SILICON NANOVELCRO TO ATTACH INORGANIC MICRODEVICES TO BIOLOGICAL MATERIAL

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ABSTRACT

This paper reports the fabrication of silicon microdevices featuring silicon nanowires as nanoscale attachment elements to increase their adhesion capability. These nanoattachment elements are bio-inspired in small animals like geckos that can exhibit high adhesion forces due to their nanostructured feet. The adhesion of small silicon chips to inorganic surfaces or biological material can have many potential applications, and many studies are based on Cell-on-a-chip approaches. Here we propose a Chip-on-a-cell strategy where silicon microchips with enhanced adhesion properties are fabricated using micro- and nanosystems technologies and demonstrated to have cell biocompatibility.

KEYWORDS: Silicon, Micro- and nanosystems technologies, Nanovelcro, Nanowire, Living Cell

INTRODUCTION

In cell biology, direct interconnection of the cells to the external world by interfacing inorganic nanomaterials may allow great opportunities to probe and manipulate biological processes occurring inside the cells [1].To date, micro- and nanotechnologies offer the possibility of producing devices smaller than cells [2] [3]. Small devices can be fabricated using MEMS technologies based on standard photolithographic processes. These techniques allow us to produce millions of low-cost reproducible devices massively with micrometer or even nanometer parts. In addition, the most used materials by semiconductor industries, silicon and polysilicon, have been demonstrated to have cell biocompatibility [4] [5].

Small microdevices can be adhered to cells if they are chemically functionalized with molecules that attach to their membranes. However, this functionalization can alter or ruin some chemical sensing capabilities of the devices. In order to solve this problem, we explore the possibility of a physical adhesion. Hence, we cover the microchips with silicon nanowires used as nanovelcro. The nanowires can be grown with a length of several microns and diameters constrained to tens of nanometers.

The present study was designed to test the fabrication of silicon chips, smaller than cells, featuring silicon nanowires to increase their adhesion. As a proof of concept, polysilicon barcodes are decorated with silicon nanowires and adhered to the zona pellucida of embryos for cell tagging.

THEORY

Silicon nanowires grow via the Vapor-Solid-Mechanism (VLS) along the <111> crystallographic directions [6]. This means that nanowires grow parallel on monocrystalline silicon. For instance, perpendicular nanowires can be obtained if they are grown on <111> silicon wafers [Figure 1 (a)]. However, non-parallel nanowires would increase the velcro effect. In theory, randomly oriented silicon nanowires could be obtained if they are grown on polysilicon layers as polysilicon is composed of randomly oriented grains of monocrystalline silicon [Figure 1 (b)]. Hence, this study investigates the fabrication of polysilicon microchips with random-orientation silicon nanowires to verify this hypothesis.

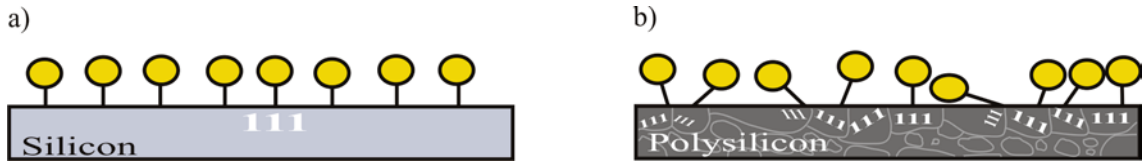


Figure 1: Silicon nanowires growing in <111> directions: a) monocrystaline (111) oriented silicon and b) polysilicon substrates.

EXPERIMENTAL

To illustrate our assumption, polysilicon barcodes, with lateral dimensions fixed to 10 µm x 6 µm and thickness fixed to 1 µm, were proposed as microdevices [7]. The fabrication of microchips is based on standard MEMS technologies using photolithographic processes in combination with silicon nanowire synthesis via the VLS mechanism.

The technology for the fabrication barcodes is based on the deposition of a 1 µm thick polysilicon device layer on a 1 µm thick silicon oxide sacrificial layer, previously coated onto a four-inch p-type silicon wafer**.** The fabrication process is shown in Figure 2. 4" p-type silicon wafers are used as initial substrates, a). Then, a 1 µm thick silicon oxide, b), and a 1 µm thick polysilicon, c), are deposited as sacrificial and device layers, respectively. A photolithographic process, d), combined with a polysilicion dry etching process is done to define the microchips, e). Later, gold nanoparticles are selectively deposited on the silicon surfaces of the wafer by a galvanic displacement process, f) and they are used as catalytic seeds for the nanowire synthesis, g) [6]. The gold nanoparticles determine the nanowire growth location and its diameter [8]. The nanowires' length is ~ 3 µm and the range of their diameter is from 30 to 80 nm. The microchips were

released by etching the silicon oxide sacrificial layer in vapors of hydrofluoric acid (HF) 49%, h). Finally, the released microchips were suspended by ultrasounds in ethanol, collected and centrifuged at 14000 rpm for five minutes (MiniSpin Plus).

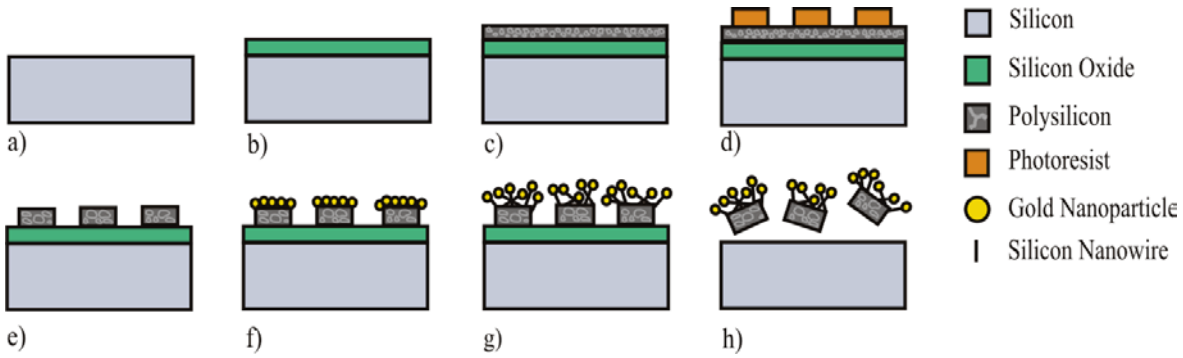
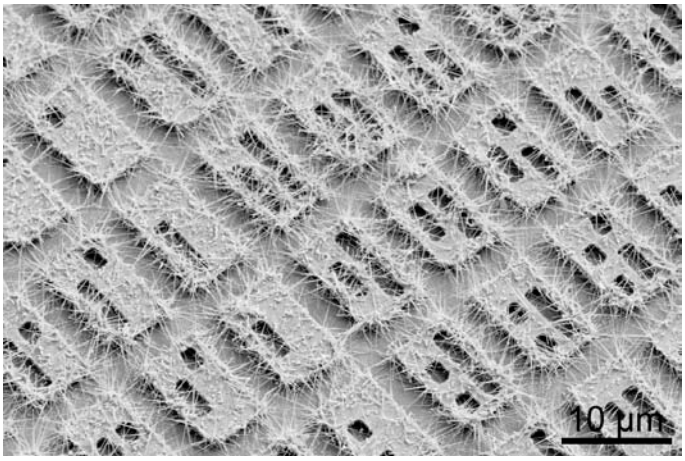


Figure 2: Fabrication process: a) silicon wafer as initial substrate, front-side deposition of b) a silicon oxide sacrificial layer and c) a polysilicon device layer, d) photolitographic step, e) polysilicon patterning by dry etching f) gold nanoparticles deposition, g) silicon nanowires growing and h) device releasing by HF etching of the sacrificial layer.

RESULTS AND DISCUSSION

In these conditions, very straight nanowires grow in the <111> directions. The orientation of the nanowires depend on the crystallographic orientation of the polysilicon grains where the gold nanoparticles are deposited. Manufactured structures before the sacrificial etching are shown in Figure 3 a) and after their release in b) and c).

a)



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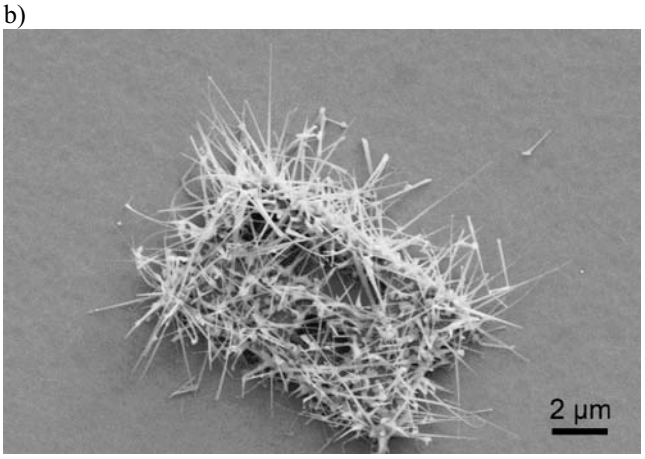

c)

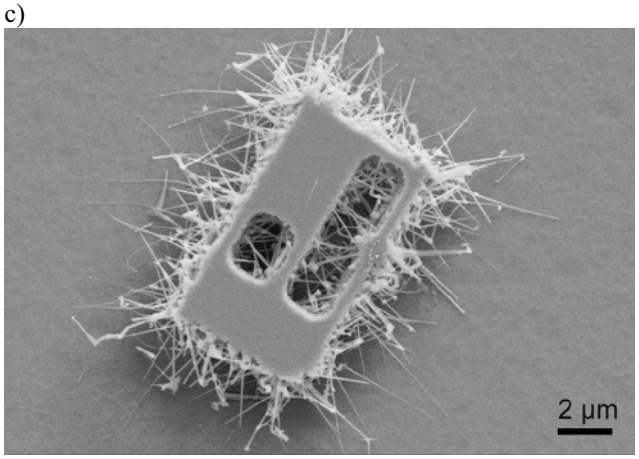

Figure 3: SEM images of silicon microdevices engineered with silicon nanowires: a) before and b and c) after their release.

Figure 4 shows the adhesion ability of these microchips. A drop of devices suspended in ethanol was dried and inspected using a SEM microscope. Several devices remained adhered after drying, figure 4 a). Some devices were also put into contact with mouse embryos and they remained adhered although they separated after some time, suggesting that the initial contact force is a crucial parameter. In conclusion, silicon nanowires can be used as nanovelcro between silicon

microdevices and even between them and mouse embryos, Figure 4 b). Further experiments are required to quantify the adhesive forces between inorganic-inorganic and inorganic-biological materials.

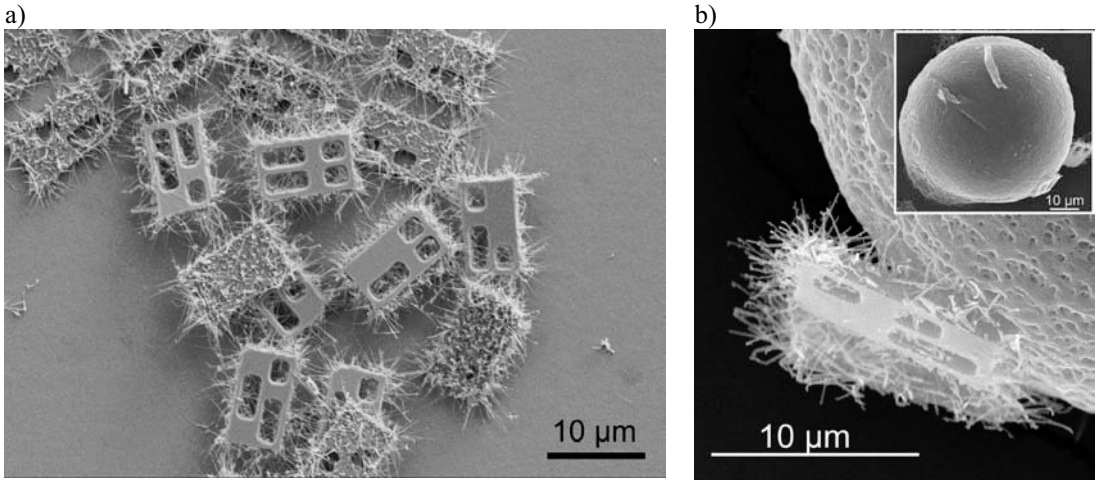

Figure 4: a) SEM images of inorganic-inorganic adhesion between silicon microdevices and b) inorganic-organic material adhesion between silicon microdevices and mousse embryo - barcode attached to zona pellucida – (Inset image does not correspond with the larger one).

CONCLUSION

In this context, we have demonstrated that we can fabricate and collect polysilicon microchips decorated with randomly oriented silicon nanowires. Inorganic-inorganic adhesion between them has been observed. In addition, cell biocompatibility with silicon and polysilicon has been previously demonstrated [7], and even with porous silicon [4]. As these devices are smaller than living cells, manufactured polysilicon barcodes decorated with silicon nanowires have been fixed to mouse embryos for cell labeling. The inorganic-biological physicochemical adhesion takes place between the silicon nanowires and the *zona pellucida*, which is an extracellular glycoprotein coat that surrounds oocytes and early embryos. Further experiments to determine the adhesion forces are required.

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