CHAPTER IV

FABRICATION OF SERPENTINE SHAPED MICROCHANNEL
AND EXPERIMENTAL SET UP

4.1 Microchannel fabrication methods

Microchannels are fabricated by a variety of processes depending on the dimensions and materials used. Common materials used for microchannels are silicon, silica, polycarbonate/polyimide, plastic, or metal. Basic microchannel configurations are rectangular, semicircular, triangular, or trapezoidal cross-sections,

4.1.1 Conventional technology

I. Micro deformation
II. Micro sawing
III. Micro milling
IV. Dicing

4.1.2 Modern Technology

I. Wet etching
II. Deep RI etching
III. LIGA
IV. Wafer bonding
V. Laser micromachining
VI. Electro discharge machining
VII. Micromolding

which are widely reported in the literature and are summarized by Nguyen and Werely (2002). Other geometrically complex microchannels may offer more attractive performance, but they have not yet been investigated. Since the first demonstration of microchannels by Tuckerman and Pease (1981), a number of microchannel fabrication methods have become standard processing approaches in
this field. These methods can be divided into two groups, conventional technologies and modern technologies. Conventional fabrication technologies include methods such as micro-deformation, micro-sawing, micro-milling, and dicing. Modern microchannel fabrication techniques include MEMS (Micro-Electro-Mechanical Systems) methods, laser micro-machining, electro-discharge machining, and micromolding. MEMS technology has grown dramatically alongside semiconductor technology and is the most widely used technology in research laboratories. Recently, laser micro-machining technology has gained the spotlight due to the method’s low manufacturing uncertainty and its potential to manufacture an unlimited number of geometries. Table 4.1 presents a summary of some fabrication methods for microchannels.

**Table 4.1 Summary of some fabrication methods for microchannel**

<table>
<thead>
<tr>
<th></th>
<th>Micro-deformation technology</th>
<th>Micromachining</th>
<th>MEMS (Deep reactive ion etching)</th>
<th>Laser micromachining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometries</td>
<td>Rectangular</td>
<td>Rectangular</td>
<td>Rectangular, circular, triangular, trapezoidal</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Materials</td>
<td>Metal and non-metal</td>
<td>Metal and silicon</td>
<td>Metal, silicon, and glass</td>
<td>Metal and glass</td>
</tr>
<tr>
<td>Channel range</td>
<td>250 channels/Inch</td>
<td>0.1–10 mm</td>
<td>Nanometer scale to millimeter scale</td>
<td>Nanometer scale to millimeter scale</td>
</tr>
<tr>
<td>Advantages</td>
<td>Low cost, fast</td>
<td>High or low aspect ratio, inexpensive, fast</td>
<td>Low manufacturing uncertainty</td>
<td>Low manufacturing uncertainty</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Some materials require post treatment</td>
<td>Complex design is impossible</td>
<td>Slow process (1 day)</td>
<td>Too expensive</td>
</tr>
</tbody>
</table>
4.1.3 Fabrication by Conventional technology

The conventional machining process, metal is removed by using some sort of tool which is harder from the work piece and it is subjected to wear. In this process tool and work piece in direct contact with each other. It is the removal of metal by compression shear chip formation. The different methods of fabrication of microchannel by conventional technology is discussed below.

4.1.3.1 Micro deformation

As indicated in Table 4.1 the micro-deformation technique can fabricate rectangular channels on any material. As reported by Kukowski (2003), the micro-deformation process can form up to 500 channels per inch. At this time, microchannels of up to 250 channels per inch are routinely formed on a broadrange of materials. The channels are cut in one continuous pass or multiple passes depending on the system used. The advantages of the micro-deformation technology include low cost and quickness. However, depending on the strain-hardening rate of the materials, some processed materials after micro-deformation processing may require additional post treatment. As shown in Figure 4.1 the working principles of the micro-deformation technology are simple. Using the patented tool and prescribed interference angles with the work piece, the process plastically deforms ductile materials. The tool moves the base material, and depending on the geometric configuration of the tool, plastically deforms that material to the defined and repeatable shape. Only one tool is required for each desired configuration. The tool with one-point landing channels the material while deforming or lifting the material to the desired geometric shape and angle, simultaneously finning and forming microchannels of a variety of repeatable contours and dimensions.

![Figure 4.1 Working principle of micro-deformation technology: 1 work piece, 2 cutting tool, 3 section with microchannels (Kukowski 2003).](image-url)
4.1.3.2 Micro sawing

Micro-sawing is a technique widely used in industry that can fabricate rectangular channels in metal or silicon with an applicable channel width in the range of 0.1–10 mm. This technology can fabricate microchannels with high or low aspect ratios. It is very fast and has the lowest manufacturing cost among all microfabrication technologies. The technology uses a fret saw to fabricate rectangular microchannels, such as those shown in Figure 4.2.

![Figure 4.2 Microchannels manufactured by microsawing technology (Jang et al. 2003)](image)

4.1.4 Modern technology

The modern technology machining process there is no direct physical contact between the tool and the work piece. Therefore the tool material need not be harder than the work piece material as in conventional machining.

4.1.4.1 MEMS (Micro-Electro-Mechanical Systems)

Much of the current research in MEMS centers on a group of batch microfabrication methods that arose from the semiconductor sector. Many technologies are included among MEMS methods: wet etching, dry etching, LIGA (Lithographie, Galvaniformung, and Abformung), and deep reactive ion etching (DRIE). The rectangular, circular, triangular, or trapezoidal channels can be fabricated using the
DRIE technique. This technology is applicable to metal, silicon, and glass with a wide range of channel sizes, from the nanometer scale to the millimeter scale. In addition, the technology has the advantage of low manufacturing uncertainty. However, the DRIE technology is not well suited for use in industrial fields due to its time consuming process. The DRIE technology process shown in Figure 4.3 is as follows: (1) Deposit Photo Resistor (PR) material on the specimen using a sputtering process; (2)

![Figure 4.3 Process of DRIE technology (Young and Kim 2012)](image)

Expose the specimen to UV light; (3) Form the channels by the DRIE process; (4) join a cover with the specimen by anodic bonding.

4.1.4.2 Laser micromachining

Recently, laser micro machining technology has been applied to the fabrication of micro channels. Laser micro-machining is applicable to any material and can produce a wide range of channel sizes from the nanometer to millimeter scale in an unlimited number of geometries. In addition, the technology has the advantage of low manufacturing uncertainty. Laser micro-machining technology is better than the technologies discussed above in all aspects except cost and process speed. For this reason, the technique has not yet been adopted by industry. A diagram of a laser micro-machining system is shown in Figure 4.4 a. The laser
enters a test section through a focusing lens while a computer controlled XYZ-stage moves the specimen to form the microchannels. Figure 4.4 b and c shows some microchannels manufactured by the laser micro-machining process.

Figure 4.4 (a) Schematic diagram of a laser micro-machining system; (b) Drilling of 1µm-thick glass with hole diameter of 1µm; (c) A scanning electron microscope image of the cross-section of microchannels fabricated using femto second laser micro-machining (Lim et al. 2008)
4.2 Designed serpentine shaped microchannel for experimentation

Figure 4.5 Dimension of the serpentine microchannel.

The designed serpentine microchannel geometry in Figure 4.5 is shown with the dimensional parameters noted in Table 4.2. The fabrication method process adopted is electro discharge machining which is discussed below.

<table>
<thead>
<tr>
<th>Channel width (mm)</th>
<th>Heat sink length (mm)</th>
<th>Heat sink width (mm)</th>
<th>Heat sink Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81</td>
<td>75</td>
<td>55</td>
<td>14</td>
</tr>
</tbody>
</table>
4.2.1 Electro discharge Machining EDM

In electro discharge machining metal is removed by producing powerful electric spark discharge between the tool and the work material. This principle is used in the fabrication of microchannel.

The electro discharge machining method is adopted for the manufacturing of serpentine shaped microchannel. The channel is manufactured using the copper material. The dimensions of the copper material and the working of Electro discharge machining process to cut a serpentine grooves in the channel is explained below see fig 4.6 and fig 4.7.
Electric discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode", while the other is called the work piece-electrode, or "work piece".

When the distance between the two electrodes is reduced, the intensity of the electric field in the volume between the electrodes becomes greater than the strength of the dielectric at least in some points which breaks, allowing current to flow between the two electrodes. This phenomenon is the same as the breakdown of a capacitor (condenser) (see also breakdown voltage). As a result, material is removed from both electrodes. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is usually conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as "flushing". Also, after a current flow, the difference of potential between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur.
4.2.2 Experimental system construction

Copper is used as a material for fabricating the micro channel. This material is selected for its greater corrosion resistance, thermal conductivity and smooth surface finishing. Initially the plates are faced to get the required thickness. The plate is grinded in a bed type surface-grinding machine in order to get a smooth surface. The machining is done on the surface of the bottom plate. As the first process inlet and outlet sumps are machined using milling process and then, channels are cut on the surface of the bottom plate using EDM process according to the dimensions shown in Figure 4.8. The map of the microchannel with fin core section is presented in Figure 4.8. In order to circulate the working fluid into the micro channel a drilling process is made on the surfaces of the bottom plate connecting the inlet sump with inlet surface and the outlet sump with outlet surface respectively. Hydraulic pipe of standard dimension is brazed in the inlet and outlet surfaces of the microchannel, which is used as a connecting medium between the micro channel and the components of the experimental set-up. The square plate of side 75 mm and thickness 55mm is taken as top plate of the micro channel. Convection fins are machined on the top surface of the plate to enhance the heat transfer rate. This plate is used to cover the machined surface of the bottom plate. The EDM is considered to be a non-conventional machining technique. It is a process whereby the material is removed through the erosive action of electrical discharge (sparks) provided by a generator. With a precision EDM dimensional tolerances up to 0.5µm could be obtained. A high speed EDM technique enables a dimensional tolerance up to 1.5 micro meter and a machining speed of 5 µ/ sec to be obtained. The smaller electrode used has a diameter of 30 micro meter, subsequent to this pioneering work. The interest in micro EDM machining remained sedate until micro-electronics era emanated. Even 3D shapes (that prove difficult for etching) are done easily with EDM. Inlet and out conduits were attached together with the two plates and brazed in vacuum furnace at 5-10 torr and about 1000°C.
Figure 4.8 Assembly of core section of the microchannel with fin.

Figure 4.9 Schematic representation of experimental setup
4.2.3 Micro channel heat sink experimental setup and working

The schematic diagram of the experimental apparatus is shown in Figure 4.9. The test loop consists of an Ultrasonic vibration Bath, Pump, Filter, Flow meter, Micro-channel, Heater, and Air cooled heat exchange. In the present study, nanofluids are stored in the ultrasonic vibration bath. This bath acts as a reservoir and sonificator. A metal heating type Nichrome heater is fixed on the surface of the microchannel of 140 watts. A pump is attached between the bath and the microchannel to circulate nanofluids through the entire circuit. The unwanted micron size particle is removed using filters. Flow meter is placed between the pump and microchannel. Fluid flow rate is controlled by the valve and it is placed between the pump and channel. The pressure gauges are fixed at the inlet and outlet of the micro channel and used to measure the pressure drop of the channel. When the nano fluid passes through microchannel, it absorbs some amount of heat supplied by the heater. The excess heat carried by the nano fluid is released when it passes through the air cooled heat exchanger then the fluid moves to the bath and the cycle is repeated. The entire set-up is kept airtight in order to prevent any leakage of the fluid. The Figure 4.10 shows the photographic view of the experimental setup.

![Figure 4.10 Picture of the experimental system](image)
4.2.4 Specification of the experimental setup

1. **Pump**
   - Displacement: 0.85 cm$^3$/rev to 5.00 cm$^3$/rev
   - Maximum pressure: 200 bar
   - Model No: 6003
   - Motor = 0.37 Kw (Three Phase Induction motor)
   - RPM = 1500

2. **Flow meter**
   - Fitting position = Vertical
   - Pressure range = 290 psi/ 20 bar
   - Flow range = 0 – 0.5 LPM
   - Weight = 150 grams
   - Accuracy: ±1%

3. **Thermocouple –J type**
   - Conductors: Positive (Iron-Magnetic) Negative (Constantan-Non magnetic)
   - Temp Range: 0 to 750 °C
   - Accuracy: ± 0.4%

4. **Pressure Gauge**
   - Dimension 2.5" (63mm)
   - Model type: Bourdon tube SUS316
   - Pressure range: 0 to 2.1 bar
   - Accuracy: ±1.6%

5. Temp. indicator –PID (Proportional-Integral-derivative)
6. Resistance heating heater-effective heating power of 10-70W
7. Wattmeter (10A, 150V), Accuracy : 1%
8. Single phase autotransformer-0.270V
9. Filter-15µm