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The Study of Velocity Field in Front Opening Unified Pod by CAE

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Abstract. The front opening unified pod (FOUP) is a packing box for contamination control for semiconductor wafer transport. As the wafer fabrication process developes towards nano or atom level, the semiconductor wafer storage device should advance from the particle prevention function into the airborne molecular contamination (AMC) removal function. Therefore, it is necessary to design/redesign a function for removing AMC or moisture inside the FOUP. This study used the design of leading diffuser tubes in the FOUP and pores in the surfaces of diffuser tubes to generate gas diffusion. This is to achieve a uniform distribution of the wafer surface velocity field and a uniform dehumidification function of the wafer surface. Based on the analysis results, when circular diffuser tubes are introduced in the FOUP and the intake air flow was set at 0.2-0.3 m^3/hr, the interlayer wafer surface in the FOUP could achieve uniform distribution of velocity field. As a result, the humidity difference among various zones of wafer surface could be reduced, and the yield and quality of the wafer cutting process could be controlled.

Introduction

The semiconductor industry is confronted with new challenges as the wafer etching process develops towards micro-miniaturization. It has been reduced from the μm level to the current nm level and with a further micro-miniaturization to the au level in the future. Therefore, the semiconductor clean-room contamination control design should evolve from particles into the airborne molecular contamination control function. Multiple sources can contaminate the semiconductor during manufacturing/packing process. These sources include chemical solvent volatilization, etching sour gas, and metal or plastic precipitates [1]. Chemical contaminants which can deposit or adhere onto wafer surfaces to form a thin layer are called airborne molecular contamination (AMC). According to the definition of SEMI F21-1102, the clean-room AMC is divided into four major items: MA, MB, MC, MD, and MM. MA, MB, MC, and MM represent acids, bases, condensable organic compounds, and metals, respectively. There are extensive sources of AMC. Therefore, effectively controlling and removing the AMC contaminants is the key to the yield control of semiconductor wafer processes [2].

In the semiconductor manufacturing/packing process, the front opening unified pod (FOUP) is a container for protecting, transporting, and storing wafers. It is a transport unit preventing wafers from long-term exposure to the clean-room environment during manufacturing. AMCs are likely to combine with the oxygen and water vapor in the air and adhere to wafer surfaces, influencing the yield [3-6]. Khoo et al. indicated that the water vapor content in FOUP is an index for influences on the wafer process yield control. Nitrogen purging is considered an effective way to remove the residual water vapor from the wafer surface as it can reduce oxidation of the wafer surface. However, the continuous purging efficiency and the cost of nitrogen cannot meet the industrial production requirements [7]. Therefore, clean dry air (CDA) is used for wafer surface water vapor purging and moisture control. Additionally, to reduce the oxide content in the FOUP, air inlet and an outlet are designed at the front and the back end of the bottom of conventional FOUP. The purpose is to remove the oxygen and water from the FOUP and to avoid the oxidation of the wafer surface, thereby influencing the wafer circuit properties [7,8]. However, a research analysis revealed that arranging 25 pcs of wafers from bottom to top, it was difficult to remove moisture from the wafer surface of No. 13 situated in the middle. Hu et al. designed a curtain structure to control the uniformity of gas purging inside the FOUP [9]. However, this structural design could not uniformly remove the moisture from the wafer surface on each layer inside the FOUP.

The diffuser tube design mode and CAE analytical software helped analyze and discuss the method of homogenizing the gas flow rate on the wafer surface of various layers inside the FOUP by setting the high-pressure air flow inputted in diffuser tubes [10]. This study aims to uniformly control ambient humidity of various zones of the wafer surface and to control the wafer process yield.

Description of Research Procedure and Method

Based on the gas diffusion theory, this study designed a front-opening unified pod with gas diffusion and gas streaming functions. It also discussed methods for improving the function of homogenizing the moisture of the wafer surface on various layers inside the FOUP during the wafer transport and storage processes.

Theory

The gas diffusion theory is based on Fick's Law principle. In the steady state diffusion process of an ideal gas, the gas flow through the unit cross-sectional area normal to the diffusion direction in unit time is proportional to the concentration gradient at the section. The larger the gas concentration gradient the higher the gas diffusion flux.

The gas diffusion flux is represented by J. The unit is kg/m^2·s, i.e., the mass per unit area of gas in unit time.

$$J=-D\frac{dC}{dx}$$

D denotes the gas diffusion coefficient(m^2/s).

C is the volume concentration of gas diffusion(atomicity/m^3 or kg/m^3).

$\frac{dC}{dx}$ is the concentration gradient " − " means the diffusion direction is opposite to the concentration gradient.

Additionally, according to the Van Der Waals equation, osmotic pressure $\pi=C\times R\times T$

π denotes the gas permeation pressure.

C denotes the permeating gas concentration.

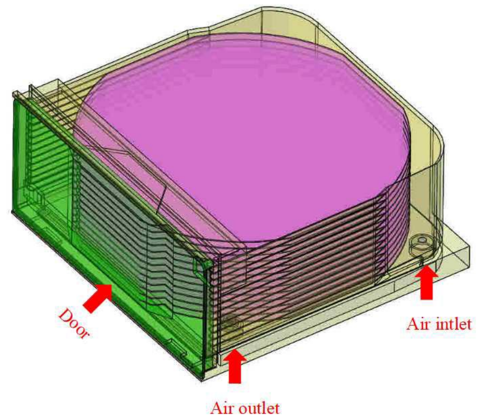
R denotes the gas constant.

T is the absolute temperature.

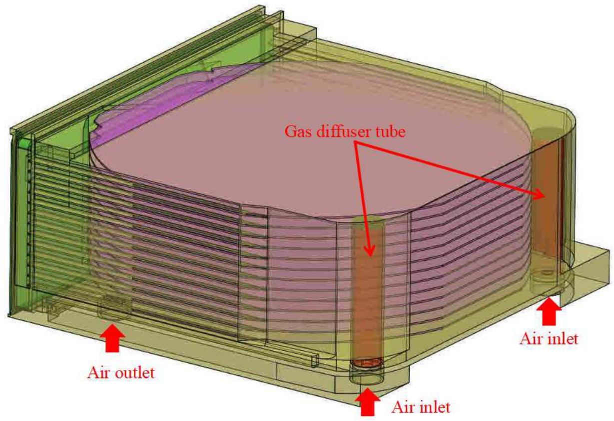
According to the theoretical basis, this study introduced the diffuser tube design in front opening unified pods. A high-pressure dry air was continuously pumped into diffuser tubes, and the dry air permeated out of the micron-sized holes in the diffuser tube surfaces while purging the fine dust particles or AMC off the wafer surface inside the FOUP. This process can dehumidify the wafer surface [11]. Diffuser tubes are hollow circular tubes, and the gas pressure difference is diffused by foaming and perforating the polymer surface. Solidworks Flow Simulation software was employed for simulations and analyses.

Analysis Model and Boundary Condition Settings

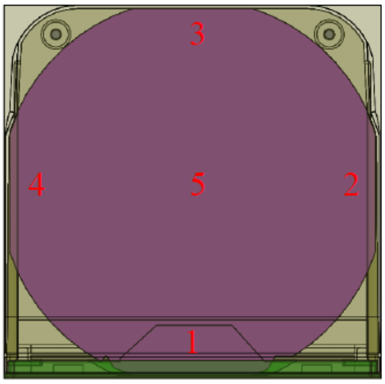
Fig. 1(a) shows the flow field analysis model of FOUP without the diffuser tube design. The structure comprises an air inlet, an air outlet, a door, wafers, and a cassette. Fig. 1(b) shows the flow field analysis model of FOUP with the diffuser tube design. The structure comprises an air inlet, an air outlet, a door, wafers, a cassette, and diffuser tubes. Fig. 1(c) shows the velocity measuring points nearby Zones 1-5 of wafer surfaces [10]. Fig. 1(d) shows the serial numbers of wafers inside the FOUP, including No. 1 to No. 13 from bottom to top, totaling 13 pcs. Table 1 shows the boundary condition settings for the FOUP flow field analysis, and the analysis time was 30 seconds.



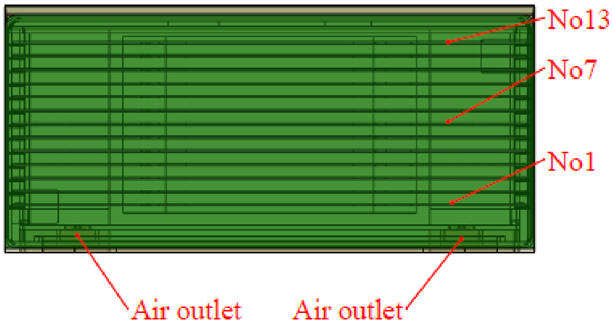
(a). FOUP without the gas diffuser tube design.



(b). FOUP with the gas diffuser tube design.



(c). Air flow velocity distributions 1-5 on wafer surface, there are 5 velocity measuring points.



(d). Serial numbers of wafers inside FOUP.

Fig. 1 Composition of Front Opening Unified Pod (FOUP)

Table 1. FOUP flow field analysis boundary condition settings

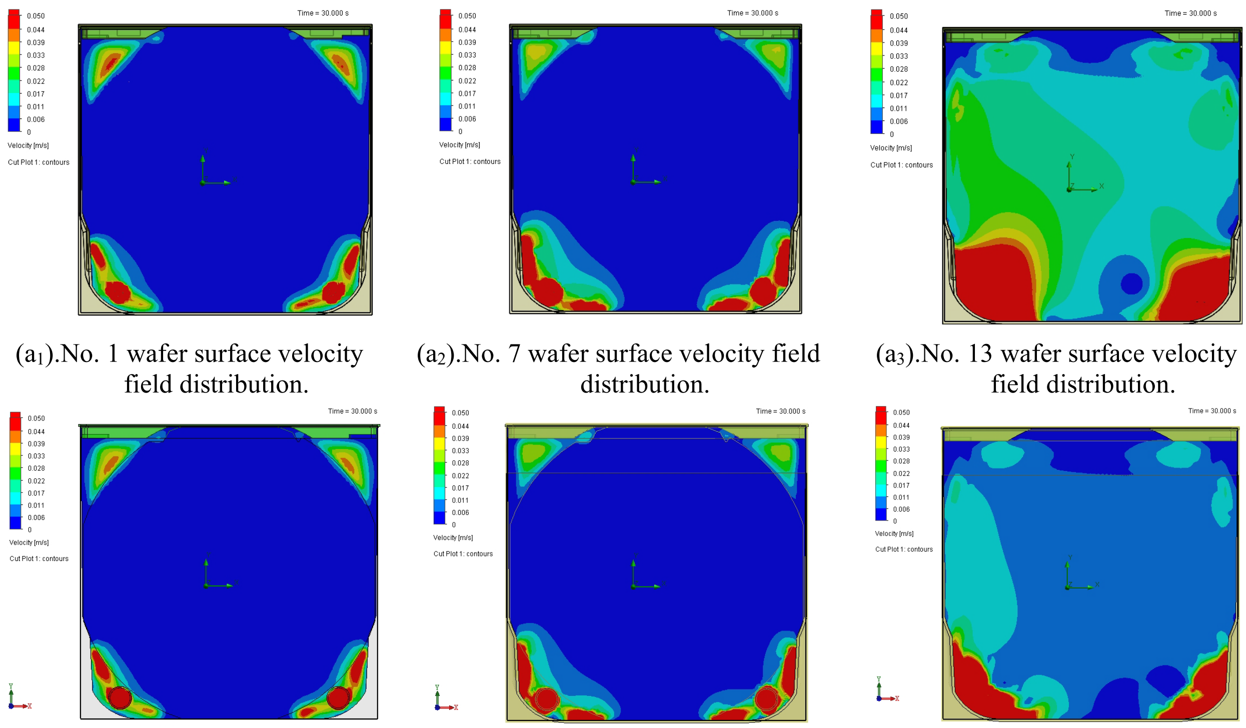
Item	Unit
CAE soft ware	Solidworks Flow Simulation
Porosity	0.5
Air inlet	20 LPM, 100 LPM, 200 LPM, 300 LPM
Total analysis time	30 seconds. Time-dependent

Results and Discussion

Differences between FOUP without the diffuser tube design and FOUP with the diffuser tube design

Fig. 2 shows the velocity field distribution on the surface of No. 1, No. 7, and No. 13 wafers in a FOUP without and with the diffuser tube design. Compared to the color bar and flow field color distribution diagrams of Figs. 2(a_1)-(a_3) with the gas flow of air-fluid fixed at 0.02 m^3/min, the velocity at Points 1-5 on the surface of No. 1 and No. 7 wafers approached 0 m/sec. This result shows that there was no apparent gas flow. The gas flow velocity range on the surface of No. 13 wafer was 0.006-0.05 m/sec. This analysis result shows that the gas generated a flow on the surface of No. 13 wafer.

With the introduction of diffuser tubes in FOUP, Figs. 2(b_1), 2(b_2), and 2(b_3) show the velocity field distribution on the surface of No. 1, No. 7, and No. 13 wafers, respectively. According to the result with the same air-flow input setting, the velocity at Points 1-5 on the surface of No. 1 and No. 7 wafers approached 0 m/sec. The gas flow velocity range on the surface of No. 13 wafer was 0.006-0.017 m/sec. This analysis shows that the gas generated a flow on the surface of the No. 13 wafer. The velocity difference range in the measuring areas 1-5 on the wafer surface was small. According to the above analysis result, when the FOUP was provided with diffuser tubes, a steady gas flow was generated on the wafer surface for wafer surface purging. Hence, a relatively uniform circuit eigenvalue can be generated for the semiconductor wafer process.



(a_1).No. 1 wafer surface velocity field distribution. (a_2).No. 7 wafer surface velocity field distribution. (a_3).No. 13 wafer surface velocity field distribution.

(b_1).No. 1 wafer surface velocity field distribution. (b_2).No. 7 wafer surface velocity field distribution. (b_3).No. 13 wafer surface velocity field distribution.

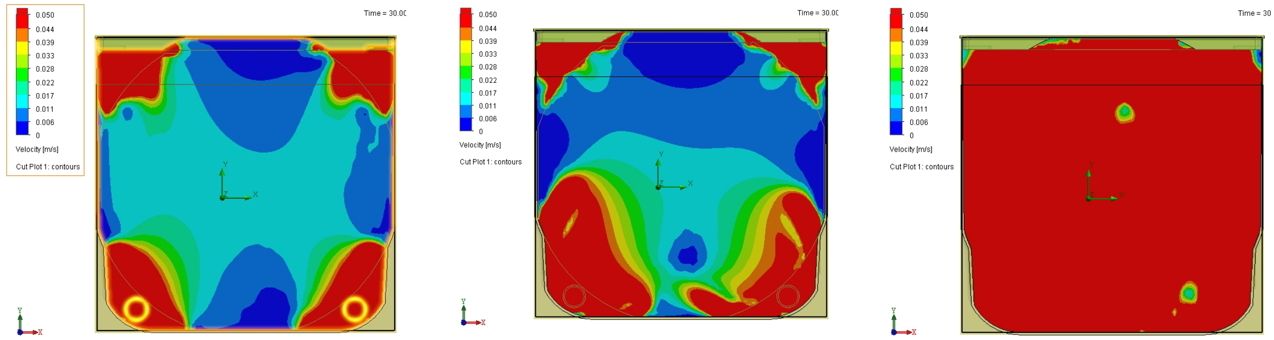
Fig. 2 Wafer surface velocity field distribution when FOUP inlet side air-flow was set at 0.02 m^3/min. a denotes without diffuser tubes; b represents with diffuser tubes.

Wafer surface gas velocity distribution pattern of FOUP with different intake air flows

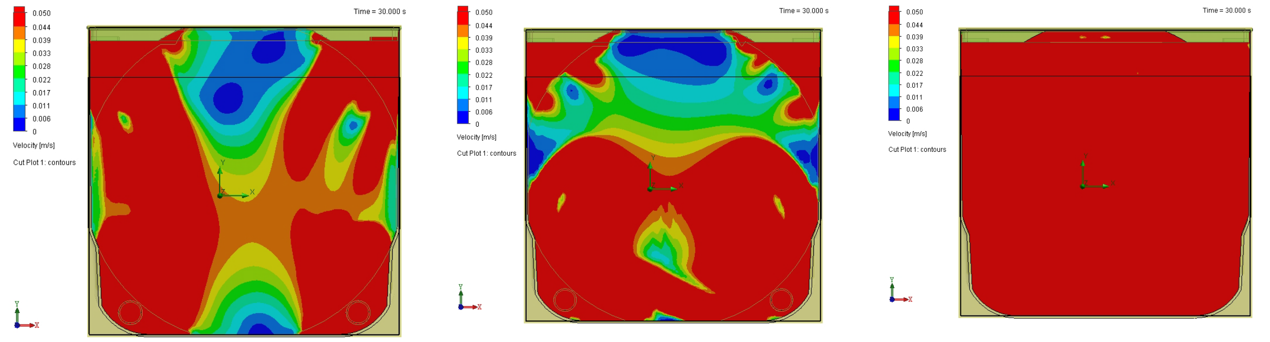
Fig. 3 shows the wafer surface velocity field distribution of FOUP with the diffuser tube design when the FOUP inlet side had different air flows. Figs. 3(a_1)-(a_3) shows the velocity field distribution on the surface of No. 1, No. 7, and No. 13 wafers, respectively when the FOUP inlet side air-flow was set at 0.1 m^3/min. According to the color bar and velocity field distribution, the gas flow velocity range on the surface of No. 1, No. 7, and No. 13 were 0-0.039 m/sec, 0-0.05 m/sec, and 0.028-0.05 m/sec, respectively. According to the analysis result, in the FOUP with the diffuser tube design, in comparison to Figs. 2(b_1)-(b_3), when the FOUP inlet side air-flow increased to 0.1 m^3/min. The difference range of wafer surface gas flow velocity decreased gradually. Therefore, this study increased the FOUP inlet side air-flow to 0.2 m^3/min and 0.3 m^3/min to analyze the velocity field on the surface of No. 1, No. 7, and No. 13 wafers in FOUP.

Figs. 3(b_1)-(b_3) show the flow field analysis result when the FOUP inlet side air-flow was set at 0.2 m^3/min. According to the result, the values at No. 3 velocity measuring point on the surface of No. 1 and No. 7 wafers were relatively low, and the value at the velocity measuring point of the color bar approached zero. The velocity field distribution on the surface of No. 13 wafer generated a uniform velocity distribution. This analysis shows that when the FOUP inlet side air-flow is increased to 0.2 m^3/min, the velocity field and uniform velocity distribution occurs at various measuring points on the wafer surface. Under this air flow setting, the air velocity value at various velocity measuring points on the surface of No. 13 wafer was 0.05 m/sec. Therefore, the FOUP inlet side air flow was increased to 0.3 m^3/min to analyze whether the velocity field distribution on the wafer surface of various layers in FOUP could be further homogenized. Figs. 3(c_1)-(c_3) shows the flow field analysis result when the air-flow increased to 0.3 m^3/min. Compared to the color bar, the velocity difference between the surface velocity fields of No. 1 and No. 7 wafers was smaller than that in Figs. 3(b_1)-(b_3).

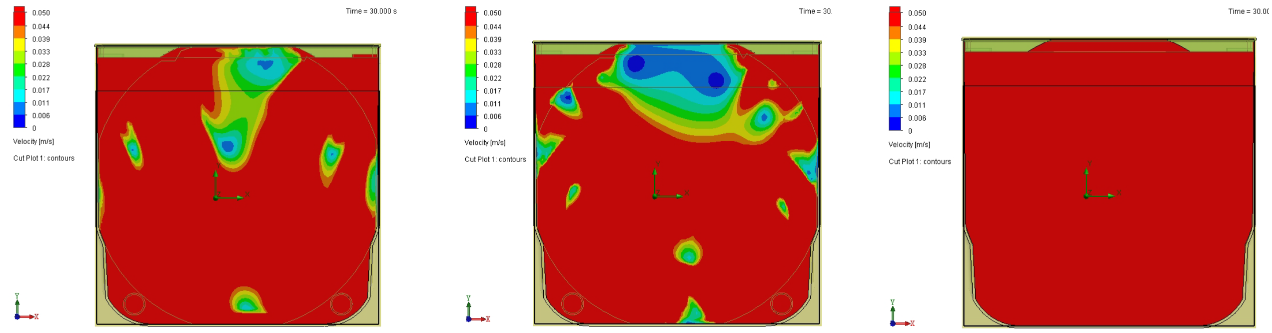
In the FOUP with the diffuser tube design, the inlet side air-flow was set at 0.2-0.3 m^3/min, and the uniform distribution of wafer surface velocity field could be controlled.



(a_1).No. 1 wafer surface velocity field distribution. (a_2).No. 7 wafer surface velocity field distribution. (a_3).No. 13 wafer surface velocity field distribution.



(b_1).No. 1 wafer surface velocity field distribution. (b_2).No. 7 wafer surface velocity field distribution. (b_3).No. 13 wafer surface velocity field distribution.



(c_1).No. 1 wafer surface velocity field distribution. (c_2).No. 7 wafer surface velocity field distribution. (c_3).No. 13 wafer surface velocity field distribution.

Fig. 3 Wafer surface velocity field distribution of different air flows on the FOUP inlet side. (a) intake air flow 0.1 m^3/min, (b) intake air flow 0.2 m^3/min, and (c) intake air flow 0.3 m^3/min.

Summary

According to the Solidworks Flow Simulation boundary condition setting and analysis results, when the front opening unified pod (FOUP) was provided with gas diffuser tubes, the intake air flow setting and diffusion method of diffuser tubes could assist in homogenizing the wafer surface velocity field distribution. A uniformed wafer surface velocity field distribution helped remove residual moisture from the wafer surface to equalize the circuit values at various measuring points. Therefore, the function of FOUP on wafer transport can be enhanced by the optimum structural design of diffuser tube shapes and setting the size of pores in the surfaces of diffuser tubes in the future.

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