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The novel chamber hardware design to improve the thin film deposition quality in both 12″ (300 mm) and 18″ (450 mm) wafers with the development of 3D full chamber modeling and experimental visual technique

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ABSTRACT

The thin film deposition property and the process difference during the wafer size migration from 12″ (300 mm) to 18″ (450 mm) in the Chemical Vapor Deposition (CVD) equipment is improved and reduced, respectively, when the chamber hardware is designed with the help of 3D full chamber modeling and 3D experimental visual technique developed in this work. The accuracy of 3D chamber simulation model is demonstrated with the experimental visual technique measurement. With the CVD chamber hardware design of placing the inlet position and optimizing the distance between the susceptor edge and the reactor wall, the better thin film deposition property and the larger process compatibility during the wafer size migration from 12″ (300 mm) to 18″ (450 mm) for the industry cost reduction can be achieved. Non-dimensional Nusselt parameter is also found to be the effective indicator to monitor the thin film deposition property.

1. Introduction

In order to continuously reduce the process cost of the electrical device chip in the semiconductor industry, the wafer size migration from 12″ (300 mm) to 18″ (450 mm) is found to be the highly potential and useful solution [1]. The key issue of this wafer size migration for the tool vender and integrated circuit (IC) manufacturer is chamber hardware design [2,3] and process matching [4], respectively. Tool vender needs the accurate three dimensional (3D) full chamber simulation models and visual technique [5,6] for the chamber hardware understanding. IC foundry wants to know how to do the process monitoring and find out the transferred formula between these two different wafer dimensions during the wafer size migration. Many different groups have studied some of these important issues for a long time. Kusumoto et al. [7] studied the effect of the different operating pressure and mass-flow rate at inlet for the flow field in the Chemical Vapor Deposition (CVD) reactor. Evans and Greif [8] investigated the different boundary condition settings of the CVD reactor wall on the simulation model. Lin and co-workers [9] had a thorough investigation on the influence of the flow field with different distance between inlet and susceptor in the CVD chamber. Weyburne and Ahern [4] presented and compared some dimensionless numbers to identify the operating mode in the CVD system. In this work, based on the developed 3D full chamber simulation model and experimental 3D visual technique, the chamber hardware designs including "the different kinds of the inlet position" and "the optimization of distance between CVD susceptor and wall" are proposed to improve the thin film deposition rate, deposition uniformity, and reduce the process migration difference between 12″ (300 mm) and 18″ (450 mm) wafers. Finally, the process matching and transferred formula among these different wafer sizes are also provided based on the investigation of the non-dimensional Nusselt parameter.

2. Experimental

Both 3D simulation model and experimental 3D visual technique for the CVD chamber are developed in this work. In order to verify the accuracy of our simulation model, we simulate a general CVD reactor with the 2 inch diameter susceptor firstly and compare it with the experimental data, observed by the Particle Image Velocimetry (PIV) visualization technique [10] built in the real CVD chamber. Fig. 1 shows the sketch of the experimental set-up for the 3D PIV visualization technique used in this work.

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Nomenclature

$\vec{g}$	gravity
C_p	heat capacity
k_{eff}	effective thermal conductivity
j	mass flux of species i
M_i	molecular weight of species i
F	source term
T	temperature
h_i	enthalpy of species i
w_i	mass fraction of species i
$R_{i,k}$	molar reaction rates of species i in reaction k

Greek symbols

ρ	density
τ	shear stress
$\vec{u}$	velocity vector

The high speed charge coupled device camera can help us to record the flow of the inserted particles in the chamber to extract the characteristics of fluid pattern and fluid velocity during the real thin film deposition process in the CVD chamber. The different reflected colors for the inserted particles under the Ar+ laser excitation in the CVD chamber can help us to get the temperature profile. The comparison on the fluid velocity profile and temperature distribution in the chamber between our 3D simulation results and the experiment data obtained by 3D PIV visualization technique is shown in the Fig. 2. It can be found that the simulated results and experimental data agree well with each other. Our 3D simulation model indeed can accurately simulate the scale of velocity and the position of vortices so as to get the characteristics of fluid pattern and understand the interaction of the fluid near the reactor wall in the CVD chamber. After the accuracy of the 3D simulation model is demonstrated, we expand our simulation model by increasing the diameter of the reactor from 2″ to 12″ (300 mm) and 18″ (450 mm) in proportion. More realistic models [11] with some configurations are also considered. For the sake of testing process compatibility of CVD reactor on 12″ (300 mm) and 18″ (450 mm) wafers, we keep the detailed structure of both models the same and only change their diametrical dimensions.

Fig. 3 shows the settings of the boundary conditions and the detailed CVD dimensions in our simulation model. The shapers and dimensions of the inlet is circular and 5 cm diameter respectively. The showerhead in the CVD reactor has the shape of a ring and gases are injected in parallel with the susceptor, which is a rotating disk. In this work, the influence of different inlet positions (case A, case B, and case C shown in the Fig. 3) and the optimization of the distance between susceptor and reactor wall are investigated, respectively. The software used in this work is Fluent. The numerical algorithm is based on the pressure-based coupled algorithm. The governing equations in this simulation include the continuity equation the Navier–Stokes equation the energy conservative equation and the mass transfer conservative equation Equations are shown as below:

$$\nabla \cdot (\rho \vec{u}) = 0 \tag{1}$$

$$\nabla \cdot (\rho \vec{u}\, \vec{u} = -\nabla p + \nabla \cdot \tau + \rho \vec{g} + F \tag{2}$$

$$\nabla \cdot (\rho C_p \vec{u} T) = \nabla \cdot (k_{eff} \nabla T) + \nabla \cdot \left(\sum_{i=1}^{n} h_i \vec{j}_i \right) \tag{3}$$

$$\nabla \cdot (\rho \vec{u} w_i) = -\nabla \cdot \vec{j}_i + M_i \sum_{k=1}^{N_k} R_{i,k} \tag{4}$$

The boundary conditions [12] as below are also imposed in the simulation:

- Negligible radiation in the reactor.
- The constant temperature is assumed on the CVD reactor wall.
- The constant velocity of the inlet gas is assumed.
- The mass fraction of trimethyl gallium ($Ga(CH_3)_3$) and Arsine (AsH_3) for the mixture of the gas is 0.15 and 0.4, respectively.
- The rotational speed and surface temperature of the susceptor is 1000 rpm and 1000 K, respectively.
- Operating pressure is 10000 Pa.
- Inlet velocity is 0.0964 m/s.
- For the chemical reaction on the wafer surface, we use the model as below:

$$AsH_3 + Ga\_s \rightarrow Ga + As\_s + 1.5H_2 \tag{5}$$

$$Ga(CH_3) + As\_s \rightarrow As + Ga\_s + 3H_3 \tag{6}$$

- Reynolds number of inlet flow for 12″ chamber is 46.68.
- Reynolds number of inlet flow for 18″ chamber is 64.17.

It is needed to note that the reasons why the validation (visualization) is on gas phase but the uniformity is judged based on surface deposition is because that Metal Organic (MO) CVD is a reaction limited operation where the deposition is not influenced by the gas transport.

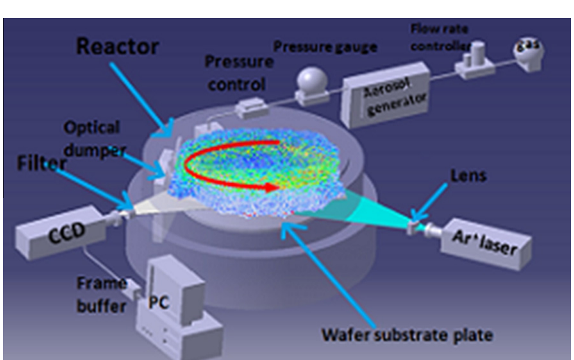

Fig. 1. Framework of the experimental particle image velocimetry equipment to investigate the fluid velocity, position of vortices, and temperature profile in the chemical vapor deposition reactor.

3. Results and discussion

Fig. 4 compares the characteristics of the deposition rate and the temperature of the susceptor across the 12″ (300 mm) wafer with different chamber designs and layouts. The cases of type A, B, and C represent the chamber with the inlet at the top side, left side, and right side of the reactor wall, respectively. The cartoon for these different chamber layouts is shown in the Fig. 3 for the reference. In addition to the temperature of the susceptor, deposition rate and deposition uniformity, important factors for the IC foundry, are needed to be examined carefully. It can be found that although there have similar characteristics of deposition among these three cases, type A with the inlet at the top of the reactor