FABRICATION OF MICRONEEDLES USING FEMTO-SECOND LASER MICROMACHINING

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Abstract: *In this work, we present the fabrication of hollow steel microneedles for transdermal drug delivery. Hollow steel microneedles are fabricated by laser ablation technique using femto second laser micromachining. A 4x3 array of rectangular microneedles with circular holes are fabricated. The processed hollow steel microneedles are 700 µm in height with 60 µm and 150 µm inner and outer diameters respectively.*

Keywords: *Micro-Needles, Steel, Femto Second Laser*

1. INTRODUCTION

Oral drug administration is commonly employed by doctors for treating deceases like diabetes etc. However, oral drug administration is not always feasible due to poor drug absorption through gastrointestinal tract. Transdermal drug delivery technology has emerged as the most common approach to overcome this disadvantage [1]. Furthermore, transdermal drug delivery technology has many advantages like specific skin area can be targeted; dose reduction and precise control over volume of drug can be achieved. In addition, use of microneedles in transdermal drug delivery system which causes less pain helps in treating patients with needle phobia.

Out of plane microneedles have tremendous applications in drug delivery system and body fluid extraction [2]. One of the most important

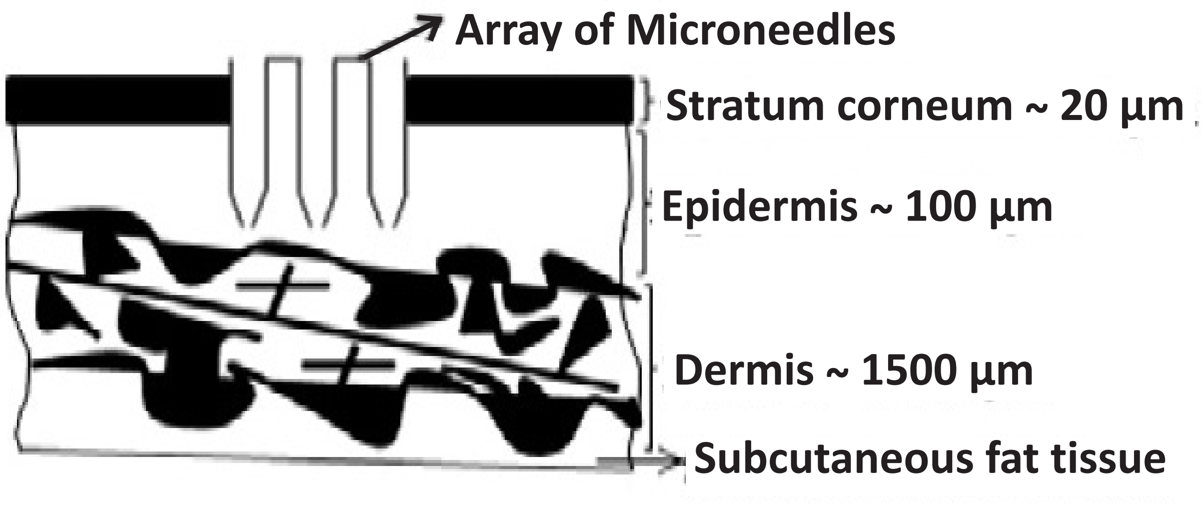

Fig 1. Cross- Section of Human Skin

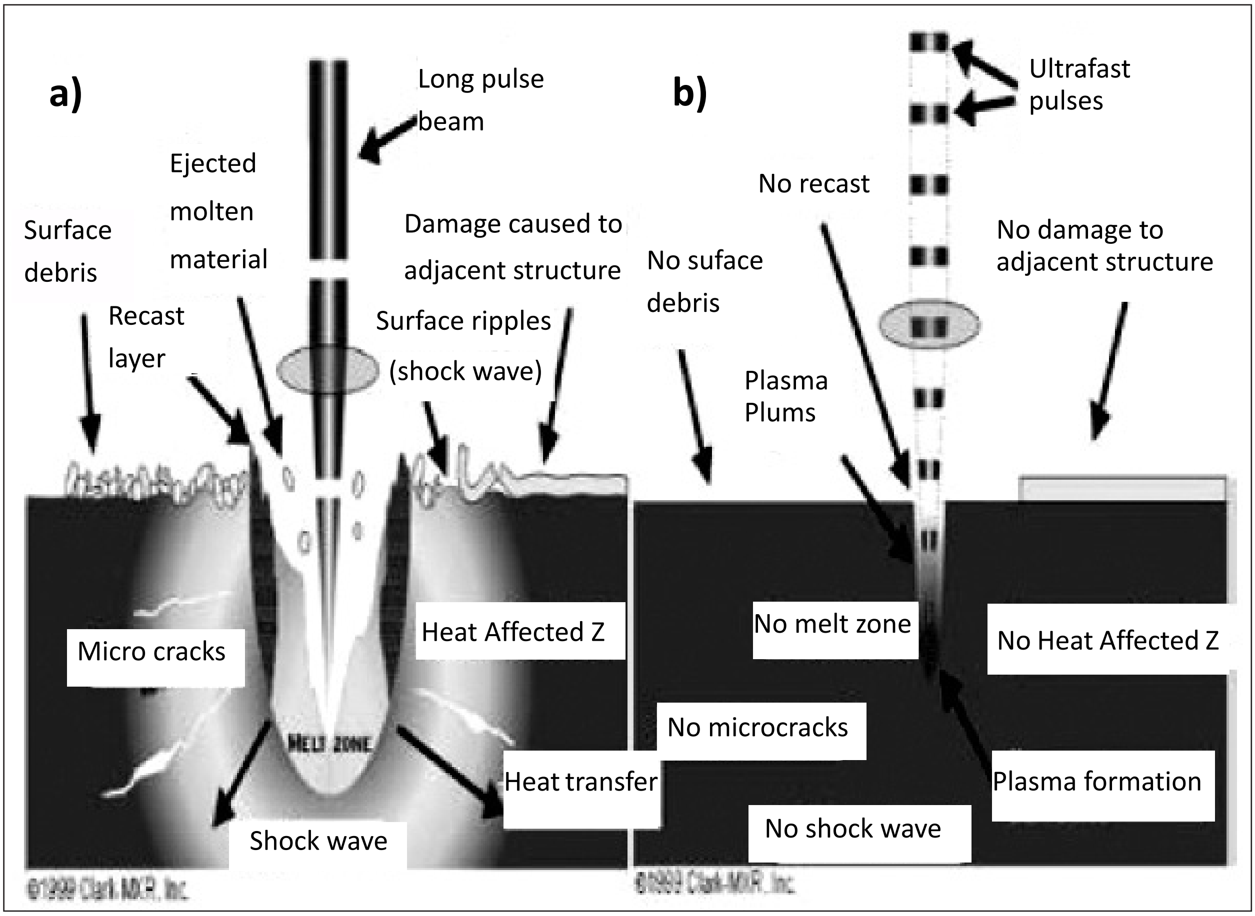

Fig 2. Laser Micromachining (a) by Long Pulses (15 ns), (b) by Short Pulses (150 fs) [15]

requirements for microneedles is the material biocompatibility. Hence, technologies have been established for realizing microneedles using various materials including silicon, metal and polymers [3]. Geometrical constraints on these microneedles are imposed by the physiology of human skin.

Cross-section of human skin is shown in fig. 1. The outer most layer of the human skin is 20-30 µm thick is known as stratum corneum. The next layer is epidermis with a thickness of 100 µm [4], [5]. For painless delivery of drug, the microneedle is desired to penetrate 150~200µm depth to deliver drug before the dermis region. Hence, these requirements impose constraint on the length of the microneedle to be in the range of 150~200 µm.

In literature, there are few reports on metal microneedle fabrication. McAllister et al. and Davis et al. fabricated out of plane electroplated metal microneedles using thick epoxy micro molds [6], [7]. Shankar et al. fabricated palladium, palladium-cobalt alloy and nickel electroplated metal microneedles of length 200 mm -2.0 cm[8]. Recently, microneedles find applications in many areas including insulin delivery [7], biological fluid extraction and insitu analysis [9], micro sampling for glucose estimation [10], ultrasonic atomizer [11], bioluminescence detectors [12], for ultrasonic surgery [13] and microcutters [14].

The micromachining of metals using nanosecond pulse lasers is a difficult task due to issues to do with melting effects around the machined site, recast material and general edge quality of the microstructure. The fine control for precision microstructures could not be possible with such laser machining. Recently, femto-second lasers have overcome these problems and high quality micromachining is now possible on metals.

The pulse duration of a femtosecond laser is so short such that there is not sufficient time for any of the pulse energy to be distributed to the substrate in the form of heat. Thus, particularly for low pulse energies, there should be no heat-affected zone (HAZ) resulting from the processing (Fig.2).

The material processing using femtosecond pulses

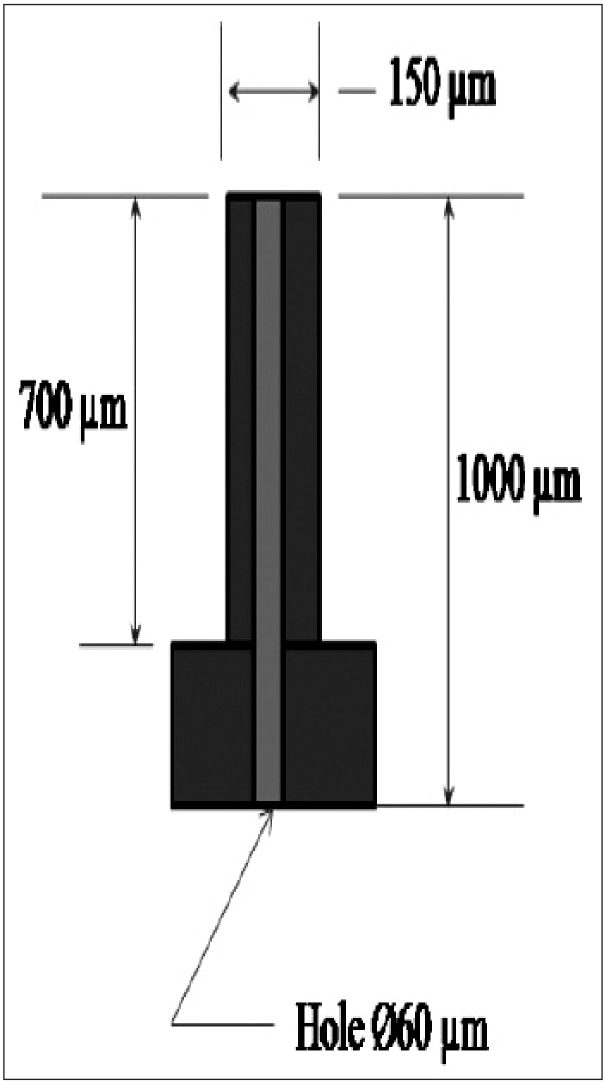

Fig 3. Schematic Diagram of Hollow Steel Micro Needle Design

give two major advantages to micromachining compared to nanosecond and picosecond pulses: first one is lower ablation threshold and the second advantage is the duration of laser pulse is shorter than the heat diffusion time which reduces the heat affected zone (HAZ).

In this paper, we present the design and fabrication of hollow Steel microneedles array using femtosecond laser micro machining. The array of machined microneedle is imaged using scanning electron microscope (SEM) and confocal microscope.

2. DESIGN AND FABRICATION OF MICRONEEDLES

Fig.3. shows the dimensions of the microneedle which is fabricated using femto-second laser machining. The total thickness of the steel sample used for fabrication is 1000 µm. The inner diameter of the hole is needed in range of 30 - 60 µm and the needle thickness is 150 µm with a height of 700 µm (Fig.3).

Experiments were carried out using femtosecond laser micromachining system. This system consists of an ultra-short pulse, Chirped pulse amplification (CPA) Ti: Sapphire laser, Make: Clark MXR Inc., USA, and Model: UMW-2010 (Fig.4). This uses a solid state Ti: Sapphire laser that

Fig 4. Clark MXR Femtosecond Laser Micro- Machining System

Table 1: Specifications of Clark MXR Inc., USA, UMW-2010 Femtosecond Laser

Parameter	Specification
Make & Model	Clark MXR Inc., USA, UMW-2010
Wave length	775 ± 2 nm
Resolution	1nm
Laser Output Power	1 W
Repetition Rate	1Hz to 2kHz
Pulse width	10 ps to 150fs
Traverse X,Y & Z	150x150x100 mm
Min Feature size	≤ 1µm

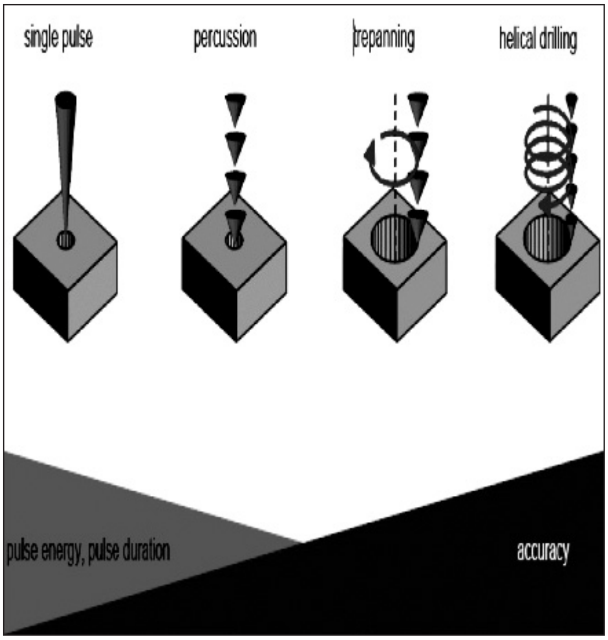

Fig 5. Process Strategies to Achieve High Accuracy in Laser Micro Drilling [16]

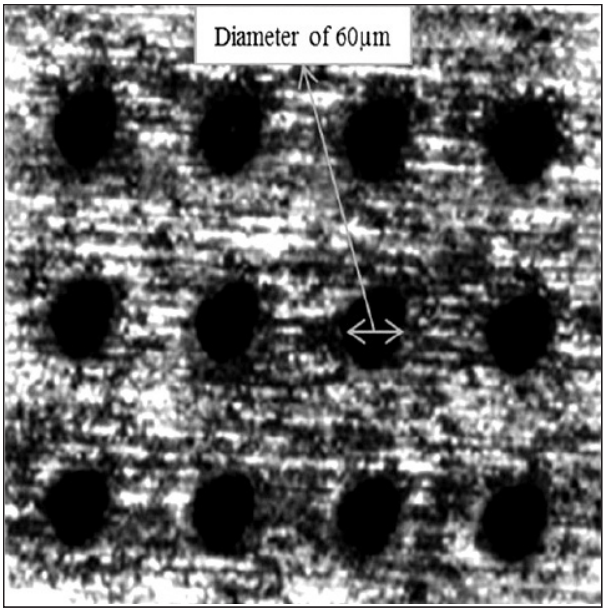

Fig 6. Confocal Microscopic Image of an Array of 4x3 Micro Holes of 60 µm Diameter on Bottom Surface of Sample at the Pitch of 500µm

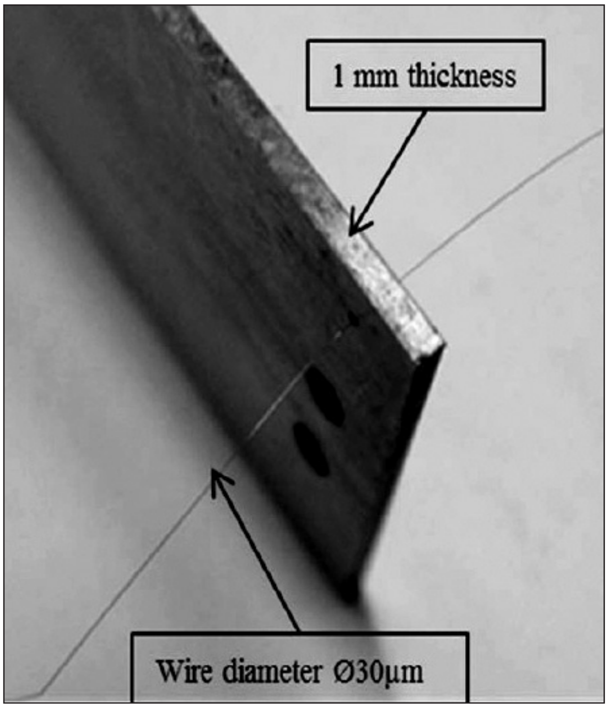

Fig 7. 30µm Wire is Passed Through 1 mm Thickness Steel Plate of 60µm Hole on Bottom and 120 µm on top side

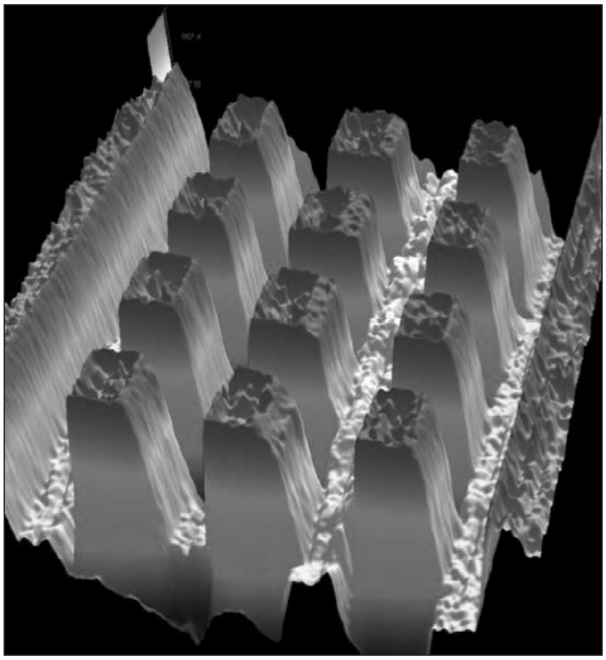

Fig 8. Confocal Microscopic Image of Fabricated Steel Microneedles (Mag. of 50X)

gives out a laser beam at a wavelength of 775nm. The laser beam was focused on the sample surface at normal incidence via Z-stage movement with 20x focus lens of 20mm focal length in air. A sample was placed on the XY-stage. The focus position of the laser beam relative to the sample surface was controlled by moving Z-stage. Laser spot size is measured to be about 10 µm when sample is placed at a distance of (Z stage to sample) of 20 mm. The diameter of drilled holes was controlled by adjusting the spot diameter of the laser beam. The spot diameter was 10 µm to drill a hole of 60 µm diameter.

In any metal removal process, the capability is limited by the minimum material removal volume, also known as unit metal removal rate. In the

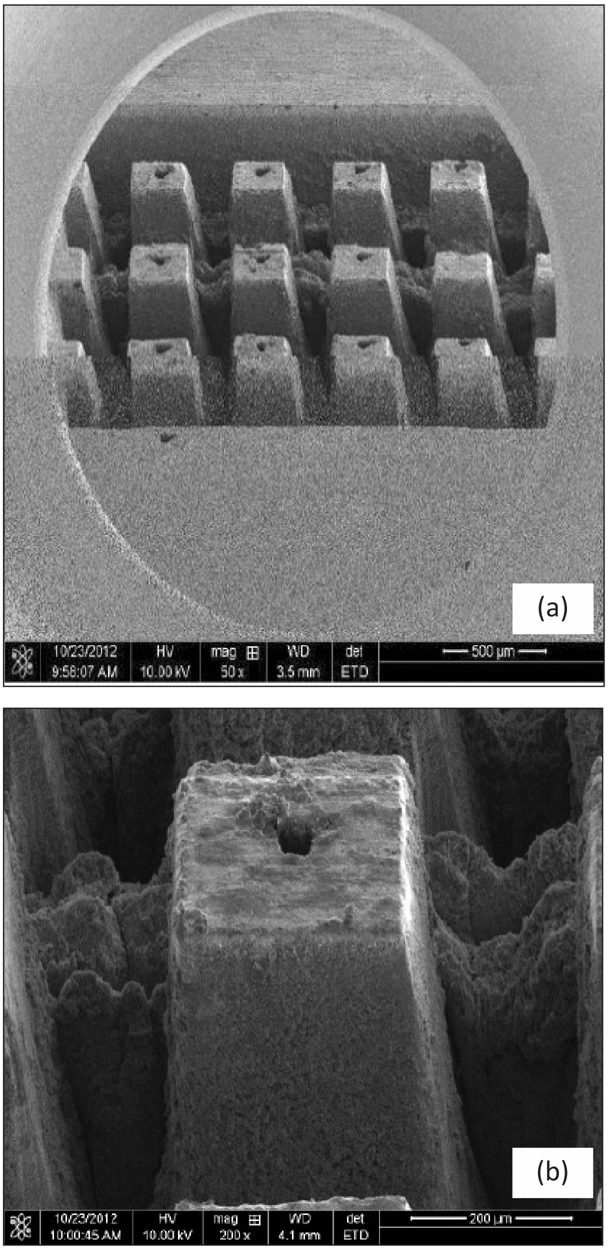

Fig 9. SEM Image of Hollow Steel Microneedles, the Height of the Structure is 700 µm. (a) An Array of Microneedles, the Separation Between Needles in the Array is 500 µm. (b) a Single Microneedle with Inner Hole Diameter of 60 µm

case laser micromachining the material removal volume is determined by penetration depth and spot diameter. Fig.5 shows various drilling techniques; Single pulse drilling, Percussion drilling, Trepanning and Helical Drilling. Trepanned laser drilling is a method used to remove a cylindrical core, or circular disc from a substrate. To drill diameters exceeding the laser spot diameter, the laser beam and work piece are moved relative to each other. This is known as trepan drilling.

In trepanning, a laser beam with spot diameters of 10 µm and 20 µm were used at feed rate of 100µm/s and 150µm/s to drill a through hole. The high aspect ratio deep holes obtained as diameter of 60µm x 1deep could be realized by this method. The produce hole has a taper of 30 µm (from diameter 60 µm at top to 30µm at bottom) (Fig. 6 and Fig. 7). After making a through hole, sample was reversed on work stage so that small diameter of 30µm was obtained as top surface. The needles (column) were machining from the small diameter of 30 µm, by keeping the small diameter on the top surface for focusing the laser beam. A 4x3 array of hollow steel microneedles obtained by fabrication of micro slot size of 2500x300 µm through a depth of 700µm in between the micro drilled through holes in XY direction respectively (Fig.9 and Fig.10). The fabricated micro slots are tapered due to deep laser cutting. The obtained microneedles thickness is gradually increasing towards the base of microneedle eventually provide more stiffness and sharpness. After fabrication the sample was cleaned by ultrasonic cleaning for three to six minutes. This process acetone used as a liquid medium. The cross section of the wall morphology and drilled holes were observed and measured by using confocal microscope and SEM.

3. RESULTS AND DISCUSSION

The array of 4x3 hollow steel microneedles is shown in Fig.8 and Fig.9. The fabricated microneedles are having a height of 700 µm with 150 µm needle thickness. The distance between the each microneedle is 300µm.

The feed rate and spot size of the laser beam used in the fabrication are 150µm/s to 100 µm/s and 10µm to 20 µm respectively. The feed rate is found to be a key parameter to improve the surface quality. With this parameter the fabricated microneedles are having high accuracy in dimension. The high aspect ratio micro through-holes are confirmed by passing a 30µm wire in through 60µm holes (Fig.7).

4. CONCLUSIONS

A 4x3 array of high aspect ratio hollow steel microneedles fabricated using femto-second laser micromachining process is presented. The high aspect ratio micro through-holes were drilled through 1 mm thick Steel plate using femtosecond laser micromachining system. This noval method of fabricating metal microneedles array could open new applications for bio medical devices.

5. ACKNOWLEDGEMENT

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