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Life cycle assessment of DRAM in Taiwan's semiconductor industry

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ABSTRACT

The semiconductor industry plays a leading role in supporting economic stabilization and social progress in Taiwan. In this paper, Eco-indicator 95 and Impact 2002+ are utilized to evaluate the potential environmental impacts from five production processes of the double data rate synchronous dynamic random access memory (DDR SDRAM). The comparisons between these two impact methods and their scopes are also discussed.

From our results, global warming potential and non-renewable energy consumption were identified as the major environmental impacts. Applications of Eco-indicator 95 and IMPACT 2002+ also suggest that summer smog and respiratory inorganics are significant impact categories. The comparison of the scopes of these two methods identifies that low GWP potential PFCs substitution and electricity saving are effective ways to decrease environmental impacts of DRAM manufacturing. In addition, IMPACT 2002+ is a more applicable LCA method for the semiconductor industry in Taiwan due to the structure and reference area of this method and the characteristics of the semiconductor industry in Taiwan.

1. Introduction

The semiconductor industry developed in Taiwan over the last 20 years, and it has become the island's most significant export industry. It not only advances high-tech human resources and employment opportunities, but also produces considerable overall GDP growth and significant industrial linkages in Taiwan's economic development. In 2006 the revenue of Taiwan's IC industry reached NTD 1393 billion with an average of 21.7% growth since 1999 (NTD 423.5 billion). Moreover, the ratio of "IC industry revenue to Taiwan real GDP" increased continuously from 4.44% in 1999 to 11.25% in 2006. Taiwan plays a major role in the global semiconductor industry, as the unique structure of its IC industry fosters close cooperation among diverse, yet essential, elements in the value chain, ranging from IC design and manufacturing to packaging and testing.

The Kyoto Protocol, ratified in February 2005, set a new milestone and challenge to the international community to reduce global greenhouse gases (GHGs) emission. The semiconductor associations of the EU, Japan and others have committed to lowering of the perfluorinated compounds (PFCs) emissions (e.g., CF_4, C_2F_6, C_3F_8, NF_3, CHF_3 and SF_6), and Taiwan's semiconductor industry association also has dedicated itself to reduce 10% PFCs emissions based on the average of the 1997 and 1999 emissions before year 2010. All of these will result in a great challenge to IC industries. Thus, how to reduce GHGs emissions and to explore feasible strategies for IC industries have become important challenges for the future. Moreover, the production processes involve many acid solutions, organic solvents and toxic gases. Most plants discharge organic/inorganic wastewater, gas, solvents and sludge, and cause complicated pollution problems [1]. To be socially responsible, some IC manufacturing processes have focused on pollution control from traditional end-pipe treatment to raw material substitution and process optimization. Presently, these manufacturers have reasonable environmental, safety and health (ESH) performance records in Taiwan. At the same time, the concept of Life Cycle Assessment (LCA) has become more popular in Taiwan; some private sectors have provided increased budgets to conduct LCA studies over several years. There are numerous applications of LCA-like identification of product improvement, decision-making, evaluation of a product's environmental performance, and market claims [2]. However, accessibility for data sharing in Taiwan is limited. The semiconductor industry has seen a move towards LCA, since LCA can be used as a tool to evaluate environmental impacts for various product design and pollution control measures of the IC manufacturing processes. A number of LCA studies have been conducted with a focus on semiconductor

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fabrication issues [3–13]. Large amounts of energy, chemicals and water are consumed throughout the life cycle of semiconductor devices, and the production stage appears to be particularly resource–intensive.

For IC fabrication companies, foundry and memory manufacturers are the two major business segments, comprising 97% of the Taiwan IC manufacturing business. Memory products accounted for 40.4% of total Taiwan IC manufacturing revenue in 2006, and dynamic random access memory (DRAM) is always the major product, comprising 91.2% [14]. Therefore, in this study we focus on the inventory of energy and chemicals used by a DRAM manufacturer in Taiwan to evaluate the impacts of five production processes. The LCA software SimaPro 7.1, including Eco-indicator 95 and Impact 2002+, was utilized to evaluate the potential environmental impacts and damage. Results from these two methods were then compared. The objective of this study is to investigate the major environmental impacts of the DRAM products in Taiwan semiconductor industry, and to determine which LCA method is more applicable. We hope the findings are helpful in the product design and the pollution improvement of this industry.

2. Materials and methods

2.1. System boundary & scope

From the point of view of the DRAM product's life cycle, the system boundary of this study has been set to include only the DRAM production and does not cover the entire life cycle (Fig. 1). Stages excluded in the analysis are silicon wafer production, assembly and packaging of DRAM, and the use and disposal of electronic equipments and facilities. In addition, the transportation of the entire life cycle is also not included because of data scarcity. DRAM production is a series of complex manufacturing processes that often includes hundreds of different procedures being completed within two months before it is finished. While different facilities may have slightly different groupings, the processes to be considered in the analysis are diffusion, photolithography, etching, thin film and chemical-mechanical polishing (CMP) [15–18].

First, the diffusion process is an additive process whereby the dopant is added to the semiconductor substrate to change its conductivity; this process requires high voltages (up to 100 kV) and use of poisonous, flammable, explosive and corrosive gases [15]. After wet or dry plasma etching, the photolithography process transfers the designed pattern from the mask or reticle to the photoresist on the wafer surface. It is the most crucial step in semiconductor fabrication, since the device and circuit designs are determined by either subtractive etching or additive deposition of metals or insulators. Next, the thin film process deposits metal layers on the wafer surface [16]. Metals with high conductivity are widely used for interconnections forming microelectronics circuits. Metal thin films can be deposited by physical vapor deposition (PVD), chemical vapor deposition (CVD), and electrochemical plating (ECP) processes [17]. Finally, the CMP process is a surface planarization technique that strips part of the deposited films by the combination of chemical reaction and mechanical polishing, thus making the surface smoother and more planarized [18].

In this study, considering emission reduction and best available control technology (BACT), we set up two different scopes. First, scope 1 (S1) concerns only about the original emissions without any pollution prevention. We calculated the pure environmental impacts directly caused by DRAM production. Second, scope 2 (S2) takes into account not only air pollution control systems and water recycling, but also BACT of electricity conservation and low global warming potential (GWP) PFCs substitution. Air pollution control systems including rotary concentrators and packed-bed scrubbers are considered in S2. The former utilizes adsorption technology to capture and destroy volatile organic compounds (VOC) from process exhaust streams. The concentrator technology is useful for relatively high destruction efficiencies (93–96%) of large air flow applications with low levels of emissions. The latter is normally used for removal of pollutant gases like HF, HCl and acid mists from air stream. Semiconductor manufacturing always takes automatic continues equipments, and is more difficult to improve electricity efficiency by optimizing the entire production processes than the air conditioning and illumination. In this study, we assume that this company could reduce 7% annual electricity use by installing the

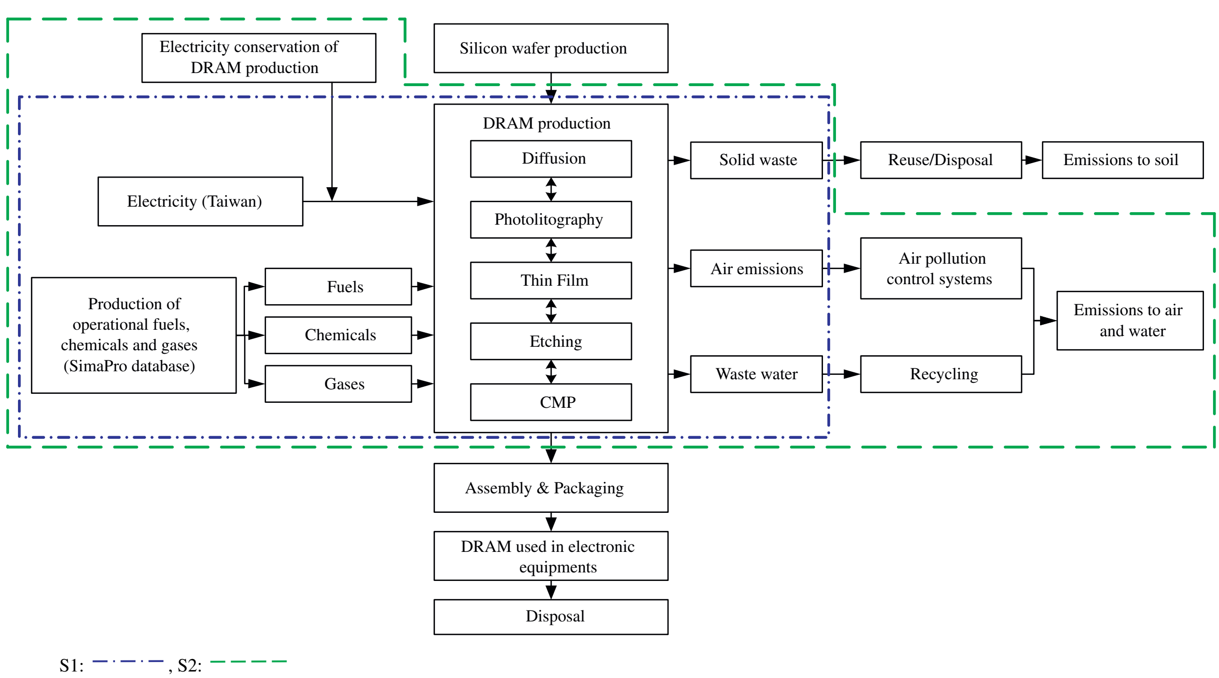

Fig. 1. The scope of DRAM fabrication.