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Study of chemical supply system of high-tech process using inherently safer design strategies in Taiwan

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ABSTRACT

The photoelectric, semiconductor and other high-tech industries are Taiwan's most important economic activities. High-tech plant incidents are caused by hazardous energy, even when that energy is confined to the inside of the process machine. During daily maintenance procedures, overhauling or trouble-shooting, engineers entering the interior of the machines are in direct contact with the source of the energy or hazardous substances, which can cause serious injury. The best method for preventing such incidents is to use inherently safer design strategies (ISDs); this approach can fully eliminate the dangers from the sources of hazardous energy at a facility.

This study first conducts a lithography process hazard analysis and compiles a statistical analysis of the causes of the fires and losses at high-tech plants in Taiwan since 1996, the aim being to establish the necessary improvement measures by using the Fire Dynamics Simulation (FDS) to solve relevant problems. The researchers also investigate the lithography process machine in order to explore carriage improvement measures, and analyse the fires' causes and reactive materials hazardous properties, from 1996 to 2012. The effective improvement measures are established based on the accident statistics. The study site is a 300 mm wafer fabrication plant located in Hsinchu Science Park, Taiwan.

After the completion of the annual maintenance jobs improvement from September 2011 to December 2012, the number of lithography process accidents was reduced from 6 to 1. The accident rate was significantly reduced and there were no staff time losses for a continuous 6882 h. It is confirmed that the plant safety level has been effectively enhanced. The researchers offer safety design recommendations regarding transport process appliances, chemical storage tanks, fume cupboard devices, chemical rooms, pumping equipment, transportation pipelines, valve manual box (VMB) process machines and liquid waste discharge lines. These recommendations can be applied in these industries to enhance the safety level of high-tech plants, facilities or process systems.

1. Introduction

Many major Taiwanese high-tech plant accidents have occurred in the past year. A fire incident occurred at a semiconductor circuit packaging and testing facility at 2 pm on May 1, 2005, which resulted in injuries to 7 people, including one firefighter. The fire in the 1F boiler ignited nearby acid drain substances and the fire burned along the channeling of the acid exhaust pipe. Another accident occurred in the same year at 11:30 on November 23rd. In this instance, a fire and explosion occurred in a cylinder room for silane and ammonia gases at a solar cell production, resulting in the death of one employee; many others were hospitalized due to choking or inhalation of harmful substances. The following year, at 8:23 on December 17th, an explosion in the furnace at a crystal growth high-tech facility resulted in the death of two workers (Yang, Yang, Yu, & Chen, 2009).

Photoelectric, semiconductor and other high-tech industries are some of Taiwan's most important economic activities. The completed raw materials, pre-processing, product manufacturing and final disposal in the production supply chain are important for whole operation activists because any fire, explosions, gas leaks, power outages and other disasters, will result in the interruption of the supply chain, thereby, causing an unsustainable operational dilemma (Chang & Chen, 2007).

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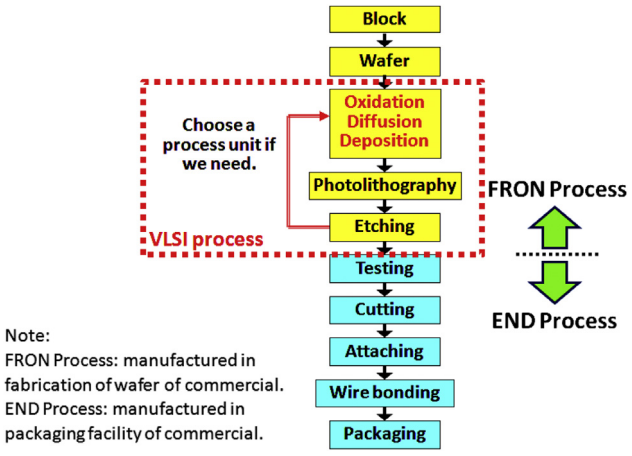

Fig. 1. Semiconductor manufacturing process flow diagram.

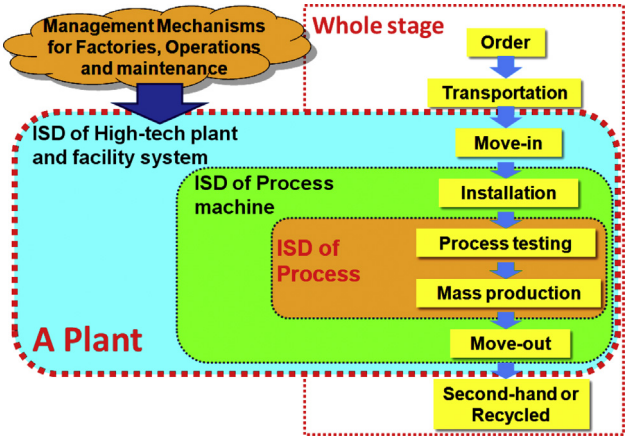

Fig. 2. Whole stage of high-tech process and facility safety using ISD strategies.

In a large-scale high-tech plant, in order to achieve physical vapor deposition (PVD), chemical vapor deposition (CVD), photolithography, etching, diffusion, ion implantation and the oxidation process, as shown in Fig. 1 (Sze & Ng, 2006), the process tool uses a lot of flammable, spontaneous combustion; toxic, corrosive, special gases and chemical materials. High-tech plants are filled with large amounts of toxic substances at any given time. Fire, explosions and chemical spills occasionally occur from flammable chemicals. High toxicity, high risk environment and a variety of disasters often increase the general public's fear of high-tech industry. Therefore, the aim of this study was to investigate the implementation of inherently safer design strategies in order to enhance the safety of the workers and the facilities.

Kletz (1984, 1985, 1998) first proposed the inherently safer design (ISD) principle, which includes the Minimize, Substitute, Moderate and Simplify strategies. Edwards and Lawrence (1993) and Crowl (1997) discussed Assessing the Inherent Safety of Chemical Process Routes, asking the question, "Is there a relation

Table 1
Statistical analysis of the cause of the fire and the loss of high-tech plant over the years from 1996 to 2010, in Taiwan.

Types of disasters	Time of occurrence	Type of company	Causes	Casualties	Property damage cost (US$)
Fire	1996.10.14	Semiconductor manufacturers	Wet cleaning machine ignition of flammable liquids	No injury	More than 2 hundred million
Fire	1997.10.03	Semiconductor manufacturers	Silane leaks	No injury	More than 2.9 hundred million
Fire	1997.11.11	Semiconductor manufacturers	Wet cleaning machine ignition of flammable liquids	No injury	More than 5.72 million
Fire	1999.09.22	Semiconductor manufacturers	Generator overheating	No injury	More than 0.71 million
Fire	2000.03.31	PCB materials	Boiler room heavy oil ignition of flammable liquids caused by leak and spray liquids.	2 Dead 11 injured	More than 1.14 million
Fire	2000.06.09	LED materials	Silane leaks	13 Injured	More than 5.7 million
Explosion	2000.09.10	PCB manufacturers	Boiler explosion	No injury	More than 28.5 thousand
Fire	2000.12.25	Semiconductor manufacturers	Generator overheating	No injury	More than 0.85 million
Fire	2001.01.18	PCB materials	Unknown	No injury	More than 0.14 million
Fire	2001.05.12	Electronic materials	Fire caused by flame	No injury	More than 1.43 hundred million
Fire	2001.05.31	PCB manufacturers	Unknown	No injury	More than 2.86 million
Fire	2001.06.28	NB manufacturers	Unknown	No injury	More than 1.71 million
Fire	2001.06.28	Smart phone manufacturers	Unknown	No injury	More than 4.29 million
Fire	2002.02.25	PCB manufacturers	Unknown	No injury	More than 22.8 million
Fire	2002.02.26	Electronic materials	Electrical fire	No injury	More than 0.85 million
Fire	2002.08.22	Automated trading equipment	Unknown	No injury	More than 0.22 million
Fire	2002.09.01	PCB manufacturers	Machine damage	No injury	More than 28.6 million
Fire	2002.12.10	Wafer manufacturers	Machine failure	No injury	More than 10 million
Fire	2003.10.02	PCB manufacturers	Unknown	No injury	More than 12.8 million
Fire	2004.01.10	Electronic materials	Machine overheating	No injury	More than 4.3 million
Fire	2004.06.10	Semiconductor manufacturers	Machine overheating	No injury	More than 0.43 million
Fire	2004.08.25	DVD manufacturers	Unknown	No injury	More than 0.429 million
Fire	2004.09.19	NB manufacturers	Electrical fire	No injury	More than 1.05 million
Fire	2004.06.11	LCD materials	Chemical fire	7 Injured	More than 8.57 million
Explosion	2005.05.01	IC packaging	Boiler explosion	1 Injured	More than 2.86 hundred million
Fire	2005.08.15	Tech chemicals	Chemical fire	1 Dead	More than 57 thousand
Explosion	2005.11.23	Solar cell manufacturers	Leakage explosion	1 Dead	More than 1.43 hundred million
Fire	2006.03.02	PCB manufacturers	Hydrochloric acid and bleach water leaks	No injury	More than 8.5 thousand
Fire	2006.04.07	DVD manufacturers	Drying chamber fire	1 Dead	More than 1.43 million
Explosion	2006.12.17	Solar wafer manufacturers	Crystal growth furnace explosion	2 Dead	More than 28.6 thousand
Fire	2010.03.30	Pharmaceutical manufacturing	Chemical fire	No injury	More than 0.29 million

Note: 1. PCB: Printed Circuit Board; 2. LED: Light Emitting Diode; 3. NB: Note Book computer; 4. DVD: Digital Video Disc; 5. IC: Integrated Circuit.