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Capacitive Carbon Nanotube MEMS Wall Shear Stress Sensors

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When was the last time your phone moved? We think of phones as stationary objects; electricity goes in, funny videos come out. Yet phones possess electric microsensors that have mechanical parts that move tiny distances. Such microelectromechanical systems (MEMS) can measure a variety of parameters: rotation, touch, temperature, and even capacitance. Yet measuring wall shear stress has proven challenging due to the need for fluctuating, time-resolved measurement[1].

Wall shear stress is a useful flow parameter describing the force per unit area associated with fluids directly moving along the face of solid objects. Typically, wall shear stress is used to find the viscous drag over a body due to the latter's significance in aerospace research, biomedicine and process controls[1]. Wall shear stress measurements can also be used to locate flow separation, check for cavitation, identify local flow direction, and characterize flow transition from laminar to turbulent regimes[2].

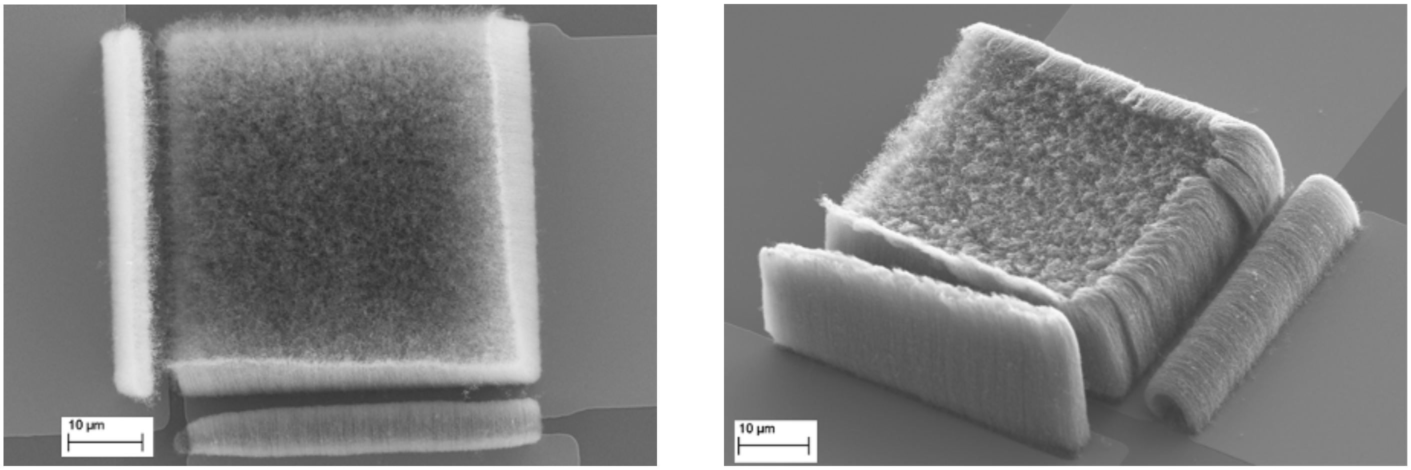

Figure 1: SEM images of a sensing element with a large square and two thin rectangles, grown previously as a proof of concept. ***Left:*** top view, ***Right:*** isometric view. The individual carbon nanotubes grow in groups like trees in a forest.

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My project in the Boutilier lab focuses on developing MEMS sensors to measure wall shear stress. The long-term goal of the project is to develop a robust capacitive MEMS sensor using silicon photolithography and carbon nanotube sensing elements. Our objective is to design, build and characterize a working gas-sensing prototype for future iteration.

We fabricate our sensors by using chemical vapour deposition to synthesize carbon nanotubes on a silicon wafer. As per standard growth processes, a carbon feedstock dissolves into a catalyst nanoparticle deposited on the silicon substrate[3]. After the catalyst is saturated, active carbon species precipitate to form tubes that propagate perpendicularly to the substate[3]. The result resembles a “forest” in which the carbon nanotubes are analogous to trees and the substate analogous to soil (figure 1).

To form a single sensing element, we pattern the catalyst to grow two forests: a thin 50nm by 5nm rectangle, and a 50nm square. The thin rectangle acts as a cantilever when exposed to moving fluid. This displacement changes the capacitance of the sensor which in turn can be read by a computer. To ensure capacitance can be read above background noise, thousands of sensing elements are arranged in parallel.

As the process requires a catalyst, the pattern of carbon nanotube growth can be controlled by precisely positioning said catalyst on the silicon substrate[4]. With the help of the Western Nanofabrication Facility, we pattern silicon with three layers of metal. Via photolithography and metal evaporation, we deposit a titanium nitride layer (50nm) to act as our sensor’s traces, an alumina layer (10nm) to act as a catalyst support material, and an iron layer (2nm) to act as our carbon nanotube catalyst (figure 2).

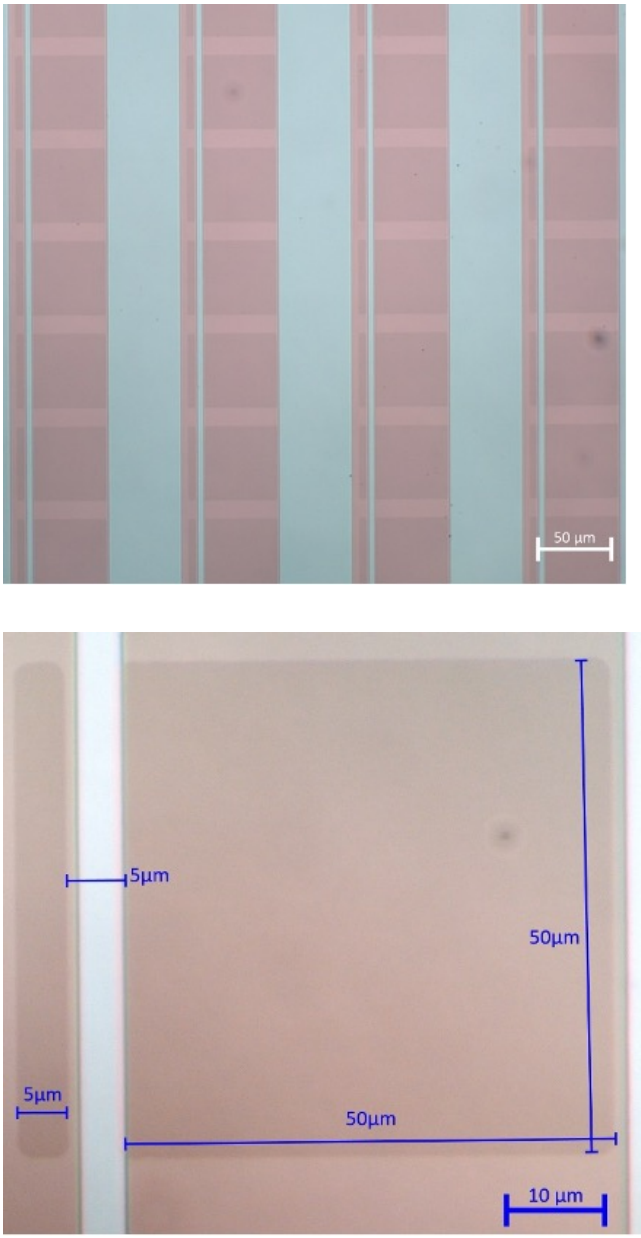

Figure 2: optical images of pre-growth titanium nitride (pink) below iron-on-alumina (dark rectangle and square on pink surface) deposition. This latest iteration of the design only uses a single square-and-rectangle catalyst pattern to grow carbon nanotube forests. ***Top:*** a portion of the sensing element array demonstrating parallel connection between each sensing element with respect to every other element. ***Bottom:*** a dimensioned view of a single sensing element before growth.

At the time of writing, we intend to produce and test these sensors in a small-scale flow channel to determine their measurement limits with plans to proceed to wind tunnel testing for more robust data. After confirming a working design, we intend to image our sensors via SEM with the help of the Western Nanofabrication Facility.

References:

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2. Pabon, R., Ukeiley, L., Sheplak, M. and Keane, C. “Characteristics of Turbulent Boundary Layer Large Scale Motions Using Direct Fluctuating Wall Shear Stress Measurements.” Physical Review Fluids. 3, 114604 (2018).
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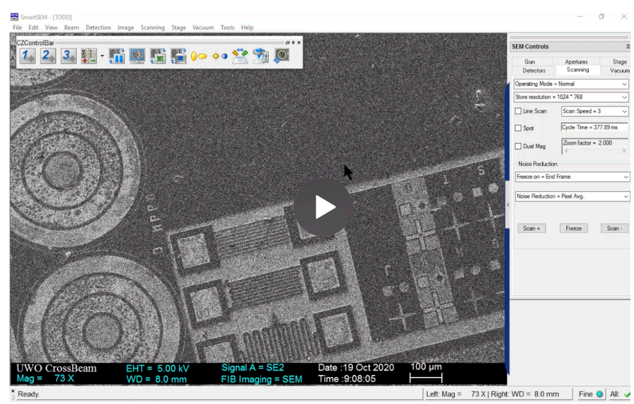
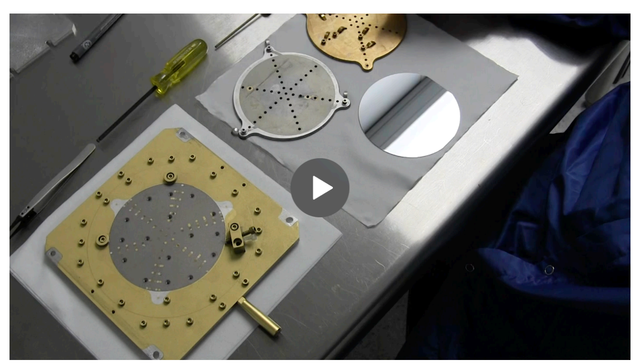
4. Jeong, G. H., Olofsson, N., Falk, L. K., & Campbell, E. E. Effect of Catalyst Pattern Geometry on the Growth of Vertically Aligned Carbon Nanotube Arrays. Carbon, 47, 696-704 (2009).





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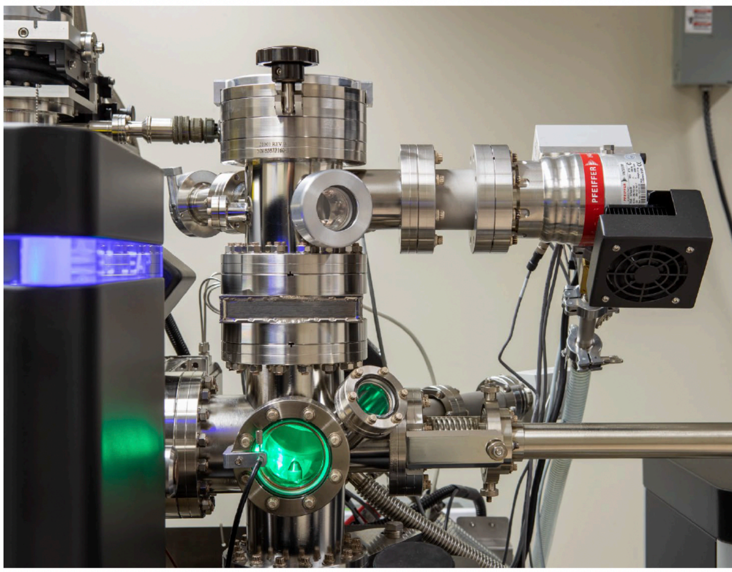

McMaster University, Hamilton, ON
CIBC Hall
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Confirmed speakers: Fibics Incorporated, MITACS, Mirexus, National Research Council Canada, NGEN, NSERC, Ontario Ministry for job creation and innovation, Surface Science Western.

Tours of CCEM, CALM, BIMR

November 17, 2022

MUSC 319 (CIBC Hall)

Registration link:
https://ccem.mcmaster.ca/events/nano-ontario-workshop/

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