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Study on the appropriateness of detector installation in chemical supply facilities for semiconductor manufacturing

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Abstract: In many industries, semiconductors are employed, and yet use hundreds of classified and hazardous materials according to its manufacturing processes. Leakage of these materials continues to occur even with the implementation of firmly established and supplied safety devices. To that end, gas detectors and liquid leak detectors are installed and managed inside the facility detecting leaks early and minimizing outflows.

In this study, the simulation was conducted through computational fluid dynamics (CFD) assuming a situation in which isopropyl alcohol (IPA) leaked in the chemical supply facility used in the semiconductor manufacturing process. The simulations were conducted for three types of facilities: area type (type 1), spot type with a gradient in one direction (type 2), and spot type with a gradient in the center of the floor (type 3). In addition, simulation was performed by assuming leak holes in two different sizes for each type.

As a result of simulation, faster detection was confirmed that the gas detector found the leak faster than liquid leak detector according to the characteristics of IPA. In addition, detection was confirmed that type 3, a new type, showed the shortest liquid detection time compared to other two types. However, this study was conducted only for IPA, and it is necessary to note that effective detectors may vary depending on various properties such as viscosity and vapor pressure of the materials.

This study is expected to help reduce wasted costs due to over-investment throughout the industry.

Keywords: *Gas detector, liquid leak detector, computational fluid dynamics, flammable liquid, IPA*

1. INTRODUCTION

Semiconductors, which are used in many industires today, are largely divided into eight processes: Wafer Fabrication - Oxidation - Photo Lithography - Etching - Deposition - Metallization - EDS – Packaging. Dozens to hundreds of hazardous and dangerous materials are used for these manufacturing processes. It is essential to prevent outflow of these materials as they may result in fire, explosion, or poisoning.

Nevertheless, seepages of these hazardous and dangerous materials continue to occur due to errors in design, problems in construction or misoperation. Therefore, various safeguards such as emergency shutoff valves, gas and liquid detectors with alarm and firefighting systems are installed in facilities to minimize the amount of leaks by detecting early even if leaks occur.[1)]

In the case of semiconductor processes, facilities are designed and constructed to stably supply numerous hazardous and dangerous materials used in the semiconductor manufacturing process. There are hundreds of materials, and they are largely divided into chemical, specialty gas, and precursor according to the properties of the supplied materials. Among them, the chemical supply system is classified into ACQC (Auto Clean Quick Coupler) – Transfer unit – Supply unit – CIB(Chemical Insert Box) – VMB(Valve Manifold Box) - Fab according to the order of supply. (refer to Figure 1) In this study, the Chemical Supply System will be reviewed.

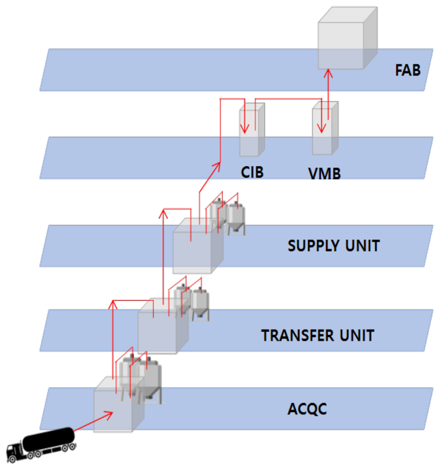

Figure 1. Chemical supply system

2. BACKGROUND

Amenities such as pumps, filters, piping, and valves are located inside the hexahedral box, which is generally called a unit. The piping route and arrangement varies somewhat depending on its use and handling materials. However, in this study, among ACQCs, transfer units, and supply units of similar size, ACQC was selected, and its structure and size are shown in Figure 2.

In the case of exhaust, the internal air is discharged with a negative pressure of over 100 Pascal, and an air intake is opened at the bottom of the facility so that air can be supplied smoothly.

Inside of the units, liquid leak detectors and gas detectors are installed for quick detection of leaks. In the case of liquid leak detector, two different types are installed: Area-type that surrounds the inside of the facility(no gradient), and a spot-type that is installed in the lowest point with a gradient. The liquid leak detectors are mainly used for the purpose of detecting leakes of hazardous materials with low vapor pressure.

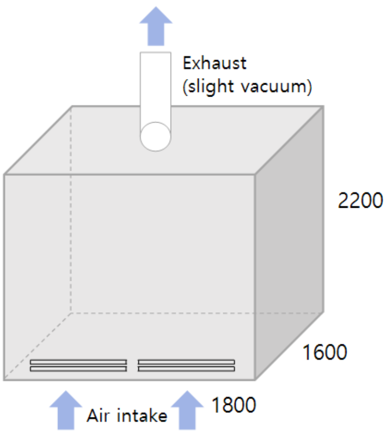

Figure 2. Shape of ACQC unit

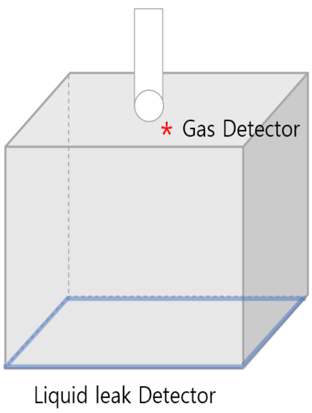

Figure 3. Detectors in ACQC unit (area-type)

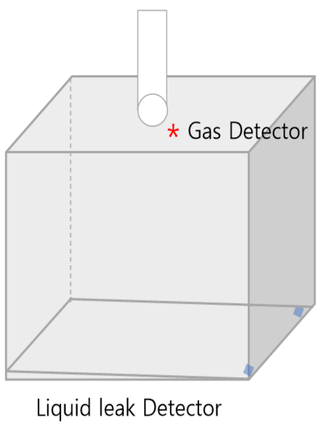

Figure 4. Detectors in ACQC unit (spot-type)

Also, gas detectors are installed to sense hazardeous gas and vapor. The gas detectors shall be installed when handling flammable liquids or flammable gases in accordance with Article 232 (Prevention of explosions or fires, etc.) of Regulations on Korean Occupational Safety and Health Standards. In order to detect flammable gas or vapor in advance to prevent fire or explosion, an alarm function shall be installed when flammable gas or vapor are sensed. [2)]

According to Regulations on Korean Occupational Safety and Health Standards, flammable liquid refers to a combustible material that has a flash point of 60 deg.C or less at standard pressure(101.3 kPa). The flammable gas refers to a substance with lower flammable limit of 13% or less or a difference between the upper and lower flammable limit of 12% or more, which is in a gaseous state at standard pressure (101.3 kPa) and 20 deg.C. [2)]

Depending on the installation year and company's policy, the liquid leak detectors and gas detectors have recently been mounted inside organic chemical facilities. This is for the purpose of detecting leaks as quickly as possible by interlocking with each other's performance, nonetheless, the investment cost reaches a considerable level because they are all installed identically in hundreds to thousands of facilities.

In addition, the maintenance work to keep the performance of the detectors and the facilities shall be opened. During the maintenance work, there are risks in which an instrument such as a valve or pipe is improperly touched, and leakage can occur.

Therefore, in this study, we are going to simulate the behavior of the leaked material according to various leak conditions through computational fluid dynamics analysis, and check the detection time of the liquid leak detector, and the gas detector to study which type of gauge is most appropriate.

3. METHODOLOGY

In this study, isopropyl alcohol (IPA) was selected. IPA is used for wafer cleaning in the semiconductor manufacturing process, and is one of the most used chemicals in this field. IPA is classified as flammable liquid under the Korean Occupational Safety and Health Act, and accordingly, liquid leak detectors and gas detectors are installed inside the handling facilities. The physical properties of IPA are shown in the Table 1.

Table 1. Properties of IPA

Properties	**Value**	**Unit**
Molar mass	60.09	g/mol
Melting point	183.65 (-89.5)	K (C)
Boiling point	355.55 (82.4)	K (C)
Vapor Pressure (at 20C)	33	mmHg
Density (liquid)	786	kg/m^3
Density (vapor)	2.725	kg/m^3
Viscosity	1.96 (at 298 K)	cP
Specific heat, Cp	161.2 (at 298 K)	J/mol-K
Thermal conductivity	0.137	W/m-K
Surface tension coefficient	21.2	mN/m
Enthalpy of fusion (at 185.2K)	5.41	kJ/mol
Enthalpy of vaporization (at 355K)	39.8	kJ/mol
Mass diffusion coefficient	1.04 * 10^-6	cm^2/s
Contact angle	53 ± 3	Deg

The facility for simulation was divided into three types by adding a new type to the currently installed two types. Simulation scenario were divided into area type (type 1), spot type with a gradient in one direction (type 2), and spot type with a gradient in the center of the floor (type 3). The shape of each type is shown in Figure 5. In the case of type 3, scenario is an improved type than type 2 scenario. Type 3 scenario is designed so that leaks can be detected by the leak detector in the center no matter where the leak occurs, and it also has the cost advantage of having only one leak detector installed.

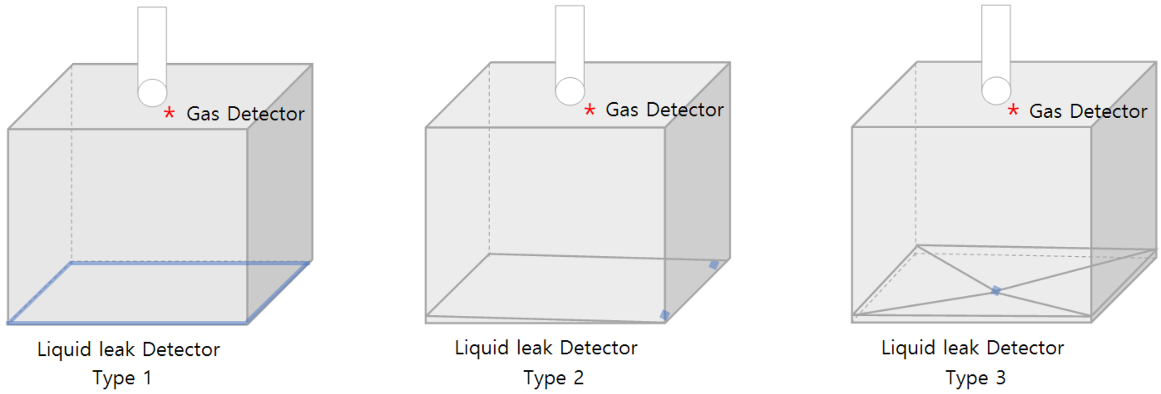

Figure 5. Three types of facilities

In the case of leak point, it is difficult to define a specific point because the composition of internal piping, and instrumentation differs depending on the facility, but a place with a high possibility of leakage was arbitrarily selected due to the location of regulators, filters and valves (potential leak point). For comparison by type, the same leak point was applied to all three types. The ground plan and elevation are shown in Figure 6.

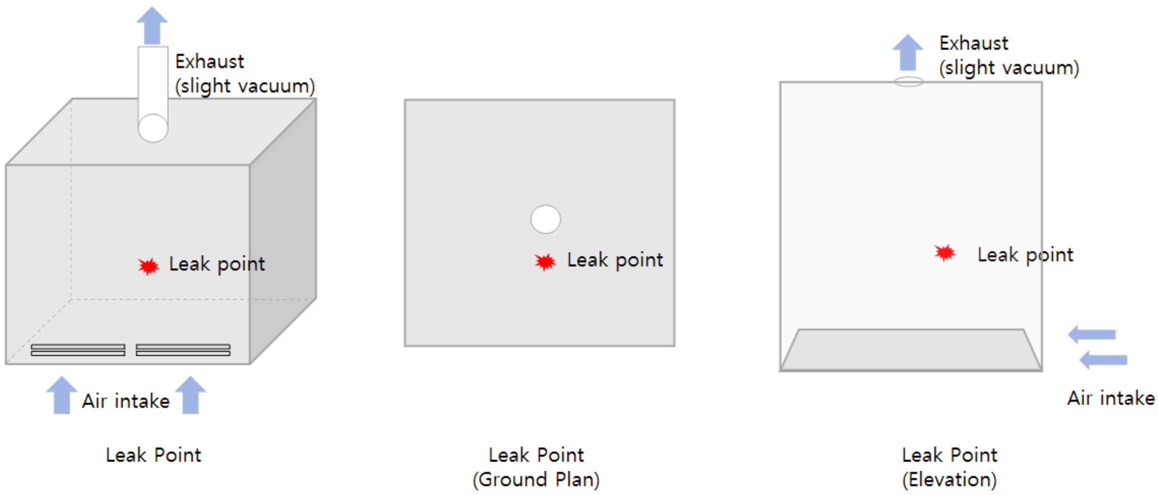

Figure 6. Leak point

The leak rate was calculated using Equation B.1 (Liquid leak rate) of IEC 60079-10-1.[3)] The leakage amount is different according to the hole diameter, and the study was conducted for two situations with a hole diameter of 1 mm and 0.25 mm. The reason is that most of the piping inside the semiconductor supply facility has a diameter of 1 in or less, and most of the leaks are due to the occurrence of fine leak holes, so the above two situations were assumed. In the case of a large leak such as pipe rupture, the gas detector, and liquid leak detector can sense the leak in an instant, so the situation of a large leak was excluded in this study.

$$W = CdS\sqrt{2\rho \Delta P}\ (kg/s)$$

Equation 1. Liquid leak rate equation

W = Release rate of liquid (kg/s)

C_d = Discharge coefficient (-)

S = Cross section of the opening (m^2)

ρ = Liquid density (kg/m^3)

ΔP = Pressure difference across the opening that leak in (Pa)

The process conditions and constant values other than the hole diameter were applied the same, and the simulation was performed by reflecting the leak rate of 0.022 kg/s for 1 mm hole and 0.0014 kg/s for 0.25 mm hole.

Table 2. Leak-rate calculation

Leak diameter (mm)	W (kg/s)	C_d	S (m^2)	ρ (kg/m^3)	ΔP (Pa)
1	0.022	1	7.85 E-07	786	490000
0.25	0.0014	1	4.9 E-08	786	490000

4. STUDY RESULTS

In the case of the liquid leak detector, the time for the leaked liquid IPA to reach the liquid leak detector was measured. Then, in the case of the gas detector, the time for 5,000 ppm (25% of Lower Flammable Limit) of the evaporated IPA to reach the position of the gas detector was measured. [4)]

As a result of simulating a total of 6 situations classified by leak detector type (3 types) and leak hole size (2 types) the time taken for the detector to sense is shown in the Table 3.

As results of the simulations, in type 3 scenario, we found that the gas detector could detect in a faster time than the liquid leak detector in general. The accelerated detection time means fast action (by interlock or operator action), which allows less leakage, so the gas detector can be judged to be more effective method than liquid leak detector.

In case of Type 3, the gas detector senses faster than the liquid leak detector, but the detection time of the liquid leak detector is considerably shorter than that of Types 1 and 2. This seems to be in accordance with the structure of Type 3, which gave a gradient to the center, and it was confirmed that this setting showed an improvement in detection method than the previous one.

Table 3. Duration time for detection

		Type 1 (sec)	Type 2 (sec)	Type 3 (sec)
1 mm hole	Gas detector	10.3	14.8	10.4
	Liquid leak detector	221.1	165.0	27.0
0.25 mm hole	Gas detector	12.4	19.7	12.4
	Liquid leak detector	more than 350	more than 350	58.0

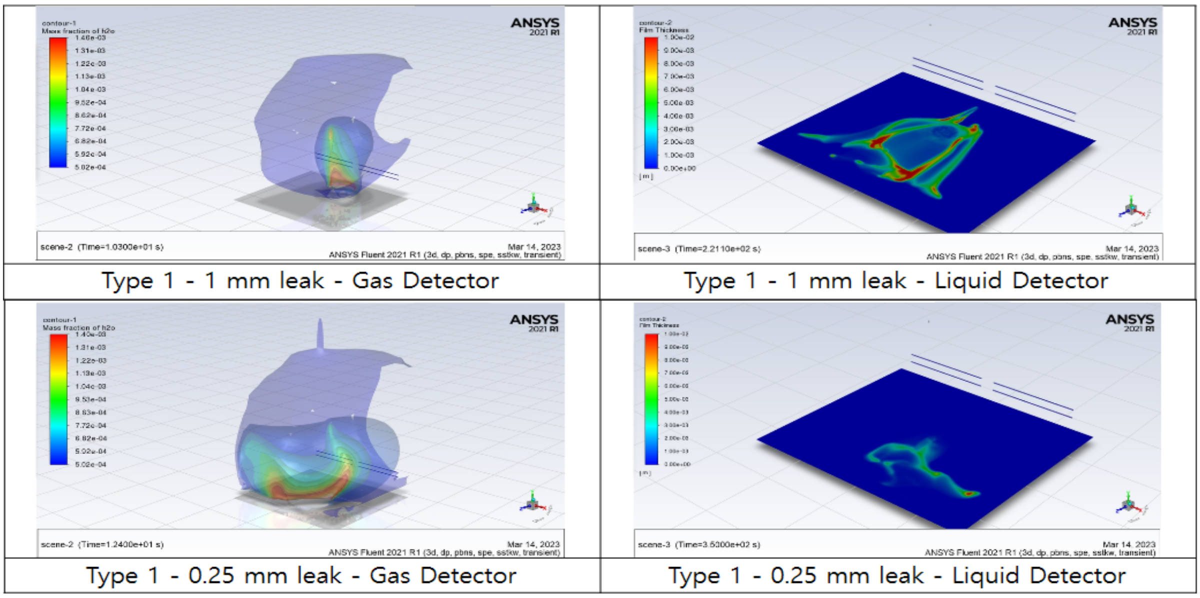

Figure 7. Results of Type 1

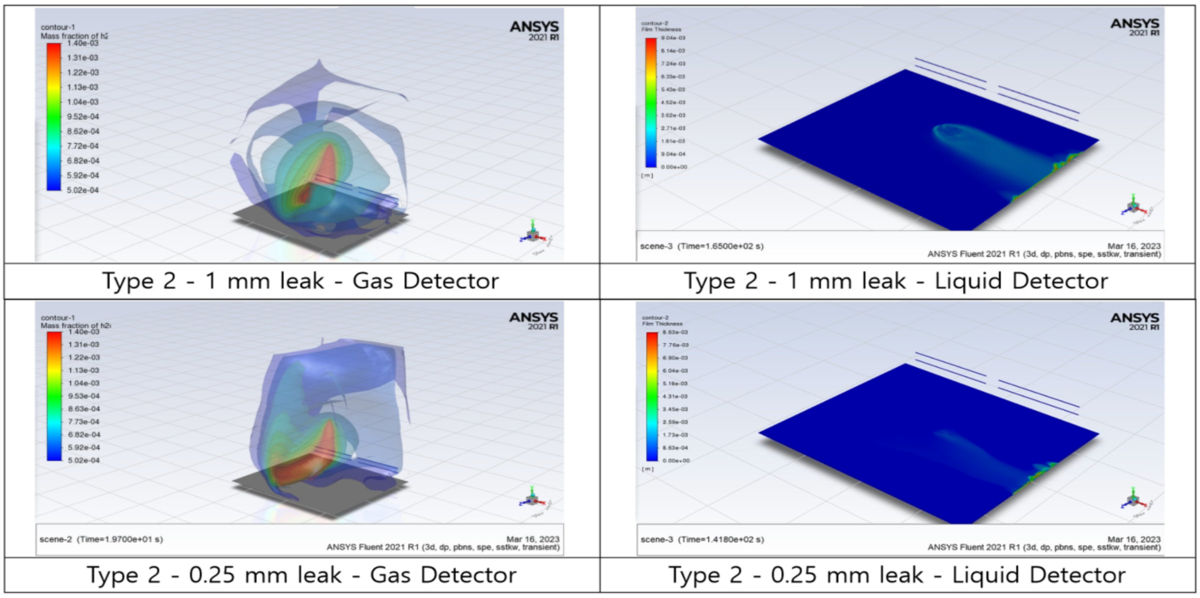

Figure 8. Results of Type 2

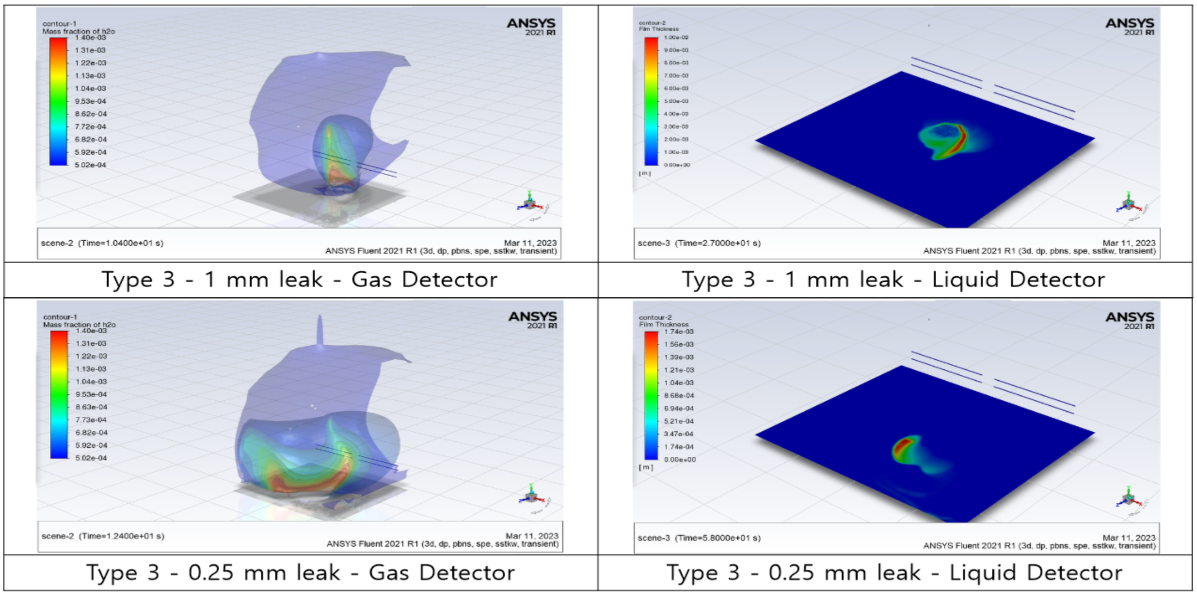

Figure 9. Results of Type 3

5. DISCUSSION AND CONCLUSION

This simulation study was based on IPA single material. Therefore, the results may not be applied to materials with different viscosity or vapor pressure. However, we confirmed that depending on the characteristics of the material, a more effective detection method could be identified. In addition, when using a leak detector, we identified that there is a method to reduce the number of detectors as well as shorten the detection time through an improved method like Type 3. Findings from this research may help reduction in costs throughout the facility by early detection of leakage and prevent to over-investment in those facilities.

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REFERENCES

International Electrotechnical Commission (IEC) 60079-10-1 Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres.

Jeong, T., 2022. Optimization of gas detector location by analysis of the dispersion model of hazardous chemicals. Journal of the Korean Institute of Gas, 26 (2), 39–48.

Korea Occupational Safety & Health Agency (KOSHA) Guide P-166-2020, 2020.