NanoScanner: Microchannel Nanoparticle Separation

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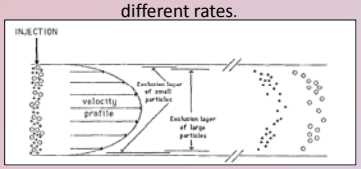
Purpose: Nanoparticle toxicity Characterization is essential to growth of the nanotechnology industry. The NanoScanner device, conceived by Dr. Stacey Harper, will evaluate toxicity of nanomaterials inexpensively and in-line with an industrial process. This device must be able to separate nanoparticles based on size.

Objective: Separate 10 and 100 nm TiO_2 particles.

Potential Separation Methods

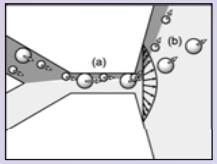
Chromatography: Separation of mixed particles by passing them through a device that transports different sizes at different rates.



Microchannel pocket feature designed to cause acceleration and deceleration unique to particle size. Pocket features increase separation of nanoparticles per Stokes' drag force

$$F_d = -6\pi\mu Rv$$

Pinch Flow Fractionation: Mixed particles travel into separate streams with unique particle size range. Pinch flow depends upon a narrow channel segment to position particles of different sizes into a unique flow regime, shown by the figure below.



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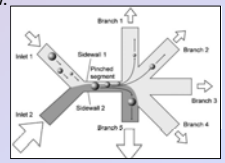

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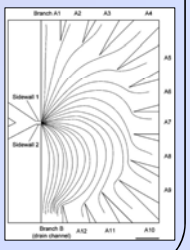
Figure 1: *Pinch point (a) particles enter separate flow regimes leading to fractionation of particles (b).* ***Figure 2:*** *Particles separated into different channels.*

Pinch flow fractionation flow dynamics are dominated by ratio of flow to drain channel over total flow rate. Majority of flow goes to the drain channel. Ratio flow is controlled using pressure drop from Poiseuille's equation:

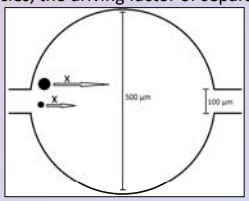
$$\Delta P = \frac{128\mu L\dot{V}}{\pi D^4}$$

Pressure drop used to control percentage of flow exiting the drain channel compared to the total flow leaving the system.

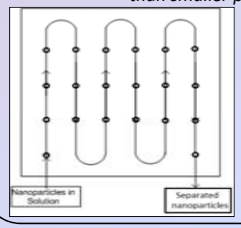


Design

Chromatography Design: The single channel chromatography device is 175 by 100 µm with pocket diameter of 500 µm. Pockets are designed to introduce fluid acceleration resulting in drag force on the particles, the driving factor of separation.



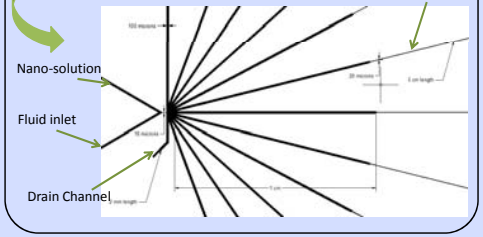
Channel feature dimensions demonstrates larger particles traveling further during deceleration than smaller particles



1 m channel length designed to allow sufficient flow disruption pockets and desired separation.

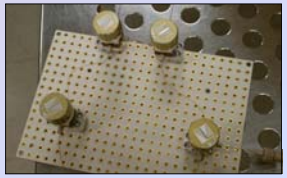
Pinch Flow Design: The microchannel has been optimized to separate 10 and 100 nm particles. The design process followed the sequence below.

- Define key channel parameters
  - Ratio of flow to drain
  - Pinch width
  - Number of separation channels
- Optimize parameters for separation
- Determine pressure drop through channel
  - Plausible
  - Not plausible



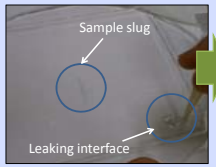
Fabrication

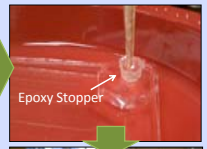
Chromatography Channel and 6-Way Valve: Microchannel cast in a PDMS substrate adhered to a blank slab of PDMS using plasma bonding . Reduction of axial diffusion requires a sample slug to be introduced into the system. The concentrated slug is formed by a 6-way valve developed by the NanoScanner team.



6-way valve introduces a 160 nL concentrated sample slug to the microchannel.

Fluid Interfacing: PDMS bonds poorly with other materials. Developing the interface between the injection device and the microchannel is difficult. Channel leaked and required creative solutions illustrated below.





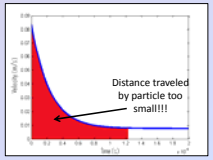
The channel interface moved from PDMS bonds to epoxy stoppers. The final solution burst the channel resulting in device failure

Pinch Flow Fabrication: Microchannel device cast in PDMS capped with a silicon substrate. The SU-8 master is developed using photolithography. PDMS is cast using the SU-8 master and feature the pinch flow design. Nanoports interface with the silicon substrate and are located at the two device inlets.

NanoScanner team developing SU-8 master for pinch flow fractionation channel.

Results

Chromatography Results: The developed model assumes all separation occurs within channel pockets and did not account for axial diffusion. Manipulation of Stokes' law results in an equation describing particle velocity inside a feature. Square channel represents the maximum acceleration of particle.



The model showed that little to no separation occurs using the chromatography microchannel design.

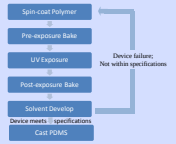
Pinch Flow Fractionation Design: Channel dimensions and pinch width were determined by specifying a desired fractionation resolution and optimizing for pressure drop across the channel. The design optimization was dominated by an alpha, α, term which represents the ratio of drain flow to total flow.

$$\alpha = \frac{Q_{drain}}{Q_{total}}$$

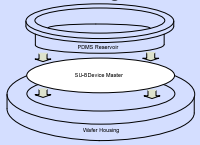
The figure at the right is an image of the pinch flow fractionation photolithography mask.

Device Manufacturing Results:

The device master was made using a photolithographic process. Recipe development is outlined below.



PDMS was poured over the master using the fixture shown below. Channel copies can be produced overnight!



Device Interfacing and Final Product:

5mm diameter holes were drilled into a silicon substrate at sample sites; 1.5 mm holes for the drain and inlets. The wafer was plasma bonded and aligned with the PDMS channel. Nanoports were epoxied to the back of the substrate at the two inlets forming the final product shown to the right.

Final Product

Future Work: Test the fabricated device for flow and separation capabilities. Vary inlet flowrates to the device and examine effect on separation. Classify the nanoparticles using the hyperspectral imaging tool in the Harper Lab. Modify design based on experimental results to obtain optimal separation.

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References:

Takagi, J et al. "Continuous Particle Separation in a Microchannel Having Asymmetrically Arranged Multiple Branches." *Lab on a Chip* 5.7 (2005): 778.