Carbon Nanotube Microfluidic Channels for Cell Manipulation

Michael Bellavia
Bioengineering, SUNY Binghamton

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor, MI
NNIN REU Principal Investigator: Anastasios John Hart, Mechanical Engineering, University of Michigan, Ann Arbor
NNIN REU Mentor: Kendall Teichert, Mechanical Engineering, University of Michigan, Ann Arbor
Contact: mbellav1@binghamton.edu, ajohnh@umich.edu, kbt@umich.edu

Abstract and Introduction:

Due to their remarkable porosity (~99%), electrical and mechanical robustness, and ability to be chemically functionalized, vertically aligned carbon nanotubes ("CNT forests") are a promising material for use in lab-on-a-chip devices. Utilizing these in bio-MEMS (e.g. for bioparticle detection) provides several prospective advantages over conventional solid materials (polydimethylsiloxane or PDMS, silicon or Si). These include the capability for flow both around and through the nanoporous structures to increase particle-surface interaction and greater selectivity for small (e.g. 10 nm) particles [1].

Current literature has illustrated the prospects of CNT structures placed within the fluid flow. Alternatively, this project aimed to demonstrate the capability of CNT forests as microfluidic channel walls. Ultimately, flow through various geometries could be exploited for potential biomedical applications.

Via photolithography, patterns for flow channels were transferred onto a Si wafer. A base layer of alumina was deposited, overlaid with a layer of iron catalyst. The wafer was diced into individual devices then placed in a tube furnace and forest growth achieved by thermal chemical vapor deposition (CVD) using a mixture of helium, hydrogen, and ethylene, at 775°C.

Testing was accomplished with a benchtop fluidic system consisting of a syringe pump, acrylic/PDMS chip dock, and a camera-equipped stereoscope for visualization. Flow through the CNT channels was verified, and experiments using polystyrene beads and human monocytes suspended in the fluid flow were observed.

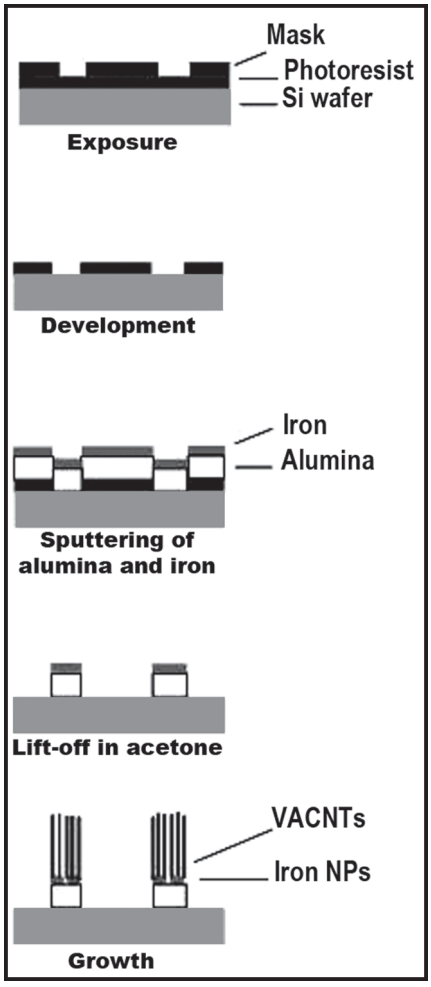

Figure 1: Step by step fabrication of microfluidic devices.

Methods:

Photolithography and sputtering (10 nm alumina and 1 nm iron) were implemented to define the catalyst regions for forest growth on a Si wafer. Afterwards, the wafer was diced into individual devices. CNT growth was performed in a tube furnace.

First the substrate was annealed in 100 sccm H_2 and 400 sccm helium (He) at 775°C for 10 minutes. Next, the substrate was removed from the furnace and allowed to cool in stagnant annealing gases (He, H_2). It was then re-inserted for growth in 400 sccm He, 100 sccm H_2, and 100 sccm C_2H_4 at 775°C for various durations. (See Figure 1.)

Difficulties in fluid transfer motivated particular mount designs. The initial concept was a short (≈ 1 cm) PDMS cylinder with a cavity extending upwards from the bottom to house the chip and forest. Holes were punched above the chip reservoirs and aligned to another punched from the side. A dispensing needle was placed in the side hole and connected via silicone tubing to a syringe pump. Fabricating the cavity properly proved challenging.

Once the PDMS covers contacted the forest, further adjustment would damage the forest. Further, leakage over the forest was noted. To circumvent this, an acrylic/PDMS chip docking system was developed (Figure 2a) and placed under a stereoscope. An adjustable stage, its vertical movement controlled by a micrometer, was positioned below an acrylic piece machined with vertical channels. These channels were aligned with the reservoirs of a bare silicon chip. A layer of PDMS with holes aligned to both those of the chip and the acrylic was placed on top of the chip. The stage was moved upward with the micrometer until the PDMS on the chip applied sealing pressure to the acrylic

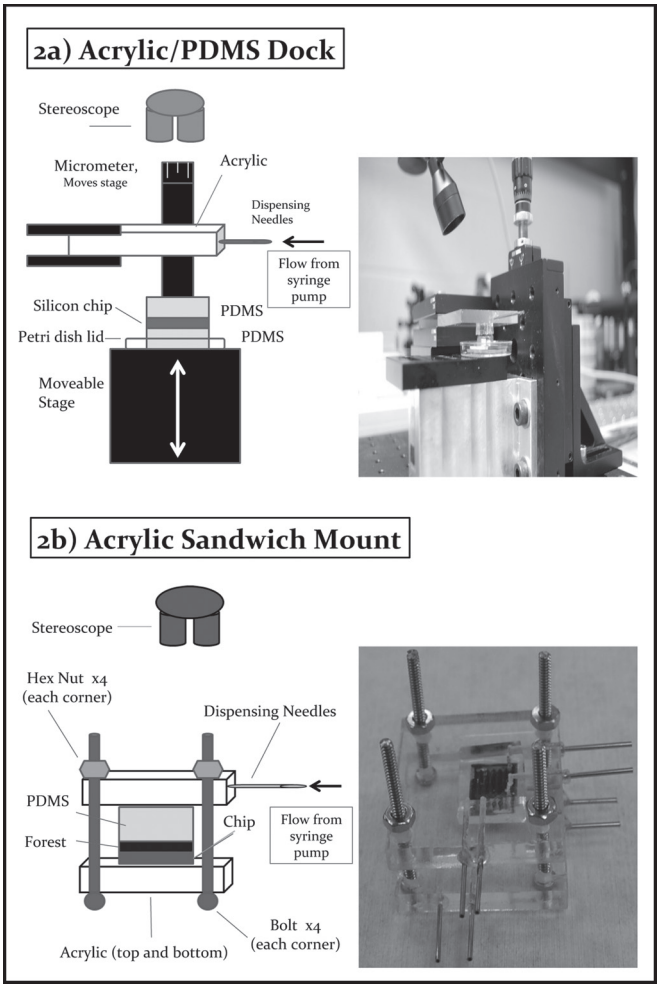

Figure 2: Schematics.

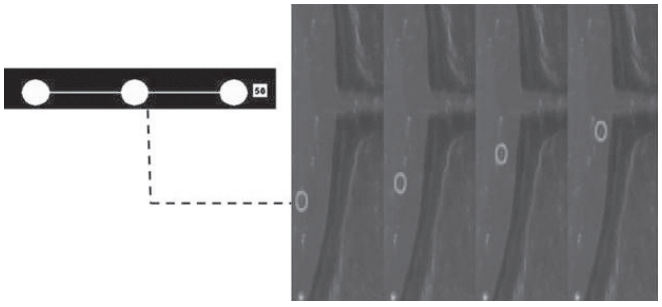

Figure 3: A monocyte (within the circle) moves from a reservoir into a channel. The frames (labeled 1-4) are each separated by a fourth of a second.

plate. An assortment of materials with different elasticity, such as rubber, foam, and PDMS were used as backing for the chip as a means of improving sealing to the acrylic. Flow tests were conducted at infusion rates between 30 μL/hr and 10 μL/min using 3, 10, and 15 μm polystyrene beads. Sandwiching the chip between $\approx$ 5 mm layers of PDMS was found to be adequate, as it most reliably prevented leakage.

A portable mount (Figure 2b) was constructed; a PDMS layer between two acrylic squares machined with vertical channels spaced to fit whatever device. With this, several flows of monocytes, a variety of white blood cell, were undertaken (Figure 3).

To simulate the pressure drops to be experienced in the flow, flow through certain designs was analyzed with COMSOL Multiphysics, a finite element software package. Pressures and velocities from select geometry were compared to pressure results found from a flow equation assuming rectangular channels cited in the Microfluidics and Nanofluidics Handbook by Mitra and Chakrabourty [1]. These flows will be related to experimental results in future work.

Results:

Preliminary flows of polystyrene beads and monocytes through CNT forests were performed successfully. Monocytes flowed rapidly even after the pump was stopped, but after a time, backflow occurred. This may be due to inadequate sealing. Imaging with the stereoscope camera did not provide satisfactory resolution. Further analyses might be conducted with fluorescence microscopy.

Close agreement was evident between the average velocities at the inlets for the COMSOL™ model and those of the fluidics equation. This asserts that COMSOL can be sensibly extrapolated to modeling other devices or new geometries.

Future Work:

The fluidic delivery system shall be improved and testing systematized for the procedure to be efficient and easily repeatable. The forests are fragile, necessitating more precise alignment strategies for the PDMS overlay such that sealing is obtained with less risk of harm to the forest. This would greatly expedite testing. A redesign of the flow geometries could contribute to this, and will be undertaken.

Optimization of the CNT growth conditions is required to fabricate CNT devices with consistent and repeatable fluidic properties. Further, the wealth of properties innate in CNTs such as photoluminescence as well as outstanding tensile strength and electrical conductance, make them attractive candidates for further integration in innovative microfluidic devices.

Acknowledgements:

I'd like to express my earnest gratitude for the guidance of Kendall Teichert. I am indebted to Professor John Hart and the Mechanosynthesis Group. Lastly, I'd like to thank the National Science Foundation and NNIN REU Program for this opportunity.

References:

[1] Fachin, F., et al., Journal of MEM Systems (2011): 1428-1438.