A Study on the As Low As Reasonably Practicable (ALARP)-Concept Risk Assessment of Silane in Semiconductor and LCD Process

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반도체/LCD 제조공정에서의 Silane에 대한 ALARP개념의 화재·폭발 위험성평가에 관한 연구

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Abstract

본 연구에서는, 반도체, LCD 공정에서 금속막을 증착하기 위하여 PECVD장비에 화재, 폭발 위험성과 독성을 가진 Silane가스를 사용하게 되는 장비인 gas cabinet, pipeline, VMB(Valve manifold box), MFC(mass flow controller)장비 등, 전반적인 시스템에 대하여 영국 HES의 ALARP개념을 도입하여 위험성 평가를 실시하여 문제점을 도출하고 대책을 강구 하는데 목적이 있고, 여러 가지 문제점중 절대적으로 수용 할 수 없는 Critical Risk로는 Gas Cylinder를 사용하여 Silane을 공급하고자 할 때에는 필히 Gas Cabinet을 사용하여 공급하여야 하고, Tube Trailer를 사용하여 공급하고자 할 때에는 필수적으로 Purge System을 갖추어 공급하여야 한다. 선택적으로 수용할 수 있는 High, Medium Risk로는 Gas Cylinder 또는 Tube Trailer를 사용하여 Silane을 공급하고자 할 때는 Inlet 부분에 RFO(Resticted Flow Orifice)를 설치하여 사용하고 Gas Supply Room에는 CO2소화설비를 적용하지 말고 Water Mist등 물 분무설비를 적용하여야한다..

Keywords : PECVD, Silane gas, ALARP-concept risk assessment

1. Introduction

The semiconductor and LCD (liquid crystal display) manufacturing consist of some processes, such as cleaning, PR (photoresist) coating, exposure, developing, implanting, etching, deposition, etc.[1~4] There exist many types of equipments for the thin film deposition process onto a substrate. Among them, sputter is used for the metal film deposition and PECVD (Plasma Enhanced Chemical Vapor Deposition) is employed for the semiconductor and insulator layer deposition, respectively. Silane (SiH_4)[5], an extremely sensitive and toxic gas with potential fire and explosion risk, is used for the PECVD.

The objective of this study is to perform the silane system risk assessment based on the concept of ALARP (As Low As Reasonably Practicable) in order to establish the design and operation guideline[3], reflecting the problems and solutions derived from the assessment results.

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2. PECVD PROCESS

PECVD process is used to deposit semiconductor or insulator film onto a substrate. In this process, the reactive gases needed for the deposition is injected into the vacuum chamber and then RF (radio frequency) power is applied when the substrate temperature reaches the desired level to let the chemical reactions take place in the plasma environment, forming the insulator and semiconductor layer on the glass substrate. The process can be described as in Figure 1, and the reaction conditions are listed in Table 1.

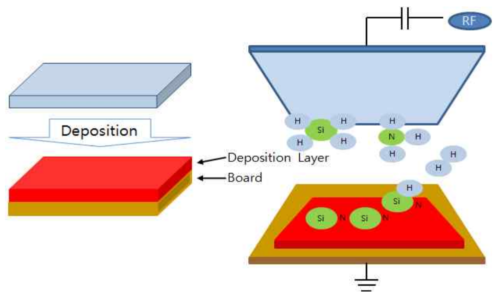

Figure 1. Process Description of PECVE

Table 1. Procecss Conditions of PECVD

Item	Process Conditions	Note
Amorphous silicon layer (a-Si), n+a-Si	Chamber temperature: 375℃ Voltage: 1 – 3.5 Kv	▸ The conditions may be varied depending on the development of the production technology, the manufacturing equipments and the methods.
Silicon nitride SiH4 Layer	Chamber temperature: 375℃, 330℃ Voltage: 0.1-1.65Kv	
Materials	SiH4, NH3,H2,N2,PH3,NF3,Ar	
Target layer	Silicon nitride layer: SiNx Semiconductor layer: a-Si:H, n+a-Si:H	
Related operation facilities	Cooling water, compressed air, toxic air ventilation before the operation	
	Gas: the pressure of each gas should be higher than 30 psi	
Scrubber exhaust pressure	Input pressure : higher than -0.5 mmH2O	
	Exhaust end pressure : -1.5 mmH2O	

Table 2. Phsical & Toxicological of Silane6-8)

Formula	SiH4
Molecular Weight	32.12
Boiling Point	-112℃
Melting Point	-185℃
Critical Pressure	42.6bar g
Critical Temperature	-7℃
Specific Gravity(gas)	1.11wit/Air
Flammable Range	1.37vol% to 96vol% in Air 1,370ppm to 96,000ppm
ACGIH TLV	5ppm TWA (Time Weighted Average)
LC50 (4-Hour Rat.)	9600ppm
LC50 (1-Hour Rat.)	~20,000ppm

3. The physical and toxicological properties of silane (SiH4)

The physical and toxic risk properties of silane are summarized as followings:

Based on the above data, it is understood that the fire and explosion risk of silane is more serious than the toxic risk.

4. Generaly silane supply systems

4.1 Silane supply system

In general, the semiconductor and LCD manufactures store and supply silane to PECVD equipment by the following two methods: one is the supply through a cylinder installed inside a gas cabinet in the gas storage room and the other is the supply through a tube trailer installed at an outdoor high capacity storage site. The two systems are shown in Figure 2 and 3, respectively.

4.2 Risk Assessment of based on ALARP concept in the SiH4 Supply System

ALARP, the abbreviation of 'As Low As Reasonably Practicable,' is the concept used in Reducing Protection People in the UK HSE (Health and Safety Executive) report. It strictly applies a matrix for the risk assessment as shown in Table 3,4,5 and figure 4.

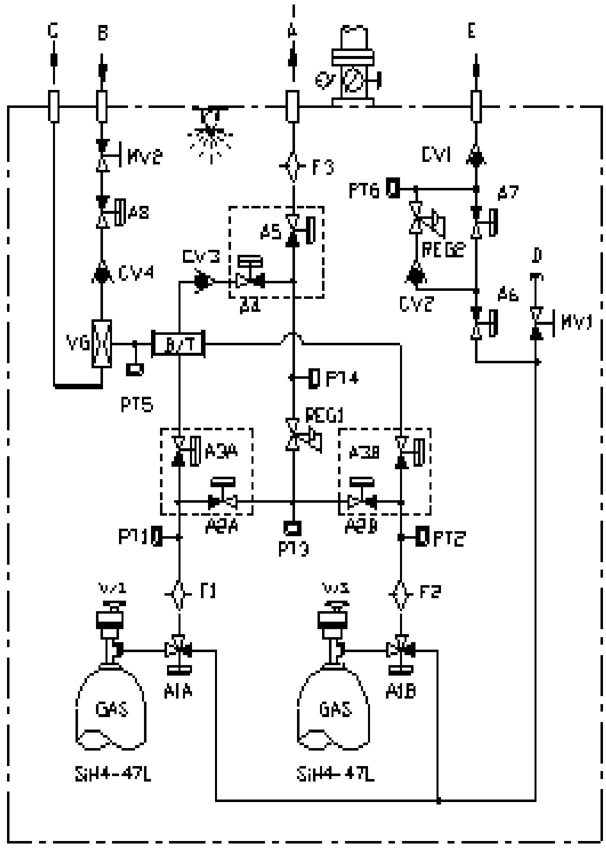

Figure 2. Cabinet Supply P&ID of Silane

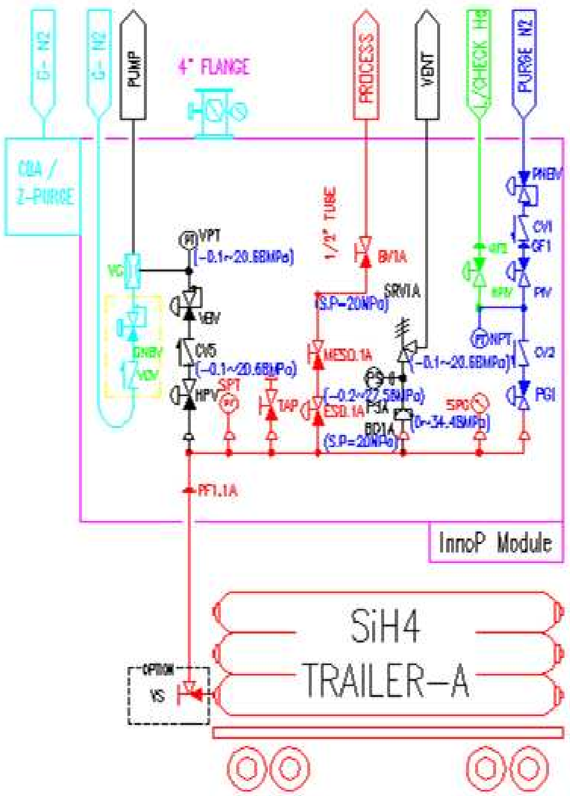

Figure 3. Tube Trailer Supply P&ID of Silane

Table 3. ALARP, Serverity Matrix

Severity Group		Personnel Injury	Equipment Loss of Use	Facility Loss of Use
4	Catastrophic	Death of one or more people	One Year	One Week
3	Severe	Disabling Injury	One Month	One Day
2	Moderate	Non-disabling injury	One Week	One Shift
1	Minor	First Acid Injury	One Day	Less than one shift

Table 4. ALARP, Likelihood Matrix

Category	Likelihood Group	Likelihood(%), (Incidents/10,000years)
A	Frequent	More than 1×10^{0} (> 100/10,000), 1%
B	Likely	More than 1×10^{-1} (> 10/10,000), 0.1%
C	Possible	More than 1×10^{-4} (> 0.01/10,000), 0.0001%
D	Rare	More than 1×10^{-5} (>0.0012/10,000), 0.00001%
E	Unlikely	More than 1×10^{-6} (> 0.001/10,000), 0.000001%

Table 5. Residual Fire Risk Ranking Matrix

Likelihood / Severity	10^{0} A	10^{-1} B	10^{-4} C	10^{-5} D	10^{-6} E
4 Death(s)	Critical	Critical	High	Medium	Low
3 Disabling Injury	Critical	High	Medium	Low	Low
2 Non-disabling injury	High	Medium	Low	Low	Slight
1 First Acid Injury	Medium	Low	Low	Slight	Slight

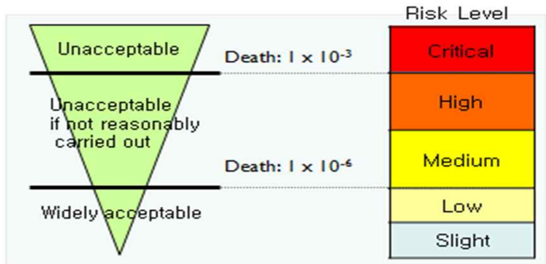

Figure 4. ALARP Likelihood & Risk Level

4.3 Accident Scenarious of SiH4 Supply System

Following three types may be considered as the silane leakage to the air: ① no ignition, ② prompt ignition and ③ delayed ignition. In the case of no ignition, the silane leakage leads to vapor cloud formation and silicon dioxide discharge to the air, causing VCE(Vapor Cloud Explosion) by the combination with oxygen, even causing detonation if in a closed space under high pressure.

In the case of prompt ignition, a very high flam

Table 6. Recommendations of ALARP Based Hazard Assessment in Process

Risk Level	Hazards	Recommendation	Remarks
Critical	Supplying SiH4 by installing the cylinder in open air	The cylinder should be put inside a cabinet since there is potential risk of explosion at the moment of valve opening.	Unacceptable risk
	No purge system in the tube trailer supply system	A N2 purge system should be installed for the operation since there is the risk of explosion by the residual gas leakage to the air.	
High	Chemical joint for the connection between the PECVD equipment and the SiH4 supply pipeline	The chemical joint needs to be replaced with a mechanical joint considering the risk of leakage due to decrepitude.	Selectively tolerable Risk
	No RFO installed at the gas cylinder and the tube trailer	RFO needs to be installed at the front end of the cylinder and the trailer valve.	
	No water spray facility available at the tube trailer storage site	A water spray system needs to be introduced in case of a fire.	
Medium	On side of the tube trailer storage site is exposed to the air.	The storage site needs to be blocked with an explosion-proof wall since an overpressure acts on the exposed side at the time of explosion.	
	An automatic CO2 fire extinguisher system is installed inside the GSR.	A water spray system is needed to be introduced since there is the risk of suffocation at the time of CO2 leakage or discharge.	
	The ventilation rate of the PECVD gas box is insufficient.	The ventilation rate needs to be increased to be less than the LFL of SiH4.	
	The empty containers are stored in the open air.	The empty containers need to be store in a gas cabinet.	
Low	The emergency countermeasures are not shared by the operators and the responsibility channel is not clear.	All the operators need to be well aware of the emergency countermeasures and the responsibility channel needs to be secured.	Acceptable risk (ALARP)
	The data related with SiH4 is managed by different departments.	The department related to SiH4 needs to secure and manage the data.	
	The ventilation rate is not sufficient and no sprinkler is installed in VMB.	The ventilation rate needs to be increased and a sprinkler needs to be installed.	
	The person in charge of SiH4 is not perfectly aware of the danger of SiH4.	The person in charge of SiH4 needs to be educated so that he can understand the risk properties of SiH4 fully.	
	The PECVD ventilation duct is an aluminum flexible pipe.	The aluminum flexible pipe needs to be replaced with a STS flexible pipe.	
Slight	HAZOP (Hazard and Operability) is not carried out with respect to the gas box and the silane pipe.	HAZOP needs to be carried out with respect to the gas box and VMB, etc.	

temperature up to 2,400℃ is generated in the form of jet fire shown. If the flame is not rapidly removed, a severe blast takes place by rupture of the container. Finally, in the case of delayed ignition, multilateral auto ignition takes place and an over-pressure equivalent to an explosion is generated. FM Global reported that an explosion takes place within five minutes after the leakage.

4.4 Recommendations of Hazard Assessment

A few problems were derived from the risk assessment based on the ALARP- concept considering the physicochemical and toxic properties of SiH4, the storage and supply system, the PECVD equipment and the ventilation system, and the accident cases as presented in Table 6.

5. Conclusions

PECVD equipment is used for the process of semiconductor and insulator deposition on the substrate which the most important process in the manufacturing of semiconductor and LCD. Since silane gas used for this process has a wide range of flammable limit and a huge explosive power in addition to toxicity, an extremely high safety is required in dealing with it. The gas is supplied to the final target equipment, PECVD, through the gas cylinder or tubetrailer.

Several problems were indicated from the risk assessment of these systems based on the ALARP concept and they are presented as following with the countermeasures:

The critical risks that are absolutely unacceptable.

- A gas cabinet must be used when supplying silane by means of a gas cylinder.
- A purge system must be prepared to supply the gas with a tube trailer.

The high and medium risks that can be selectively tolerable.

- An RFO (Restricted Flow Orifice) needs to be installed at the inlet part when supplying silane with a gas cylinder or a tube trailer.
- A water spray facility such as water mist, not a CO2-based fire extinguisher facility, needs to be applied to the gas supply room,

The low and slight risks that are widely acceptable.

- The ventilation rate in VMB (Valve Manifold Box) and PECVD gas box needs to be increased.
- HAZOP needs to be carried out with respect to the omitted parts in the entire gas supply system.

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