Heat transfer enhancement using nanofluids in micro channel

COURSE: THERMAL DESIGN OF ELECTRONIC EQUIPMENTS

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List of figures:

List of tables:

INTRODUCTION

The fast growth of electronic devices is the urgent need for compact modern cooling technology to provide better performance with reliable operations. The high-power consumption and lesser life are the challenging issues of electronic components. Several methods of electronic cooling technology are being proposed by the researchers such as Microchannel Cooling, Vapour chamber cooling, two phase cooling and cooling using nanofluid.
In general, the traditional electronic cooling systems supply the coolant by using a circulating mechanical pump. But these systems are of bulky mass, consume more power and they provide uncertain measurements.
Generally, we use water as a circulating coolant but its conductivity is very low and if we can somehow increase its thermal conductivity than we can increase heat transfer rate. One way of increasing thermal conductivity of water is to add nano-sized particles in the range of 1-100nm in the water or base fluid.
We are particularity interested in use of nanofluid in cooling to see its effectiveness and will compare it with only water using simulation in ANSYS Fluent.

Configuration and inputs

In this report we are going to simulate heat transfer analysis of practical problem of semiconductor
As you can see in the figure1 below Schematic Diagram of channel heat sink with semiconductor. The heat sinks are designed with a channel to extract more heat from the semiconductor surface. The length of the single channel is 30mm, inlet and outlet diameter of a channel are 1.5mm, while the total dimensions of the heatsink are 50 mm *65 mm with a wall thickness of 2.5mm and dimension of semiconductor is 30mm *37.25mm with thickness of 0.2mm.

The bottom wall of the heatsink is getting heated by a uniform generation of heat flux 60W/cm^2. The flow of fluid depends on laminar. The coolant is utilized in this numerical calculation through the inlet is water, and CuO/water nanofluid and its relating thermo-physical properties are revealed in Table 1. We have varied Reynold Number(Re) from 2000 to 2300 for both water and nanofluid.

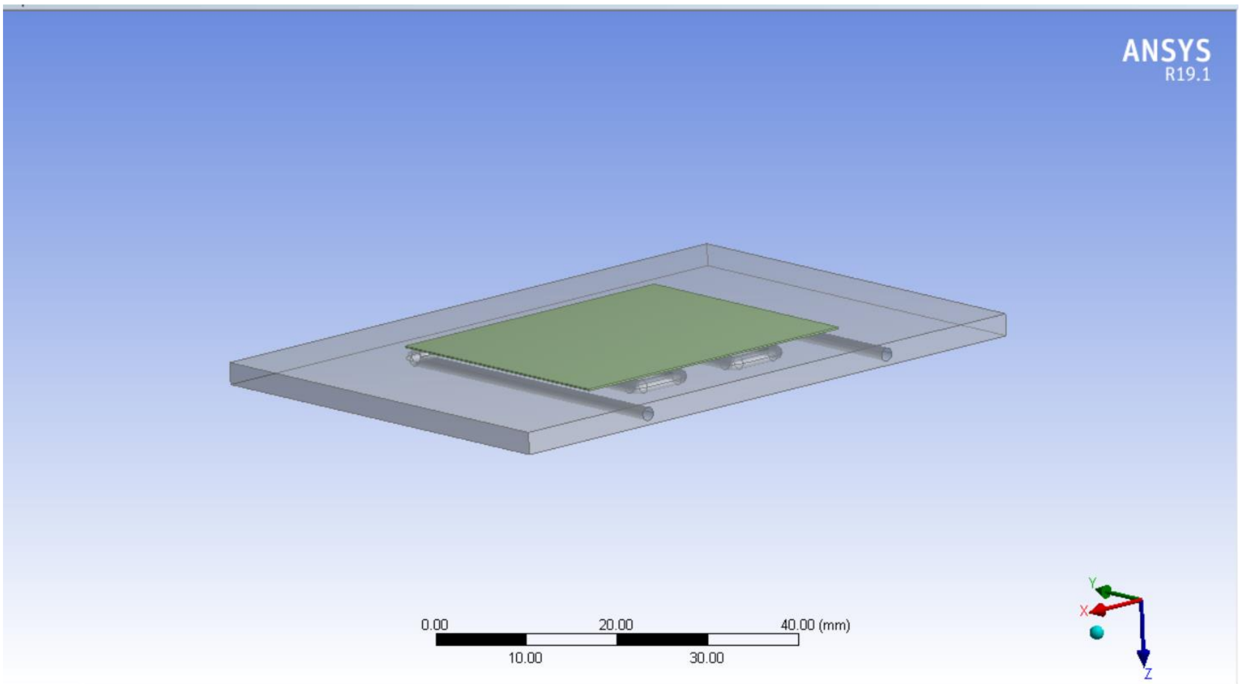


Figure 1 Geometry of heat sink channel

Table 1

Properties	Distilled Water	CuO Nanoparticle
Density(kg/m^3) ρ	997.1	6500
Specific Heat(J/Kg.K) C_p	4179	540
Thermal Conductivity (W/m.K) K	0.613	18
Dynamic Viscosity ($N.s/m^2$) μ	0.001003	-
Mean Diameter (nm)		29

Assumption:
1)laminar flow throughout pipe
Boundary condition:
1)top semiconductor plate: uniform heat flux (value described below)
2)other surfaces: natural convective heat transfer (air h=5W/m^2K)
3)ambient temperature is taken 27-degree Celsius

Equations and Sample Calculation

1. Water sample calculation

$$Re = \frac{\rho V D}{\mu}$$

For Re=2000

Velocity, $V = \frac{Re * \mu}{\rho D}$

$$\mathrm{V} = \frac{2000 * 0.001003}{997.1 * 1.5 * 10^{-3}} = 1.341 \text{ m/s}$$

Mass flow rate, $\dot{m} = \rho A_c V$

$$\dot{m} = 997.1 * \frac{\pi}{4} * \ 1.5^2 * 10^{-6} * 1.341 = 2.362 * \ 10^{-3}\ Kg/s$$

2. Nanofluid (Cuo+water) with $\emptyset = 0.025$ Volume Concentration (2.5%)

Effective Density, $\rho_{eff} = (1-\emptyset)\rho_f + \ \emptyset\rho_p \ = (1-0.025) * 997.1 + 0.025 * 6500$
$= 1134.6725\ Kg/m^3$

Effective Specific Heat, $C_{p,eff} = \frac{(1-\emptyset)(\rho C_p)_f + \emptyset(\rho C_p)_p}{\rho_{eff}} = \frac{(1-0.025)*(997.1*4179)+0.025*(6500*540)}{1134.6725}$
$= 3657.847\ \frac{Kj}{Kg.K}$

Effective Viscosity, $\mu_{eff} = \ \frac{\mu_f}{(1-\emptyset)^{2.5}} = \frac{0.001003}{(1-0.025)^{2.5}} = 0.0010685\ N.s/m^2$

Effective Thermal Conductivity, $K_{eff} = \frac{K_p+(n-1)*K_f-(n-1)*\emptyset*(K_f-K_p)}{K_p+(n-1)*K_f+\emptyset*(K_f-K_p)} * K_f$

$K_{eff} = \frac{18+(3-1)*0.613-(3-1)*0.025*(0.613-18)}{18+(3-1)*0.613+0.025*(0.613-18)} * 0.613 = 0.655$ W/m.K

For Re = 2000

Velocity, $V = \frac{2000*0.0010685}{1134.6725*1.5*\ 10^{-3}} = 1.255\ m/s$

Mass flow rate, $\dot{m} = 1134.6725 * \frac{\pi}{4} * (1.5 * 10^{-3})^2 * 1.255$
$= 2.516 * 10^{-3}\ Kg/s$

Theoretical Calculation of Heat Transfer

Assumptions:

1. Steady State
2. Total heat generated by Semiconductor is carried away only by water in the pipe

3. Solution of Nanoparticle+ water is considered as single composed fluid
4. Assuming inlet temperature of water (T_{in}) is 27 °C

Surface area of Semiconductor, As = 3 cm*3.74 cm = 11.2275 cm^2
Heat flux Generated by Semiconductor, q = 60 W/cm^2

Total heat generated, Q = q*A_s = 673.65 W

$$Q = \dot{m}C_p\Delta T$$

$$\Delta T = \frac{Q}{\dot{m}C_p}$$

1. For Water

$$\Delta T = \frac{673.65}{2.362 * 10^{-3} * 4179} = 68.24$$

$$\Delta T = T_{out} - T_{in}$$
$$T_{out} = \Delta T + T_{in}$$
$$T_{out} = 68.24 + 25 = 93.24℃ = 366.24\ K$$

2. For nanofluid (CuO+water)

$$\Delta T = \frac{673.65}{2.516 * 10^{-3} * 3657.847} = 73.19$$

$$T_{out} = 73.19 + 25 = 98.19℃ = 371.19\ K$$

Grid Independence study:

Table 2

Re_2000	Nodes_764303	Nodes_579600
Maximum semiconductor temp(K)	421.41	421.116
Heat transfer coefficient(W/mK)	5712.4	5710.257
Outlet mean temp(K)	370.3994	370.3175

The results show that changing the more numbers of nodes will not change the solution much.

From Simulation We got the following Results:

1. Maximum Temperature of Semiconductor (T_{max})

Table 3

Re	Water (T_{max})(Kelvin)	Nanofluid (T_{max})(Kelvin)
2000	421.116	419.688
2100	418.234	416.543
2200	415.683	413.835
2300	413.368	411.663

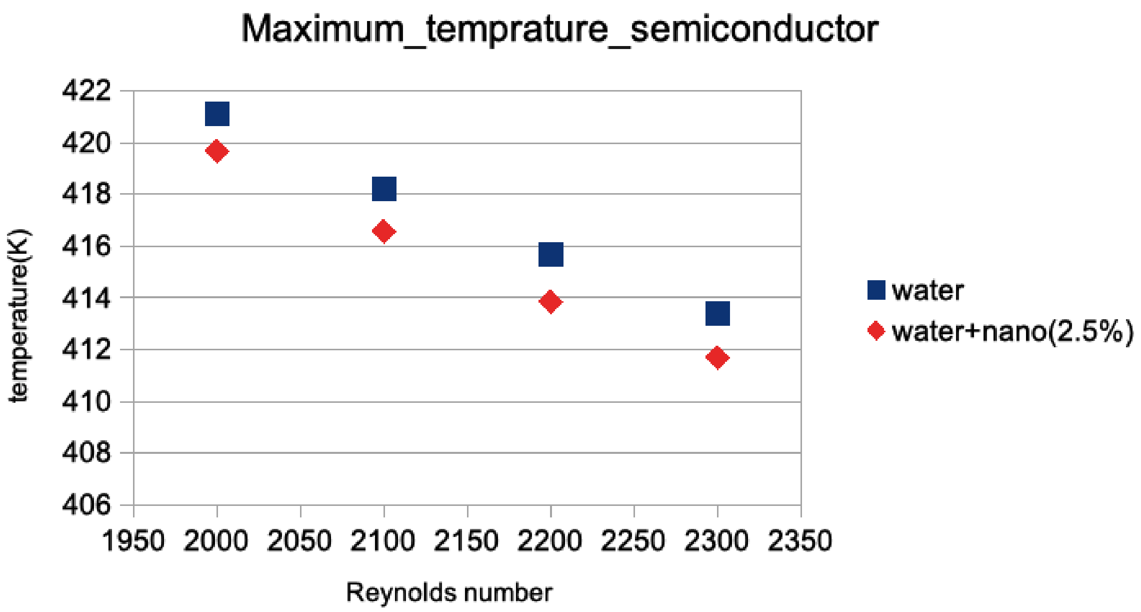


Figure 2 maximum temperature of semiconductor versus Reynolds number

2. Convective Heat transfer Coefficient (h)

Table 4

Re	Water heat coefficient (W/m^2K)	Nanofluid heat coefficient (W/m^2K)
2000	5710.257	5918.655
2100	5823.714	6047.542
2200	5928.156	6162.4024
2300	6027.646	6259.342

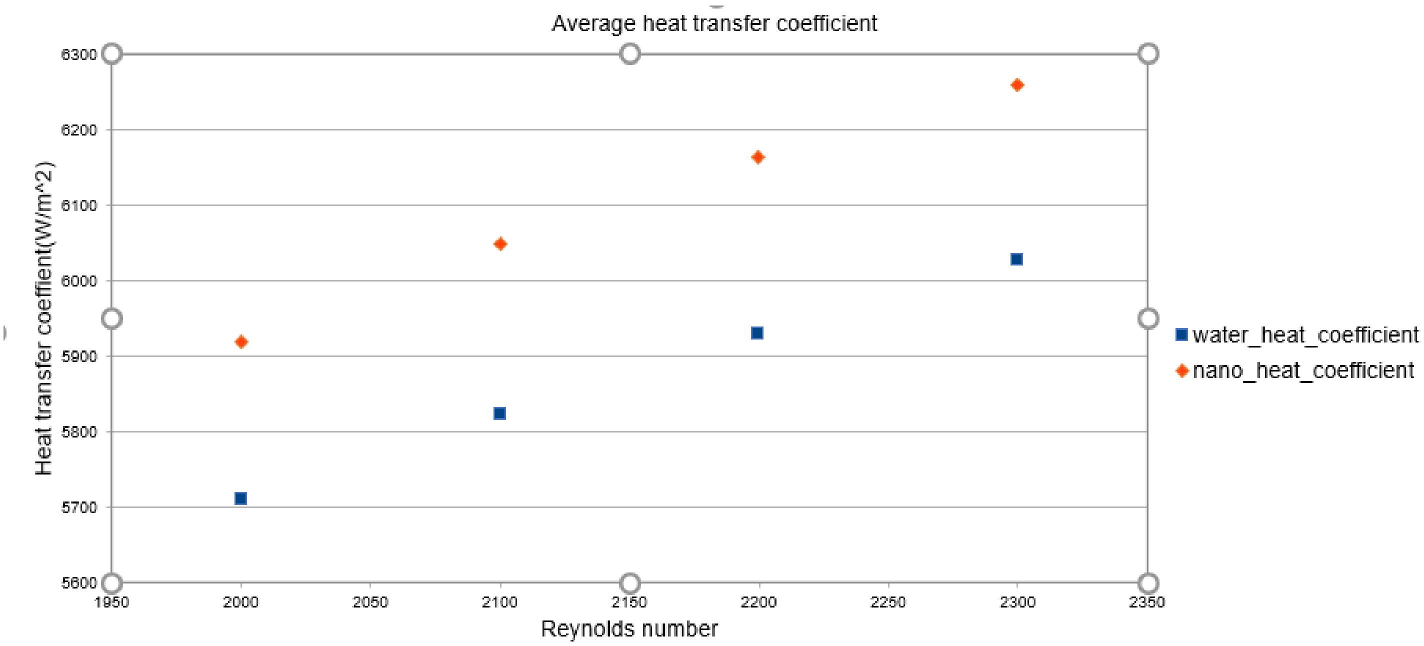


Figure 3 heat transfer coefficient versus Reynolds number

3. Nusselt Number (Nu)

Table 5

Re	Nu for water	Nu for Nanofluid
2000	13.97289641	12.98900146
2100	14.25052365	13.27185516
2200	14.50609135	13.52392626
2300	14.7495416	13.73666862

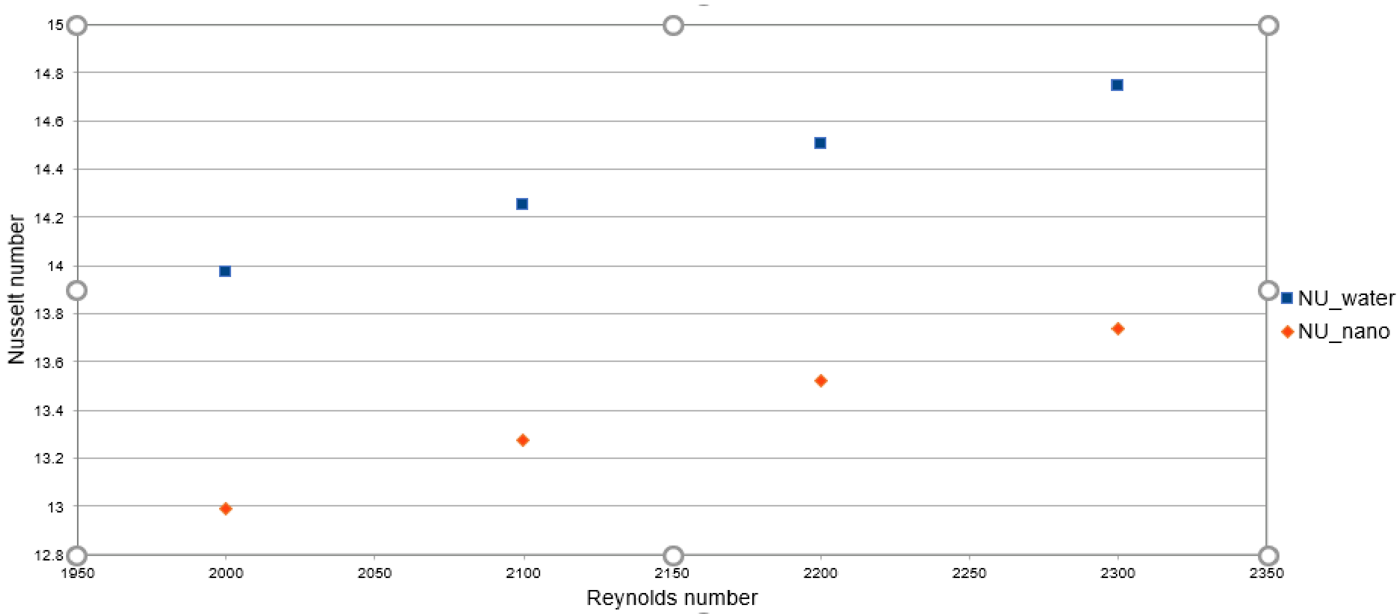


Figure 4 Nusselt number versus Reynolds number

4. Thermal Resistance (R_{th})

Table 6

Re	R_{th} for water (K/W)	R_{th} for NanoFluid (K/W)
2000	0.00020186	0.00019948
2100	0.000197057	0.000194238
2200	0.000192805	0.000189725
2300	0.000188947	0.000186105

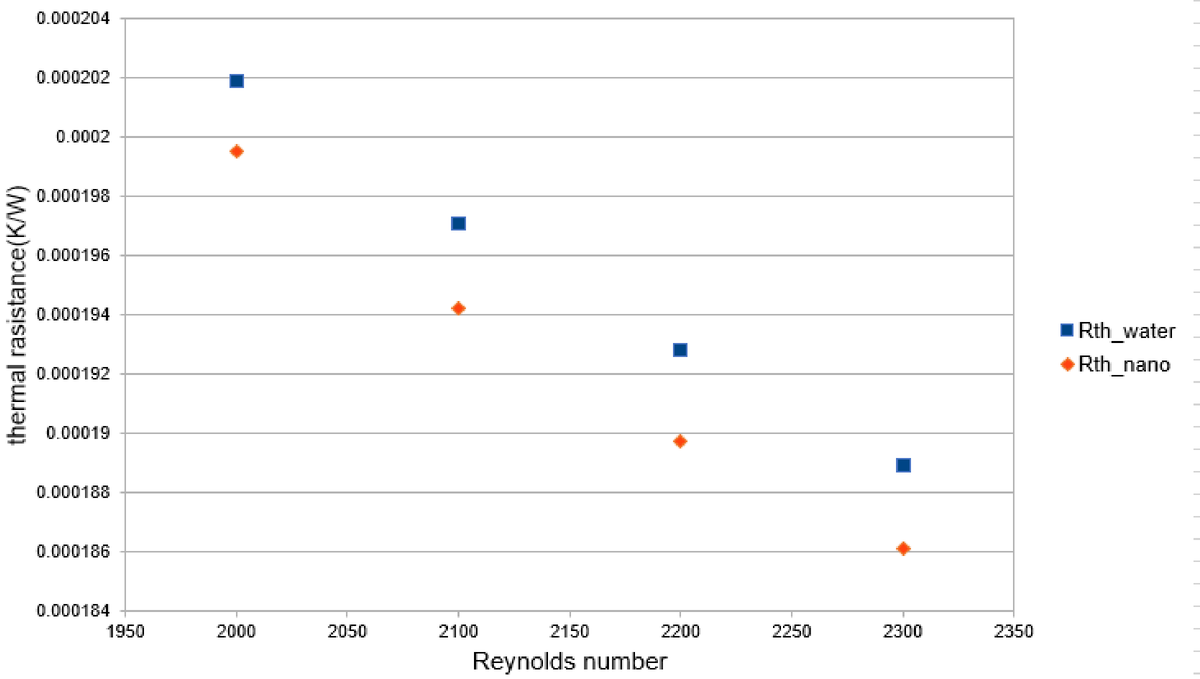


Figure 5 thermal resistance with Reynolds number

5. Pumping Power (Watt)

Table 7

Re	Pumping Power for water (W)	Pumping Power for Nanofluid (W)
2000	0.035973688	0.033731205
2100	0.0403425	0.037686438
2200	0.044942304	0.042014579
2300	0.049761145	0.045704603

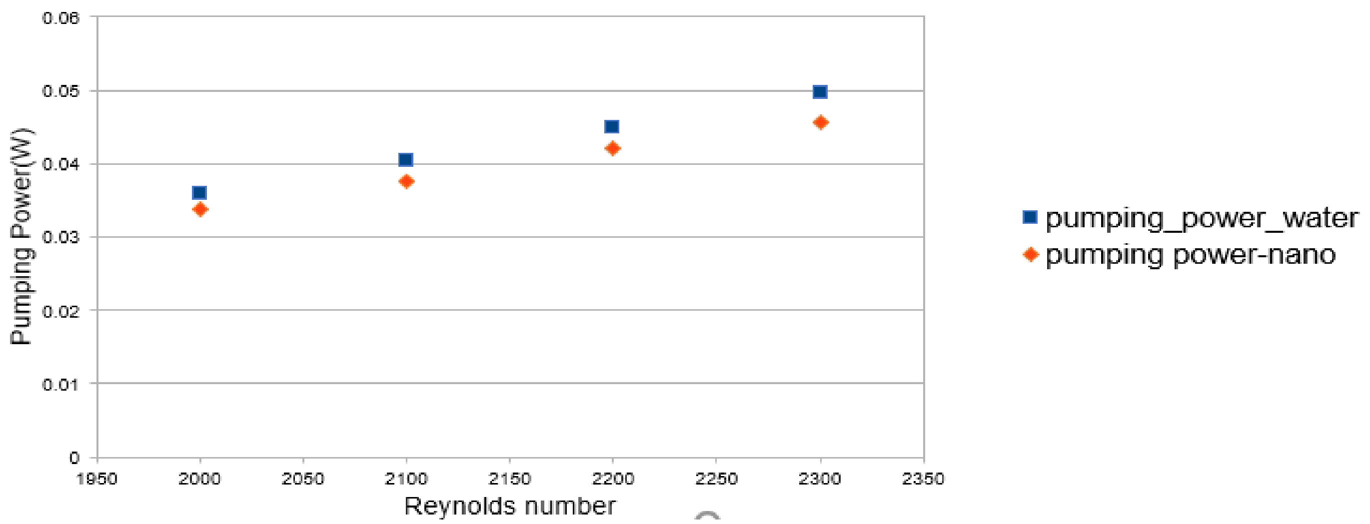


Figure 6 pumping power with Reynolds number

As far as we know simulation and experiments on this kind of configuration and parameters are not investigated.

But to know better our results energy conservation study of simulation give us flavour for validation.

Details are given below for Re=2000 case for mixture of water and nano particles

1)mass flow rate:

Table 8

inlet(kg/s)	outlet(kg/s)	sum
0.0024750347	-0.002474928	1.06699999999522E-07

2)Energy balance

Table 9

Semiconductor top plate heat flux(W)	673.425 1	
Pipe inlet heat flux(W)	16.82386	

Pipe outlet heat flux(W)	-688.33476
Convection heat flux from other surfaces(W)	-1.9149039
total sum	-0.000803900000051

Temperature Contours of surfaces:

Figure 7 Tempreture contuor of cooling fluid

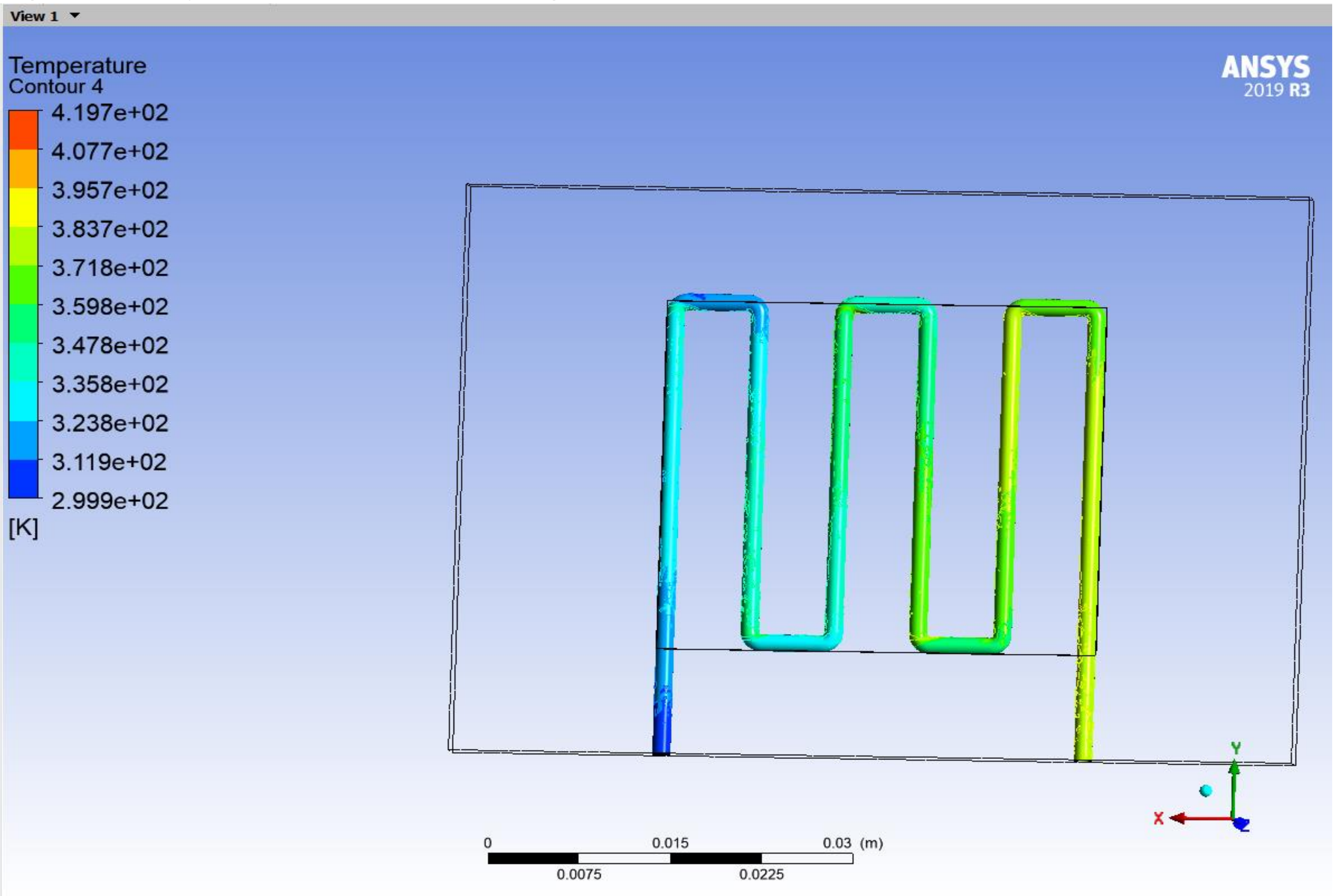
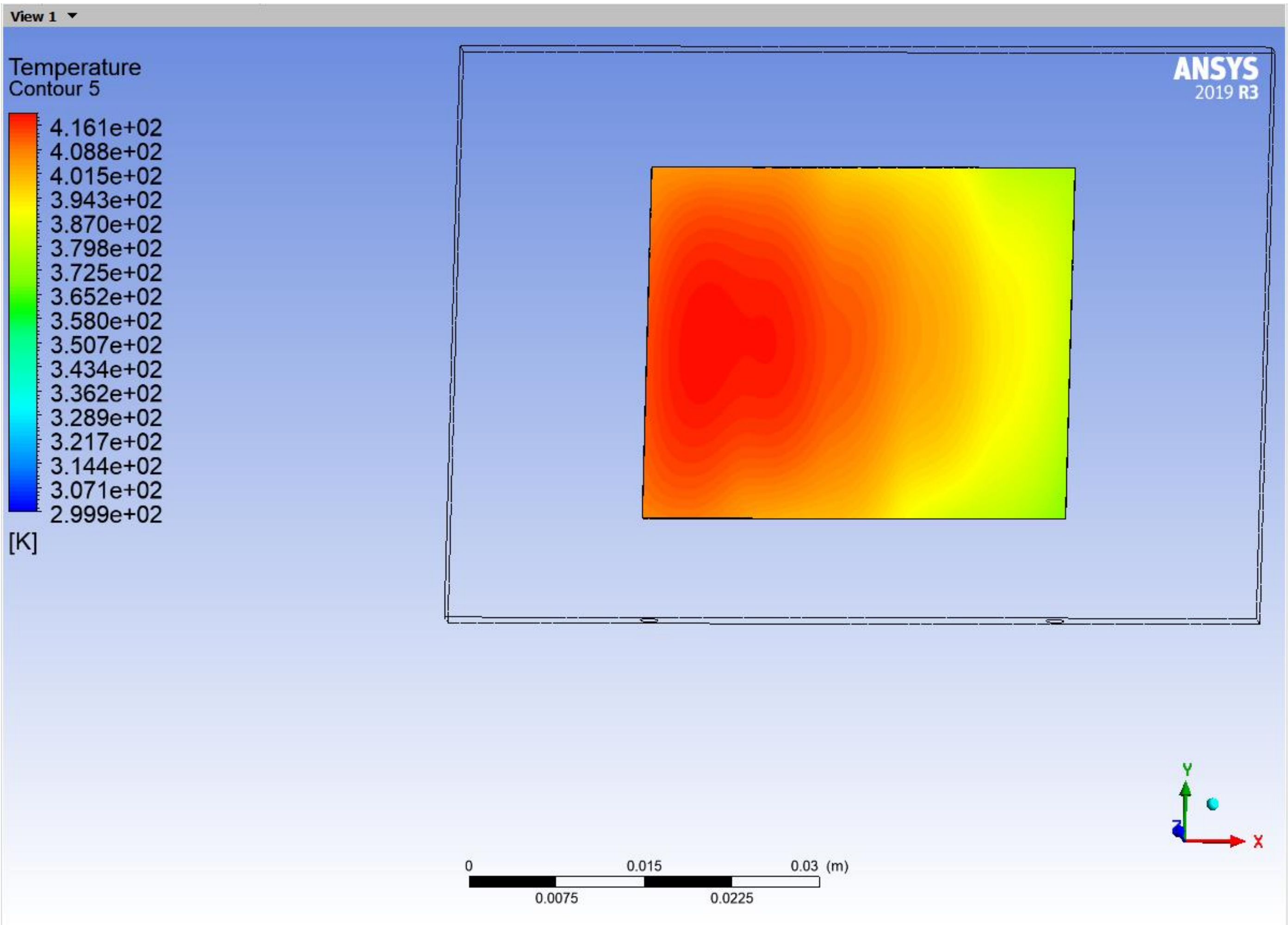


Figure 8 Tempreutre contuor of top of semiconductor



Conclusion:

- The results show that the heat transfer coefficient increases with increase in Reynolds number.
- From the results shows that by using Cuo Nano particle at 2.5% vol fraction maximum around ~4% increase in heat transfer coefficient with respect to pure water.
- The maximum temperature of semiconductor decreases by maximum 3K.
- The pumping power requirement is low (approximately ~7%) in the case of fluid with Nano particle for all Reynolds number.

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