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Modeling and Analysis of Micro Fluidic Channels

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Abstract: The paper addresses the design, simulation and analysis of circular, semicircular, square and rectangle microfluidic channels. The analysis has been done for compressible and incompressible fluids. The materials like glass, silicon and polyimide has been used for the rectangular channel wall to analyze surface roughness. *Copyright © 2009 IFSA.*

Keywords: Microfluidic, Sizing effect, Laminar to turbulent transition, Surface roughness

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1. Introduction

Micro fluidics is the science and engineering of systems in which fluid behavior differs from conventional flow theory primarily due to the small length scale of the system. A micro fluidic device can be identified by the fact that it has one or more channels with at least one dimension less than 1 mm. Advantages of microfluidics compared to conventional fluidic systems are low fabrication cost, enhancement of analytical performance, low power and low consumption of chemicals. Micro channels can be fabricated in many materials - glass, polymers, silicon and metals - using various processes including surface micromachining, bulk micromachining, molding, embossing and conventional machining with micro cutters. The flow of a fluid through a micro fluidic channel can be characterized by the Reynolds number. Due to the small dimensions of micro channels, the Reynolds number is usually much less. In this Reynolds number regime, flow is completely laminar and no turbulence occurs.

Micro fluidic systems have diverse and widespread potential applications. Some examples of systems and processes that might employ this technology include inkjet printers, blood-cell-separation equipment, chemical synthesis, genetic analysis, drug delivery, electro chromatography, micro-scaled cooling systems of electronic devices which generate high power.

The hydrodynamic characteristics study of laminar Newtonian incompressible flows in micro-channels in the range of hydraulic diameter from 15 to 4010 µm, with Reynolds number varying from Re = 10^{-3} up to Re = 2100, and Knudsen number from K_n = 0.001 to K_n = 0.4 has been reported by Hetsroni [1]. Surface roughness is likely responsible for the early transition from laminar to turbulent flow and the increased friction factor and Nusselt number [2]. The pressure gradient measurements is reported for Knudsen numbers in the range of 0.003 to 0.4 based on the hydraulic diameter of 151.7 µm and the length-to-height ratio of about 50. The effects of entrance geometry on the pressure distribution and friction factor were also studied for 2D and 3D cases [3]. Also the Taylor and Arkilic have reported the effect of the surface roughness on the laminar flow in micro channels. The variation of the Poiseuille number in the regime of high Reynolds numbers is higher than the conventional theory predictions and increases with increasing Reynolds number, rather than remaining constant, has been verified in [4, 5]. However, such effect can be neglected for low Reynolds numbers.

In this paper, the scaling effect is analyzed for micro fluidic channels of different cross sections like circular, semi-circular, rectangular and square channels. The analytical and numerical simulations for different characteristic lengths are performed by applying different pressures. The numerical simulation is performed using Coventorware. The circular channel diameter range from 1 µm to 4000 µm is analyzed for which the laminar to turbulent transition is analyzed. The analysis has been done for 2 compressible and 2 incompressible fluid flows through channels. The diameter at which laminar to turbulent transition has occurred is found, by varying the inlet pressure in the range of (1-1000) pa and the lengths from (1-1000) µm. The same analysis has been carried out for other cross sections like semi-circular and square channels. The rectangular channel for the width of 150 µm to 600 µm and depth of 22.71µm to 26.35 µm is analyzed numerically and analytically for fluid flows. The different materials like glass, silicon, stainless steel and polymer has been used for rectangular channels.

The paper is organized as, in Section 2.1, Design, simulation and analysis of flow in circular channel is analyzed. The analysis of microfluidic channels for the transition from laminar to turbulent flow has been discussed. In Section 2.2, Design, simulation and analysis of flow in semicircular channel is analyzed. In Section 2.3, Design, simulation and analysis of flow in square channel is analyzed. In Section 2.4, Design, simulation and analysis of flow in rectangular channel is analyzed. The effect of using various channel wall materials for rectangular channel is also discussed in this section.

2. Design, Simulation and Analysis of Flow in Micro Fluidic Channel

The design of microfluidic channel has been carried out in the numerical analysis tool Coventorware. The channels like circular, semi-circular, square and rectangle have been attempted. The fluids like water, transformer oil, air and hydrogen are used.

2.1. Circular Channel

The circular channel has been created using fluidic mesh generator in Coventorware with the dimension of 1 µm diameter and with the length of 1 µm. The circular channel created in fluidics mesh generator in Coventorware is shown in Fig. 1.

For a pressure driven flow in a circular tube of radius a, the flow rate is given by Equation (1)

$$Q = \frac{\pi a^4 dp}{8 \mu L}, \tag{1}$$

where dp/L is the pressure gradient over the length L and µ is the viscosity of fluid. The flow rate is calculated analytically by using the Equation (1). For the inlet pressure of 1 pa and 1000 pa, the flow rate is computed by varying the diameter of circular channel from 1 µm to 4 mm, for a length of 1 µm and for the length of 1000 µm circular channel by DC analysis in the coventor ware. From the analysis the diameter at which the Laminar to turbulent transition occurs is identified .The same simulation is performed for four different fluids and the diameter at which the transition occurred is tabulated in the Table 1. The variation of Reynolds number and flow rate with pressure for water is shown in the Fig. 2.

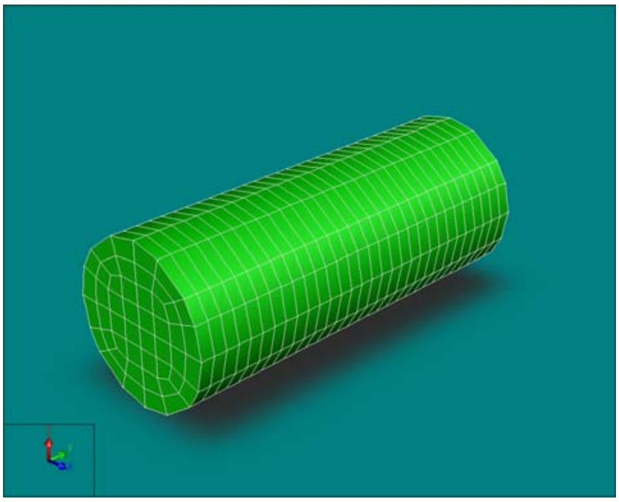


Fig. 1. Circular channel.

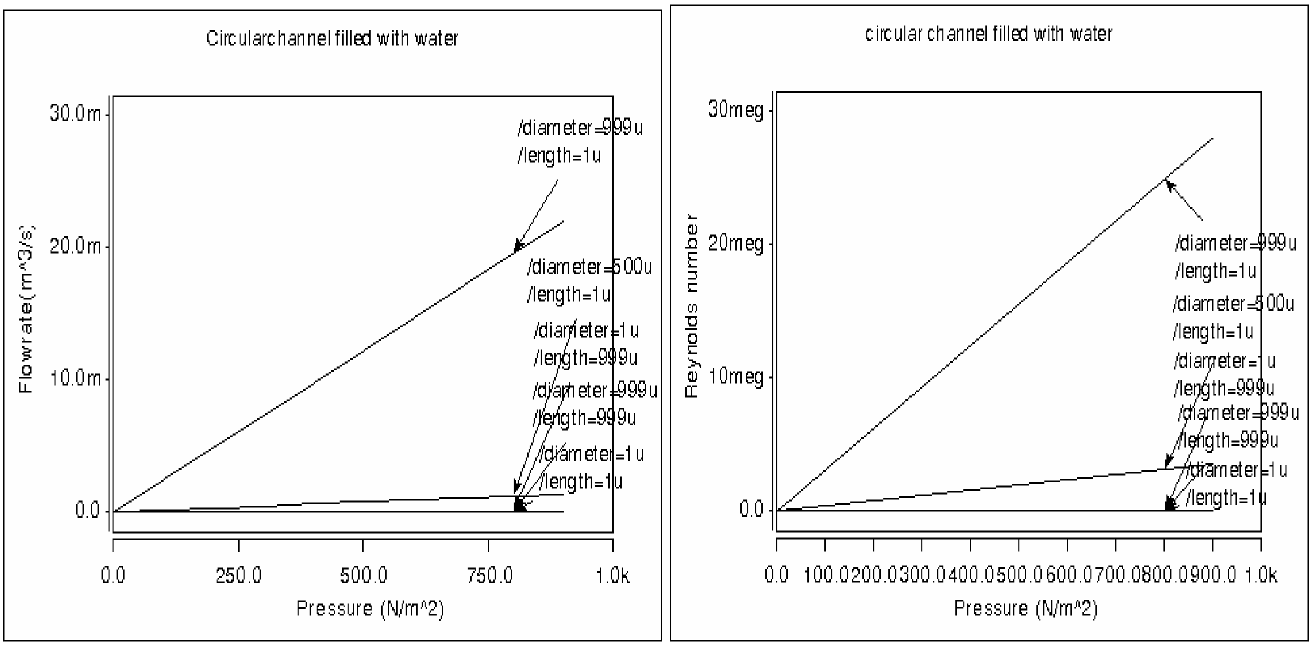


Fig. 2. Variation of flow rate and Reynolds number with pressure for water.

Table 1. Laminar to turbulent transition Diameter.

Length in µm/Pressure in pa	For Water Diameter in µm	Transformer Oil Diameter in µm	Air Diameter in µm	Hydrogen Diameter in µm
1/1	406.6	3231	250.7	375.1
1000/1	4066	32310	2507	3751
1/1000	40.66	323.1	25.07	37.51
1000/1000	406.6	3231	250.7	375.1

2.2. Semi-Circular Channel

The semicircular channel has been created using fluidic mesh generator in Coventorware with the dimension of 1µm diameter and with the length of 1 µm. The semi circular channel created in fluidics mesh generator in Coventorware is shown in Fig. 3.

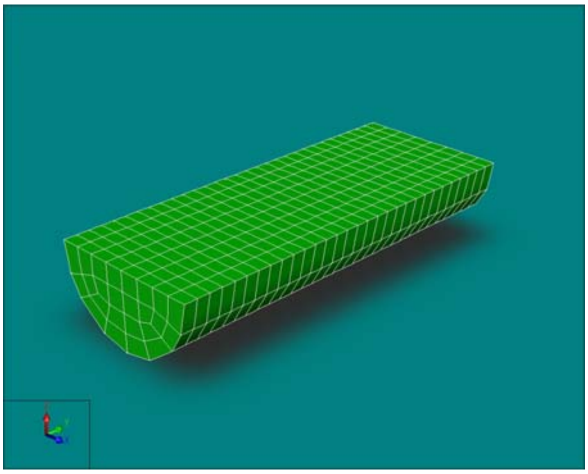


Fig. 3. Semicircular channel.

For a pressure driven flow in a semicircular tube of radius a, the flow rate is given by Equation (2)

$$Q = \frac{\pi a^4 dp}{16 \mu L}, \tag{2}$$

where dp/L is the pressure gradient over the length L and µ is the viscosity of fluid. The flow rate is calculated analytically by using the Equation (2). For the inlet pressure of 1pa and 1000pa, the flow rate is computed by varying the diameter of semicircular channel from 1µm to 4mm, for a length of 1µm and for the length of 1000 µm circular channel by DC analysis in the coventorware. From the analysis the diameter at which the Laminar to turbulent transition occurs is identified .The same simulation is performed for four different fluids and the diameter at which the transition occurred is tabulated in the Table 2. The variation of Reynolds number and flow rate with pressure for water is shown in the Fig. 4.

Table 2. Laminar to turbulent transition Diameter.

Length in µm/Pressure in pa	For Water Diameter in µm	Transformer Oil Diameter in µm	Air Diameter in µm	Hydrogen Diameter in µm
1/1	357	2837	220.1	329.4
1000/1	3570	28370	2201	3294
1/1000	35.7	283.7	22.01	32.94
1000/1000	357	2837	220.1	329.4

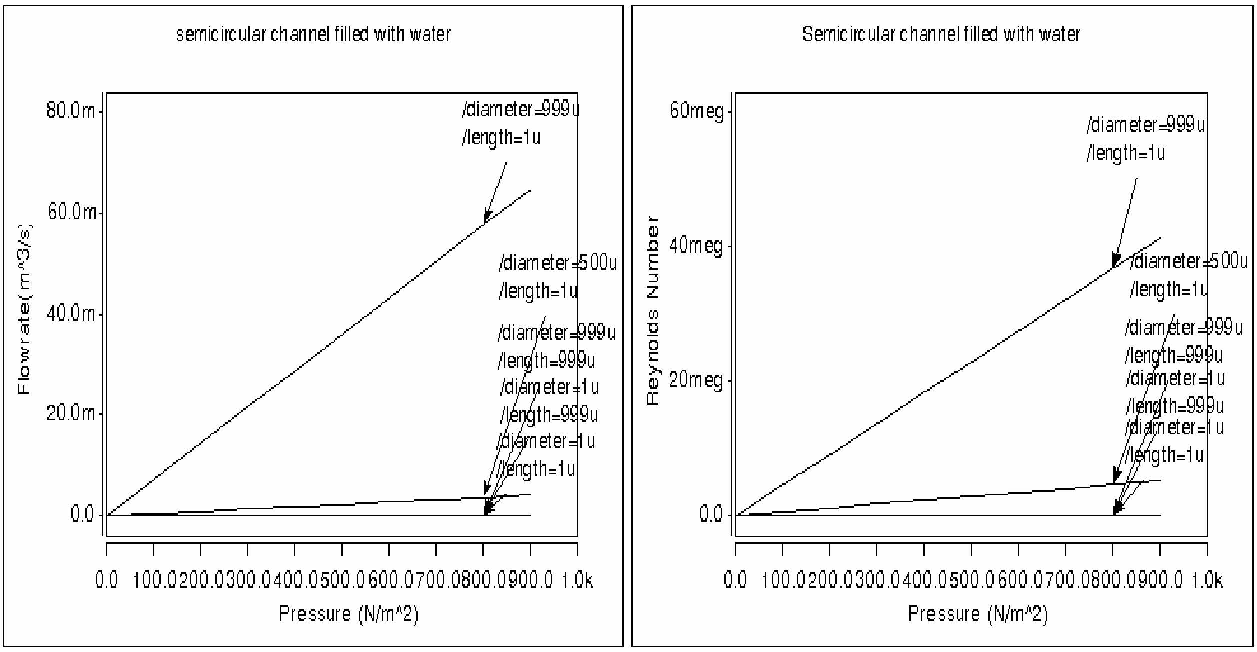


Fig. 4. Variation of flow rate and Reynolds number with pressure for water.

2.3. Square Channel

The square channel has been created using fluidic mesh generator in Coventorware with the dimension of 1 µm side and with the length of 1 µm. The square channel created in fluidic mesh generator in Coventorware is shown in Fig. 5.

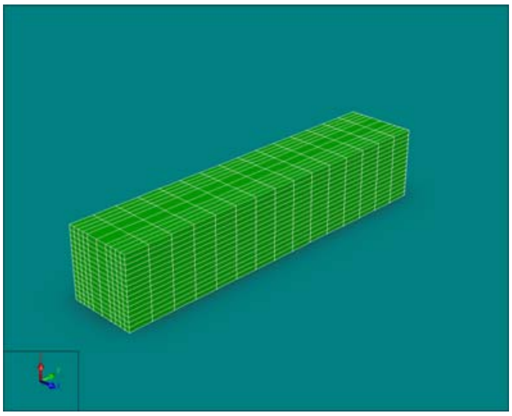


Fig. 5. Square Channel.

For a pressure driven flow in a square tube of side a, the flow rate is given by Equation (3)

$$Q = \frac{a^4 dp}{12 \mu L}, \tag{3}$$

where dp/L is the pressure gradient over the length L and µ is the viscosity of fluid.

The flow rate is calculated analytically by using the Equation (3). For the inlet pressure of 1 pa and 1000 pa, the flow rate is computed by varying the side of square channel from 1 µm to 4 mm, for a length of 1 µm and for the length of 1000 µm square channel by DC analysis in the coventorware. From the analysis the side dimension at which the Laminar to turbulent transition occurs is identified .The same simulation is performed for four different fluids and the diameter at which the transition occurred is tabulated in the Table 3. The variation of Reynolds number and flow rate with pressure for water is shown in the Fig. 6.

Table 3. Laminar to turbulent transition Diameter.

Length in µm/Pressure in pa	For Water Diameter in µm	Transformer Oil Diameter in µm	Air Diameter in µm	Hydrogen Diameter in µm
1/1	391	3107	241	360.6
1000/1	3910	31070	2410	3606
1/1000	39.1	310.7	24.1	36.06
1000/1000	391	3107	241	360.6

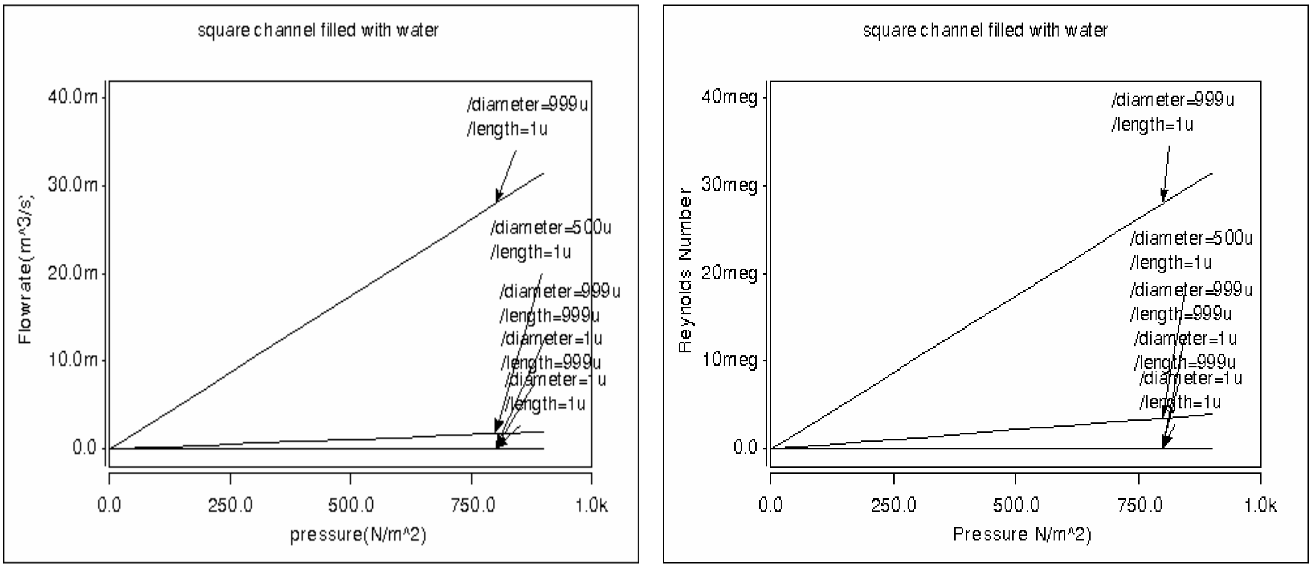


Fig. 6. Variation of flow rate and Reynolds number with pressure for water.

2.4. Rectangular Channel

The dimensions of the rectangular channel considered for analysis are of width 150 µm to 600 µm and depth of 22.71 µm to 26.35 µm and the channel created using fluidics mesh generator is shown in Fig. 7.

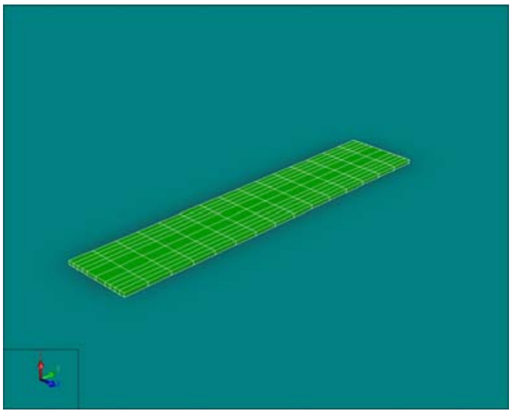
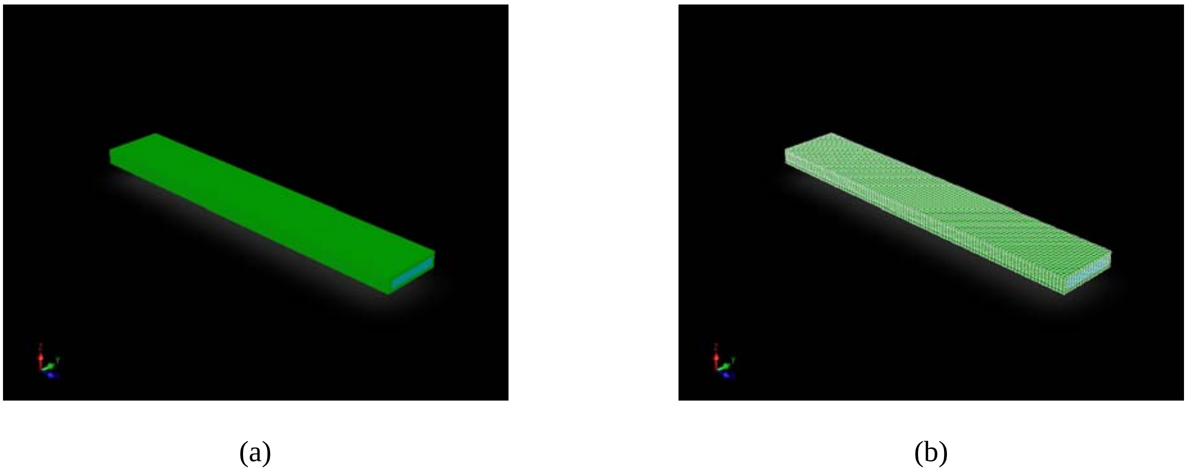


Fig. 7. Rectangular channel.

The flow rate in a rectangular channel of width w and height h is given by Equation (4)

$$Q = \frac{wh^3 dp}{12\mu L}, \tag{4}$$

where dp/L is the pressure gradient over the length L and μ is the viscosity of fluid. The rectangular channel has been created by depositing a 10 μm glass over the silicon substrate and again depositing 22.71 μm glass and etching for the planar filling of water and again depositing 10 μm glass to cover the channel. By creating the rectangle of 150 μm by 1000 μm dimensions in the layout, we get the rectangular channel as shown in the Fig. 8a. The Fig. 8b represents the channel after meshing in (x, y, z) axes with the corresponding element size of (10, 10, 5).



(a) (b)

Fig. 8. Rectangular channel with and without mesh.

When the water is used as the working fluid, using DC analysis in Coventorware, and the variation of Reynolds number from 0.9062 – 1.482 was observed when the width is varied in the range of 150 μm to 600 μm with a depth variation of 22.71 μm to 26.35 μm. With the transformer oil same analysis is performed and the Reynolds Number finds to vary in the range of 0.0018-0.078.

The fluid structure interaction has been analyzed for the rectangular channel of length 1000 μm, width of 150 μm and depth of 22.71 μm using MemFSI module in Coventorware. The analysis has been carried out by using materials like glass, silicon and polyimide. Table 4 shows the variation of displacement magnitude and misesstress for the different channel materials. The Fig. 9 shows the pressure, stress, velocity and displacement distributions for silicon channel.

Table 4. Channel properties for the different materials

Material **Properties**	**Glass**	**Silicon**	**Polyimide**
Velocity, µm / s	1.287e2	1.287e2	1.287e2
Pressure kg / (µm· s)^2	3.97e-6	3.97e-6	3.97e-6
Flowrate µm^3 / s	2.4e5	2.4e5	2.4e5
Displacement Magnitude, µm	9.106e-13	2.2369e-11	1.417e-11
Misesstress, kg /(µm· s^2)	5.682e-7	6.726e-7	4.244e-7

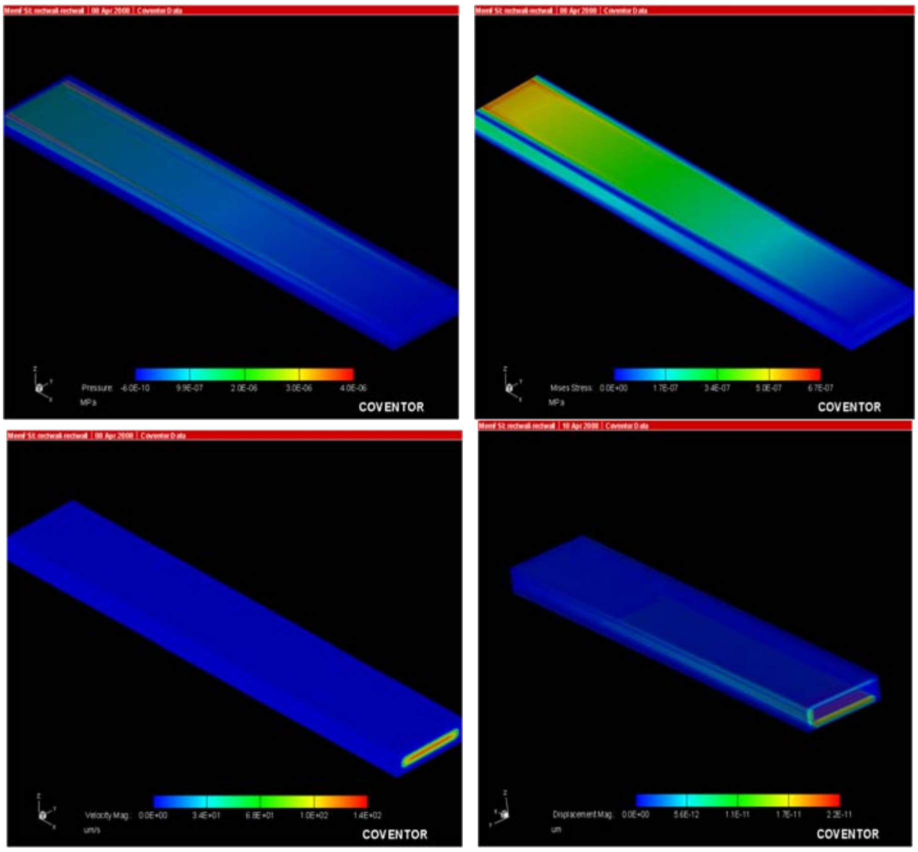


Fig. 9. Pressure, Stress, Velocity and Displacement distributions in the silicon channel.

3. Conclusion

The sizing effect of microfluidic channels like circular, semicircular, rectangular and square channel has been analyzed for compressible and incompressible fluids. When the viscosity is increased from 1centipoise to 21 centipoises, the Reynolds number found to be decreased. When the highly viscous fluid like transformer oil is used, we found that the diameter at which laminar to turbulent transition is increased. The surface roughness is analyzed for rectangular channel by varying the surface wall materials like silicon, glass and polyimide. The stress experienced by the silicon wall surface is greater than glass and polyimide. The stress experienced by glass is greater than polyimide.

References

[1]. G. Hetsroni, A. Mosyak, E. Pogrebnyak, L. P. Yarin, Fluid flow in micro-channels, *Int. J. Heat Mass Transfer*, 48, 2005, pp.1982–1998.

[2]. Zeng-Yuan Guo, Zhi-Xin Li, Size effect on microscale single-phase channel flow and heat transfer at micro scale, *Int. J. Heat Fluid Flow*, 24, 2003, pp. 284-298.

[3]. Xiaohui Guo, Chihyung Huang, Alina Alexeenko, John Sullivan, Numerical and experimental study of gas in 2D and 3D microchannels, *J. Micromech. Microeng*, 18, 2008, pp. 025-034.

[4]. James B. Taylor, Andres L. Carrano, Satish G. Kandlikar, Characterization of the effect of surface roughness and texture on fluid flow - past, present, and future, *International Journal of Thermal Sciences*, 45, 2006, pp. 962–968.

[5]. Errol B. Arkilic, Martin A. Schmidt, Kenneth S. Breuer, Gaseous Slip Flow in Long Microchannels, *Journal of Micro Electro Mechanical Systems*, Vol. 6, No. 2, 1997, pp. 167-177.

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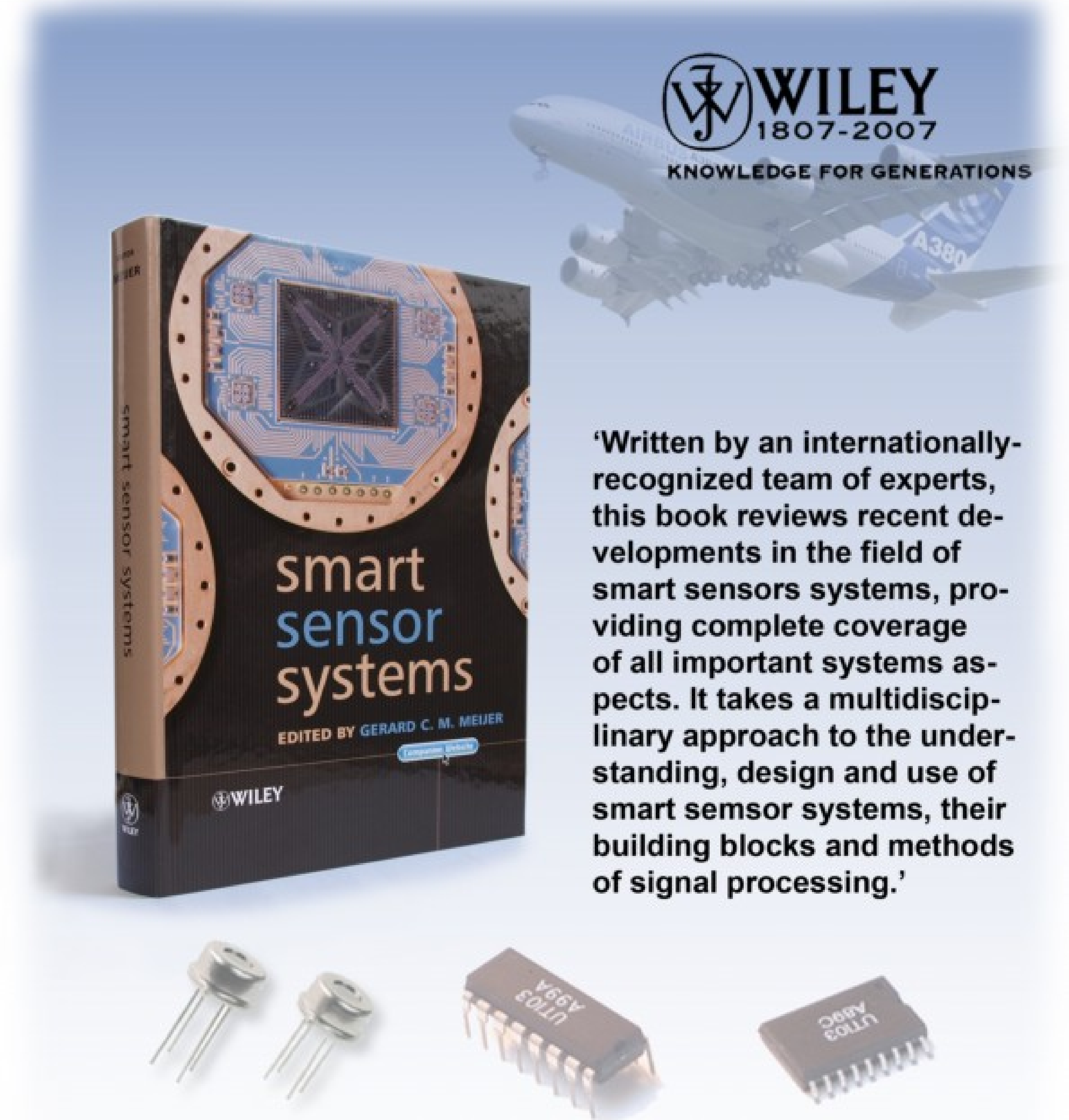

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