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Micro Electro Mechanical Systems in Micro-Surgical Bio-Tools

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Abstract:
Micro Electro Mechanical Systems (MEMS) technology is empowering a wide variety of biomedical systems by integrating micro scale sensors, actuators, microfluidics, micro-optics and micro machined surgical tools in order to improve human health. This paper presents an introductory overview on surgical applications in Bio-MEMS which can improve existing functionality and add new potential capabilities for surgeons to develop new techniques. Surgical microsystems which consist of the micro-invasive surgical tools like tiny forceps, micro needle arrays and tissue debriders help enhance surgical outcomes by lowering the risk and by providing real-time feedback during the operation. Derived from the micro fabrication technology used to make integrated circuits, Bio-MEMS is expected to revolutionize the way medicine is practiced and delivered. Also, incorporation of sensors on the surgical tools allows the surgeon to note tactile responses during the surgery. [1]

Keywords*: Micro Grippers, Micro Needle Arrays, Tissue Debriders*

1. Introduction

MEMS is a technique of combining electrical and mechanical components together on a chip to produce a system of dimensions less than the thickness of human hair. Bio-MEMS which is typically more focused on mechanical parts and micro fabrication technologies suitable for biological applications has a considerable overlap with Lab-On-a-Chip (LOC) and Micro Total Analysis Systems (µTAS). Bio-MEMS devices are designed to provide viable neutral interfaces for long term, high density and two way communication with selected areas in the body. From the patient's viewpoint, Bio-MEMS devices can be categorized into:

- **Diagnostic microsystems:** It includes rapid point-of-care, systems on a chip, cell and molecule sorting and also DNA diagnostics.
- **Surgical microsystems:** Minimally Invasive Surgery (MIS), CAD assisted surgery (micro robotics).
- **Therapeutic microsystems + prostheses:** Drug and gene delivery, tissue augmentation and repair, bio-capsules, micro invasive surgical systems.

This paper concentrates on "Microsurgical tools in Bio-MEMS". During a surgery, the maximum trauma to the patient is caused by the surgeon's incisions to gain access to the surgical site. MIS procedure aims to provide detection, monitoring or treatment of diseases by performing operations with very small incisions or sometimes through natural slits. Advantages of MIS over conventional open surgery includes less distress, minimal injury to tissues, little scarring, reduced recovery time, shorter hospital visits, speedier return to normal activities and often economical cost to the patient. General MIS procedures include angioplasty, endoscopy, laparoscopy, neurosurgery etc. MEMS based microsurgical tools have been identified as a key enabling technology for MIS.

Several materials and methods were considered for manufacturing and operating the required microsurgical tools. Bulk micro machined silicon and wire Electrical Discharge Machining (EDM) metal foils provide two possible solutions. The tool must be as small and thin as the electrode to minimize surgical agony but at the same time it must also be stiff enough to penetrate target tissues easily. Additionally, the device should also be biocompatible, relatively easy to fabricate and be relatively inexpensive. It must also provide a place to hold the electrode during the surgical insertion procedure and allow the microelectrode to remain in the brain while the insertion tool is removed. Present day surgeons operate within a domain restricted by the mobility and control of the surgical tools at hand. However MEMS based surgical tools provide the flexibility and accuracy to perform precision surgery.We are elaborately going to discuss the three main micro machined surgical tools which are:

- Micro Grippers
- Micro Needle Arrays
- Tissue Debriders

A pair of silicon MEMS based micro tweezers and metal MEMS based biopsy forceps are shown in Figure 1 and 2 respectively.

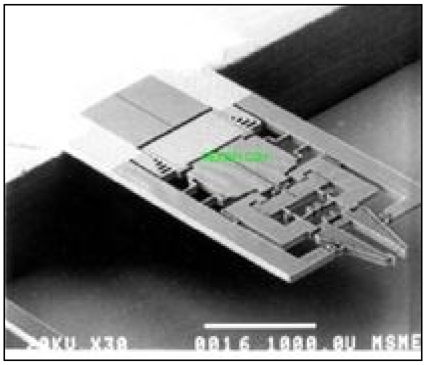
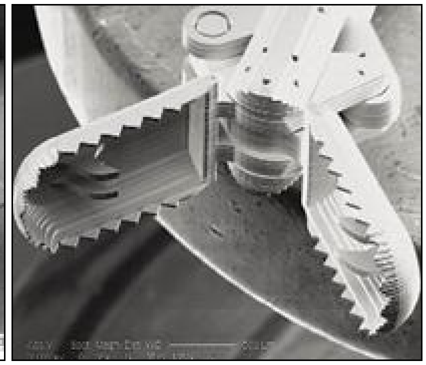



Figure 1: MEMS based micro tweezers [2] *Figure 2: MEMS based micro forceps [2]*

2. Theory

2.1. Micro Grippers

Micro grippers have been developed to collect samples in the human body during surgeries. Most grippers that have been developed are operated by an open loop control method. A micro fabrication process for constructing arrays of compliant tool tips and a friction based assembly strategy was expanded, which effectively conquered existing difficulties in miniaturizing modular gripper designs to sub-micrometer scale. In-situ tool tip change was signified inside a Scanning Electron Microscope (SEM) for gripping objects that vary in size by two orders of magnitude(15µm- 100nm) with a single micro gripper body. The assembly process takes approximately one minute to complete inside SEM while the disassembly technique only takes a fraction of a second.

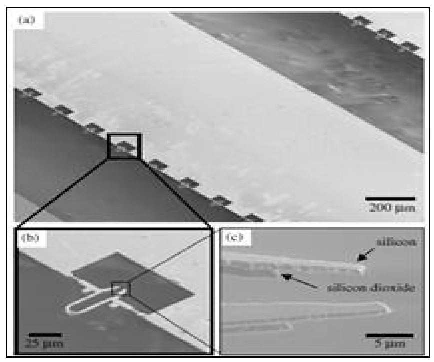


Figure 3: Arrays of gripping tips [3]

A modular approach of assembly and disassembly of fabrication of large arrays of gripping tips is shown in the adjacent Figure 3. The tool tip can be selectively and reversibly assembled onto a micro gripper body which usually is made of three electrostatically actuated arms. Focused ion beam is used to create narrow slits of different dimensions onto the sidewalls of the two micro gripper arms. In order to disengage the tip of the tool, the comb drives the middle arm of micro gripper were actuated to push the tool tip out of the narrow slits.

One major drawback of these micro grippers with respect to thermal or electrostatic actuation is found in biological applications. Micro grippers based on thermal, magnetic or high voltage electric actuation could easily kill or destroy biological and living samples. A substitute to heating grippers which require comparatively high heating temperatures is the use of Shape Memory Alloy (SMA) actuators. Micro grippers based on SMA often require lower temperatures than thermally actuated bimorph or unimorph grippers. SMA based three dimensional micro grippers have been used to grip an insect nerve for recording the nerve activity.

2.1.1. Design and Fabrication of Micro Gripper

For handling of objects larger than 1 micrometer, tool tips can be constructed using a standard micro fabrication process with Silicon-On-Insulator (SOI) wafer. It involves patterning and etching of the Si device layer into tool tips, followed by the wet HF etching of buried oxide layer to suspend the tool tip structures. This micro fabrication process is not suitable for use to construct smaller tool tips for manipulating sub-micrometer sized objects, since the tool tip's lateral dimensions are limited by standard photolithography resolution and further reduction in thickness results in poor structural aspect ratio. As a result, a new micro fabrication process was developed for the construction of tool tips suitable for sub-micrometer object manipulation.

Technical specifications of Zyvex's patented nano effector micro grippers are [4]:

	BB Microgrippers	SM-BB Microgrippers
Thickness	50±0.5 μm	5 μm ±0.5 μm
Max gripping force	0.55 mN	0.21 mN
Max mechanical potential	6.9x10^-9 Joules	4.9x10^-10 Joules
Allowable in-plane deflection	55 μm	9 μm
Out-of-plane stiffness	122 μN/μm	2.2 μN/μm
Allowable out-of-plane deflection	15 μm	25 μm
In-plane gripper arm stiffness	22 μN/μm	27 μN/μm

Model Number	Inside Opening (± 2 microns)	Powered	Outside Opening (± 2 microns)
SM-BB-0	0	open	12
SM-BB-5	5	close	17
BB-10	10	open	60
BB-50	50	open	110
BB-100	100	open	150
BB-150	150	open	200
BB-500	500	open	550

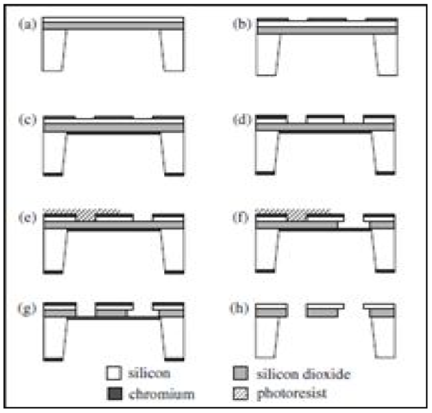


Figure 4: Construction of arrays of gripping tips [3]

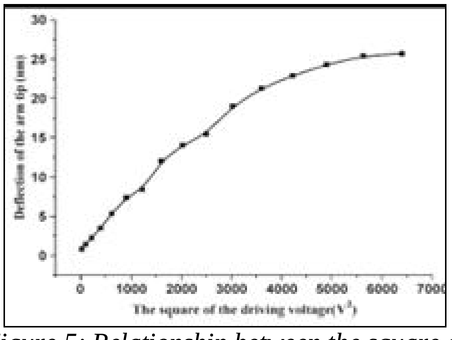
The Figure 4 can be briefly stated in the following points:

- Handle layer of an SOI wafer is KOH etched
- Deposit and pattern Cr on the front side
- Deposit Cr on backside
- RIE etch device silicon layer
- Pattern top side with photoresist and expose selected region, including gripping tips
- BOE etch exposed oxide layer to create undercut
- Strip photoresist and RIE etch exposed oxide layer
- Wet Cr etch for device release [3]

Using the new micro fabrication process, the gripping tip structure other than the very ends has an additional SiO_2 layer underneath silicon to increase the structural aspect ratio and minimize undesired out-of-plane bending. This fabrication process combined with the compliant tool tip design ensures sufficiently accurate alignment between the gripping tips for secure grasping of sub-μm objects.

2.1.2. Test Characteristics of Micro Gripper

For a test setup which could help characterize the performance of the micro gripper, the following graphs were obtained.



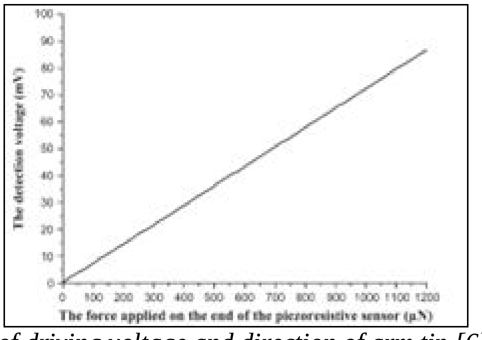
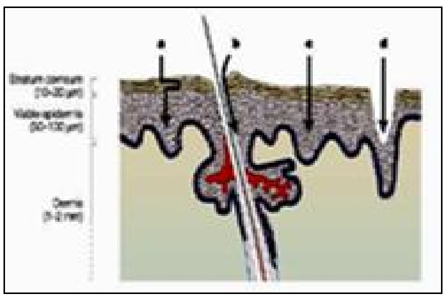


Figure 5: Relationship between the square of driving voltage and direction of arm tip [6]
Figure 6: Relationship of force applied on the sensor and detection voltage [6]

2.2. Microneedle Arrays

Transdermal drug delivery using micro needle is a novel method of drug delivery. Micro needle is like conventional needles only fabricated in micro scale. The advantage of using micro needle is that it does not pass the stratum corneum. Hence it can be used for dosing in microgram quantities. The technique is based on temporary mechanical disruption of skin. The drug, in the form of bio molecules is encapsulated within the micro needles. Further, it is incorporated into the bloodstream through the skin just like nitroglycerine. Within some time, the needles dissolve, releasing the trapped cargo at the intended delivery site. Various methods of drug delivery like Poke with patch approach, Coat and poke approach, Biodegradable micro needles, Hollow micro needles and Dip and scrape can be used.

MEMS enable hundreds of hollow micro needles to be fabricated on a single patch of area. This patch is applied to the skin and drug is delivered to the body using micro pumps. These micro pumps can be electronically controlled to allow specific amounts of the drug and also deliver them at specific intervals.Micro needles are too small to reach and stimulate the nerve endings, and hence cause no pain to the body. Due to wide variation in skin thickness and elasticity among different age groups and ethnicities, it is difficult to obtain a reliable and consistent penetration depth for micro needle arrays when using simple manual insertion. To gain clinical acceptance for micro needle transdermal drug delivery, it is necessary for micro needle arrays be applied to consistent depths in every patient every time.Examples of manual applicators include derma rollers (originally designed to be used for cosmetic purpose) covered with stainless steel micro needles and a similarity constructed roller with micro fabricated plastic micro needles. Fig. 7 and 8 help us visualize about micro needles.



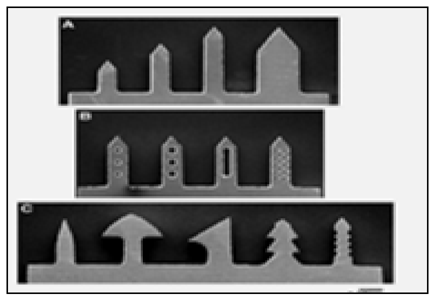


Figure 7: Delivery site of micro needle technology [5]

Figure 8: Different shapes of micro needles [5]

2.3. Tissue Debriders

'Debridement' is the medical removal of dead or infected tissue to improve the healing potential of the surviving tissue which is healthy. Besides surgical, removal may also be mechanical, chemical and autolytic. In dentistry, debridement refers to the removal of plaque and calculus that have accumulated on the teeth which can be performed using ultrasonic instruments. Originally developed for orthopedic endoscopic joint surgery, sinus debriders and other power instruments have been so modified as to have a useful role in sinus surgery. Early sinus debriders were primarily arthroscopic bone or cartilage cutting instruments that used soft tissue blades within a protective outer cannula. They functioned well in the water filled environment of joint surgery but had several shortcomings in sinus surgery. Although clogging still remains a problem primarily due to bone fragments, soft tissue removal has been significantly improved by introducing irrigation into to the debridder cannula at the cutting head.

Also known as skin resurfacing tools, MEMS tools used as debriders have been found to overcome many drawbacks.They can be used to remove raised skin lesions as well as lesions up to certaindepths. These MEMS structures are packaged onto rotary elements and used over the affected areas. The debris can then be sucked outusing a suction pump.

3. Advantages

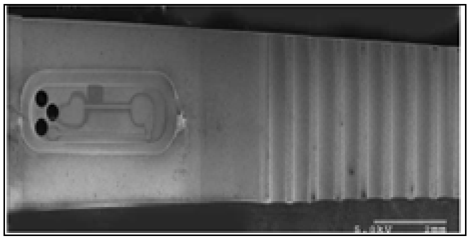
MEMS devices offer competitive advantages due to their batch fabrication capabilities, small size, improved functionality and low cost due to Integrated Circuitry (IC). The incorporation of MEMS devices in surgical tools represents one of the greatest growing areas of improvement in the medical sector. Not only does MEMS technology improve surgical outcomes by reducing the incumbent risk attached to such procedures, it also ameliorates costs by providing surgeons with real time data about instrument force, performance, tissue density and temperature, as well as providing better and faster methods of tissue preparation, grasping, cutting and extraction.

4. Applications

By incorporating sensors on the tools to get feedback during operations. Also, long term sensors can be used for prosthetic devices while sensor arrays can be used for rapid monitoring and diagnosis at home. Now, biosensors are devices that consist of a biological recognition system, called the bio receptor and a transducer. The most common bio receptors used in bio sensing are based on enzymatic, cellular and biomimetic interactions. Common transducer techniques include mechanical, electrical and optical detection.

Mechanical detection in bio-MEMS is achieved through micro and nano scale cantilevers for stress sensing and mass sensing. When a biochemical reaction takes place and is captured on the cantilever, the mass and the resonant frequency of the cantilever changes. Mass sensing is not as effective in fluids because the minimum detectable mass is much higher in damped mediums, something that is overcome with plates or membranes. The advantage of using cantilever sensors is that there is no need for an optically detectable label on thebio receptors. As compared to optical detection, electrical and electrochemical detection are easily adapted for portability and miniaturization.

Amperometric biosensors have been used in bio-MEMS for identification of glucose, lactose, urea, and cholesterol. They are also used for gas detection and DNA hybridization applications. In potentiometric biosensors, measurements of electric potential at one electrode are made in reference to another electrode. In conductometric biosensors, changes in electrical impedance between two electrodes are measured as a result of a biomolecular reaction. They have been used to detect various biochemical and nucleic acids. Some microsurgical tools incorporated with these sensors are shown in the images below.



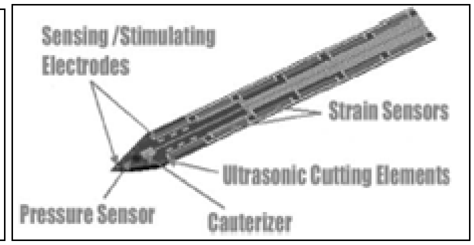


Figure 9: Strain gauges and temperature embedded in robotic micro gripper [2]
Figure 90: Data knife smart scalpel [5]

5. Future Directions

The advantage of polymer needles is that they may be produced much more inexpensively (compared to silicon) and they should not pose a problem if they break in the skin since they are biodegradable. Yet other groups are working on needles which are made of materials that incorporate drugs which are released when the needles dissolve. Some other key points are:

- Culture based biochip for speedy diagnosis of environment mycobacteria
- Bio MEMS for drug delivery and Pharmaceutical analysis
- Capillary electrophoresis microchip for DNA examination
- Bio MEMS devices for study of proteomics
- Single cell and molecule analyses using microfluidic devices

6. Conclusion

In 1959 Richard Feynman gave his famous talk “There’s Plenty of Room at the Bottom”. In it he had talked about being able to put a surgeon in a blood vessel who would be able to look around one’s heart. There are still many challenges, which must be overcome before we will see the widespread commercialization of surgical microsystems. In the next five years we will begin to see the proliferation of MEMS technology into surgery. Initially these new surgical tools will be focused on measuring or detecting a specific parameter, be it pressure, blood flow, velocity, temperature, etc. Sensor systems will continue to be refined and improved. As surgical MEMS technology becomes more mature and established, we will see the integration of multiple sensors on surgical tools.

Power systems will need to be shrunk or eliminated altogether. This will require advances in micro batteries and wireless power transmission schemes. Nanotechnology integrated into MEMS will play an important role leading to new materials and miniature sensor systems. This level of miniaturization will require new MEMS devices which stress the “systems” part of the acronym. Sensors, actuators, embedded control systems, and power systems will have to be tightly coupled to each other and the macro world operating room. The result will be smart surgical tools which will communicate with the surgeon, even turning themselves off or resisting the surgeon’s movements if they sense danger to the patient.

Eventually we will have highly integrated probes, which will do everything a surgeon needs. These tools will fit through a standard 5-mm port and will have built-in 3-D cameras for visualization, biopsy samplers with microfluidic processing capability to do tissue analysis, ultrasound transducers, and tactile sensors for feedback to the surgeon. With the proper funding, collaboration between surgeons and MEMS engineers, and advances in technology, the future look bright for MEMS applications in surgery.

7. References

1. www.wikipedia.com
2. www.electroiq.com
3. B.K. Chen and Y. Sun, “A MEMS Microgripper with Changeable Gripping Tips”, “University of Toronto, Canada”, M3P.121
4. www.zyvex.com
5. www.ijpbs.net
6. Tao Chen, Liguo Chen, Member, IEEE, Lining Sun, and Xinxin Li, “Design and Fabrication of a Four-Arm-Structure MEMS Gripper”, IEEE Transactions on Industrial Electronics, VOL. 56, No. 4, April 2009