Fujitsu HDD (Hard Disk Drive) Defect

【July 2002, HDD defect since summer 2002, in personal computers or servers 】

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Fujitsu internal Hard Disk Drive (HDD) for personal computers and servers failed at a high rate. Under conditions of high temperature and humidity, terminals within the HDD controller LSI package (produced by another vendor) shorted after a half to one year of use of the HDDs. The short circuit between these terminals was the sealant of the package, which contained red phosphorus made by Sumitomo Bakelite Co. Sumitomo Bakelite Co., who provided the sealant, defended itself stating they used material certified by the packaging company. It developed into a legal dispute regarding who would take responsibility. Free replacements and other corrective actions cost around 10 billion yen.

1. Event

The problem in a Hard Disk Drive (HDD) for personal computers made by Fujitsu occurred after a half year to a year of use. The defect rate of 0.8% was higher than usual by more than two digits.

The failures occurred especially under the condition of high temperature and humidity where the internal pins of the HDD controller LSI package (produced by another vendor) shorted.

Manufacturers started to receive complaints from their customers about failing drives from the summer of 2000. IC manufacturers and PC set makers also received numbers of reports of the same nature in 2001.

2. Course

Manufacturers started to receive complaints from their customers about failing drives from the summer of 2000. Equipment and IC manufacturers also received numbers of reports on the same type of problem by 2001.

Fujitsu officially admitted on July 2002 that its certain products contained defective chips, and replaced such devices without charge for manufacturers of personal computers. The cost of recalls and replacing faulty disk drives were estimated to be more than 10 billion yen.

Fujitsu claimed that its certain hard drive products contained semiconductor devices defective in a certain epoxy-molding compound manufactured by Sumitomo Bakelite, and high-temperature and humidity caused a short circuit in the controller chip, rendering Fujitsu disk drive products inoperable.

The controller chips of the failed Fujitsu hard drives were supplied by Cirrus Logic Inc, a fabless semiconductor company in the U.S., which outsourced IC packaging to a Korean packaging company Amkor Technology. The faulty encapsulation resins manufactured by Sumitomo Bakelite caused failures in Fujitsu devices through two intervening semiconductor companies. The semiconductor industry's trend toward outsourcing resulted in the unusually high failure rates in products.

The failures due to faulty encapsulation resins started to surface in the summer of 2000 with Fujitsu hard disk drives. Products of other equipment and IC manufacturers followed Fujitsu drives, and many problems of the same type were reported in 2001. By May 2002, this mass chip failure had already become a huge issue in the U.S. According to the research conducted by the Computer Aided Life Cycle Engineering (CALCE) Electronic Products and Systems Center (an entity in the University of Maryland whose researches are driven by more than 50 industrial partners in electronics, aviation, automotive, semiconductor, computer and telecommunication who make up the CALCE Consortium), failures occurred in devices within 6 to 12 month of operation, and the failure rate was significantly higher than normal, making up almost 1% of the production volume. Originally the issue was thought to be affecting only hard disk drives, but similar defects have begun appearing in a range of other equipment including cable set-top boxes, computer mainboards, IC test systems and industrial machinery. While equipment and IC manufacturers negotiate with Sumitomo Bakelite over possible resolutions, some including Cirrus Logic filed third party claims against Amkor Technology as being the company that recommended and sold them the goods that allegedly failed, Amkor in turn have made a claim against Sumitomo Bakelite, the company that sold the alleged defective goods to Amkor.

Advantest Corp of Japan, a semiconductor testing device manufacturer, experienced problems very similar to Fujitsu's hard disk drive troubles in its analog IC test systems. Since the fall of 2000, Advantest started using semiconductor materials supplied by a U.S. IC company to manufacture its new model of IC test systems. The systems started failing at an unusually high rate, almost 1% of the production volume (150 times the normal rate) in 2001 during hot and humid summer days. The analysis pointed out defective epoxy-molding compound and Advantest received compensation from the semiconductor company.

The primary cause of the IC failures in both Fujitsu and Advantest products was the EME-U series of red phosphorus containing epoxy-molding compounds manufactured by Sumitomo Bakelite who has the largest market share in the world in the IC encapsulating materials. The catch was using inorganic phosphorus in place for the conventional material that produced toxic gas when combusted would better preserve the environment. The test by Advantest, however, showed that the poor quality of the inorganic phosphorus

led to the troubles under high temperature and high humidity.

Sumitomo Bakelite completed development of the EME-U series of resins in 1995, and initiated their sample shipping and mass production in June 1996. After receiving complaints from customers in May/June 2001 that the EME-U series resins were causing numbers of IC failures, Sumitomo Bakelite opened a support center in June and informed its customers in August 2001 that it would discontinue the EME-U series of resins. The scheduled end of the EME-U series production in November, within 3 months after the notification to customers, was postponed to July 2002 due to persistent demand among customers for the EME-U series of resins. The total shipment of the EME-U series to 13 customers worldwide reached approximately 1,000 tons by July 2002 when its production was halted. Note that this shipped volume only accounts for less than 1% of the total production volume.

While equipment and IC manufacturers reported unusually high failure rate in their products that contain chips using the EME-U series of resins, Sumitomo Bakelite's pre-shipment inspections gave a defect rate of several 10s of ppm from a sample of about 1,000 tons. Sumitomo Bakelite did not deny that the resin caused spread of encapsulation-related problems to various types of equipment and ICs; however, it admitted no liability, claiming that no through investigation had been conducted to rule out all of other possible causes. Sumitomo Bakelite claims that the customers' specification for product delivery had only 7-pages describing generic reliability tests, physical and chemical characteristics of the resin. No description was found about the conditions of use. Sumitomo Bakelite denied the allegations against it for rampant failures in equipment and ICs, claiming that encapsulation-related problems occurred in products of only limited numbers of Sumitomo Bakelite customers, and the cause of device and chip failures was not only the EME-U series of resins but also other numerous factors combined.

Setting the conflict between companies aside, consumer's concerns would be whether similar malfunctions would spread to other electronic products. The entire volume of shipments from the start to the end of sales of this sealant is said to be 1,000 tons, and it is less than 1% of all sealant that Sumitomo Bakelite had shipped during the same period. Dr. Hillman from CALCE, however, warns that the machinery equipped with the semiconductor with this sealant cover a wide range from the armed forces to communications and the aviation industry, that there are probably companies which have not tested their products and have not noticed the problem, and that the influence may possibly spread in the future.

3. Cause

(1) Direct Cause of malfunction (technical cause)

The cause was a short circuit between pins by migration (cf. note) of Ag that was a

material of the pins in the LSI package. The sealant of the LSI that had caused the malfunction was "EME-U" made by Sumitomo Bakelite who had the top share in the global market, and EME-U was a sealant, which used inorganic phosphorus instead of the conventional material that generated strong toxic gas when combusted. Red phosphorus, chemically stable compared to other allotropes, was used as the flame retardant, and moreover it was coated by $Al(OH)_3$ to prevent chemical reaction of the phosphorus. Poor quality of the red phosphorus or the coating in this case produced phosphoric acid from a reaction with water in the package under high temperatures and humidity. The phosphoric acid, water, and electric field induced by electric current through the pins, dissolved the pin material Ag that then migrated to other pins (Figure 1). As a result, the pins were short-circuited.

Note) Migration

The phenomenon that metal or compound deposit is produced by metal ions moving from one metal electrode to the other when the voltage is supplied to the PCB under high humidity.

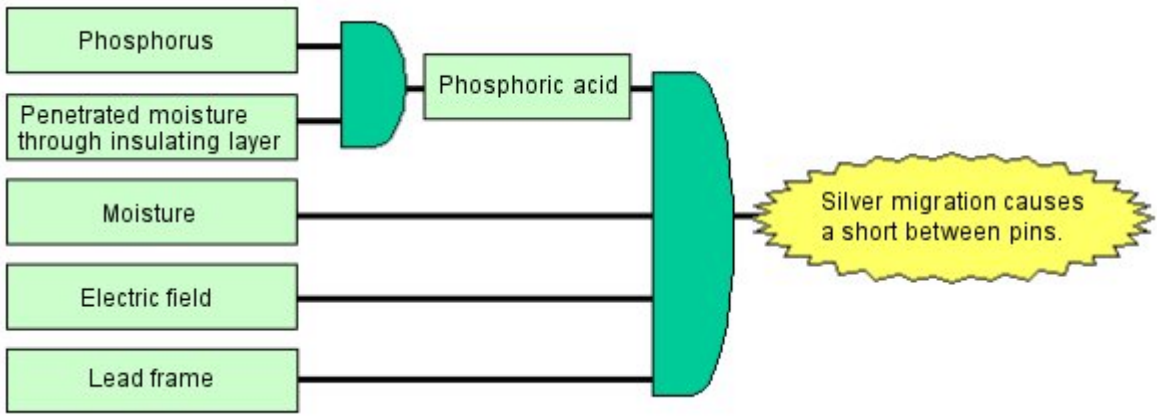

Figure 1　Mechanism of unexpected short circuit between pins

(2) Indirect Cause of Malfunction (Organizational/Social Cause)

Outsourcing of IC manufacturing processes made it difficult to identify the liable party for product failures.

(As a result, LSIs were placed in the machines without verifying their reliability.)

The semiconductor industry recognizes outsourcing as a cost-effective solution, and many IC manufacturers routinely employ outsourcing technologies and supply chain models. This trend worked the other way this time and made it difficult to isolate the contributing factors, which then caused the wide spread of IC failures across the industry. Device quality or product reliability issues commonly occur in outsourcing to the third-party silicon foundries, fabless, IC packaging and assembly firms due to their lack of standards

or technological weakness, which are rarely observed among integrated device manufacturers (IDMs).

The packaging industry and fables manufacturers, actively pursuing outsourcing, pushed the use of phosphorus encapsulating material. The Japanese IDMs had evaluated phosphorus-based flame retardants; however, their reactive characteristics in the presence of humidity and past experiences in metal migration issues found in phosphorus silicate glass (PSG) film turned many away from implementing them in their products. Fabless, IC packaging and assembly firms originated so IDMs can outsource part of their work, specifically LSI design, wafer processing and packaging. In the beginning of such trend, IDMs were still responsible for overall chip reliability, however, as outsourcing progressed, subcontractors turned capable of building chips themselves without the IDMs. Then the packaging companies or fables would then be liable for the testing and warranty. These companies, which used to take responsibility for single processes, lacked the technology and experience for the reliability of the overall performance of chips. IDMs used to be liable for the overall reliability, however, outsourcing spread out not just the processing but also the responsibilities as well (Figure 2). Materials suppliers, packaging companies, semiconductor manufacturers, or the end product manufacturer only have the information about their own processes and the quality chain is broken. At the end, the responsibility for the overall reliability was dispersed.

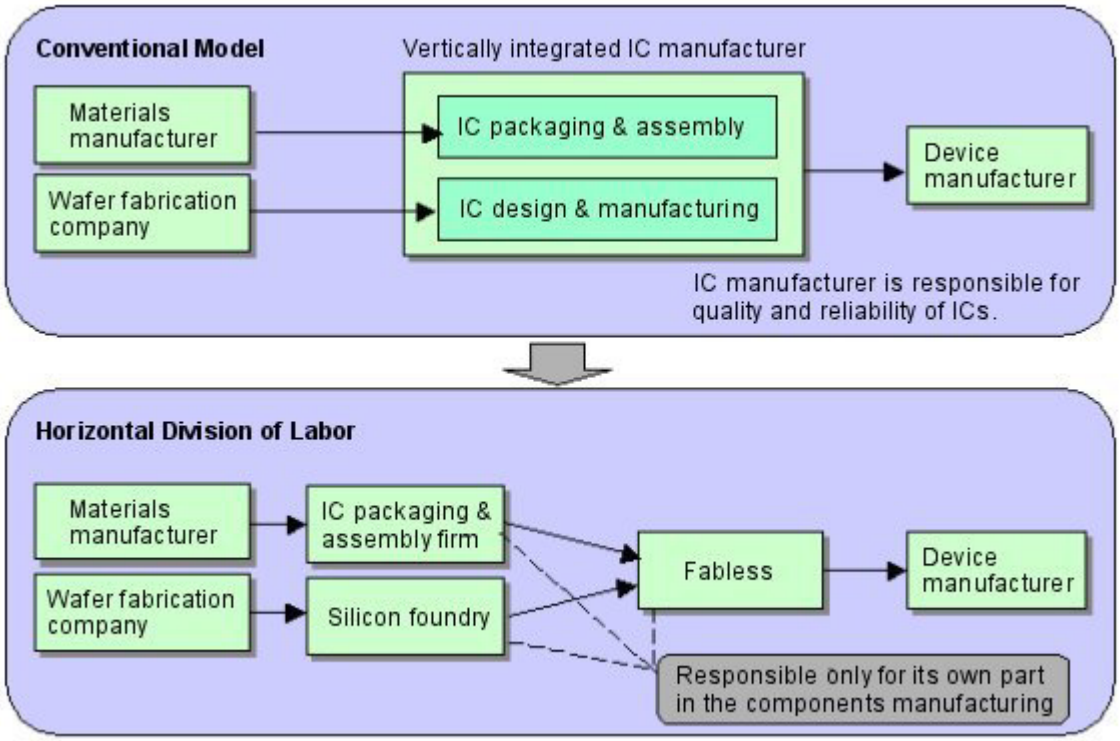

Figure 2. Difference between Conventional Model and Horizontal Division of Labor

4. Immediate Action

(1) Device manufacturers and IC manufacturers checked their products and stopped the use of

epoxy-molding compounds containing red phosphorus.

(2) After receiving complaints from customers in May/June 2001 that the EME-U series resins were causing numbers of IC failures, Sumitomo Bakelite opened a support center in June and started its own investigation on the cause of failures.

In August 2001, a manufacturer announced its decision to discontinue the use of red phosphorus in the epoxy sealant.

Sumitomo Bakelite informed its customers on its decision to discontinue the use of this resin to switch to an alternative flame retardant to red phosphorus. The new flame retardant system was fully implemented by the end of July 2002.

5. Countermeasure

(1) Do not use the sealant containing phosphorus (P) in packages.

(2) Develop reliability chains involving material suppliers, IC packaging and assembly firms, semiconductor manufacturers and the end product manufacturers.

(3) Actions were taken to prevent recurrence of failures and ensure reliability of components in complicated IC manufacturing outsourcing.

- Intervention of third-party auditors

  Certified third-party auditors were introduced to outsourcing of IC manufacturing (Figure 3a). They test reliability of material systems and ICs to ensure that they are properly qualified for lifetime requirements of the device manufacturers.

- LSI vendors with the sole mission of assuring reliability

  LSI manufacturers with advanced technology in reliability and quality (Figure 3b), will take full responsibility about the overall reliability of chips.

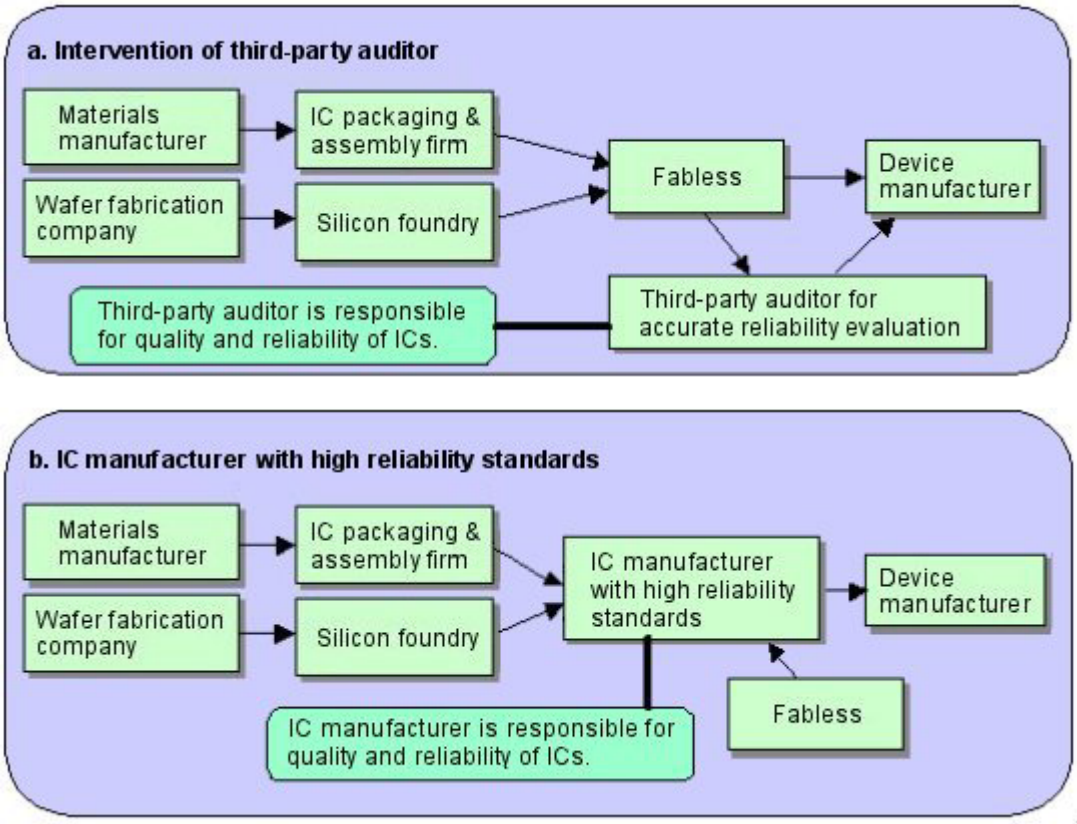

Figure 3. Reliability Assurance in Outsourcing

6. Summary

The encapsulation-related problem found in Fujitsu hard disk drives exerted a large-scale influence on the high-reliability electronics industry. Similar problems with package encapsulation resins may surface across industries. The incident force the industries to recognize the importance of components' reliability, while it revealed the shortcomings of outsourcing. The Fujitsu device failures were caused by reformulation of the epoxy mould compound containing red phosphorus used in the ICs. The cause being one of the material led to propagating the issue to the entire electronic device industry. The reliability of one of the base parts, LSI, has started to shake. The trend towards outsourcing is blurring where the responsibility lies about reliability, and accelerated technology for finer processes is leaving the evaluation and analysis parts behind.

Before outsourcing was popular, computer manufacturers developed ICs and components for their products. They also purchased materials from established materials manufacturers, to whom they provided detailed specifications on their final products. The outsourcing trend has now broken the chain of quality. Quality and reliability of the final products became difficult to maintain as production process is divided among numbers of specialized firms. It is critical for the industry to establish the quality and reliability chain which can be implemented by all firms involved in device manufacturing, including

material manufacturers, IC packaging and assembly firms, semiconductor manufacturers and the device manufacturer.

Intervention of certified third-party auditors will help assuring components' compliance to such industry standards.

This incident was a wakeup call to remind the industry that managing manufacturing costs is not all that matters and manufacturers must rethink their supply chain models and technologies on the basis of products' reliability.

7. Knowledge

(1) Metal migrate by phosphorus (P), water and electric field.
(2) Scrupulous attention is necessary to employ phosphorus (P) in an LSI package.
(3) Reliability of a semiconductor product deteriorates due to outsourcing processes in the semiconductor industry.
(4) Chain of quality and reliability and their implementation are required in all firms involved in device manufacturing, including material manufacturers, IC packaging and assembly firms, semiconductor manufacturers and the device manufacturer.
(5) Intervention of certified third-party auditors is effective to ensure components' compliance to prevailing industry standards, which ultimately ensure reliability of the final products.

8. Background

A decline in reliability resulted from less awareness and poor technical capability for reliability of the whole LSI industry. In addition, since low cost, shorter product development cycle, or shipment have given priorities due to the greater competition among LSI manufacturers, they are short in the budget to invest in reliability or quality control to add such staff as reliability engineers for quality control. Reliability, including the number of failure analysis engineers, within each LSI company is decreasing and those engineers are aging. This causes a decline in the reliability while its evaluation turns more difficult due to the accelerated miniaturization of LSIs. Insufficient time to evaluate reliability and the outdated evaluation technology are blamed for the decline of reliability of LSIs. Efforts to shorten the evaluation time have led to relying on simulation results of other devices similar the one that should be tested. There are cases where such data would not match and such corner-cutting would cause failures. The evaluation technology has lagged far behind the accelerated miniaturization.

In addition, in the LSI industry, supply chains in the electronics industry complexly divided into outsourcing among sealant manufacturers, packaging manufacturers, LSI manufacturers, HDD manufacturers, and PC manufacturers. The problematic package

sealant material was shipped in a total of 1,000 tons, which can roughly count to 1 billion LSIs. LSIs for HDD are only one small part, and failure cases has also been reported in LSIs for set top boxes for cable television, LSIs mounted on PC main boards, or IC inside LSI testers. There is a risk that the problem will further spread to other electronic products in the future.

<References>

[1] LSI “A Reliability Crisis”: Nikkei Micro Device, November 2002, pp64-71

[2] “Fujitsu HDD defect, flow in the material manufactured by Sumitomo Bakelite”: Nikkei Business, September 30, 2002, pp6-7 JiryuChoryu

[3] A short circuit between pins occurs frequently in a LSI package, complaint continued, a lawsuit case”: Nikkei Micro Device, September 2002