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低速空氣噴流撞擊一大直徑加熱圓板之混合對流新渦流結構及其不穩定特性研究(2/3)

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低速空氣噴流撞擊一大直徑圓板之混合對流新渦流結構及其不穩定特性研究(2/3)

Investigation of New Vortex Flow Structures and Their Transition Characteristics in a Low Speed Confined Air Jet Impinging onto a Large Heated Disk (2/3)

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主持人:林清發 交通大學機械系

一、中文摘要

本三年期研究計畫主要是利用實驗量測與觀測來探討在垂直 MOCVD 製程中，由一大直徑的高溫晶圓所驅動之不穩定混合對流現象及各種可能出現的渦流結構，找出各種渦流出現及存在的條件，及其熱傳及流動之特性，特別針對渦流結構之改變過程詳細研究。在本年度計畫裡(民國 94 年 8 月至民國 95 年 7 月)，我們已改善實驗系統，並完成初步雷諾數和雷利數對噴流裡渦流結構影響的實驗。將來我們將繼續探討噴流裡各種可能出現的渦流結構。

關鍵字: 渦流結構，MOCVD 製程，噴流撞擊

Abstract

A three-year research project is proposed here to investigate the possible presence of new vortex flow structures and the associated flow and thermal characteristics in an impinging jet over a large horizontal heated disk modeled that encountered in the vertical MOCVD processes. The detailed flow and thermal characteristics will be obtained by combining the flow visualization and transient temperature measurement. In this year of the study (August 2005 to July 2006), the experimental system for the present vortex flow investigation has been improved and initial tests of the effects of Reynolds and Rayleigh numbers have been investigated. Then in the third year, we visualize various vortex flow structures in the jet and measure the associated thermal characteristics.

Keywords: vortex flow structures, MOCVD processes, impinging jet

二、計畫源由與目的

The complex vortex flow and associated thermal characteristics simultaneously driven by the buoyancy and inertia in a laminar convective gas jet impinging vertically downwards onto a heated horizontal disk confined in a vertical cylindrical chamber are directly relevant to the growth of single crystal thin films from the metal-organic chemical vapor deposition (MOCVD) processes in a vertical reactor and have been extensively investigated in the past decades [1]. The recent fast increase of the wafer size to reduce the fabrication cost needed in various microelectronic applications causes the buoyancy driven flow and heat transfer in MOCVD processes to become relatively complex and unstable. Vortex flow in the form of circular rolls has been unveiled. Depending on the jet Reynolds number and buoyancy-to-inertia ratio, up to four inertia-driven rolls and two buoyancy-driven rolls were observed in the impinging jet flow [2-4]. Besides, both the inertia- and buoyancy-driven time dependent vortex flows were identified. In spite of these findings, a more fundamental question on the low speed jet impinging onto a large heated disk considered here is the possible presence of other vortex flow patterns such as the radial rolls, bifurcation rolls, incomplete rolls, cells, etc. Under what conditions these new vortex rolls appear. This is still poorly understood and needs to be explored. In the present research project the experiment is conducted to unravel the possible presence of new vortex flow structures and the associated flow and thermal characteristics in a confined impinging air jet over a large horizontal heated disk. To simplify the experiment system, the disk is not placed in a cylindrical chamber but the impinging jet is considered to be confined by an upper horizontal plate. Effects of the jet Reynolds number and Rayleigh number on the predicted flow and thermal structures will be examined in detail.

Considerable amount of work has been carried out in the past to study the fluid flow and heat transfer in the round or slot jet impinging vertically downwards onto a large horizontal plate without any confinement. Most of the studies focused on quantifying the highly efficient heat transfer and fluid flow associated with the high speed impinging jets. For instances, heat or mass transfer in the impinging jets over a large plate was experimentally investigated by Scholtz and Tr ass [5], Sparrow and Wong [6], Masliyah and Nguyen [7], and Hrycak [8]. Simulation investigations on the cooling efficiency of the impinging jets were carried out by Chou et al. [9] and Chung and Luo [10]. Some recent numerical simulation predicted location of the centers of inertia driven vortexes for liquid jet by the Reynolds stress model was reported by Morris et al. [11, 12]. And effects of buoyancy on the flow field and heat transfer rate for aiding or opposing mixed convective impinging jets were investigated by Sarhini and Ruocco [13]. Heat transfer in laminar impinging jets with upper plate confinement were numerically predicted by Saad et al. [14] and Law and Masliyah [15]. A pair of big flow recirculations around the wall jet region in the form of circular vortex rolls was noted to result from the confinement plate (Chua et al. [16], Voke and Gao [17]). The characteristics of the recirculation were found to be influenced by the jet Reynolds number Re_j and nozzle-to-plate spacing H (Fitzgerald and Garimella [18], Park et al. [19], and Ichimiya [20]). Their numerical predictions revealed that the centers of the flow recirculations moved away from the jet axis and the recirculations were larger at increasing Re_j and H. Moreover, the secondary flow in a confined impinging jet includes a large recirculation roll vortex around the jet axis and a comparatively smaller neighboring vortex roll right above the impinging plate (Law and Masliyah [15, 21]). Details on the size and locations of the inertia driven primary and secondary vortex rolls affected by the Reynolds and Richardson numbers for laminar confined slot-jet (Re_j = 100 - 500) were recently examined by Sahoo and Sharif [22]. Moreover, for a confined laminar impinging jet (Re_j <1000) the critical jet Reynolds number for the onset of unsteady flow was numerically shown to be between 585 and 610 [23] and the breaking in the axisymmetry impinging jet structure began to appear at Re = 750 for H/W = 5. The unsteady jet was characterized by a dominant frequency corresponding to the formation of shear layer vortices at the jet exit. Critical reviews on impinging jets were conducted by Viskanta [24] and Jambunathan et al. [25]. A recent investigation from Santen et al. [26, 27] pointed out the onset of thermal instability for axisymmetric and three-dimensional vortexes. Besides, the secondary flow in the form of circular rolls, transverse (radial) rolls and three-dimensional irregular rolls were mentioned. Moreover, the buoyancy induced secondary flow is composed of regular torus-shaped rolls near the inlet jet due to the suppression by the jet inertia. The three-dimensional irregular rolls appear in the region at larger radial distance from the jet axis because the buoyancy force dominates there. But the detailed characteristics of the transverse and irregular rolls were not investigated.

In the impinging jet flow confined in a chamber encountered in the chemical vapor deposition CVD, the gases input to the CVD chamber are at relatively low flow rates and the wafer upon which thin crystal films are grown and processed is at an elevated temperature with the Reynolds and Rayleigh numbers respectively ranging from 1.0 to 100.0 and from 0 to 10^5 [1]. Under such circumstance the buoyancy in the flow is no longer small compared with the jet inertia. Significant flow recirculation can be induced by the combined effects of the inertia and buoyancy. The importance of the buoyancy on the recirculating flow in a vertical CVD reactor was demonstrated by Wahl [28]. Similar investigations have been carried out for various types of CVD reactors including the MOCVD [29-31] and organometallic vapor phase epitaxy (OMVPE) [32]. In these studies for the processing of the microelectronic circuits [28-33] various vortex flow patterns were reported in the jet impinging flow.

The above literature review clearly reveals that in a jet impinging onto a heated disk the inertia and buoyancy driven vortex rolls aside from the circular rolls may be induced. But the patterns of these new vortex flows and the associated thermal characteristics remain largely unexplored. The experimental vortex flow patterns will be visualized in the present study to examine the possible presence of the inertia and buoyancy driven new vortex rolls in an air jet impinging onto a large heated disk with an upper plate confinement. Attention will be focused on delineating the conditions leading to the appearance of these rolls and the detailed flow characteristics of these rolls.

三、結果與討論

(1) At first, the typical vortex flow pattern for the case in the space between the horizontal disks with the injection pipe for D_j=20.0 mm at long time when the flow is already at statistical state for the unheated disk (Ra=0) is illustrated in Fig. 1. The results clearly show that the vortex flow consists of one circular vortex roll. The circular roll directly surrounds the downward air jet, which is considered as the primary inertia-driven vortex roll. This roll is normally stronger and larger at a higher jet Reynolds number.

(2) Then, how the jet Reynolds number affects the vortex flow pattern in the space between the horizontal disks is manifested in Figs. 2 and 3 by presenting the side view flow photos for the cross-plane $\theta=0^\circ$ & 180° at selected Re_j and Ra. The results in Figs. 2 and 3 indicate that at this low buoyancy the flow is dominated by a inertia-driven roll and a buoyancy-driven roll. Besides, at decreasing buoyancy-to-inertia ratio Gr/Re_j the inertia-driven rolls grow in size and intensity slightly accompanying with the decay is the buoyancy-driven roll.

(3) Finally, effects of various parameters on the flow and thermal structures will be examined later.

四、計畫成果自評

Up to this point an initial test of the effects of the Reynolds and Rayleigh numbers is investigated. Moreover, in the third year of the study experimental will be conducted to visualize various vortex flow structures and measure the associated thermal characteristics.

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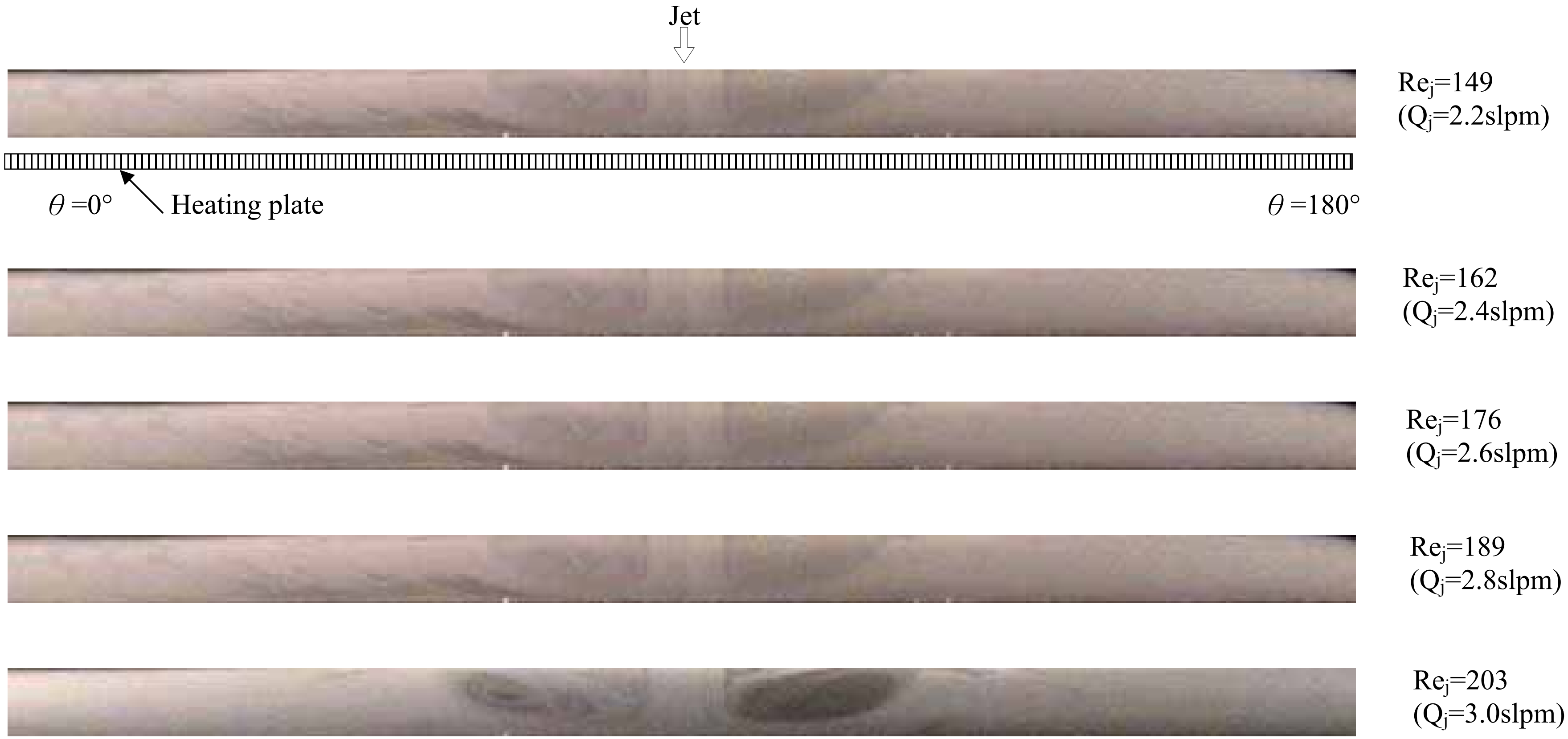

Fig. 1. Side view flow photos taken at the cross plane θ=0° & 180° for various jet Reynolds numbers at Ra=0 for D_j= 20.0 mm and H=20.0mm.

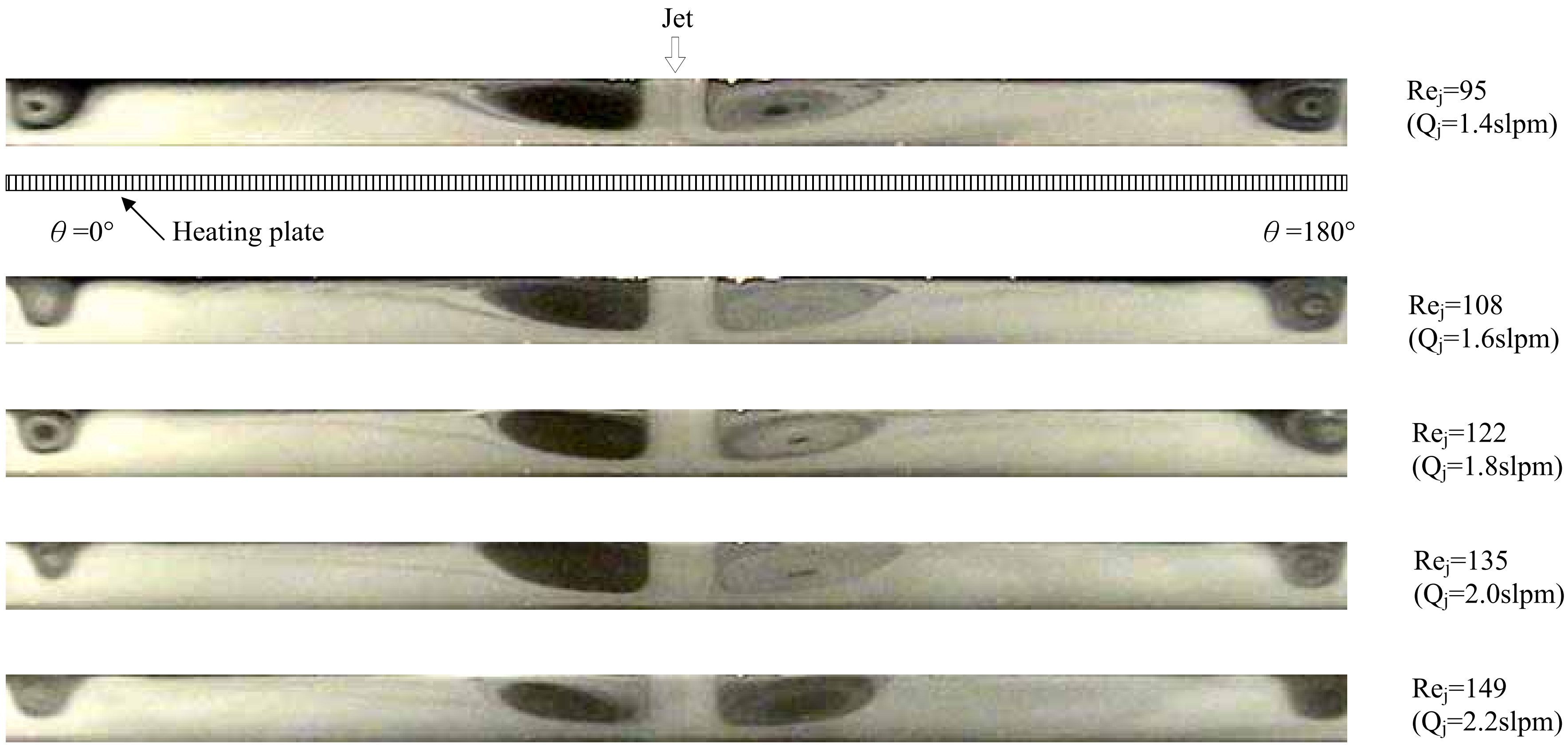

Fig. 2. Steady side view flow photos taken at the cross plane θ=0° & 180° for various jet Reynolds numbers at Ra=3000 (△T=4°C) for D_j= 20.0 mm and H=20.0mm.

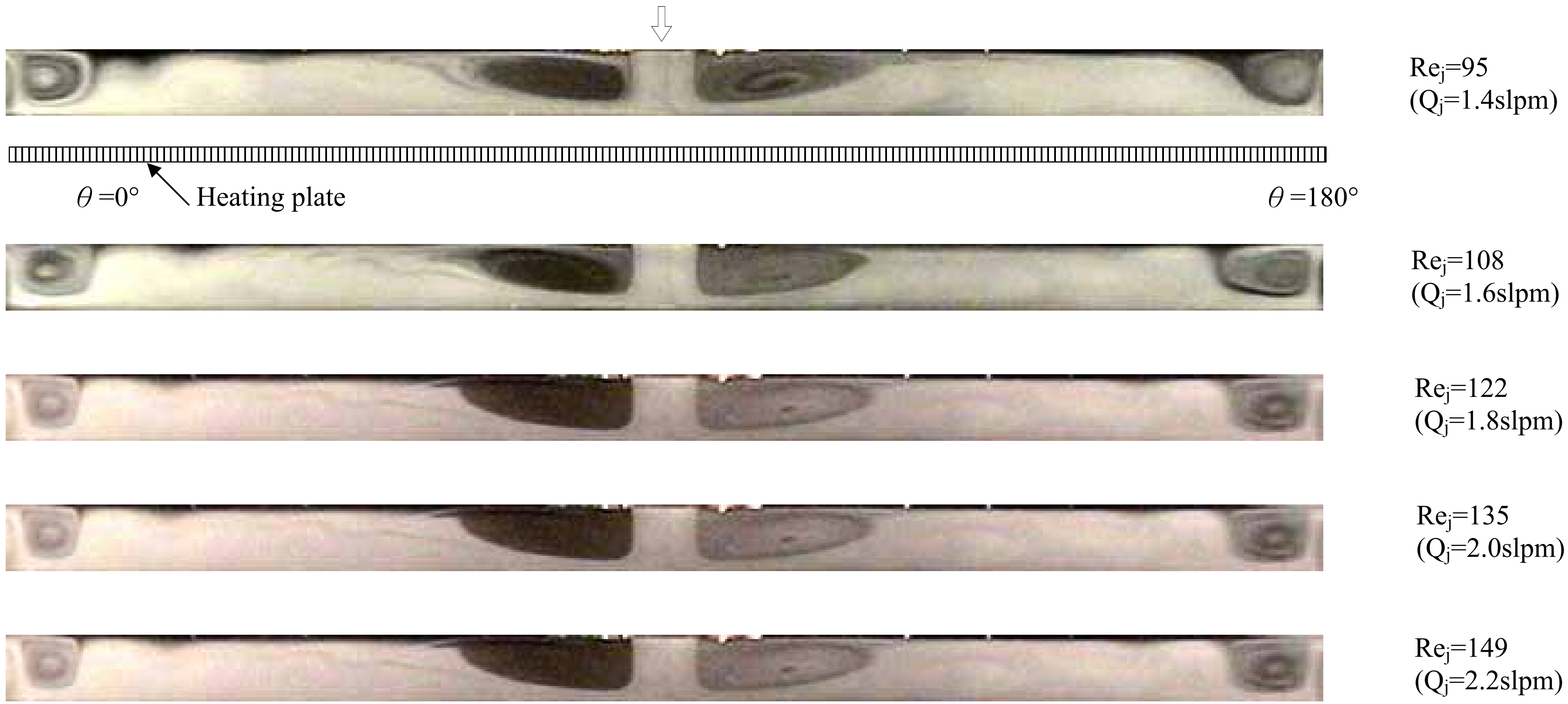

Fig. 3. Steady side view flow photos taken at the cross plane θ=0° & 180° for various jet Reynolds numbers at Ra=5111 (△T=6.8°C) for D_j= 20.0 mm and H=20.0mm.