Optimal Thermal Design of a Converged-Diverged Microchannel Heat Sinks using Numerical Simulation

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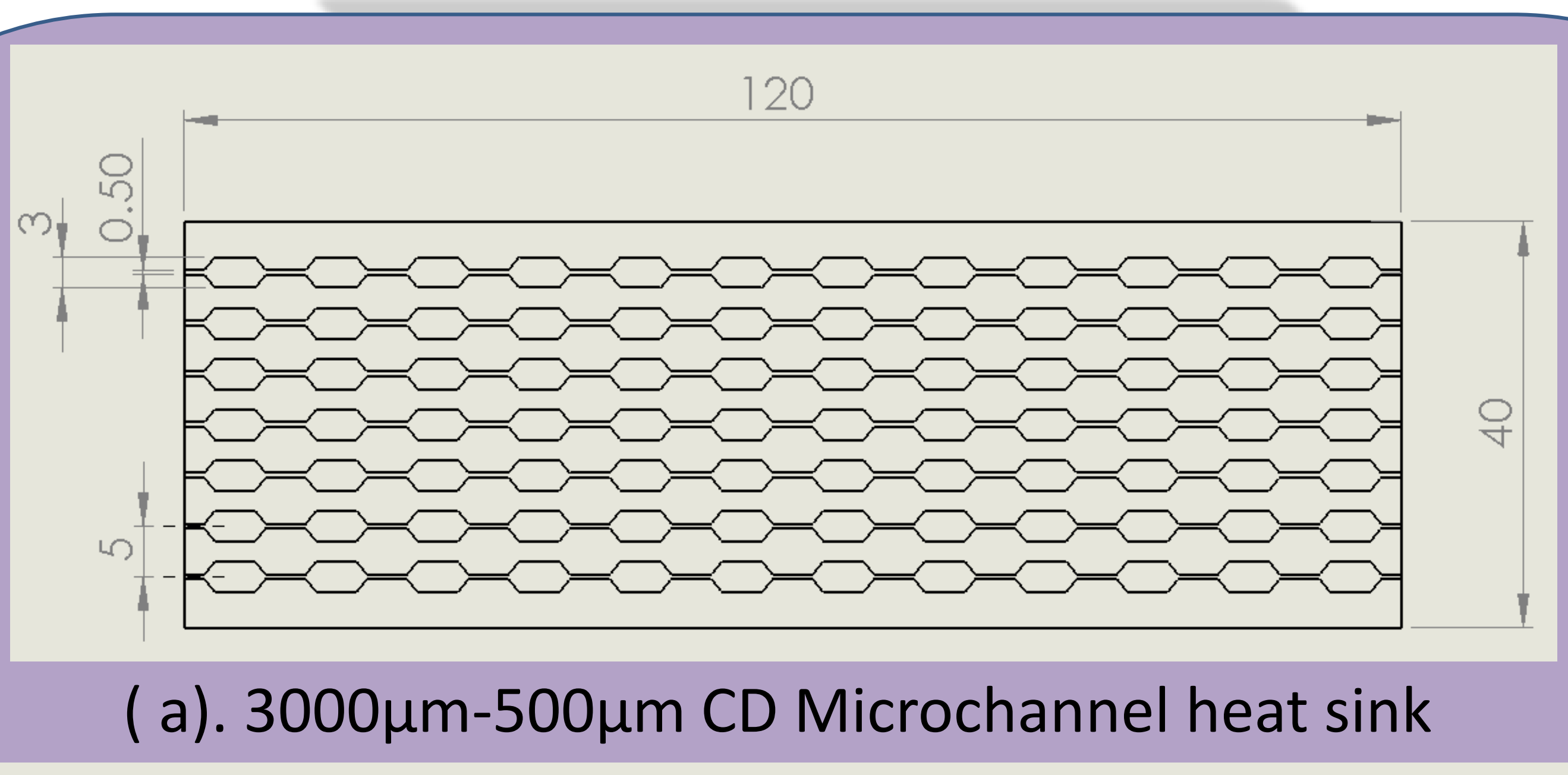
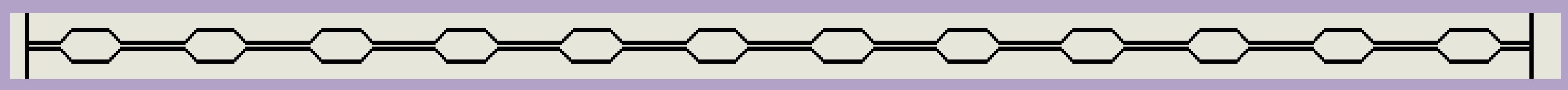
Introduction

With the advancements in aerospace technology, micro-electromechanical systems, hybrid data centres and microfluidics, the miniature size electronic chips in such applications are the need of the century. The major challenge in microelectronic chips is to eliminate the generated heat for stable and reliable operation of the devices. Microchannel heat sinks are efficient method to dissipate heat when the generated heat flux is more than 120 W/cm^2. The pressure drop and thermal resistance in the microchannel are the important parameters which determine the efficiency of the microchannel heat sink. The configuration of the microchannel in terms of thermal resistance and pressure drop is prior attention to design the microchannel heat sink. In this study, a converged-diverged (CD) microchannel heat sink was designed and optimized for the efficient pressure drop and thermal resistance condition.

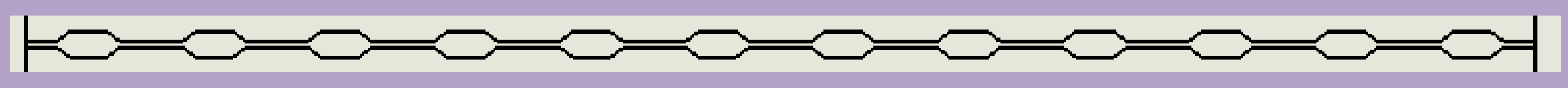
Geometrical Modelling



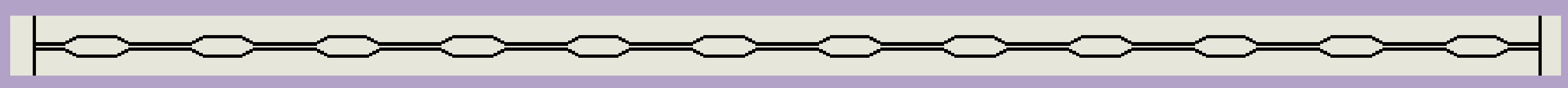
(a). 3000µm-500µm CD Microchannel heat sink



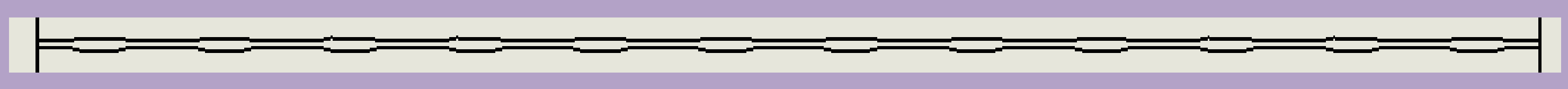
(b). 2500µm-500µm CD Microchannel heat sink



(c). 2000µm-500µm CD Microchannel heat sink



(d). 1500µm-500µm CD Microchannel heat sink



(e). 1000µm-500µm CD Microchannel heat sink

Fig.1 Microchannel Heat sink considered in this study

The configuration of converging-diverging microchannel used in the present study is as shown in Fig.1. The thermal performance of the proposed microchannel is compared with two of the basic straight microchannels of size **3000µm and 500µm**. The material heat sink is Aluminium (**Al 6061**). In this study, the constant heat flux applied on the surface of microchannel heat sinks. The geometry in computational domain is subjected to uniform wall conditions and given boundary conditions. **Deionized water** is the working (cooling) fluid which enters the microchannels at 25ºC and exits at environmental pressure.

Computational Method

Conjugate heat transfer module uses NS equations to obtain Pressure drop and Maximum temperature in CD microchannels.

Conservation of Mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0$$

Conservation of Energy:

$$\frac{\partial T}{\partial t} + \mathbf{V} \cdot \nabla T = \kappa \nabla^2 T + H/\rho c_P$$

Conservation of Momentum:

$$\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V} \cdot \nabla)\mathbf{V} = \frac{1}{\rho}\nabla \cdot \boldsymbol{\sigma} + \mathbf{g}$$

Optimization module uses BOBYQA algorithm to obtain optimum Width of Microchannel for minimized Surface temperature and thermal resistance

Boundary Conditions

- ➢Fluid flow is **laminar** in the computational domain
- ➢All surfaces were **non-radiant**
- ➢ Process of heat transfer was under **steady state** condition
- ➢ Inlet wall is "**velocity**" while the outlet wall is "**environmental pressure**"
- ➢Heat flux is constant which is **120 W/cm^2** on top surface of CD Heat sink

Results

Fig. 2 shows the temperature distribution in CD Microchannel Heat sink. In CD microchannel, pressure drop is minimum due to change in velocity in each unit of CD section. Pressure drop is minimum in 3000µm-500µm CD microchannel. Viscous forces in solid-fluid boundary reduces due to formation of flow recirculation vortices as in **Fig.3**. At exit furrows, symmetric vortices are formed despite high mainstream velocity flow. These vortices induces hot fluid from main stream flow to mix and recirculate with cold fluid .

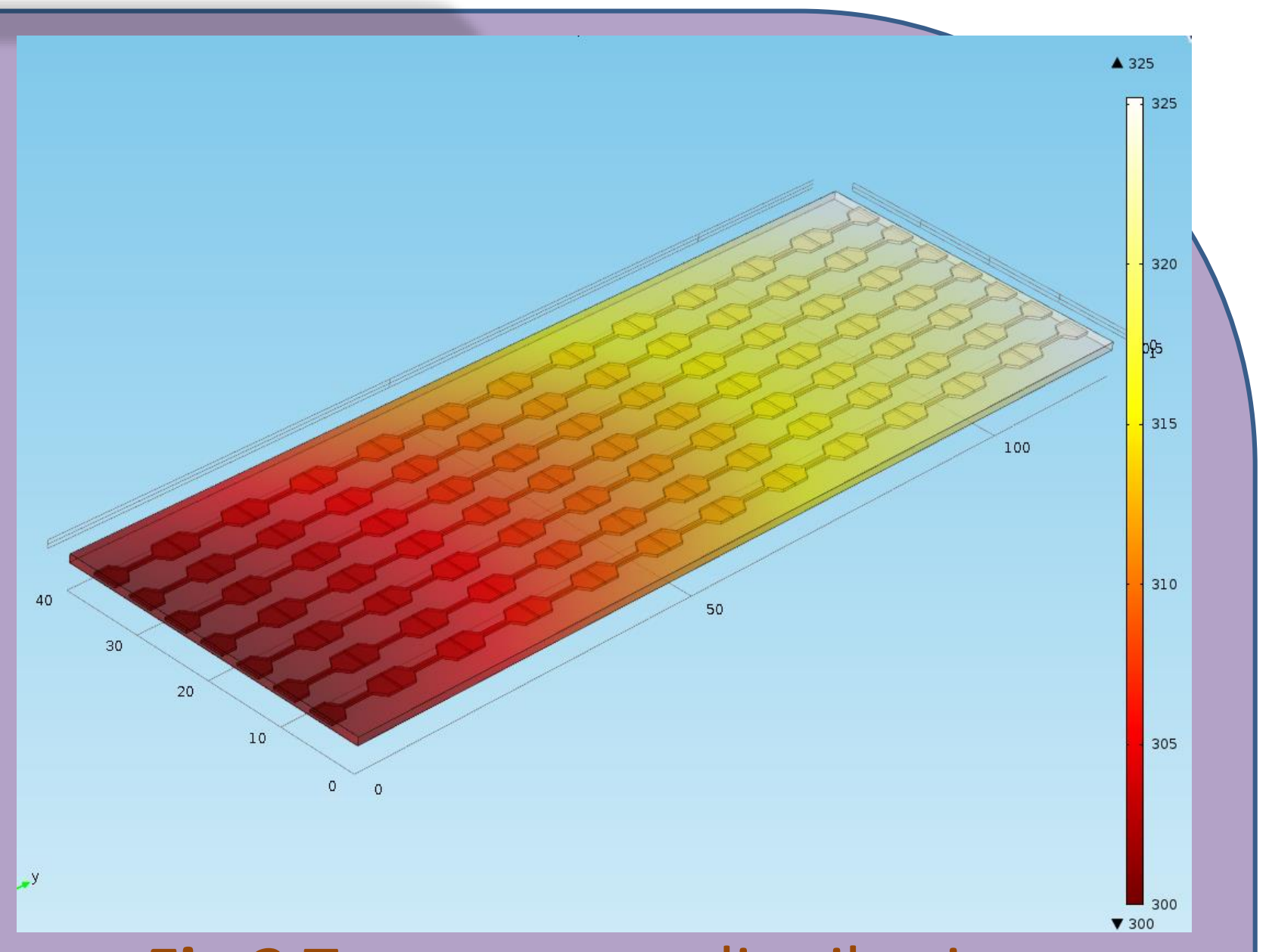
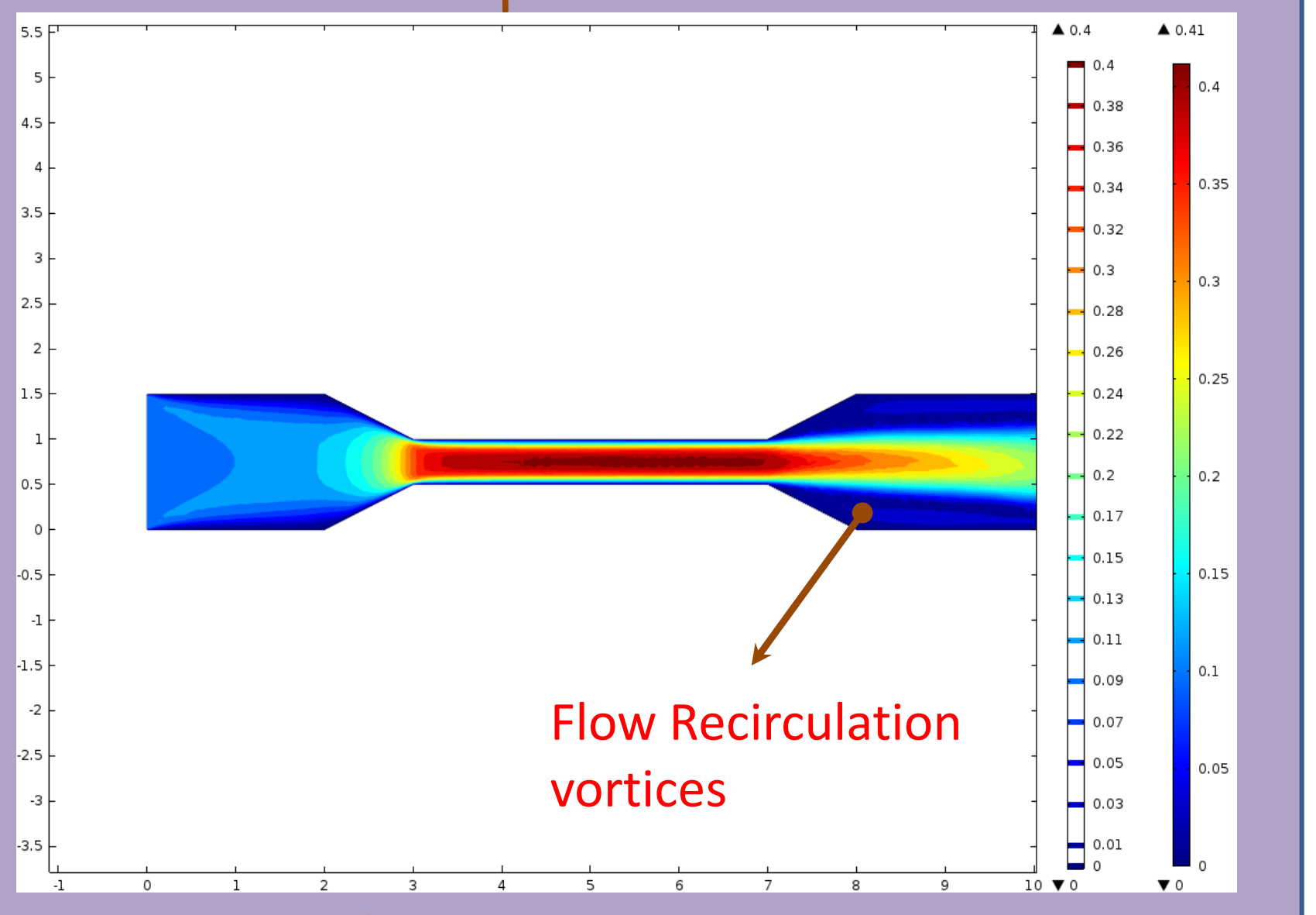


Fig.2 Temperature distribution in 3000-500µm CD microchannel



Flow Recirculation vortices

Fig.3 Velocity contour in CD section

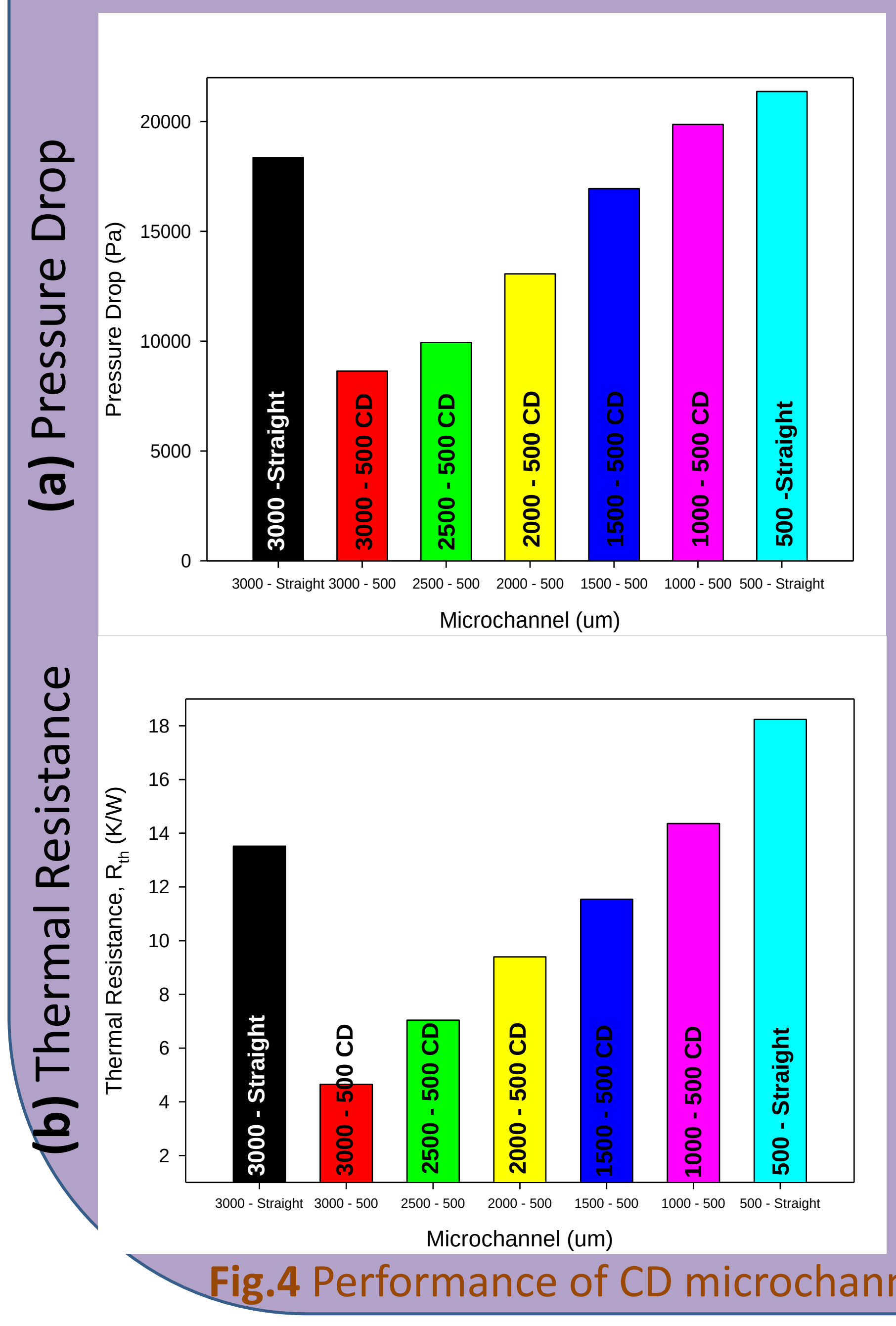


Fig.4 Performance of CD microchannel

Variation of pressure drop for increase in width is shown in **Fig.4a**. R_{th} of the CD microchannel heat sink is 74% lower than 0.5mm straight microchannel and 65% lower than 3mm straight microchannel as shown in **Fig.4b**. To be noted that R_{th} decreases with increase in maximum width of CD dimension. CD section in channels helps in mitigating the nucleation effects and increased heat transfer coefficient. This adds value to proposal of CD microchannel as an **efficient** one.

Conclusion

Innovative converging-diverging microchannel is designed and simulated in this study. The thermal resistance was found to be low for microchannel dimension of 3000µm-500µm by Optimization module. Pressure drop is calculated 53% higher than 3mm straight microchannel. Converging Diverging section in the CD microchannel prompts for non-nucleated flow and periodic velocity rise which contributes for increased heat transfer. R_{th} of CD microchannel heat sink is 4.652 K/W which is superior than straight microchannels. Hence, proposed CD microchannel heat sink increases the overall thermal performance.

References

- ➢Gong, Liang, Krishna Kota, Wenquan Tao, and Yogendra Joshi. "Parametric numerical study of flow and heat transfer in microchannels with wavy walls."Journal of Heat Transfer 133, no. 5 (2011): 051702.
- ➢Xuan, Xiangchun, and Dongqing Li. "Particle motions in low-Reynolds number pressure-driven flows through converging–diverging microchannels."Journal of Micromechanics and Microengineering 16, no. 1 (2005): 62. 7.

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