**Korea-Japan Trade Dispute**

In July 2019, the Japanese government changed the export policy. The new rule requires exporters of three different types of chemicals to obtain license per each shipment, which may take up to 90 days. Since these items are indispensable inputs of Korea’s key industries, it has been said that the policy is a reaction of the Japanese government to the Korean supreme court’s judge that private parties have claims for forced labor in Japanese private companies during World War II. The Japanese government has not been explicit about the background of the policy but kept warning that it will take appropriate actions if the Korean government tries to override the Treaty on Basic Relations between Japan and the Republic of Korea in 1965, which stated that all claims between Japan and Korea during colonial period are resolved.

Apparently, the Japanese government carefully considered which items to restrict. All of three restricted items are indispensable intermediate inputs of Korea’s key industries. Especially, the memory chip industry, which takes the largest part of Korea’s export worldwide, requires two of the three items: photoresist (PR) and hydrogen fluoride (HF). In late 2010s, Japanese companies used to take 70 to 90 percent of global market shares in these products. By targeting the value chain between Japanese intermediate goods producers and Korean chip producers, Japanese government may have aimed to show that they can cripple Korea’s core industries. Whether such goal was achieved or not, however, depends on the substitutability of these highly specific Japanese intermediate goods. If they can easily be replaced with domestic products or imported goods from other countries, the trade measure would do nothing but reduce the sales of Japanese intermediate goods producers.

The dominating market share of Japanese intermediate goods producer may have indicated, at least in perspective of METI (Ministry of Economy, Trade and Industry) of Japan, that the targeted intermediate goods are rather difficult to replace with other countries’ products. The reason for low substitutability might be low cost or high quality of Japanese products or fixed costs incurred when the chip producers in Korea change the intermediate goods supplier.

Did the restriction effectively depress the chip production? If so, how severe was the damage on each global value chain related to memory chip production? In typical literature on GVCs, the effect of this trade policy would have been computed by taking increased trade costs between chemical inputs and memory chip. Unfortunately, current world input output tables (WIOT) are too crude to deal with the agenda, although the data sets already take enormous effort to keep the record; the items of interests with respect to the Japanese government’s trade policy dive deeper than HS10 digits, while WIOT record trade of items in HS2 digits. Alternatively, knowledge on how chips are made, what roles the restricted inputs play in production process, and how memory chips are used in subsequent downstream global value chains may shed lights on our questions.

**A Brief Introduction of Chip Production**

Typical chip production consists of eight production stages: Wafer manufacturing; Silicon oxidation; Photolithography; Etching; Ion implantation and film deposition; Metalization; Electrical Die sorting; and Packaging. PR and HF are used in the third and fourth stage of chip production, photolithography and etching respectively. Although the inputs subject to export control measure are relevant to small portion of stages, it turns out that without these items the chip production cannot continue.

Given production technology, a chip producer’s goal is to build intricate integrated circuit (IC) with as high yield rate as possible. To accomplish this, she rigorously follows prespecified chip production recipe. The chip making starts from preparing wafer, a disc-shaped silicon single crystal. A single wafer transforms into dozens of chips at the end of production stages. Throughout these stages, the yield rate of a factory is computed as the average number of good chips made on a wafer divided by the possible chips that can be made from it. The yield rate depends on how stringently the production procedure follows the recipe. A single particle, little heat energy, or one more agitation can result in erratic product. As a wafer is ready in first stage, a thin layer of oxide covers it in the second stage. This layer is etched with HF in the fourth stage.

The third and fourth stages are key steps to engrave the replica of circuits on the wafer prepared in the first and second stage. In photolithography stage, the shape of the desired circuit is printed on the wafer. First, PR covers the oxide layer which was formed in the second stage. Once PR is exposed to ultraviolet (UV), the photosensitive compound of PR reacts to UV and becomes solvable. The producer selectively exposes the PR on wafer to UV, using a tool called photomask. Photomask is designed to describe the desired circuit, with transparent and opaque regions alternately appearing. The regions selectively exposed to UV by photomask becomes solvable to development solution. Then, the PR layer dives into the solution, which takes the exposed part away. This process within photolithography stage is called development due to the analogous process of photo development.

After development, the production stage moves on to the etching stage, and the removed PR parts are etched by HF. Pure HF has strong acidity so if not protected by PR the oxide layer melts away. Then the silicon wafer changes its shape into the desired circuit.

Why would the source location of PR and HF matter? Aside from the unit cost differences, via few possible channels changing intermediate producers can interfere production stages. First, the purity of intermediate inputs can affect the yield. Japanese HF producers are known to be able to supply HF with 12-nine level of purity (1/10^10 of impurity), while other producers have 8 to 10-nine levels. Higher level of impurity can result in a pinhole, constriction, or short within the circuit. More likely an erratic production, lower the yield rate and a higher the unit cost. In addition to the lower yield, input restrictions disproportionately hider the production of high-end products. For instance, a key challenge of photolithography stage is to maintain the resolution of circuit. As high-end products require more sophisticated blueprints and lower critical dimension (CD), a change in PR producer, typically not available to provide top-notch products, may depress the production of chips with larger storages and faster transfer rates more than the production of low-tier chips.

**HF and PR Industries in Japan**

Unlike photoresist, hydrogen fluoride has a simple way to make. When sulfuric acid is added to fluorite, endothermic reaction occurs and generates HF and calcium sulfate. Since both ingredients sulfuric acid and fluorite are easy to source, the specific or recipe does not matter too much. Rather, in perspective of chip producer, the unit cost and the purity of HF is crucial. Japanese firms are known to be able to produce HF with top-notch purity, which ensures the yield protected from the impurity in HF. Unless other producers can provide HF with the same cost and purity, the trade control would have caused an increase in unit cost of chip.

However, the increase in production cost can be alleviated by imports from the same companies’ foreign production sites. There are three major Japanese HF producers, taking about 70% of global HF market: Morita Chemical Industries Co., Ltd, Stellar Chemical Corp, and Showa Denko K. K. The main production sites of these companies are located in Japan, but Morita Chemical has production facility in China and Korea, and Stellar Chemical can produce HF in Singapore. Since the export control in 2019 does not restrict the export via a third country or products made by foreign affiliate established in S. Korea, these firms have ability, although limited due to the small production capacity in foreign facilities, to circumvent the restriction.

On the other hand, photoresists can be made in different ways. These inputs consist of photosensitive compound, base resin, and organic solvent. Each PR producer adopts different recipe in accordance with chip maker’s needs, its technology and cost function. Different suppliers different PR: PR varies in different threshold energy, contrast ratio, and most importantly, critical dimension (CD) which determines the delicacy of chip production process.

A handful of Japanese photoresist producers such as JSR corporation, ~~Shin-Etsu Chemical Co., Ltd~~, Tokyo Ohka Kogyo Co., Ltd, Sumitomo, and Fujifilm take 9 to 24% of global PR market share, which enable Japan to have more that 90% of dominating market share. Japanese firms located more upstream GVC, for instance Taito chemics and Toyo Gosei, supplies photo acid generator (PAG) and its compound (PAC). The complete mix or recipe to make each type of photoresist is usually unknown. These photoresist producers and their input suppliers have intimate relationship in form of shareholding. This relationship may have caused competing PR producers to have higher unit cost by making the core inputs difficult to source.

In addition to unit cost increase or lack of supply, the restriction on PR exports may hinder chip production through different channels. Importantly, with different types of PR, even when making the same chip, the producer must modify the photolithography process. It may require changes in exposure energy, exposure time, distance between the photomask and the wafer, or wavelength of radiation. Furthermore, a change in PR supplier may reduce the least critical dimension available. Since high-end type products usually requires smaller dimensions, the export control may have disproportionately depressed the fabrication of larger and faster memory chips.

PR (Photoresist)

한국산업기술평가관리원

JSR Corporation | 9 worldwide 24%

Shin-Etsu Chemical Co., Ltd | 5 in Japan 23%

Tokyo Ohka Kogyo Co., Ltd | 8 in Japan 22%

Sumitomo | only in Japan 16%

Fujifilm | 9%

HF (Hydrogen Fluoride)

Morita Chemical Industries Co., Ltd |Shanghai and Zhāngjiājiè, China, Gwangju, Korea

Stella Chemifa Corp | Singapore and Japan

Showa Denko K. K.| Japan

**A Brief introduction to chips**

Semiconductors widely used in modern electronic devices are classified into two categories: memory chips and system chips. The first type of chips store information either in the long term or short term. The memory chips that can permanently store data typically have larger storage than short term memory chips do, but it takes longer time to access stored data each time. On the other hand, short term memory chips are much faster in data access, but once the power turns off all information is removed from the chips. The typical long term memory chips are called NAND flash, while short term memory chips are usually called as d-ram.

When a computer is assembled on a motherboard, typically it allows to install two to four d-ram and one to three NAND flash memories. For instance, d-ram has different storages such as 4GB, 8GB and 16GB and so on; different generations called DDR3 and DDR4; and different speeds measured in megahertz. NAND flashes such as Solid-state drives (SSD) also have differentiated capabilities in a similar way. Smartphones, consoles, and other electronic devices have similar ways to enhance its computing power under a limited number of slots to install long and short-term memories.

In early 2000 South Korea started to take the memory chip market which had been dominated by Japanese companies such as Toshiba or Hitachi in 1980s and 1990s. In late 2010s, two largest Korean chip makers, Samsung Electronics and SK Hynix, took about 45% of NAND flash market and 75% of d-ram market. Especially, with US d-ram maker Micron, more than 95% of market share goes to three big players.

Although memory chip market is only about one third of system chip market, it has played a key role determining Korea’s position in global value chains. The exports of memory chips account for 17% of the country’s total exports in 2019. The industry was unarguably the most important source of gross export, followed by automobile sector that took about 5%.

Samsung (China) Semiconductor (SCS)

SK hynix Semiconductor (China) Ltd.(SKHYCL)(\*6)

SK hynix Semiconductor (Wuxi) Ltd.(SKHYMC)

SK hynix Semiconductor (Chongqing) Ltd.(SKHYCQL)(\*9)