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Fabrication of Polymeric Micro needle Array by Micromachining & Micro molding

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***Abstract*— Microneedles are expected to have greater demand in biomedical applications like sensing, electroporation & drug delivery in the future and there is need for development of fabrication process which is simple, economical and productive. Present work discusses about fabrication of PDMS (polydimethylsiloxane) micro needle array electrode for bio-potential signal measurement like EEG by micromachining and micro molding process as PDMS structures are flexible and can withstand relative movement with skin without breaking. Customized tungsten carbide tools are manufactured and used in precision micromachining followed by micromolding process. Study has been carried out to relate the size of tool with the size of microneedles fabricated.**

***Index Terms*— Microneedles, Micromachining, Micromolding.**

I. INTRODUCTION

Microneedle array based devices are reported in literature to have many biomedical applications like sensing [1], stimulation [2], electroporation [3], and drug delivery [4]. Studies have confirmed about pain free application of microneedle array on human subjects which will be one of the major factor for microneedle array patches to replace the conventional devices in near future [3], [5]. With respect to material selection, already silicon, metals and polymeric microneedles have been fabricated and the methodology for fabrication of microneedle arrays that has been reported so far include microinjection molding [6], [7], reactive ion etching (RIE) [8], LIGA process [9], photolithography [10], [11]. Polymers will be safer option for skin insertion due to flexibility, biocompatibility and biodegradability as there is appreciable tendency for widely fabricated silicon microneedle to break mostly during patch insertion and removal. PDMS material's ability for replication of high aspect ratio microstructures is studied [9], [12]. Fabrication of PDMS microneedle by soft lithography is demonstrated for stratum corneum penetration to acquire EEG signal [13]. Rapid prototyping technique is studied for fabrication of PMMA microstructure using PDMS master by hot embossing [14]. In this work we are presenting methodology for fabrication of PDMS microneedles.

II. MICRONEEDLE FABRICATION

Previously, microneedles have been fabricated by combining micromachining and injection molding with microneedle dimensions about 500µm tall and 25µm tip diameter [7]. The present work focuses on fabrication of PDMS microneedles preferably shorter than 250µm after understanding the skin anatomy for ensuring minimal interaction of microneedles with nerves in dermis layer for pain free application. The fabrication methodology involves grinding carbide tools followed by using these micro tools for creating microhole array in mold and finally PDMS casting. The steps involved in fabrication of microneedles are illustrated in figure 1.

A. Micro tool Design and Manufacture

Design and manufacture of carbide micro tools was done with the objective to transfer tool dimensions on tool to final microneedle structure to be fabricated with good dimensional accuracy. Two types of tools have been machined with one for drilling and other for indenting operation. Tungsten carbide microtools were machined for this purpose using conventional precision tool grinder (Make: Ewag; Model: WS11). Tools were made from Tungsten Carbide material. With Tungsten Carbide tool sharper tool tip can be achieved due to higher hardness. Out of two types of conical tools machined, micro drill tool is provided with additional relief for edges to act as cutting edge and to assist in chip flow during drilling operation whereas the micro indenter tool has plain conical tip. Tools were measured using confocal microscope to have included angle of 24º as desired and tip diameter was found to be 10µm as shown in figure 2.

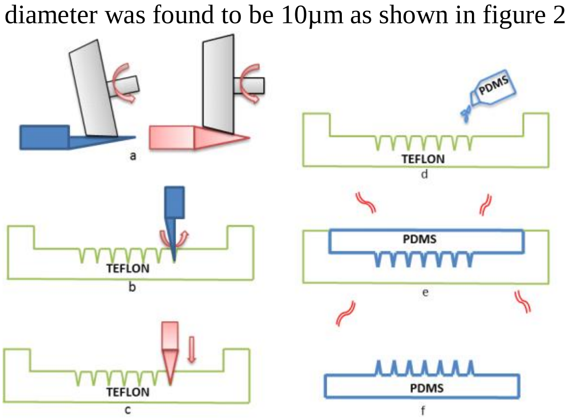

Fig.1. a) Microtool grinding, b) Microhole drilling, c) Indentation, d) PDMS casting, e) PDMS curing, and f) PDMS microneedle array

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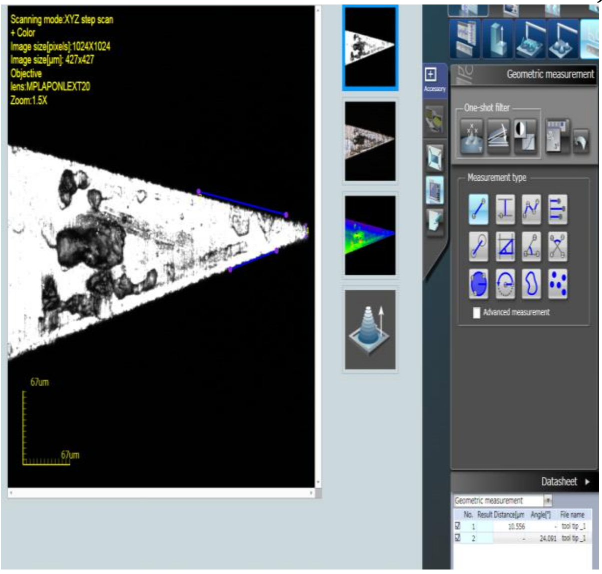

Fig.2. Confocal microscope image of micro engraving tool (Tip Dia: 10.5µm; Cone angle: 24.1°)

B. Micromolding Process

In general, the micromolding process involves master structure fabrication, negative mold fabrication, casting and separation. To fabricate micro master structures for use in micromolding, several different techniques can be used like LIGA, UV & X-ray Lithography, RIE/ DRIE/ ICP-DRIE, FIB, Laser Micromachining (Excimer and Femtosecond laser), micro-EDM.

In present work micromachining & micromolding methodology followed involves two stages. In stage 1, micro drilling is performed using micro drill tool figure 4. The carbide micro tool machine is having tip sharpness around 10 µm. Tungsten carbide tools are harder but brittle and at this tip sharpness the cutting force that tool can withstand is very low. Present work requires 100 no array size of conical microholes to be drilled and there is tendency for tool to gradually loose the sharpness during machining. To increase the tool life of this pointed carbide tools, Teflon was selected as mold material due to its softness, ease in machining, better thermal and chemical stability. Teflon mold selected as shown in figure 3 has pre-machined 10mm diameter 2mm deep slot. Micro drilling operation was carried out using ultra-precision micromachining centre (Make: Kern; Model: Evo) making 10x10 array 350µm deep holes in 10mm slot in Teflon mold with distance between two adjacent microneedles being 400µm. In stage 2, the micro indenter tool was plunged into the microholes for hole finishing. PDMS is used for casting considering its property to replicate features in microstructures with good accuracy and easiness in separation from mold. PDMS offers greater flexibility in deciding curing temperature to suit with the functional polymer to be casted. Low viscosity curable PDMS is a commonly used silicon elastomer in micro fabrication as demonstrated [15], [16]. It is highly flexible, chemically and thermally stable and also biocompatible. It is also well-known as an excellent soft material for soft-lithography, especially in biological and medical usage, due to a number of reasons described [17].

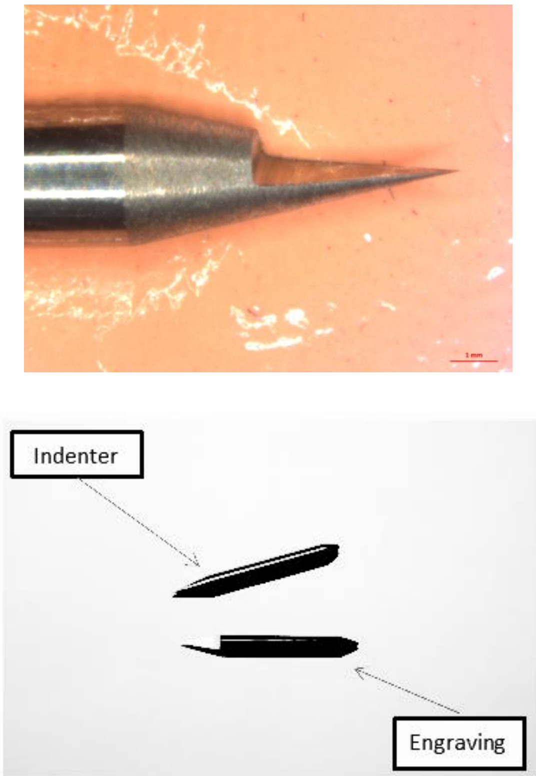

Fig.3. Micro engraving tool photographic image (left), Carbide micro indenter & micro drill tools image (right)

Fig.4. a) Teflon mold on which microneedle holes are made, b) Microholes drilling on micromachining centre

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For micromold casting, PDMS prepolymer (Sylgard 184, Dow Corning) was used in mixing weight ratio 10:1. Binder and elastomer was thoroughly mixed and filled into Teflon mold which is a negative mold of microneedle array. The mold is degassed at 20 inch Hg vacuum in a desiccator for 1 hour to remove entrapped air for enabling PDMS to fill microholes. Uncured PDMS filled Teflon mold was placed in oven maintained at 100°C for 1 hour. PDMS positive microneedle mold was gently demolded from Teflon mold.

III. RESULTS AND DISCUSSION

To study the microholes drilled and PDMS microneedle structure and dimensions, characterization was done. Figure 5 shows the image of drilled microholes measured using confocal microscope. Figure 6a and 6b are the photographic and SEM images of PDMS microneedle array respectively. From SEM image it is found that the height of needle and tip diameter measured are around 350µm and 50m respectively whereas the microtools used in mold fabrication had tip diameter between 10µm.

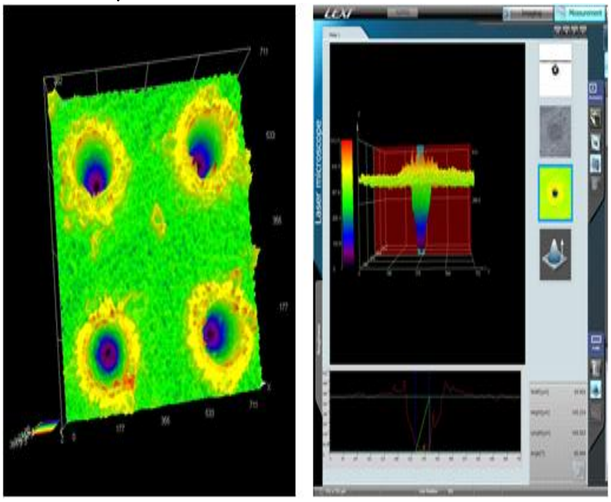

Fig.5. Confocal microscope image of holes drilled in Teflon mold (Height: 345.2µm; Tip: 54.9µm)

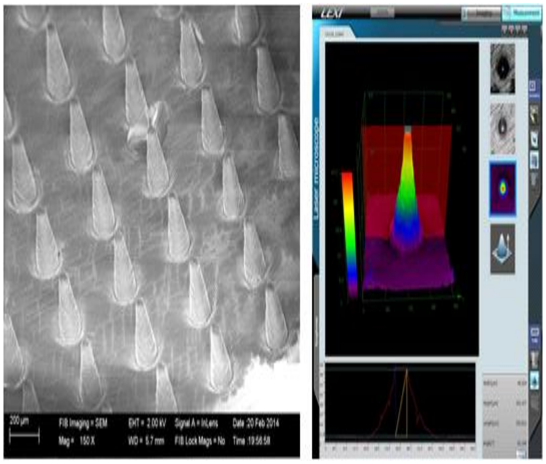

Fig.6. a) SEM Image of PDMS microneedle array, b) Dimensions of PDMS microneedle measured using Confocal microscope (Height: 352.4µm; Tip: 48.6µm)

The depth of drill into Teflon mold was set to 430µm in machine whereas the actual depth of hole formed as seen in figure 5 is around 350µm. The reason is that during micro indentation (stage 2) the burrs on the inner wall of hole got pushed to the bottom of the hole resulting in reduction in hole height 80 micron. It has been observed that Teflon forms burs during micromaching holes and slots at certain cutting condition [18]. The author's optimized cutting speed and spindle RPM to reduce burr formation. In present work spindle speed and cutting speed were set at 8000RPM and 250mm/min respectively. The burr was formed inside the hole and also at hole entry edges. The plot shown in figure 7 briefs the process capability achieved at each stage. It is observed that there is close dimensional tolerance between the fabricated PDMS microneedles and microholes in Teflon mold.

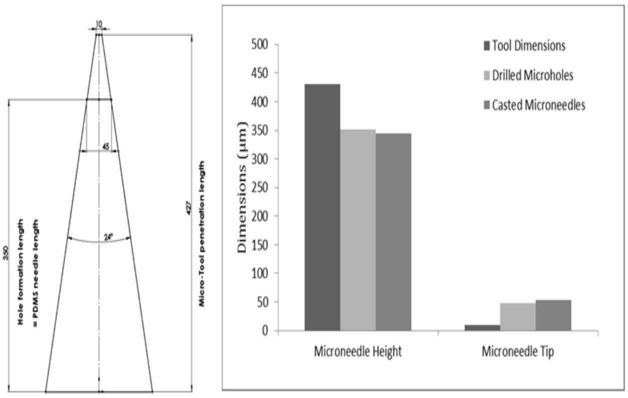

Fig.7. Replication of microneedle dimensions at different stages in process adopted

IV. CONCLUSION

We have demonstrated a simple hybrid approach combining Micromachining & Micromolding processes for fabrication of solid polymeric microneedles. We found that there is good and acceptable replication at every stage in the process. The biocompatible PDMS microneedle fabricated by present work can be used directly as biosensor and can also be used as master for fabrication and replication of microneedles by several different methods.

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