CHAPTER 2

LITERATURE REVIEW

2.0 Introduction toMicrofluidics

Microfluidics technology, a branch out from MEMS (Micro electro mechanical systems) refers to the research and development of micro-scale devices which incorporates miniscule amount of fluid in its operation. Microfluidics is the science of designing, manufacturing and formulating devices and processes that deal with miniscule volumes of fluid.

The key issue of MFD (Micro fluidic devices) is the microscopic quantity of fluid it requires for the operation. It is not about the miniaturization of the device. However, to handle such small quantities of fluid, the channels have to be miniaturized as fluid dynamics are different from the macro-scale physics.

2.1 Microfluidics: A History

Research on microfluidic devices date back 20 years ago in Stanford University where it began as a chromatograph. The idea was then developed by IBM where it was incorporated in the ink jet printers. Microfluidics possesses potential in a wide range of technologies.

Andreas Manz and Micheal Ramsey are among the pioneers to have fabricated microfluidic devices on silicon glass by conventional planar fabrication techniques in the early 1990s. They adopted the nonphotolitographic Microfabrication processes which actually post numerous problems like inflexibility and high fabrication cost.

2.2 Scaling Effects on Microfluidics: Opportunities and Challenges

Due to down sizing, different effects dominate the dynamics of the fluid. E.g. *Faster thermal diffusion*, predominantly *laminar flow*, *surface forces*, *capillary* effect, and formation of *electric double layer* (EDL).

Laminar flow: is due to low *Reynolds number* (Measures between inertial forces and viscous forces) which means the flow is streamlined to no turbulences. Reynolds number of 1500-2000 denotes laminar flow.

$$R_e = \frac{\rho L V_{avg}}{\mu} \qquad (2.2 \quad - \quad 1)$$

ρ : fluid density
L : Relevant channel length
V_{avg} : Average velocity of the flow
M : Fluid viscosity

When a surface comes into contact with an electrolyte, it acquires electric charges. The charges affect the electric field by attracting opposite charges and repelling like charges. These spontaneously formed charges are called Electric Double Layer. The fluid then flows electrostatically rather than mechanically.

Liquid evaporation becomes more significant in Microfluidic devices as the surface to volume ratio is increased tremendously. Evaporation occurs more efficiently.

A challenge is posed in the assembly and packaging departments. The connections made must stand high pressure and protected from harsh environments. Though the system has to be air tight, there must still be an opening somewhere for fluid introduction.

Particles of fluid and particles suspended in fluid become comparable to the device dimensions. This may dramatically alter the system's behaviour. This phenomenon may not post a threat in the macro scale devices.

2.3 Capillary Effect

The friction existing in the fluid channels creates non-slip boundary. The surface tension and cohesion bonds to the side walls of the micro channel aid fluid flow. This fluid driving force will be applied in this project to help flow of fluid from the reservoir to the channels.

2.4 Fluid Resistance in the Microchannel

Resistance is the a force that hinders the flow of fluid or electron. In case of fluid flow, resistance in that sense means a ratio of pressure drop (ΔP) to the volumetric flow rate of the medium (Q) along a specific length of the channel.

$$R = \frac{\Delta P}{Q} \qquad (2.4-1)$$

In a rectangular channel, the fluid resistance is determined by the channel length, depth and width:

$$R = \frac{12\mu * length}{width * height^3} \qquad (2.4 - 2)$$

2.5 Reynolds Number

Reynolds number refers to the ratio of inertial forces ($v_s\rho$) to viscous forces (μ/L). Two flow regimes can be identified using Reynold number; laminar and turbulent flows. Laminar flow occurs at lower Reynolds numbers (<2100). In such flow, viscous forces are dominant and are characterized to be smooth and constant flowing. At high Reynolds numbers, flow is turbulent, as it is dominated by inertial forces producing random eddies, vortices and other flow fluctuations.

2.6 Materials Used

It all began with fabrication on silicon as substrate. Now, it has evolved to other materials like polymers and glass as substrate. The trend however is moving from glass with premium optical properties to polymers as they are easier to process and possess mechanical flexibility. Different materials are used as electrodes or active materials such as Aurum, platinum and nickel.

Some active polymers are used. Under electrical stimulation, they change shape. Such polymers are called electro-active polymers (EAP). They are activated either on ionic or electronic influences.

2.7 Advantages of Microfluidics

Three are several benefits of this technology. One, it is smaller in size. This makes it more applicable where space constraints become an issue. The cost of fabrication is reduced dramatically under high production volume. Material usage is optimized and throughput is enhanced. Relative to the mass production of larger channels, the fabrication of micro-scaled channels would be faster.

Smaller sized devices have better power management. They require less energy to power them up, thus reducing the power consumption. This consequently provides suitability in wireless solutions.

Only small volumes of expensive reagents are needed to carry out a test. This makes it a compatible appliance when sample is unavailable in large quantities. Performance of the device improves in smaller scale. There will be less propagation delay in charge transportation and excellent ion mobility.

The high end technological advancement has allowed it to be integrated almost anywhere in any circuitry, hence providing the benefits of multifunctionality. ‘Lab-on-chip’, describes best this characteristic. Automated sample preparations can be done with built-in detection systems and on chip synthesis. This reduces the need for highly skilled individuals to perform critical analytical steps manually.

More parameters can be monitored at once. The device sensor may be built in with several detectors that work simultaneously. Additional functions are available when the device is downscaled. Different physical dynamics as a result of scaling may provide opportunities for more functions in the near future.

Smaller devices also mean less heat dissipation and handling of smaller quantities of hazardous substances. This poses less risk of explosion and hazardous reactions hence enhancing its safety.

2.8 Microfluidics: Application

The application of microfluidic is widespread. Some examples of applications include inkjet printers, portable blood analyzers, DNA and proteomic chips, lab-on-a-chi system and micro total analysis system. Microfluidics made its way successfully not only in the diagnostic, pharmaceutics, biotechnology and environmental technology but also in consumer electronics, pulp, paper chemical, and also in automotive and food industries.

Microfluidics application as a diagnostic tool unveiled a new era in contemporary science. Handling of DNA (deoxyribonucleic acid), the genetic essence of all living creatures in high levels of efficiency have been made possible. With the dawn of a new era, manipulations of DNA have successfully been implemented. DNA molecules are very small and delicate. They have to handled carefully to observe their nature. Before microfluidics, genetic manipulations were not possible at the level of efficiency as today. Point-of-care analysis and total analysis systems are among other areas where microfluidic is implemented.

Ink jet printers are faster than dot matrix printers. They are also cheaper and more compact than the laser printers. They work on a combination of two dimensions of of physics; thermal physics and microfluidics.

In vitro fertilization shone a ray of hope to inconceivable couples. While there are a number of assisted reproductive technologies (ART) available to infertile couples, in vitro fertilization (IVF) is by far the most utilized of these methods. In fact, IVF accounts for more than 95% of all ART procedures. Researches have found that the use of microfluidic in this area requires lower concentrations of sperm as compared to culture dish fertilization. In IVF, egg taken from the women’s uterus is fertilized with sperm outside the body. The fertilized egg is then implanted into the women’s uterus for normal development of the embryo. Researches have conducted tests on mice and say that more tests have to be made and more auxiliary technology is needed before IVF by microfluidics can be a viable option for humans.

In the pharmaceutical departments, process quality control and drug testing are done with the aid of microfluidic technology. In the medical arena, drug administration and in vivo diagnostics benefit from this technology.

The food industry and also reaps the benefits of microfluidic in Food diagnostics and smart sensors in packaging. In the chemistry lab, applications are for micro-reactions that requires miniscule devices with fluidic compatibility. In the process industry, it is used as sensors for profile measurements, process control and on-line measurements.

This technology also contributes a great deal in the environmental studies where it is used for water and soil condition measurements. In the automotive industry, fuel-injection, oil quality monitoring and exhaust gas analysis uses microfluididc applications. Some consumer electronics like the ink-jet printer, local cooling of electronics and fluidic power systems are fruits of this technology.

2.9 A Capacitor

Capacitors are components that have the ability to store electrical energy. This energy is stored in an electrostatic field which is created by electrical charges accumulating on conducting plates placed across an electrical potential and separated by an insulating medium. Capacitance as a value is dependent upon the distance between the conducting plates, the dielectric constant of the insulating medium, and the common area of the conducting plates.

There are three categories of capacitors in the market; electrolytic, electrostatic and electrochemical.

Electrolytic capacitors are polarized units which use tantalum oxide or aluminum oxide as the dielectric. The oxides are very thin which result in very high capacitance values. The negatives are low insulation resistance, sensitivity to changes in temperature and frequency, and a high dielectric absorption.

Electrostatic capacitors have sub-categories that they are divided into such as Film, Air, Mica, Ceramic, and Vacuum. Mica and Vacuum capacitors are usually found in high frequency, high voltage applications because of their dielectric characteristics. Air capacitors are low loss devices that are most commonly used for variable tuning. Ceramic capacitors offer a wide range of physical configurations and electrical characteristics and come in Low K class I ceramics and Higher K class II ceramics.

Electrochemical capacitors forms a dielectric layer in the electrolyte when voltage is applied. A thin double layer charges is formed around the electrodes. So, charge in this capacitor is strored electroctaically.

Most capacitors are designed to maintain a fixed physical structure. However, various things can change the structure of the capacitor. The resulting change in capacitance can be used to sense those things; the same concept adapted in the application of microfluidic devices.

By changing the dielectric, the effects of varying the physical or electrical characteristics of the **dielectric** can also be of use. Capacitors with an exposed and porous dielectric can be used to measure humidity in air. By varying the distances between the two electrodes, the capacitor can be used to measure fuel level in air planes. Capacitors with a flexible plate can be used to measure strain or pressure. Capacitors are used as the sensor in condenser microphones, where one plate is moved by air pressure, relative to the fixed position of the other plate. Some accelerometers use MEMS capacitors etched on a chip to measure the magnitude and direction of the acceleration vector. They are used to detect changes in acceleration, for example as tilt sensors or to detect free fall and as sensors triggering the air bag deployment.