Magnetically Actuated Elastomeric Pillars for Cellular Force Measurement

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Cells generate traction forces via the cytoskeleton during adhesion and migration.[1] Much effort is currently being applied to understand the biomolecular interactions involved in these force generating processes. One very popular and successful platform for quantifying cellular forces is arrays of elastomeric pillars.[2,3] These substrates work as independent force sensors and provide direct measurement of the traction force at specific locations. The forces are inferred from the deflection of the pillars and can be as large as several nN.[2] Cells are also responsive to externally applied force, however few studies have been done to date in this area because of the difficulty in engineering biocompatible, micron-scale mechanical actuators that can be integrated into a cell assay system.

In this work, we have developed a simple system in which mechanical force can be applied to cells as they migrate and spread on a surface. Using the same platform consisting of arrays of elastomeric pillars mentioned above, we embedded a microscale magnet within each pillar, so that groups of pillars in a given region can be deflected by an external magnetic field. Cells adhering to the tops of the pillars will experience a force as the pillars are deflected. In this way, we can quantitatively study the response of cells to externally applied force.

The fabrication process is shown schematically in Fig. 1. A rigid template is created for elastomer molding. The template is formed from a Si substrate with a 950 nm-thick thermal oxide. Optical lithography is used to form an array of micron-scale holes in resist. After developing, the resist is treated with a long post exposure bake in order to smooth the sidewalls, followed by a descum in an O_2 plasma. The oxide layer is reactive ion etched using a fluorine-based chemistry. The underlying Si is then etched to the desired depth using Cl_2 as the etch gas and the oxide layer as a hard mask. This etch determines the height of the elastomeric pillars, which are molded by the Si template. Following oxide stripping and cleaning, the template is silanized with vapor phase tridecafluoro-trichlorosilane. Cr is deposited at a 30 °angle by thermal evaporation, resulting in Cr deposition on the top surface and sidewalls of the etched holes but not on the bottoms, as in Fig. 1f. A 10 nm layer of Au is then deposited normal to the template surface followed by a 300 nm layer of Permalloy. 5 nm of Ti is added to aid adhesion of the material to the elastomer. Removal of the Cr sacrificial layer results in a Si mold with Au+Permalloy+Ti at the bottoms of the etched holes (Fig. 1h). Poly-dimethyl-siloxane (PDMS) is poured over the mold, cured at 70 °C for 12 h and peeled off in ethanol. The PDMS pillars with embedded magnetic plugs behave like individual magnetically actuated springs (Fig. 1i). Figure 2 shows a DIC micrograph of magnetic pillars. This new fabrication technique enables localized force transduction that will help to understand the relation between forces generated and sensed by cells.

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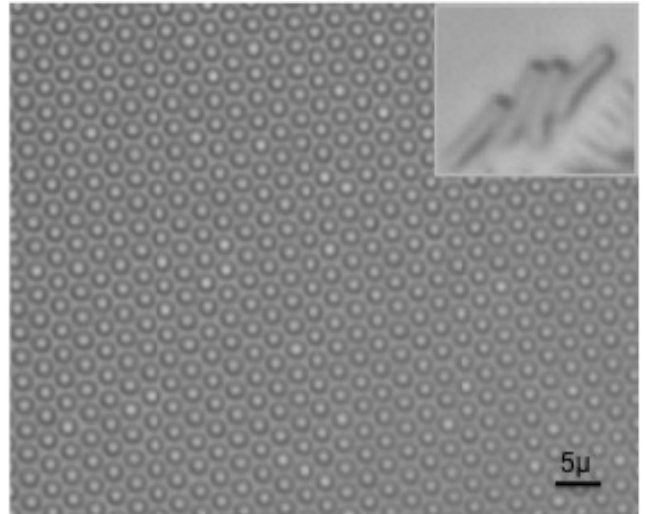3. A. Saez, A. Buguin, P. Silberzan and B. Ladoux, Biophys J **89** (6), L52-54 (2005).

Fig. 2. DIC micrograph of magnetic PDMS pillars

Fig. 1. Schematic drawing of the fabrication of PDMS pillars with Permalloy layer on the top