based on the incoming inspection result. However, this is practically too late to discover a defective photomask. The defective photomask needs to be shipped back for repair or even reproduction. The entire production schedule will consequently be delayed. The experts stated that real-time quality information is not shared during the manufacturing process between buyers and vendors. Besides, the buyers do not understand the quality status of vendors' production line as well. Therefore, buyers cannot request the vendor to make certain and timely improvements to avoid potential quality problems. Some buyers have monthly quality indices reviews with vendors based on the incoming inspection records. However, it is still a passive method because the damage and loss may have already occurred.

In addition to the inefficient quality management system, the cost is also a critical issue. The check-based quality management method requires expensive investment. The wafer foundries must invest in multiple mask inspection equipment units to ensure mask quality. According to the experts, the essential mask inspection equipment includes: low-end die-to-die/die-to-database comparison equipment (about 10 to 20 million US dollars per unit) and high-end soft defect (including die-to-die/die-to-database comparison) inspection equipment (about 30 million US dollars per unit). As IC fabrication technology continuously evolves, the minimum dimension of mask design patterns shrinks, the number of patterns increases, and the quantity of mask inspection equipment must increase accordingly and significantly.

2.2 Delivery management in current practice

From the comments of the experts, the buyers inform the delivery plan to the vendors by purchasing orders and passively wait for the delivery. Some of the buyers have daily reviews with vendors by using email to monitor the delivery and manufacturing plan. However, they cannot detect any potential delay in advance due to the fact that they cannot understand the actual production and loading status inside the vendors operation. Hence, if the vendor delays the delivery, the buyer cannot take any effective alternative solution in advance.

2.3 Summary of current management flow and issues

Figure 1 introduces the current photomask order and supply flow which was a summary from the interviews with the experts. The IC design house sends the design data to the foundry first. The foundry then sends the photomask specification and delivery request to the photomask vendor. The photomask vendor manufactures the photomasks based on customer requirements. After passing quality control (QC) procedures at the photomask vendor site, the masks are shipped to the wafer foundry. The foundry must make an incoming quality check to verify if the masks meet the specifications. If the masks meet the specification, then they will be used for wafer production. If any mask is defective, it is required to be reworked or reproduced. In most cases, IC design houses authorize foundries to manage the quality for them. We discovered some problems from the current process flow. They included inefficient communication, unshared quality and manufacturing information, high cost investment, and passive supplier management based on the traditional check-based quality management mechanism. We summarized five major problems as shown in Table 1.

3 Literature review

The literature review was conducted according to the research topic and the findings of the imperfection in current photomask supply management from the interviews of the experts in Taiwan's semiconductor industry. Through the cross-comparison of the academic researches and current issues, this paper can then propose a solid solution which can be applied to the real practice.

3.1 Outsourcing and supply chain management

Extensive researches concluded that outsourcing is a typical operation model for companies to release some of their noncore business or manufacturing processes to outside suppliers for pursuing quality, costs, flexibility, and dependability objectives [1, 2, 8, 9]. These researches pointed out that the main benefits of outsourcing were

Fig. 1 The current supply and management flow for foundry operators

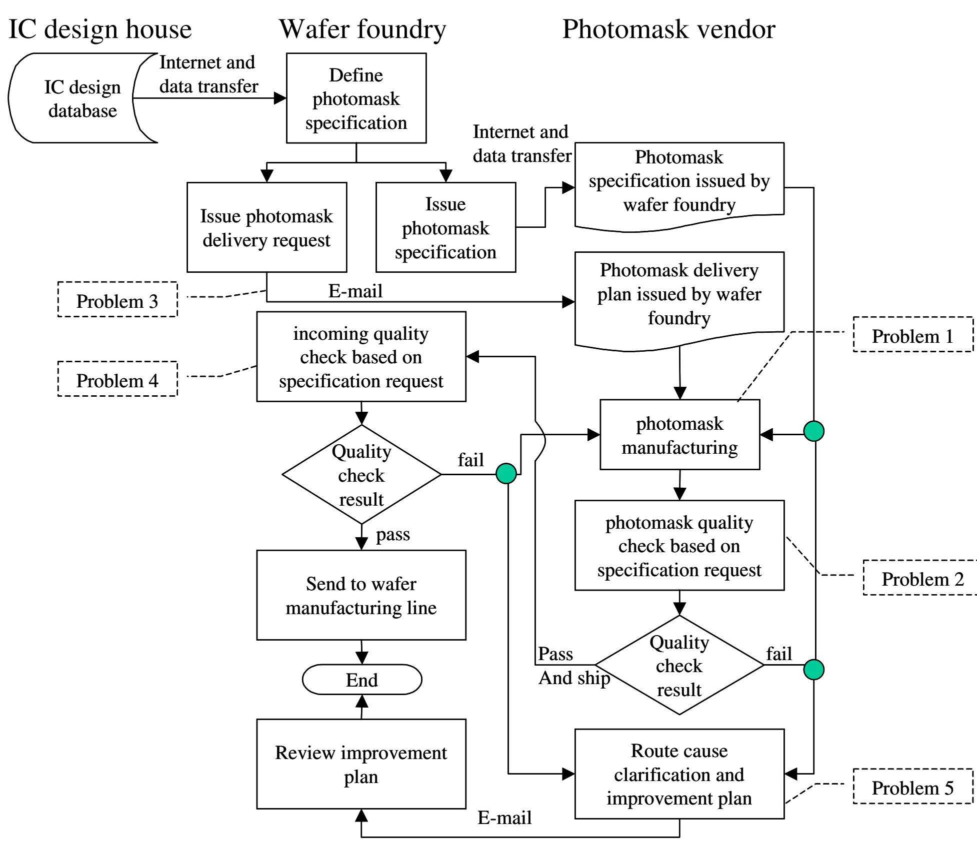

Table 1 Problem list for the current photomask supply management mechanism

Problem item	Problem description
Problem 1	Quality management and timely delivery systems did not exist. The real-time manufacturing information at the photomask vendor's site such as manufacturing process status, process flow, and load on the manufacturing line was not available to buyers. Without sharing manufacturing information, photomask buyers cannot manage their allocation plan, adjust the priority for all orders, or make necessary back up plans
Problem 2	Quality issues are not shared between the customer and vendor. The buyer is not informed of the vendor's in-line quality status because the information cannot be shared through a workable system. If any quality issue occurs in the process, the buyer will not receive timely information, as well as the vendor's overall manufacturing performance. The buyer will not be able to request effective improvement timely
Problem 3	Although the Internet is a powerful and popular tool for information sharing, most of the buyers use the Internet only for email in information transferring. The information exchanged cannot be used for systematic management and automatic communication between systems
Problem 4	It is still a traditional check-based quality management in the current practice. The photomask buyer cannot manage the in-line quality at the vendor's site. As a result, the buyer needs to conduct incoming quality checks to verify if the masks meet the specifications. The buyer cannot trust and rely on the vendor and must make double efforts to insure the quality. The defective photomask needs to be shipped back for reworking or reproducing. It is always too late for buyers to discover quality issues. Mask inspection tools are also expensive, costing $10 to $30 million dollars per set for each function. If the incoming check can be deducted, buyers can save significant cost
Problem 5	A timely system to manage the VOC and status or result of ongoing improvement projects does not exist. The buyer can only ask the vendor to provide case-by-case reports

reduced costs, improved quality of service, increased management focus on core activities, and access to new capabilities. ElMaraghy and Majety [10] indicated that a well-managed outsourcing for manufacturing possesses significant opportunities for improving profit margins and reducing cost. In the worldwide semiconductor industry, outsourcing is the main stream and the trend. The companies in this industry focus on their core competence and business since the technical and capital investment barriers are increasing, which limit them to manipulate in all segments or functions.

Because outsourcing is the main stream, it is necessary to manage all upstream vendors that provide input (directly or indirectly) to the buyers [11–15]. The outsourcing management concept has been widely adopted. However, it is necessary for the practitioners to know the most concerned items which require management. Based on the extensive literature reviews, this research has summarized the key vendor management items including supply reliability, quality, manufacturing time, and delivery. The management not only need to ensure the overall supply performance, at the same time, it also need to reduce the cost in the rapidly changing market [16–20]. The literature review has matched the concerns addressed by the experts in Taiwan's semiconductor industry with respect to the photomask supply management. Therefore, this research utilized the two indices, quality, and delivery to monitor and manage the daily operations of their suppliers; ultimately, the buyers can have a better control of the photomask manufacturing and achieve better customer satisfaction and overall performance.

3.2 Information management system for supply chain management

Choi, Kang, Chae, and Kim [21] suggested the collaboration of companies in a supply chain requires all of the enterprise elements to interact efficiently with each other in the network. Therefore, after verifying the management key items for improving the photomask supply performance, the next step is to study an efficient management method to resolve the imperfection of current communication method suggested by the experts. The information management system has been concluded as a powerful tool for supply chain management from researches [22, 23]. The academic researches above have emphasized on the importance, functionality, and benefits of utilizing information technology in the supplier or supply chain management. The major benefit of the information technology in management is improvement of the operation performance which is achieved by the real-time information sharing between upstream and downstream vendors and customers. The information technology can help the company to manage the suppliers in a flexible, dynamic, responsive, and even reconfigurable way to meet the rapid changes in the industry. Therefore, the information management system is a critically effective tool [22, 23]. The most adopted IT approaches are electronic data interchanges and Internet-based networks. There are numerous researches proposed to utilize the Internet-based information technology and management system to share all manufacturing information in the supply chain and achieve a better performance and efficiency [14, 24, 25]. Vezzetti [26] and Ali, Chen, and

Lee [27] indicated that the Internet- and web-based approaches are the most feasible hybrid solution for the information management tool. Jones, Robinson, O'Toole, and Webb [28] emphasized that new technology has enabled enterprises to do things that were not feasible before. Sari, Sen, and Kilic [29] indicated that recent developments in information technology have been relatively inexpensive, reliable, and fast to support supply chain management in real time. Consequently, companies increase their investment on information technologies and tools to improve the efficiency, quality, delivery, inventory, and overall performance in manufacturing operations.

The aforecited literature review has provided a hybrid concept to enhance the supply chain management. However, there are insufficient case studies in those researches to show how a real practical framework works and the way to evaluate the cost and potential benefits. Therefore, this research is written to make up the inadequacy and knowledge gap. Demonstration of the implementation procedure of building an IT- and Internet-based supply chain management framework has shown its capability in solving the current difficulties of seamless supply management for the photomask. Additionally, the estimated cost and potential benefits are also addressed which can provide a better understanding and reference to the readers from academic and industries.

4 Proposed photomask supply management framework and system for semiconductor industry

From the collection of imperfections in current practice through interviews, we observed that semiconductor companies were mainly focusing on a check-based methodology for the photomask supply management which was inefficient and expensive. In order to cope with this critical issue, this research proposes to develop an Internet-based outsourcing management framework and system for photomask buyers in the semiconductor industry. The estimated benefit will be illustrated in Section 5.

4.1 Introduction of the framework

The proposed management framework consists of the most concerned management items and information technology. This hybrid method can generate the most benefit for the buyers and vendors. There are three parties in this mechanism: the IC design house, wafer foundry, and photomask vendor. The information channel between these parties is the Internet. There are different subsystems in each party, including IC design database, enterprise resource planning (ERP), manufacturing management, delivery management, and quality management systems. The conceptual framework is briefly demonstrated in Fig. 2. The detail steps for constructing the framework are illustrated in the subsections.

1. Define the management information items in each subsystem

After structuring the system framework, this step is to define the items and modules that need to be managed by all subsystems. We define all items based on a literature review of the related researches and interviews with experts in Taiwan's semiconductor industry. The ERP, delivery, and quality management systems are cross-company systems that can exchange the same real-time data. The key modules and functions of these three systems are the same for both the customer and vendor sites.

(a) Photomask tooling system

The modules and functions needed in this system include IC design data, optical proximity correction, framing, and design for wafer manufacturing. The function description is listed in Table 2.

(b) ERP system

The ERP system modules and functions are related to purchasing requests. Most of the companies in semiconductor industry have an ERP system. According to the interviews, there are various related solutions such as SAP, Oracle, and other commercial software. The existing modules such as purchasing, mask specification, goods receiving, accounting, and financing are basically ready for photomask purchasing. Only some minor modifications are needed to fit the photomask purchasing demand. The modules and functions are listed in Table 3.

(c) Delivery management system

This system manages all delivery-related requests based on information from the ERP system. The subsystem is dedicated to delivery management and can obtain better efficiency than the ERP system. The delivery management module includes cycle time management, delivery forecasting, delivery abnormal alarm, delivery performance records, production loading status, and advanced shipping notice. The modules and functions are listed in Table 4.

(d) Quality management system

Quality system is the most important part of the proposed photomask supply management mechanism, which is recognized and concluded both from well-cited researches and interviews with experts in the semiconductor industry. A report of International Technology Roadmap for

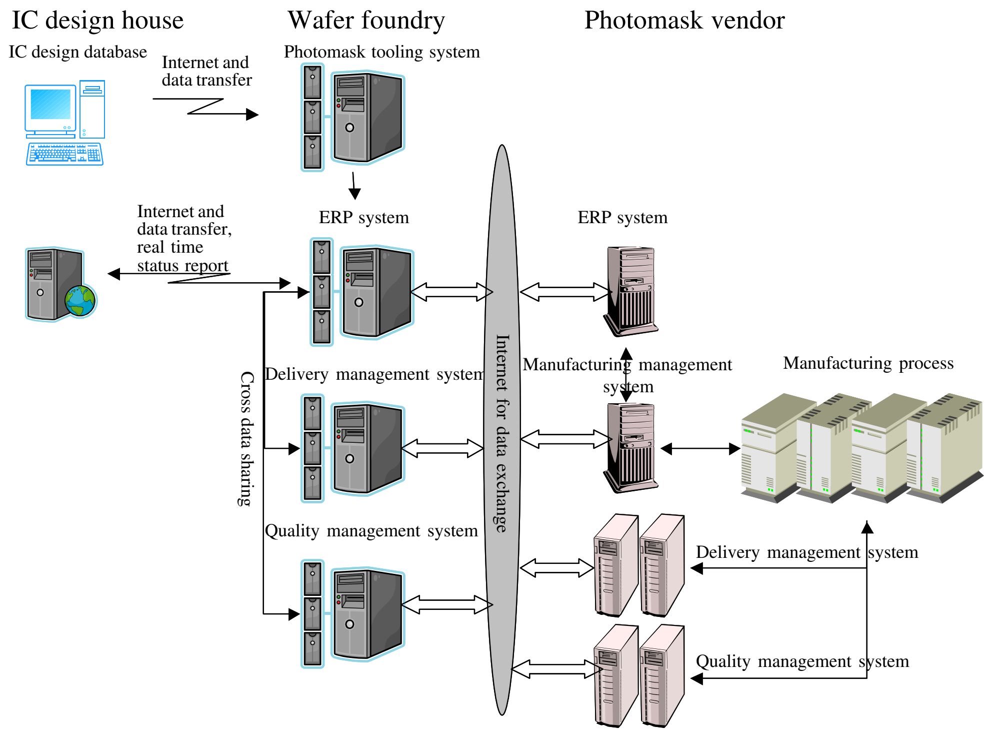

Fig. 2 The conceptual framework of the Internet-based photomask supply management mechanism

Semiconductors [30] listed the most important photomask specification items that a photomask buyer need to monitor and control. Since the statistical process control (SPC) method is highly suggested for quality management [31–35], we utilized this method to monitor and control the quality in manufacturing processes. Moreover, this research collected many suggested management items from the interviews with the experts in the industry. The key items we summarized include QC inspection, in-line SPC management, line yield management, quality indices management, voice of the customer (VOC) management, and improvement status management. The modules and functions are listed in Table 5.

(e) Manufacturing management system

The main purpose of this subsystem is to manage production procedures including the production plan, production control, and productivity optimization. Thus, better manufacturing efficiency can be obtained. After referring to the photomask vendors' current practices and collected comments from the experts, this research suggests to construct the following modules: production control (scheduling), equipment operation management, manufacturing performance management, production stability management, and production line loading management. The modules and functions are listed in Table 6.

2. Information exchange flow

The proposed photomask supply management framework is focused on using information technology and the Internet to enhance supply performance. Therefore, after the framework has been set up, the information exchange flow is another key success factor affecting this proposed framework and system. The information exchange items

Table 2 Module and function descriptions of the photomask tooling system

Module	Function description
IC design data	Receiving and storing customer IC design data. Wafer foundry operators will manufacture wafers according to the received data
Optical proximity correction	Making IC design shaping to optimize lithography printing results on wafers
Frame making	Creating the optical IC placement on the mask in order to make most ICs on a wafer
Design for wafer manufacturing	Placing the necessary process items on the mask to fulfill wafer process demand, e.g., test keys, scribe lines, dummy patterns, test patterns, and design rule check

Table 3 Module and function descriptions of the ERP system

Module	Function description
Purchasing	This module manages purchasing details from the requests including photomask specification, price, quantity, request delivery date, payment terms, trade terms, and other business-related information. The purchasing order information will be sent to the vendor and receive vendor's confirmation through internet
Mask specification	The tooling system will provide mask specifications to the ERP system and the purchasing orders accordingly
Goods receiving	Generating the goods receiving records.
Accounting	Handling account process based on the purchase order deals and goods receiving records
Finance	Handling payment process based on the purchase order deals and goods receiving records

should be flowed seamlessly within the whole framework. The proposed information exchange flow and contents among the related systems are briefly shown in Fig. 3.

The new supply and management flow with the proposed approaches are shown in Fig. 4. The figure shows not only the current supply flow and management mechanism, but also the corresponding proposed subsystems. This figure can provide a comparison of current practice and proposed improvement.

5 Costs and benefits

5.1 Costs

According to the result from the wafer foundry experts in Taiwan's semiconductor industry, the cost of developing the management framework and system for one vendor and one customer is estimated at 410K US dollars. This includes the software of manufacturing management, delivery management, quality management, computing servers, the Internet leasing, and labor implementation service. If the customer wants to extend this mechanism from one vendor to another vendor, then the cost will increase by 170K US dollars per additional vendor site because it is not necessary for the customer to invest in a duplicated system and Internet. This can help the customer to benefit from economic scale. As we can expect that 410K US dollars is not a minor investment for many small and medium size IC design houses, therefore, the most efficient approach for them is to empower wafer foundries to manage the photomask supply performance. These IC design houses can use Internet browser technology to inquire the status from the wafer foundries instead of invest the entire system themselves. This approach can prevent repeated investment and make the wafer foundries more willing to invest in this system to provide a better service to IC design houses. The estimated cost will only be 8,000 US dollars for each individual IC design house which can save significant cost for IC design houses. Not only the small- and medium-sized IC design houses, the large-scale IC design houses can also consider this concept for obtaining the best combination of cost and benefit. The following Table 7 shows the itemized cost breakdown:

Table 4 Module and function descriptions of the delivery management system

Module	Function description
Cycle time management	This system manages each product's cycle time in each process. Therefore, the whole process can be managed to achieve the delivery target
Delivery forecasting	According to the manufacturing plan and cycle time information, this system can forecast the planned delivery schedule to both vendors and customers. Both parties can decide if it is necessary to adjust the manufacturing plan
Delivery abnormal alarm	The function is to notify both the vendors and customers if there is any abnormal alarm based on current process status, accumulated cycle time, and delivery forecasting. This notice enables both vendors and customers to take necessary actions to catch up the schedule
Delivery performance records	This module collects all cycle time and delivery records, and thus, it can provide cycle time and delivery performance information for analysis. Through the analysis, it can help to find out the root cause and take improvement actions accordingly
Production loading status	The manufacturing management system at the vendor site can provide manufacturing information such as work-in-process status and backlog order status. This module can calculate the production load status based on this information. This function can help the vendor to control their order priority. The customer can adjust the allocation plan to prevent potential delay risk
Advanced shipping notice	This module can provide advanced shipping notice to the logistic departments of both parties. Therefore, the logistic departments can prepare shipping transportation and custom declaration for exporting and importing

Table 5 Module and function descriptions of the quality management system

Module	Function description
QC inspection	This is the typical quality management system module. This module sets all specification items. All products are checked according to the specification. All results need are managed and delivered to the other related modules or subsystems as required
In-line SPC management	This module monitors and controls manufacturing quality. This module helps both manufacturers and customers to check the quality results from each process present the timely quality status of each production procedure. This achieves early notification for potential quality issues. The information provided by this module is used for further improvement or taking necessary timely solutions
Line yield management	The line yield stability is related to quality performance and cost. The higher the line yield is, the higher the productivity can be generated and also lower the rework cost. This module monitors and controls the overall production line yield. Combined with the in-line SPC module information, it also helps both parties to identify process steps that have abnormal situations. Consequently, they can take necessary action accordingly
Quality indices management	The quality indices management concept is the same as the key performance index. Both vendors and customers can set up key quality indices in the module such as reject rate, defect density, and statistical records on each specification item. Combined with information from other modules, both parties can use this module to verify the effect, trend, and contribution of each improvement action
VOC management	This module helps collect the voice of the customer. The related department, which is responsible for this case, can input their follow up status in this module. The customer can trace and manage a vendor's formal reply using the information from this module through the Internet, unlike the traditional fragmentary emails and documents. This completed database provides sufficient records and information for further analysis and continuous improvement
Improvement status management	An improvement plan is always requested after some quality issue has occurred. Through this module vendors can update their current improvement status for each case. The customers can inquire about the timely status information and report from this module through the Internet. This database can be extended as a knowledge management tool for both parties

5.2 Benefits

This research concluded the benefit of the proposed Internet-based supply management system is obtained from two perceptions: the buyers/vendors and the whole photomask industry. Although some benefits cannot be clearly or reliably translated into financial figures, the benefit simulation is still useful in evaluating the investment of a new management system or tool [20]. Therefore, this research still suggests that the financial cost and benefit comparison can be a referenced quantitative method for assessing the implementation of this solution.

The benefits this proposed framework will generate are numerous, significant, tangible (from dollar viewpoint), and intangible. For the buyers and vendors, the primary expected benefits from the proposed framework are the reduced management efforts, cycle time and quality check cost, increasing manufacturing and delivery efficiency,

Table 6 Module and function descriptions of the manufacturing management system

Module	Function description
Production control (scheduling)	The purpose is to make an optimized arrangement for all products that need to be manufactured in the production line based on the manufacturing procedure and delivery request. Both parties can set up indices to analyze production performance. These indices include manufacturing cycle time, hit rate, abnormal rate, etc
Equipment operation management	Photomask is an industry requiring high investment, the greatest investment, and cost are the manufacturing equipment. To optimize the equipment productivity and thus, lower the unit cost of fixed assets, this module provides operation management functions including equipment utilization, up time, through put, mean time between failure, mean time between repair, and etc. Vendors can monitor the performance of each equipment and take the necessary improvement actions
Manufacturing performance management	This function manages manufacturing performance by analyzing the indices provided by the production control and equipment operation management modules. Both parties can set up targets for all indices and compare the differences for all items
Production stability management	This function maintains production stability because the frequent and huge variance in production procedures will cause extra cost and human resource effort. Both parties can set up indices, such as the average production productivity, manufacturing, variance in production procedures, and equipment operations
Production line loading management	This function analyzes the work-in-process and backlog sales orders and provides production line load information. Vendors can provide backup solutions to customers in advance if the forecast load will be high. Customers can adjust their allocation based on the load information

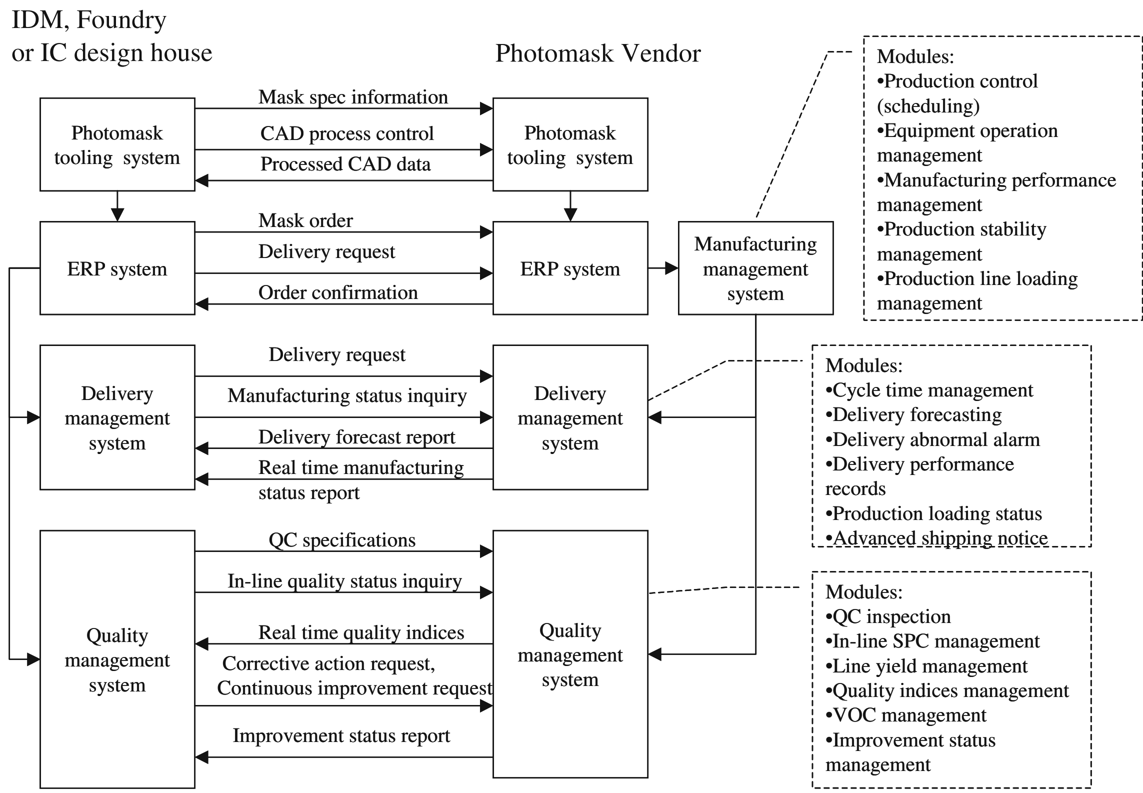

Fig. 3 The conceptual structure of the proposed Internet-based photomask supply management mechanism

Fig. 4 The proposed mechanism compared with current supply and management flow

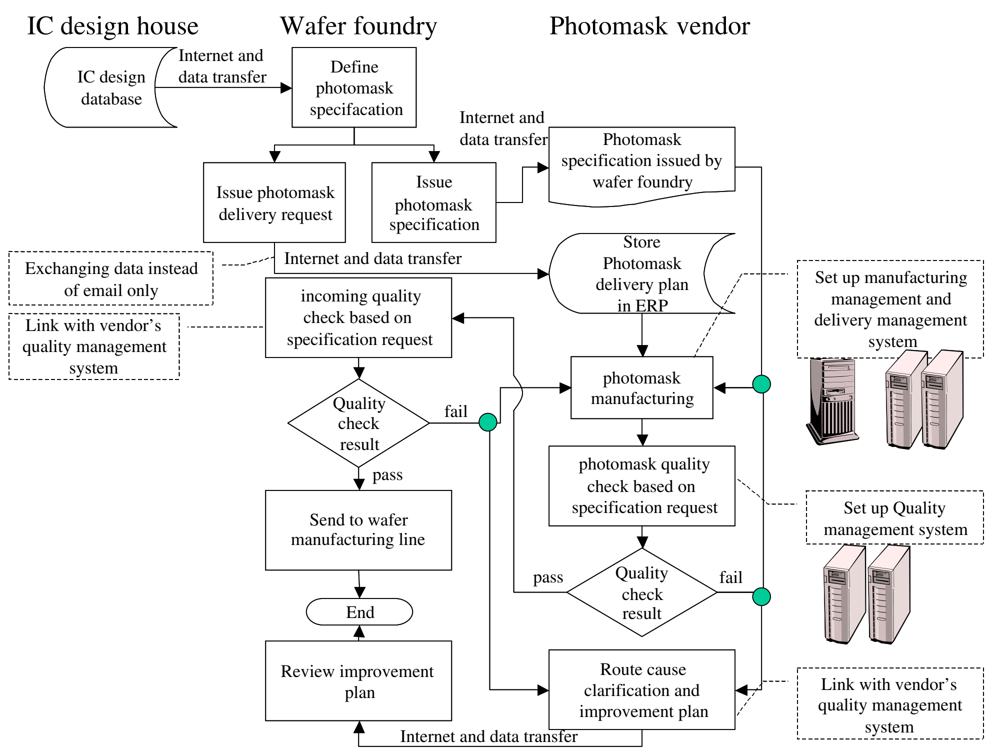

Table 7 Cost breakdown for mask manufacturer

Item	Estimated quantity	Estimated total cost (USD) for one vendor and one customer	Estimated total cost (USD) for extending to another vendor by the same customer	Estimated total cost (USD) for each IC design house to set up a system for report inquiry only
Manufacturing management software	2	$ 100,000	$ 50,000	$ 3,000
Delivery management software	2	$ 50,000	$ 20,000	$ 0
Quality management software	2	$ 50,000	$ 20,000	$ 0
Server	10	$ 100,000	$ 40,000	$ 0
Internet communications link	1	$ 10,000	$ 0	$ 0
Manpower (both external and internal) for system implementation	10	$ 100,000	$ 40,000	$ 5,000
Total cost (USD)		$ 410,000	$ 170,000	$ 8,000

timely information, and better overall performance. The expected business benefits to the photomask outsourcing management are summarized below:

- Timely photomask manufacturing information exchange can enable photomask vendors and customers to manage and control the production status and make necessary production plan adjustments to achieve customer requests from the information exchange. Customers will also have better planning and schedule control from this system.
- Timely quality information sharing will enable customers to understand their mask quality in real time. The customers can, thus, make quality management decisions extending to the vendor site instead of passive incoming quality checks. This will enable customers to have better quality management of their suppliers and improve the quality of the photomasks.
- The in-line quality status of the photomask vendors can be monitored by the customers in real time. The customers can take appropriate actions to solve issues with vendors efficiently. This enables both vendors and customers to lower the potential quality risk and money loss. Quality improvement plans can be conducted after discovering quality issues accordingly. The vendor's quality can, thus, be continuously improved.
- The overall production performance improvement plan can be conducted based on the collected data and information from this system.
- Reduce the communication time, cost, and process flow.
- Reduce human and paper work in the process flow.
- Timely status tracking and reporting of manufacturing schedule, delivery, quality, and improvement status.

To have better and clearer understandings of the tangible benefits in terms of money, this research exploited a real company to simulate the estimated cost and benefit below as a reference. Due to the business confidential concerns and the nondisclosure agreement (NDA) restriction, this research can only obtain some reference numbers from photomask vendors. They suggested to assume the photomask outsourcing amount of one of the worldwide leading wafer foundry companies (we hereby address it as company A due to NDA restriction) was 230 million US dollars in 2007 (the number was adjusted by photomask companies due to NDA restriction). If company A implements this

Table 8 The cost and benefit comparison

Item	Estimated cost (USD) for company A
Basic system of photomask supply management system (between company A and one vendor)	$ 410,000
Extend the supply management system to another three vendors	$ 510,000
Total invested cost (USD)	$ 920,000
Cost saving by reducing rejection rate from 0.13% to 0.026%	$ 239,200 per year
Cost saving by reducing the investment for one set of inspection equipment	$ 10,000,000
Total benefit for the first year cost saving (USD) including rejection and investment reduction	$ 9,319,200
Payback time for the investment based on reducing rejection rate only	4 years

system with four photomask suppliers, the cost will be 920K US dollars (410K+170K×3). According to the statistics from Mask Industry Assessment: 2006 [6], the average mask rejection rate in the industry was 0.13%. Hence, company A can save the cost for repairing or reproduction if it reduces the reject rate from 0.13% to 0.026%, resulting in an estimate of 239.2K US dollars per year. The original rejection rate for the photomasks shipped to company A was much higher than average because company A's product mix was in more advanced technology nodes which meant more difficult in manufacturing. The payback time for this system will be roughly less than 5 years. In addition, company A may also reduce their investment for incoming quality check if the quality management system can be synchronized and aligned between vendors and company A. At least one basic inspection machine can be reduced, which results in a 10 million US dollars cost saving according to the comment stated by the experts. This contributes significantly to the cost reduction effect. The summary and comparison are listed in Table 8. Although the numbers listed above are based on an assumption and are not very precise due to confidential issues, the company can evaluate the real cost and benefits based on the proposed mechanism and evaluation procedures, which is the main purpose of this research.

For the entire photomask industry, we can also estimate the financial benefits according to the reduction in the photomask rejection rate. The improvement can also increase productivity and unit cost based on the existing manufacturing cost structure. According to the statistics from Mask Industry Assessment: 2006 [6], the average mask rejection rate in the industry was 0.13%. If the mask rejection rate can be reduced by 80% by implementing this photomask supply management system, the average mask rejection rate in the industry could come down to 0.026%. According to Gartner Dataquest report [36], the photomask global market size is 2,883 million US dollars. And according to the survey of Grenon and Hector [37] and Shelden and Marmillion [6], the market share of merchant mask shops in year 2006 was 68%, equivalent to 1,960 million US dollars. Hence, the savings to the global mask manufacturers is estimated to be around 2 million US dollars per year. The cycle time delay due to a mask reproduction is estimated to be from 4.8 to 15.1 days [6]. If the average mask rejection rate in the industry could drop from 0.13% to 0.026%, then the cycle time delay due to mask reproduction can be reduced by 80%.

From the analysis and simulation above, there are numerous positive, significant, and far-reaching benefits from the implementation of the proposed photomask supply management system, not only to the buyers and vendors, but also to the entire photomask industry. These simulation and expected benefits were also be concurred by the experts of Taiwan's semiconductor industry from the second interview, which made the whole proposal more convincing and practical.

6 Conclusions

While the competition in the worldwide semiconductor industry increases year by year, improving the overall supply performance is an essential issue. This research interviewed the experts of Taiwan's semiconductor industry and observed the imperfection management mechanism of photomask supply. After the literature review for the collected valuable comments from the experts, this research concluded that the advanced Internet-based supply management system is the most cost efficient approach for improving the supply competence of photomasks in the semiconductor industry. The proposed Internet-based photomask supply management framework and system can help IC foundry in terms of quality improvement, cost reduction, manufacturing cycle time reduction, efficiency enhancement, and ultimately, provide a better supply performance overall. There are numerous tangible and intangible benefits from the proposed management system listed as following: The quality improvement can be obtained by a timely quality management function. The proposed system enables semiconductor companies to extend their quality management to vendors instead of passive check-based and result-oriented management method. In terms of the cost reduction, it can be achieved by increasing the supply quality of photomasks, reducing mask inspection equipment investment and rejection rate. In addition, the detailed and real-time monitoring of vendors' manufacturing procedures and status can also effectively enhance their overall manufacturing performance. The whole analytical information from the system can further enable the buyers to make vendor performance assessment and thus, set up different procurement strategies or improvement requirements accordingly. Another finding through this research process is that IC design houses should develop a closer relationship with wafer foundries and leverage their resources instead of spending twice the efforts to improve the performance in the same supply chain. IC design houses are suggested to empower wafer foundry operators for the overall outsourcing management which is more cost efficient. This proposed solution is particularly feasible for semiconductor companies due to the in-depth and specific case study. But it can be modified by a company in different supply domains and industries to enhance the outsourcing and supply management.

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