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Flow field investigation in a rotating disk chemical vapor deposition chamber with a perforated showerhead

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ABSTRACT

A flow field in a simulated rotating disk chemical vapor deposition chamber in which the inflow gases entered through a showerhead inlet was experimentally investigated using particle image velocimetry. The deposition uniformity was highly related to the flow pattern, which was influenced by the buoyancy, centrifugal, and flow inertia forces. This study investigated flow patterns for different processing parameters, namely chamber heights (20 and 40 mm), jet-to-disk temperature differences (0–500 °C), and disk rotational speeds (0–500 rpm). The time-averaged axial and radial velocity profiles were determined for examining the effects of rotation and heating on flow uniformity above the rotating disk. The Reynolds stress and turbulence intensity was found to be influenced by the buoyancy and rotation induced flow. At a high jet-to-disk temperature difference, the upward buoyancy force lifted the flow and prevented the inlet flow from reaching the disk surface. The buoyancy-induced flow can be suppressed through disk rotation or chamber height reduction. Moreover, the nondimensional parameters (Grashof number and rotational Reynolds number) can be used to construct flow regime maps and quantify the effects of rotation and heating even with the contribution from different chamber heights, disk temperatures, and rotational speeds.

1. Introduction

Thin films grown through rotating disk chemical vapor deposition (CVD) can be used for large-scale production of semiconductor materials. The epitaxial process for producing thin-film materials must achieve a high degree of uniformity in compositional layers, which is strongly influenced by the flow field. A smooth reacting gas flow over the substrate without flow recirculation is preferred for higher deposition uniformity. In an actual deposition process, the strong buoyancy force from a high-temperature substrate or the strong centrifugal force from a rotational substrate can break flow uniformity and detrimentally affect the deposition layer.

Studies of the hydrodynamics inside the deposition chamber have typically involved flow visualizations or numerical simulations. Winters et al. [1] investigated the mixed convection in a rotating disk CVD reactor. The flow can be analyzed using the convection parameters on the basis of the density difference of the incoming flow. A more unstable flow is generally related to higher pressures, lower temperatures, and greater inlet density differences. Lowering the inlet flow velocity leads to a more uniform boundary layer on the rotating disk and enhanced mixing at the disk surface. Joh and Evans [2] numerically investigated the heat transfer and flow stability in a rotating disk reactor with particular emphasis on the effect of the spacing between the stationary gas inlet and the rotating disk. The flow recirculation was observed above the rotating disk at a very low inlet flow velocity. Soong et al. [3] predicted the thermo-flow structure in a rotating disk metal-organic CVD reactor. They observed that the large rotating disk could generate premature flow unsteadiness and instability because of strong rotational forces. Santen et al. [4] numerically investigated the flow symmetry breaking in a CVD reactor. They observed that the symmetry breaking was due to the buoyancy effects alone and not from an interaction between forced and free convection. Symmetry breaking can be suppressed using a relatively low inlet flow or disk rotation rate. Vanka et al. [5,6] investigated the mixed convection flow in an impinging jet CVD reactor for deposition of thin films at atmospheric pressure. Highly uniform deposition at atmospheric pressure can be achieved in this impinging jet reactor by the appropriate choice of the inlet flow rate, substrate rotational rate, and reactor dimensionless length. Employing round corners in this reactor can streamline the corner flow and suppress the instabilities of the shear layers [7]. Kadinski et al. [8] examined the effects of process parameters and reactor

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Nomenclature

D_i	diameter of showerhead flange (m)
g	gravitational acceleration (m/s^2)
Gr	Grashof number ($=g\beta\triangle TH^3/\nu^2$)
H	chamber height (m)
Q	inlet volume flow rate (slpm)
r, z	radial and axial coordinates
R	radius of the rotating disk (m)
Re	Reynolds number ($=\rho V_i D_i/\mu$)
Re_ω	rotational Reynolds number ($=\omega R^2/\nu$)
T_i	inlet fluid temperature (°C or K)
T_R	reference temperature ($=\frac{T_w+T_i}{2}$, °C or K)
T_w	disk temperature (°C or K)
ΔT	temperature difference between the disk and the inlet fluid (°C or K)
$\bar{V}$	average velocity (m/s)
V_i	flow velocity from the showerhead inlet (m/s)
V'_r, V'_Z	fluctuating velocity components in radial and axial directions (m/s)
V'_{rms}	root-mean-square of the turbulent velocity fluctuations (m/s)
V_r, V_z	radial and axial velocity components (m/s)
β	thermal expansion coefficient ($=1/T_R$)
μ	dynamic viscosity of fluid (Pa·s)
ν	kinematic viscosity (m^2/s)
ρ	density of fluid (kg/m^3)
ω	rotational speed (rad/s)

geometry on the growth rate and uniformity in a GaN-based vertical rotating disk reactor. They observed that growth uniformity and alkyl efficiency can be improved by modifying the injection system, which simultaneously controls the alkyl concentration and injection speed. Kim et al. [9] examined the effects of showerhead shapes on the flow fields in a CVD reactor. They examined the effects of the number of injection holes and rotational speed of the susceptor and concluded that the buoyancy-induced flow regime must be avoided to achieve greater deposition uniformity. Mitrovic et al. [10–12] conducted a series of studies regarding flow stability for different processing parameters and reactor design. Flow regimes can be classified as plug, buoyancy-induced, and rotation-induced regimes. Process optimization was investigated to obtain the maximum deposition rate and uniformity. They observed that the increased total flow rate can achieve higher operating pressures and deposition rates; however, the deposition rate could also be reduced because of the higher dilution of the reactants.

Experimental measurement in a CVD reactor can also provide useful information regarding the flow regime and deposition uniformity. Nondimensional parameters are effective in identifying the flow regimes and analyzing the flow instability. Biber et al. [13] investigated the flow regime map and deposition rate uniformity in a vertical rotating disk reactor, identifying the flow regimes as plug, buoyancy-induced, and rotation-induced flow regimes. The plug flow regime, in which the flow circulation was not induced, was preferred because of the highest deposition rate uniformity. Horton and Peterson [14] used Rayleigh light scattering to measure the transient gas temperature and performed flow visualization in a simulated rapid CVD reactor. The flow field became unstable when the Gr/Re^2 ratio reached a value of 5 because of the buoyancy-induced plume and recirculation. Mathews and

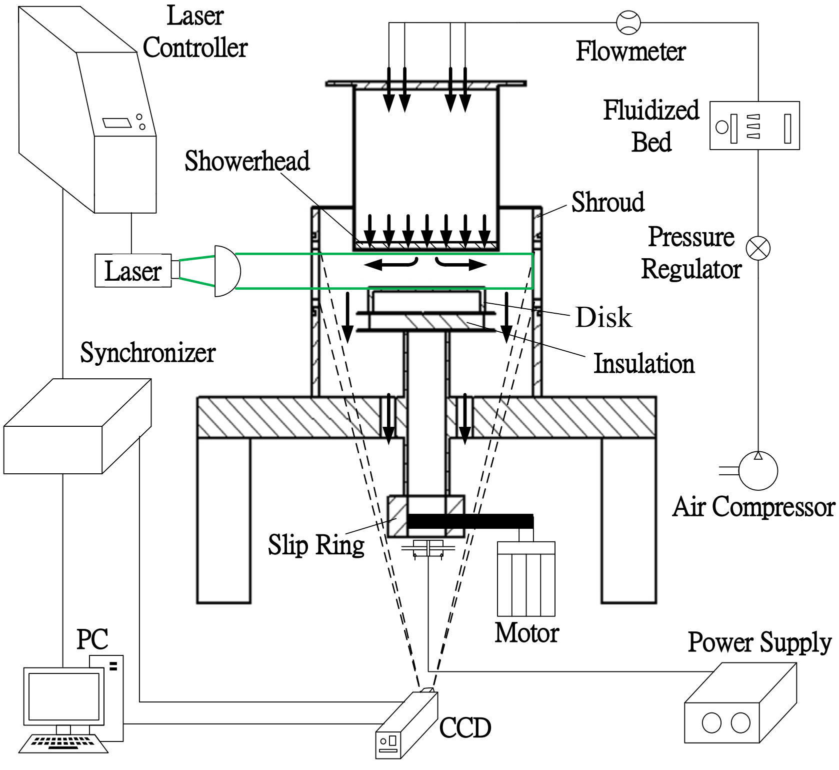

Fig. 1. Experimental setup.