CHAPTER 5

CONCLUDING REMARKS

A transient three-dimensional numerical simulation has been carried out in the present study to investigate the vortex flow resulting from an air jet impinging onto a large horizontal heated disk with an upper plate confinement. Effects of the jet flow rate, temperature difference across the horizontal disks, and jet-to-disk separation distance have been investigated in detail. Attention is focused on the possible presence of the new vortex flow patterns aside from the circular rolls. Major results obtained here can be briefly summarized in the following.

1. For the cases with the target plate unheated, two steady circular rolls are induced by the impinging jet, which are the primary and secondary inertia-driven rolls. These rolls are stronger and larger at high jet Reynolds numbers and longer jet-to-disk separation distance.
2. The typical buoyancy induced secondary flow is in the form several circular rolls in the outer region of the space between the two disks. These rolls are unsteady and deformed to a certain degree even at low and subcritical Rayleigh numbers. At intermediate Rayleigh numbers the rolls are significantly deformed and the roll termination and splitting appear.
3. At a certain high jet Reynolds number, the primary inertia-driven roll may split into a number of short radial rolls under the action of the upward buoyancy associated with the heated disk.

More computations are needed to explore the full picture of the new vortex roll patterns in the impinging jet.

REFERENCES

1. M. L. Hitchman and K. F. Jensen, Chemical vapor deposition (Principle and application), Academic Press, San Diego (1993).
2. J. C. Hsieh, T. C. Cheng and T. F. Lin, Characteristics of vortex flow in a low speed air jet impinging onto a heated disk in a vertical cylindrical chamber, International Journal of Heat and Mass Transfer, 46 (2003) 4639-4656.
3. C. Y. Soong, Gasdynamic characteristics and thermal-flow design of metal organic chemical vapor deposition reactors for semiconductor thin-films, Instruments Today, 25(3), (1993) 71-82.
4. J. H. Wu, Characteristics of unstable vortex flow resulting from a round jet of air impinging onto a heated horizontal disk confined in a vertical cylindrical chamber, M. S. thesis, National Chiao Tung University, Hsinchu, Taiwan, R. O. C., 2004.
5. M. T. Scholtz and O. Trass, Mass transfer in a nonuniform impinging jet, AIChE J. 16 (1970) 90-96.
6. E. M. Sparrow and T. C. Wong, Impingement transfer coefficients due to initially laminar slot jets, International Journal of Heat and Mass Transfer 18 (1975) 597-605.
7. J. H. Masliyah and T. T. Nguyen, Mass transfer due to an impinging slot jet, International Journal of Heat and Mass Transfer 22 (1979) 237-244.
8. P. Hrycak, Heat transfer from round impinging jets to a flat plate, International Journal of Heat and Mass Transfer 26 (1981) 1857-1865.
9. Y. J. Chou, and Y. H. Hung, Impingement cooling of an isothermally heated surface with a confined slot jet, ASME Transac. C, Journal of Heat Transfer 116

(1994) 479-482.

10. Y. M. Chung and K. H. Luo, Unsteady heat transfer analysis of an impinging jet, ASME Transac. C, Journal of Heat Transfer 124 (2002) 1039-1048.

11. G. K. Morris, S. V. Garimella and J. A. Fitizgerald, Flow-field prediction in submerged and confined jet impingement using the Reynolds Stress Model, J. Electronic Packaging 121 (1999) 255-262.

12. G. K. Morris, and S.V. Garimella, Orifice and impingement flow fields in confined jet impingement, J. Electronic Packaging 120 (1998) 68-72.

13. F. Sarghini, and G. Ruocco, Enhancement and reversal heat transfer by competing modes in jet impingment, International Journal of Heat and Mass Transfer 47 (2004) 1711-1718.

14. N. R. Saad, W. J. M. Douglas and A. S. Mujumdar, Prediction of heat transfer under an axisymmetric laminar impinging jet, Int. Eng. Chem. Fundam. 16 (1977) 148-154.

15. H. S. Law and J. H. Masliyah, Mass transfer due to a confined laminar impinging axisymmetric jet, Int. Eng. Chem. Fundam. 23 (1984) 446-454.

16. L. P. Chua, S. C. M. Yu and H-S. Li, Flow visualization and preliminary measurements of a confined jet with and without target, International Communications in Heat and Mass Transfer 27 (2000) 191-200.

17. P. R. Voke and S. Gao, Numerical study of heat transfer from an impinging jet, International Journal of Heat and Mass Transfer 41 (1998) 671-680.

18. J. A. Fitzgerald and S. V. Garimella, A study of the flow field of a confined and submerged impinging jet, International Journal of Heat and Mass Transfer 41 (1998) 1025-1034.

19. T. H. Park, H. G. Choi, J. Y. Yoo and S. J. Kim, Streamline upwind numerical simulation of two-dimensional confined impinging slot jets, International Journal

of Heat and Mass Transfer 46 (2003) 251-262.

20. K. Ichimiya and Y. Yamada, Three-dimensional heat transfer of a confined circular impinging jet with buoyancy effects, ASME Transac. C, Journal of Heat Transfer 125 (2003) 250-256.

21. H. S. Law and J. H. Masliyah, Numerical prediction of the flow field due to a confined laminar two-dimensional submerged jet, Computers & Fluids 12 (1984) 199-215.

22. D. Sahoo and M. A. R. Sharif, Numerical modeling of slot-jet impingement cooling of a constant heat flux surface confined by a parallel wall, International Journal of Thermal Sciences 43 (2004) 877-887.

23. V. A. Chiriac and A. Ortega, A numerical study of the unsteady flow and heat transfer in a transitional confined slot jet impinging on an isothermal surface, International Journal of Heat and Mass Transfer 45 (2002) 1237-1248.

24. R. Viskanta, Heat transfer to impinging isothermal gas and flame jets, Experimental Thermal and Fluid Science 6 (1993) 111-134.

25. K. Jambunathan, E. Lai, M. A. Moss and B. L. Button, A review of heat transfer data for single circular jet impingement, International Journal of Heat and Fluid Flow 13 (1992) 106-115.

26. H. V. Santen, C. R. Kleijn and H. E. A. Van Den Akker, Mixed convection in radial flow between horizontal plates- I. Numerical simulations, International Journal of Heat and Mass Transfer, 43 (2000) 1523-1535.

27. H. V. Santen, C. R. Kleijn and H. E. A. Van Den Akker, Mixed convection in radial flow between horizontal plates- II. Experiments, International Journal of Heat and Mass Transfer, 43 (2000) 1537-1546.

28. G. Wahl, Hydrodynamic description of CVD processes, Thin Solid Films 40 (1977) 13-26.

29. A. H. Dilawari and J. Szekely, A mathematical representation of a modified stagnation flow reactor for MOCVD application, J. Crystal Growth 108 (1991) 491-498.
30. P. N. Gadgil, Optimization of a stagnation point flow reactor design for metalorganic chemical vapor deposition by flow visualization, J. Crystal Growth 134 (1993) 302-312.
31. H. V. Santen, C. R. Kleijn and H. E. A. Van Den Akker, Symmetry breaking in a stagnation-flow CVD reactor, J. Crystal Growth 212 (2000) 311-323.
32. C. R. Biber, C. A. Wang, and S. Motakef, Flow regime map and deposition rate uniformity in vertical rotating-disk OMVPE reactors, J. Crystal Growth 123 (1992) 545-554.
33. H. V. Santen, C. R. Kleijn and H. E. A. Van Den Akker, On turbulent flows in cold-wall CVD reactors, J. Crystal Growth 212 (2000) 299-310.
34. S. V. Patankar and D. B. Spalding, A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows, International Journal of Heat and Mass Transfer 15 (1972) 1787-1806.
35. Adapco and Computational Dynamics Ltd, STAR-CD, New York and London (1987-1989).
36. F. C. Hsieh and T. F. Lin, Investigation of new flow structures and their transition characteristics in a low speed confined air jet impinging onto a large heated disk, Report for the project NSC 93-2212-E-009-016 (2005) 1-10.