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NITROGEN PURGING OF FRONT-OPENING UNIFIED POD (FOUP) FOR 450MM WAFER MANUFACTURING

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Abstract

This study aimed to investigate the nitrogen purging of front-opening unified pod (FOUP) with nitrogen for 450 mm wafer which involves stringent cleanliness requirement of water vapor content (RH ≤ 3%) within the container, besides airborne molecular contamination (AMC). A parametric study was conducted with factors considered to affect the extraction of water vapor content includes the configuration of plenum injector, purging outlet and FOUP. Computational fluid dynamic (CFD) was employed and Langmuir adsorption models were used to construct physical models of contaminant concentrations in the FOUP. The results showed that the configuration with nitrogen entering from the rear inlets and the front vent holes and porous ceramics plenum demonstrate favourable water vapor depletion rate within the gaps formed between the wafers in a fully loaded FOUP. Elaboration of nonlinear fitting was applied to theoretical model and experimental data yields the desorption coefficient K_d as 0.4 kg/s.

1. Introduction

FOUP is a container that stores the wafer and is sealed airtight to shelter the wafer from contact with the clean room environment in the conveying process to prevent particle contamination. In each FOUP there are a total of 25 pieces of wafer, and their positions are labelled from the bottom to the top in ascending order. In general, purging the FOUP with inert gas provides the following advantages: the wafers are not easily oxidized, thus preventing oxide layers from forming on their surfaces, deposition of hydrocarbon compounds on the wafer surface is avoided, and the pollution of metal particles can be avoided [1].

The technology roadmap toward miniaturization in semiconductor manufacturing leads more attentions towards yield-affecting factors from the air quality of manufacturing environment such as water vapor, oxygen, water vapor and Airborne Molecular Contaminations (AMCs). The control on AMCs has been the major issue in the yields management of semiconductor production [2-4] as well as the most noticeable water vapor and oxygen contents. With the transition of 300 mm towards 450 mm wafer manufacturing, the stringent cleanliness requirement of a 450 mm wafer FOUP is not only limited to AMCs, but also oxygen and water vapor content (≤100 ppm and RH ≤ 5%) within the container.

Moisture vapor in a FOUP was reported as more difficult to be expelled than oxygen, due to the ingress of moisture vapor of the ambient air through the polycarbonate (PC) surfaces of the FOUP [5]. On the other hand, through the computational fluid dynamics (CFD) study, it was reported that higher depletion rate of oxygen with the use of a plenum injector could be achieved compared to that without a plenum injector [6].
Nitrogen gas was presented as an effective means applied in purging carriers in semiconductor manufacturing for reducing contaminants such as 300 mm wafer FOUP and photomask box [1,7,8].

This study aims to accomplish the following objectives: (1) to optimize purging gas inlet/outlet locations, and (2) to determine effect of varied inlet plenum design, and (3) to quantitatively identify the desorption coefficient of water vapor content on FOUP surfaces. The desorption coefficient of water vapor content is then compared with those results of the 300mm wafer FOUP.

2. Experiment

Figure 1 depicts the top view of four purging/vent holes at the base of a 450 mm wafer FOUP nitrogen purge system based on SEMI 4570B Standard [9].

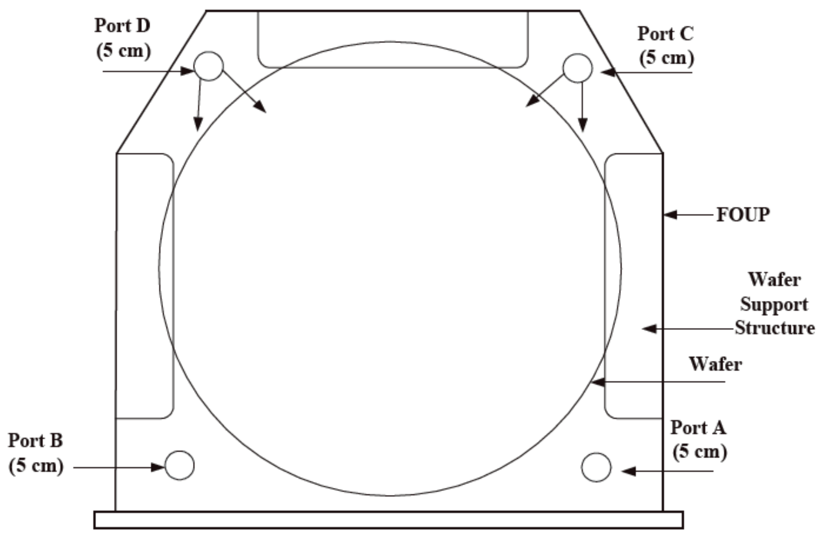


Figure 1 Top view of FOUP nitrogen charge system, showing the nitrogen inlet/outlet locations.

2.1 Model Equations

Assuming that the purge gas at a flow rate of Q (m^3/s) is completely mixed with FOUP air with volume of V (m^3), the concentration C (kg/m^3) of species (could be oxygen or water vapor content) at purge time t (s) in a FOUP can be derived from Langmuir's isothermal adsorption equation [10]:

$$C(t) = C_{t=0}\exp\left[-\frac{(K_a A+Q)}{V}t\right] + \frac{(K_d MA)}{(K_a A+Q)}\left\{1-\exp\left[-\frac{(K_a A+Q)}{V}t\right]\right\} \quad (1)$$

where K^a [kg/(sm2)], K^d (kg/s), M (kg), and A (m^2) are the adsorption coefficient, desorption coefficient, ingression mass of species, and surface area, respectively. The time t needed for an initial concentration to decrease drop below a certain level in a purge system is analytically expressed.

The CFD study was performed using FLUENT software (version 6.0 (2003)). The species transport equation for the k' th species is in the following general form [11]:

$$\frac{\partial}{\partial t}(\rho c_k) + \frac{\partial}{\partial x_i}(\rho u_i c_k) = \frac{\partial}{\partial x_i}\left(\Gamma_{c_k}\frac{\partial c_k}{\partial x_i} - \rho\overline{u_i' c_k'}\right) + S_{c_k} \qquad k = 1,\ldots,N \quad (2)$$

where N is the number of species, Γ_{Ck} the effective exchange coefficient for the C_k species, the species C_k, ui the i-th velocity component, and S_{Ck} the source term of C_k species. In this study, two species i.e., nitrogen and water vapours were considered.

Grid testing for both space and time domain were performed. The final grid number and time step adopted were 733,346 and 1 second, respectively.

2.2 Cases Description

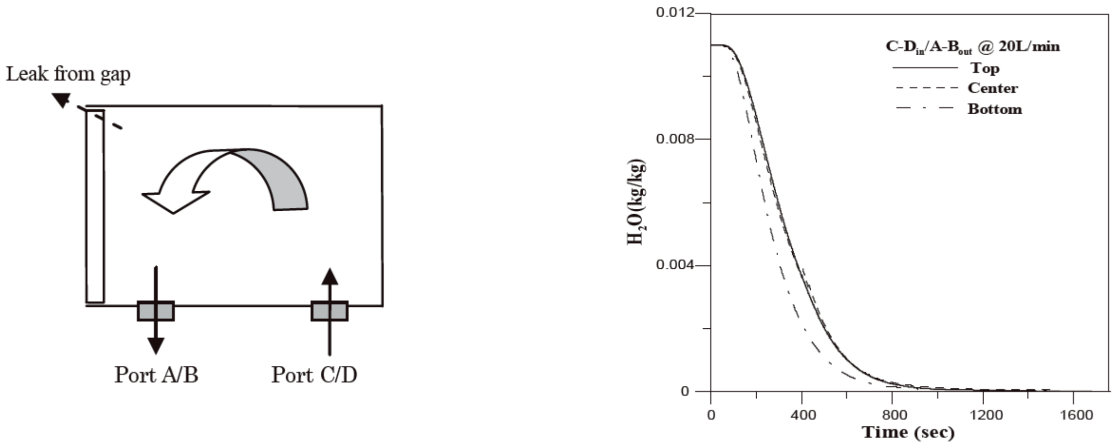
In the measurement system, the outlet is connected to an exhaust fan. A mass flow controller with an operational range of 0 to 50 L/min was used to control inlet volume of 99.999% nitrogen. Nitrogen with flow rate range of 10 L/min, 15 L/min and 20 L/min were tested. Nitrogen entering the FOUP can be arranged through either the front ports (Port A-B) or the rear ports (Port C-D) with plenum injectors to diverge the incoming stream. In Case 1, Port C and Port D at the rear of FOUP were set as inlets while Port A and port B were set as outlets. Conversely, Port A and Port B located near the opening of FOUP were set as inlets while Port C and port D were set as outlets in Case 2. For each case, a total purging time of 30 minutes was set to simulate the purging process once the mass flow controller was modulated to lead-in nitrogen.

As dew point temperature and relative humidity (RH) were important measures in the study, dew point sensors (each 2 cm L x 3 cm W x 0.5 cm H) with specifications of measuring range of - 20°C to 70°C and RH range of 0% to 95%, and measuring precision of ± 1°C and ± 2% RH were installed for monitoring the dew point temperature within the FOUP, respectively. Cleanliness requirement of water vapor content (RH ≤ 3%) within the container was served as key evaluation factor. Three types of inlet plenum injector with diameter of 18 mm were applied in the study for better purging effect including slit (two columns of 260 mm length x 2 mm diameter), round pinhole (two columns of 2mm diameter holes) and porous ceramics types. By considering the gap above the 1st wafer as the most critical spot to reach the desired purging effect, these sensors were placed on the 1st wafer to detect the residue water vapor during the purging process. The FOUP door was modified to obtain better tightness.

3. Results and Discussion

3.1 Effects of the Configuration of Purge Holes (Inlets) and Vent Holes (Outlets)

Based on schematic diagrams shown in Figure 2(a), as for Case 1, the nitrogen from inlet plenum will have sufficient time to well mix with the air in FOUP and further remove the air through the vent holes that located in the vicinity of the front opening of FOUP, with minor leak out through the tiny gap at front opening. In Case 2, as the inlets are placed near the front opening of FOUP, accumulation of high concentration of nitrogen in this domain can easily bypass from purging inner space and tend to leak out through the tiny gap at front opening. Consequently, longer lead time will be required for complete purging and some dead-corner will be developed in the FOUP where contaminant retained. Such unfavourable conditions will incur higher consumption rate of nitrogen, affect the yields of products and thus increase the operating cost. It is desirable to decrease the consumption of purging gas to decrease cost [1]. Figure 2(b) demonstrates the profile of water vapor depletion rate in the FOUP obtained at three detecting points placed at bottom (1st wafer), centre (13th wafer) and top (25th wafer) of the FOUP with nitrogen purging rate of 20 L/min for Cases 1. It is noted that the profiles of the measured water vapor depletion in both cases are similar generally. It is found out that an additional 350 seconds of purging lead time is required to eliminate the water vapor down to 0.002 kg-water/kg-air in Case 2 compared with those in Case 1. The configuration with nitrogen entering from the rear inlets (Port C and D) and the front vent holes (Port A and B) is superior to that with the front inlets (Port A and B) and the rear vent holes (Port C and D).



(a) (b)

Figure 2 Schematic diagrams and depletion of water vapor in FOUP during nitrogen purging process for Case 1 (C-Din/A-Bout).

3.2 Effects of Inlet Plenum Injector Design

In a 450 mm wafer FOUP with full loading, dead zones are said to be developed within the gaps between these 25 pieces of wafers, where the trapped air within these zones is difficult to be depleted during purging process as the physical structure of the wafer layers will form a resistance against the flow stream of purging gas. However, these zones are still managed to be purged but with longer lead time, and as the zones with the lowest purging efficiency. In order to improve the purging effect, three different types of inlet plenum design were experimentally studied. Figure 4 depicts the profiles of water vapor depletion in FOUP till the requisite of RH level (below 3%RH) with varied flow rates of nitrogen in the purging process using slit, pinhole, and porous ceramics plenum, respectively.

In general, it is noted that rapid depletion of water vapor took place in the first 200 seconds for all types of plenums applied and subsequently followed by a declined depletion rate. Besides, the water vapor depletion rate is increased as the flow rate of nitrogen supply is increased from 10 L/min to 20 L/min. In Figure 3, it is also demonstrated that the water vapor content in FOUP was expelled below 3% RH within the approximated lead time of 650 seconds by using porous ceramics plenum at all varied flow rates of nitrogen during the purging process. Moderate outcomes were obtained as nitrogen purging with slit plenum. Adversely, the water vapor content in FOUP was remained above 5% RH by using pinhole plenum at all varied flow rates of nitrogen. With high porosities physical structures, high static pressure will be developed within the porous ceramics plenum and thus yields the extrusion of purge gas current with balanced velocity which improves the purge effects on water vapor depletion within the wafer gaps.

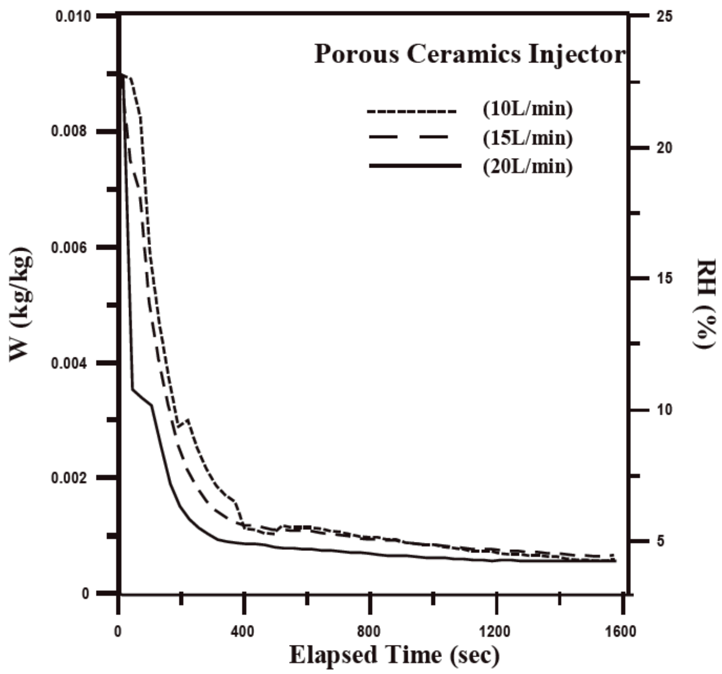


Figure 3 Profiles of water vapor depletion in FOUP during nitrogen purging process using porous ceramics plenum injector.

3.3 Desorption Coefficient (*Kd*)

An elaboration of non linear fitting was applied to the theoretical model and the experimental data. The total amount of water desorbed from the FOUP interior surface (*M*) was assumed to be 1 mg (Frickinger et al.)). By incorporating *M* = 1 mg, volume of 450 wafer mm FOUP, *V* = 0.073528 m3, concentration of water vapor at initial time, *Ct =0* = 0.012 kg-water/kg-air, nitrogen flow rate, *Q* = 0.01 m3/min, and total surface area (including wafers), *A* = 1.075 m2 into Equation (1), the non linear fitting elaboration to experimental data yields desorption coefficient *Kd* = 0.4 kg/s.

4. Conclusions

Based on the results and discussion, the following conclusions are drawn:

1. The configuration with nitrogen entering from the rear inlets (Port C and D) and the front vent holes (Port A and B) is superior to that with the front inlets (Port A and B) and the rear vent holes (Port C and D).

2. The water vapor depletion rate is increased as the flow rate of nitrogen supply is increased from 10 L/min to 20 L/min. The water vapor content in FOUP was expelled below 3% RH within the approximated lead time of 650 seconds by using porous ceramics plenum at all varied flow rates of nitrogen during the purging process. Porous structures within the ceramics plenum helps to develop high static pressure and subsequently generate balanced purge gas velocity which improves the purge effects on water vapor depletion within the wafer gaps.

3. Elaboration of non linear fitting was applied to the theoretical model and the experimental data yields desorption coefficient *Kd* as 0.4 kg/s.

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