DESIGN AND FABRICATION OF A MICRO THERMAL ACTUATOR FOR CELLULAR GRASPING*

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ABSTRACT: The development of a novel polymer-based micro robotic gripper that can be actuated in a fluidic medium is presented in this paper. Our current work is to explore new materials and designs for thermal actuators to achieve micromanipulation of live biological cells. We used parylene C to encapsulate a metal heater, resulting in effectively a tri-layered thermal actuator. Parylene C is a bio-compatible dielectric polymer that can serve as a barrier to various gases and chemicals. Therefore, it is suitable to serve as a thermal/electrical/chemical isolation material for protecting the metal heater from exposing to an aqueous environment. We have demonstrated parylene actuators (2 mm × 100 μm × 0.5 μm) to operate in an aqueous environment using 10 to 80 mW input power. The temperature of these actuators at full deflection was estimated to be ~ 60°C, which is much lower than the typical requirement of > 100°C to actuate other conventional MEMS actuators. Danio rerio follicles in fluidic medium were captured successfully using these actuators. Moreover, these actuators were found to be responsive to moderate rise in environmental temperature, and hence, we could vary the fluidic medium temperature to actuate trimorphs on a chip without any input of electrical energy, i.e., raising the fluidic temperature from 23°C to 60°C could actuate the trimorphs to grasp follicles of ~ 1 mm in diameter. At 60°C, the embryos inside the follicles were observed to be alive, i.e., they were still moving in the biological fluid isolated by the follicle membrane. The smallest follicles grasped were ~500 μm in diameter using 800 μm × 130 μm × 0.6 μm actuators. The fabrication process, modeling, and optimization of the trimorph actuators are presented. Based on the successful operation of these polymer-based actuators, we are currently developing multifinger thermal microgrippers for cellular grasping and manipulation, which can potentially be hybridly integrated with circuits for computer control.

KEY WORDS: thermal actuator, microgripper, cell manipulation, underwater microactuator

1 INTRODUCTION

Microrobotics consists of a variety of research areas including microassembly[1], microhandling[2], micro mobile robots and etc. Some of the potential applications of microrobotics with growing interest are cell manipulation, cell isolation, and micro injection in the biomedical field. For example, biologists usually use pipettes for cell isolation prior to carrying out micro injection. However, the functionality of this method is limited by the size of the cells, i.e., the cells cannot be too small compared to the pipette; otherwise, a bundle of cells could be drawn into the pipette at once. In addition, the pipette cannot be used to rotate individual cells, a function which is highly desirable during a micro injection process. To address these problems, we are currently developing a system that can manipulate and isolate cells controllably, and that can potentially be used to conduct localized cell probing and measurements.

Most of the existing MEMS actuators are limited to specific or narrow applications due to their limited displacement, force output, and necessary working environment. As described by S. Shoji[3], each micro actuation principle, including electrostatic, piezoelec-
tric, electromagnetic and thermal, has their own advantages and disadvantages. For example, the problem encountered in electrostatic and piezoelectric is limited deflection. Magnetic actuators currently still need off-chip magnetic source to actuate them effectively. Thermal actuators, however, can produce large force and deflection but they require large power and may affect the temperature of the surrounding environment. For the purpose of micromanipulation, more specifically for cell manipulation, actuators are required to operate in biological fluid environment. Electrostatic actuation is inefficient in ion-rich fluid and the deflection is small\[4\]. Therefore, thermal actu-ators were considered by some researchers to operate in solution-based environments. Generally speaking, thermal actuator consisting of two layers, in which one of the layers would be a heater, is called a “bimorph”.

For thermal actuators to operate in for aqueous environments, heat convection to a solution medium can be as significant as conduction to the substrate. Consequently, micro actuation in an aqueous medium requires much higher input power than actuation in air. Lin et al.\[4\] have demonstrated a 2-layer thermal/electrostatic actuator (200 μm × 45 μm × 1.1 μm with polyimide/Au layers). This thermal actuator can operate in air with 7V at 4mA. However, for actuation in liquid, it requires voltage as high as 100V and causes overheat of the actuator. Ataka et al.\[5\] also fabricated a thermal bimorph actuator (500 μm × 100 μm × 6 μm with polyimide/Au layers). The temperature of the actuator rose up to 260°C for actuation, which will definitely kill cells.

Owing to the disadvantages of silicon- and metal-based thermal actuators to operate in aqueous environments, new materials and designs for thermal actuators must be explored to achieve micromanipulation of live biological cells. In this paper, parylene C is chosen to encapsulate a middle metal heater, resulting in a tri-layered thermal actuator. Parylene C, which is a polymer, has excellent mechanical and electrical proprieties. Comparison between the properties of parylene C and common used materials in MEMS are shown in Table 1. It has a large coefficient of thermal expansion (CTE) and a high dielectric constant. It can withstand temperatures up to ~180°C and is extremely conformal\[6\]. It is bio-compatible and can serve as a barrier to oxygen, moisture, chemi-cals, solvents, and carbon dioxide. Therefore, we have chosen it to protect the metal from exposing to fluid while the actuator is working in an aqueous environment. Moreover, as the metal heater is covered by parylene, heat can be trapped and thus heat loss to the surrounding can be reduced. Also, it can protect the metal layer from reacting with the fluid. Parylene C has been used to create microfluidic devices such as microchannel\[7\] and micro check valve\[8\] by other researchers. Here, we explore the advantage of parylene to potentially develop a polymer-based micro thermal gripper for micromanipulation in aqueous environment to capture cells.

### Table 1: Comparison on Physical Properties of Various Thin Film Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of Thermal Expansion (CTE)/K⁻¹</th>
<th>Density/(kg.m⁻³)</th>
<th>Young’s Modulus/GPa</th>
<th>Thermal Conductivity/(W.m⁻¹.K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum</td>
<td>9 x 10⁻⁶</td>
<td>2145</td>
<td>146.9</td>
<td>69.23</td>
</tr>
<tr>
<td>PolySi</td>
<td>2.5 x 10⁻⁶</td>
<td>2300</td>
<td>2300</td>
<td>28</td>
</tr>
<tr>
<td>SiO₂</td>
<td>12 x 10⁻⁶</td>
<td>2300</td>
<td>3.2</td>
<td>1.38</td>
</tr>
<tr>
<td>Parylene</td>
<td>3.5 x 10⁻⁵</td>
<td>1289</td>
<td>83</td>
<td>0.082</td>
</tr>
</tbody>
</table>

2 MODELING

2.1 Design of the Dimension of Actuator

The motion of this polymer-based thermal actuator can be estimated by a three-layer cantilever beam model. In our current design, the middle layer is platinum and the top and bottom layers are parylene. When current passes through the platinum, the entire structure will be heated up. Due to the difference in coefficient of thermal expansion (CTE) between platinum and parylene, each layer would expand differently and lead to the curling up of the beam. By considering the interaction of forces and moments between the layers, the bending radius of curvature \( r \) due to temperature change \( ΔT \) can be calculated by Eqs.(1)~(5).

\[
r = \left( 1 - \frac{1}{2} AD^{-1} C \right) / -AD^{-1} B ΔT
\]

\[
g(A, B, C, D)\cdot \frac{1}{ΔT}
\]

where

\[
A = \frac{1}{3} \sum_{i=1}^{3} E_i I_i \left[ \frac{t_1}{2} + \frac{t_2}{2} + \frac{t_3}{2} \right]
\]