A NEW HIGH PERFORMANCE ELECTROTHERMAL MECHANISM FOR NEURAL PROBE RELOCATION

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ABSTRACT
We have proposed a new method for neural probe repositioning, using a high precision mechanically controllable microstructure. The method involves efficient electrothermal driving of probes, and a bidirectional operation has been provided. At the same time, the mechanism design is quite simple to reduce the fabrication costs. This can facilitate commercial application of this type of devices. Also a push and latch scheme has been implemented for the device operation using two set of similar actuator, which enhance power consumption and also reduce reverse sliding effects. Our simulation estimates a 150 mw consumption for a step movement of 1.9 μm.

KEY WORDS
Biomechanic, Micro-Technology and BioMEMS, Reconfigurable Neural Probe, Implantable Neural Prosthesis

1. Introduction
We have proposed a new method for probe repositioning, using a high precision mechanically controllable microstructure. The current techniques mostly involve electrically selectable sites to be able to reject invalid neural signals. Electrical reconfiguration, despite of its efficiency has the disadvantages of loosing signal quality. This is resulted from degradation of sites under the biochemical interaction between the probe and the environment. Although reselecting the active site could partly resolve the signal, full probe relocation is the only choice in most cases. The mechanically active probes have been recently received attention. Muthuswamy J. et.al. [1] has introduced a latching thermal actuator to relocate the probe. In spite of the high performance operation of the proposed techniques, the mechanism is too complicated from the implementation points of view, and the power consumption is too high for limited energy resource applications such as implantable probes. Therefore the main challenges in spreading the probe applications are to reduce the power consumption and also device complexity. We have practiced a new technique to achieve similar mechanism in a very efficient manner. The mechanism based on electrothermal chevron beam actuators [2] similar to the ones in [1], but the driving actuators and the latching mechanism are developed on the same substrate as the probe which, in turn, simplifies the fabrication process of actuation and control mechanism. Implementing the driving systems and the moving probe on the same substrate eliminates the out-of-plane mechanism as required in [1] to engage the driver with the probe.

2. Background
As already specified, mechanical relocatablity improves probe susceptibility to the environmental and aging conditions. It could also enhance the signal condition by migrating the probe to the best achieved position. This is not fully achievable by changing the electrical sites, as from technical point of view, there are limitation to the number of sites. Mechanical relocation on the other hand, has its own limitations. The main challenging issues in the probe movements are the driving mechanism for low energy consumption as well as precise motion of the probe to minimize cell damages. Muthuswamy J. et.al. [1] has proposed the multi-step actuation using electrothermal actuators with iterative actuation-latch phases. The mechanism has best suited the above schemes, but the actuation mechanism urges a multilayer stacked structure, which engages with the probe by an additional step-down movement. The structure requires complicated (SUMMIT) process to be realized and therefore not efficient enough for commercial applications in neural prosthesis. We have proposed a simpler probe relocation mechanism with the advantages of single layer standard bulk micromachining techniques based on planar actuation and also latching mechanism.
The probe is driven by a set of beams, attached to chevron shape bent beam electrothermal actuators. Instead of off-plane engagement as used in [1], in our design the driving mechanism travels in-plane to get engaged with the probe. This could in turn eliminate the 5-layer process steps in the latter design.

Fig 1. illustrates a simplified schematic of the system, which consists of two set of move forward and backward electrothermal actuators, arranged along the probe. Each side of probe contains similar type of actuators confronting each other to produce a symmetric movement in the selected direction and also reduces the friction of probe against the sidewalls of groove.

Fig 1. Schematics of driving system

The probe itself is made with pawls on its sides, which form a ratchet system together with the driving probes. To move the probe in each direction, the associated links have to push forward slightly to engage with the probe teeth. Links are driven by attached actuators. To form a ratchet operation, driving beams are excited in a special regime, so that one set of beams are pushing the probe, whilst the other pair is passive and forms a ratchet with probe pawls. The displacement between the links is an odd multiplicand of L/2, where L is the teeth displacement. This causes one beam to engage with the pawls and push it forward, while the other is subject to bending by the adjacent teeth. This arrangement allows one side movement with no risk of sliding backward. The idea has been shown in Fig 2.

From mechanical point of view, the link beams are cantilever beams, subject to two different forms of elastic behaviour. The engaged beam is pushing the probe forward, so that the probe reaction is in the form of axial forces, balanced with beam buckling forces. The other beam is bent by pawls. Since both beam subject to the same forces and the ratio of \( P_{\text{buck}}/P_{\text{bend}} \propto L_{\text{link}} \), the link beam can be designed so that they easily bends while resists to buckling. As a result the two actuator system can easily drive the probe in one direction whilst impede the reverse sliding.

Fig 2. Drive-Ratchet operation of link beams

To change the direction, one only needs to disengage the beams of the unwanted side and re-engages the desirable ones. The switching operation can be done in a predefined sequence so that the whole probe left unaffected.

To reduce the power demands of the electrothermal devices, the beams are made with latching system [3], which retains the beam in the positions with no power requirements. The latch structure is illustrated in Fig. 3 with associated release actuators.

Fig 3. A ratchet type latch system and associated release actuator

3. Discussion

As already described, the whole set of chevron beams are arranged so that the probe can move in a dedicated path in both directions. V-beam thermal devices provide large amount of forces [2], in addition to acceptable range of
The deflection required to drive the probe in each step. The power consumption is kept low at the same time by complementary operation of the driving beam. The two set of driving beams in Fig. 2 are arranged so that each beam drives the probe only half the way until the other beam can engage with the pawl. Then the active beam is deactivated and as a result retracts to the passive position till the next stage. Along this retraction process, the complementary beam latches the probe.

The operation of above mechanism has been assessed using commercial finite element package ANSYS 11.0 and a typical deflection through 3 stages of load steps has been extracted. Fig. 5 shows the deflected vs. steady probe. The results achieved using coupled electrothermal-elastic analysis, which estimates a total power consumption of 156 mw (142 mA @ 1.1 Volt) to move the probe of about 1.88 μm.

From fabrication point of view, the whole process steps can be performed using standard single-sided Si-bulk micromachining, which greatly reduce the fabrication complexity and so cost. The probe itself should be made separately and assembled in the grooves, prepared over the mechanism substrate.

Fig. 4 shows the required packaging for the complete device. The whole device is implemented over standard SOI substrate, with 20 μm bonded layer. Typical probe thickness is obtained as 15 μm [4]. The fabrication process are standard lithography followed by DRIE and sacrificial layer removal. The package lid can also be fabricated over ordinary Si substrate but two layer lithography step is required. The first step is a 25 μm bulk etching to provide area to cover the whole mechanism. Then next patterning is performed to open cooling holes for the thermal devices. The etched features along the first step are aligned with corresponding markers over the SOI wafer. Some cooling holes are also considered over the lid to allow the electrothermal components cooling.

The actuation procedure requires a precise sequence of driving pulses to apply to the actuators to ensure a proper sliding of the probe in the specified direction. This predefined sequence stimulate one of the beams while keep the other in the hold state.

When no displacement required, all beams can be placed in the engaged position to assure probe latch up. To start the operation, the reverse movement probes retract whole the way and only the probes of the corresponding direction left in the active position.

We are investigating different behaviour of this type of devices including thermal and mechanical parameters in static and dynamic modes of operations and if possible to fabricate and characterizer the device.

4. Conclusion

A new structure is proposed for relocation of neural probes. The structure exploits a special arrangement of electrothermal actuators in a drive-latch loading cycles which ensures precisely controlled movement of a neural probe. Bidirectional motion of the probe is also possible by activating the proper actuators while retracting the unwanted ones. A ratchet latch system is also used in the actuators to hold the position with zero power consumption.

The simulation results predict an acceptable range of power consumptions and the planar arrangement of the driving system presents a simple standard fabrication process.

References