DYNAMIC STUDY OF CELLULAR INDENTATION USING ELECTROMAGNETIC MEMS DEVICE

Jin-Sung Hong and Jennifer H. Shin

Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea

hjs0811@kaist.ac.kr and j_shin@kaist.ac.kr

Introduction

Cellular indentation technique such as the atomic force microscopy (AFM) has been widely used in various researches to measure the mechanical properties of cells. However, this method is limited to small deformation of 1–2 μm and is not friendly enough for the end user [1].

In this paper, a MEMS based μ-actuator driven by electromagnetic (EM) force is developed to measure the elastic property of living cells and to locally stimulate cells in vitro. The device consists of a probe, flexible beams with embedded electrodes and a permanent magnet. While the beams deflect in lateral directions by Lorentz force, the probe positioned at the middle of the beams indents the cells. The deformation of the cell is measured using an optical microscope coupled with a CCD camera, and its elastic property is estimated based on the Hertz contact model. The force needed for the μ-actuator is estimated to be several μN for our purpose but can be varied over a wide range by changing the current and the magnetic field if necessary.

Materials and Methods

EM driven μ-actuator: The schematic and microscopy image of EM driven μ-actuator are shown in Figure 1. With the applied magnetic field, the current along the actuator base induces the electromagnetic force which enables two parallel actuator beams to deflect. This leads to the forward movement of the probe, attached in the middle of the beams, to indent a specific target, in our case, a cell.

Figure 1. Schematic and microscopy image of EM driven μ-actuator.

Design parameters: The actuator is made of single-crystal silicon (Si) with a Young’s modulus E = 170 GPa. The length of each actuator beam is L = 2000 μm. The cross section of the beam is rectangular, with height h = 20 μm and width w = 2 μm. The stiffness of the actuator beam is estimated to be \( k = 43.5 \, \text{nN/μm} \), by \( k = \frac{6EI}{h^3} \), where \( I = \frac{1}{12}hw^3 \) is the moment of inertia of the beam [2].

Fabrication: For the fabrication of the device, a silicon based MEMS technique is utilized. The wafer is patterned based on the mask design and is etched 20 μm by deep reactive ion etching (DRIE). Next, 400 nm oxide layer is formed and a reactive ion etching (RIE) is performed to open the sites for the isotropic etching. Using HNA (HF/HNO3/CH3COOH) solution, these open sites are etched away to release the beams. Then 400 nm of an aluminium layer is sputtered to make the electrodes and then coated with parylene and photoresist (PR) for protection prior to etching. The device is then diced to reveal raw silicon on the sides and etched further with HNA solution to release the tip. Lastly, the device is recoated with parylene for insulation after the removal of the old parylene and PR by ashing.

Experiment: The fabricated device is manipulated by a micromanipulator (MP-225, Sutter) for the cellular indentation experiment. For the target cell, Hep-G2 cell line (human liver hepatocellular carcinoma, ATCC HTB-22) is used. The permanent magnet (3000G) is placed under the device to produce the sufficient magnetic field for the beams to deflect while a function generator applies the desired current. The cellular indentation response is then obtained from \( F = k \delta \) (Hertz model), with \( \delta \) being the deflection of the cell membrane [3]. Therefore, the stiffness of the cell membrane can be calculated from known applied force and measured cellular membrane deformation. The deformation is observed from the CCD camera on the optical microscope that has resolution of 0.015 μm/pixel.

Results and Discussion

The applied force by the device is ~10 μN and the indentation depth can be as large as 20 μm depending on the degree of the beam deflection. Moreover, the beam deflection can be operated at a wide range of frequencies. By using this device we can calculate the stiffness of the cell and define its mechanical property.

On the other hand, this device can be used to investigate the cellular response by dynamic poking. For example, we can apply sinusoidal indentation to a cell and study how the cells may respond to the dynamic mechanical agitations by investigating the changes in cytoskeletal arrangements and protein expressions [2].

Conclusions

Preliminary experiments have shown the versatility of this indentation method in measuring cellular mechanical properties and also in applying local stimuli to the cells. We demonstrate that this EM force driven cellular indenter is a feasible and compatible tool which can further be utilized in evolving cell mechanics research.

References