Miniature Sensors for Airborne Particulate Matter

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ABSTRACT

Our group is working to design a small, lightweight, low-cost real-time particulate matter (PM) sensor to enable better monitoring of PM concentrations in air, with the goal of informing policymakers and regulators to provide better public health. The sensor reads the mass concentration of $PM_{2.5}$, or particles smaller than 2.5 μm in diameter, and includes a virtual impactor (VI) to separate out particles larger than 2.5 μm.

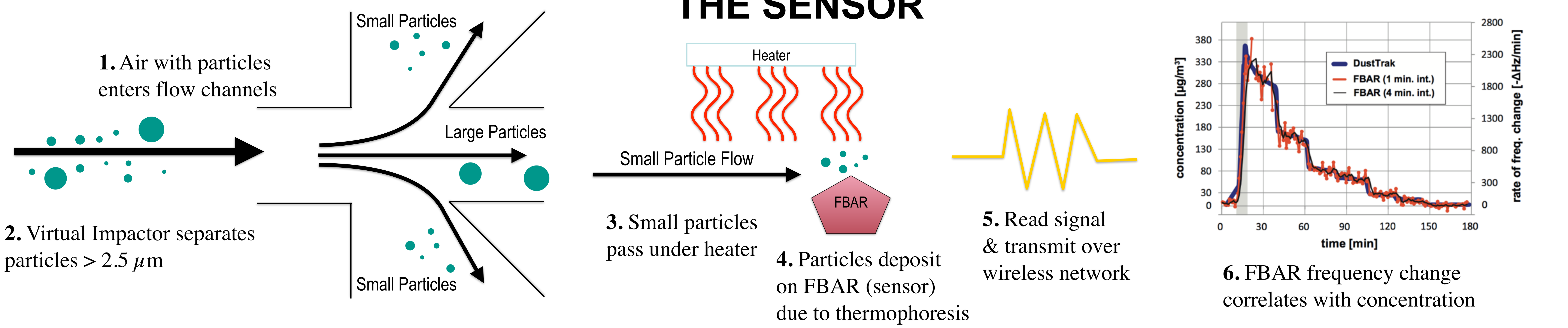
Airborne particles enter the microfabricated microfluidic channels, where the virtual impactor separates particles by size. A thermophoretic heater causes deposition of particles onto a thin-film bulk acoustic resonator (FBAR), whose resonance frequency changes linearly proportional to mass loading. The change in frequency is processed by a microcontroller and sent to a receiver.

BACKGROUND

In 2012, seven million deaths - or one in eight - were caused by air pollution, primarily airborne particulate matter (source: WHO). In addition, black carbon particles (BC) from incomplete combustion are a major short-lived radiative forcing agent and the third largest contributor to climate change (source: IPCC 2013). PM of all types, including BC, causes respiratory illness, lung cancer, heart disease, and pulmonary disease. PM smaller than 2.5 μm in diameter ($PM_{2.5}$) are particularly harmful, as they penetrate further into the lungs. Major sources of anthropogenic PM include biomass cookstoves, fossil fuel-burning power plants, and automobile emissions.

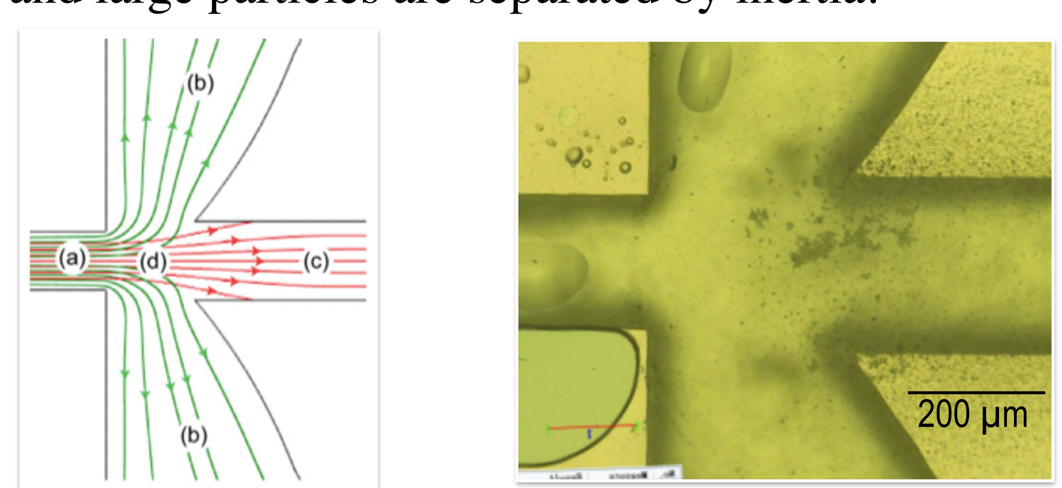
The EPA sets standards for outdoor PM concentration under the Clean Air Act, but the ability of regulators and researchers to monitor and understand PM is limited by the cost and size of existing air monitors, which often stand several feet tall and cost thousands of dollars. Smaller sensors are cheaper to manufacture and deploy, and can provide new insights on short-term (<1 hr) and spatial variations in PM concentration that affect human health.

THE SENSOR



VIRTUAL IMPACTOR

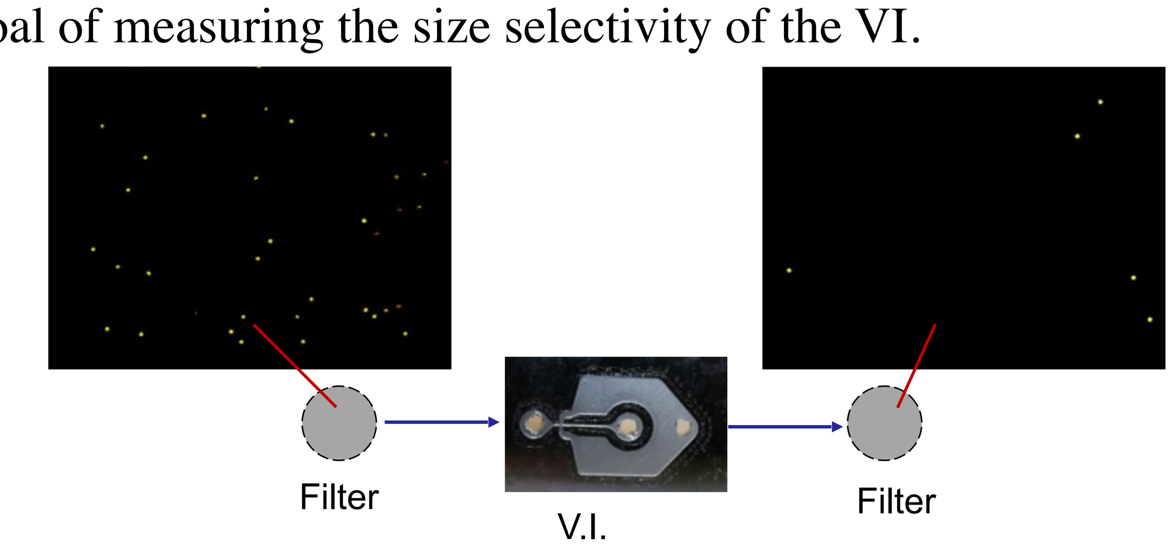
The VI consists of four channels. On the image below left, (a) is the flow entryway, (b) are the two major flow channels (45% of the total flow each), and (c) is the minor flow channel (remaining 10% of the flow); (d) is the region where small and large particles are separated by inertia.



In the separation region, small, light particles are able to make the turn with the major flow (green channels), while large, heavy particles continue in the minor flow (red channel). Above right, an optical microscope image of a virtual impactor with particles deposited in the minor flow entryway.

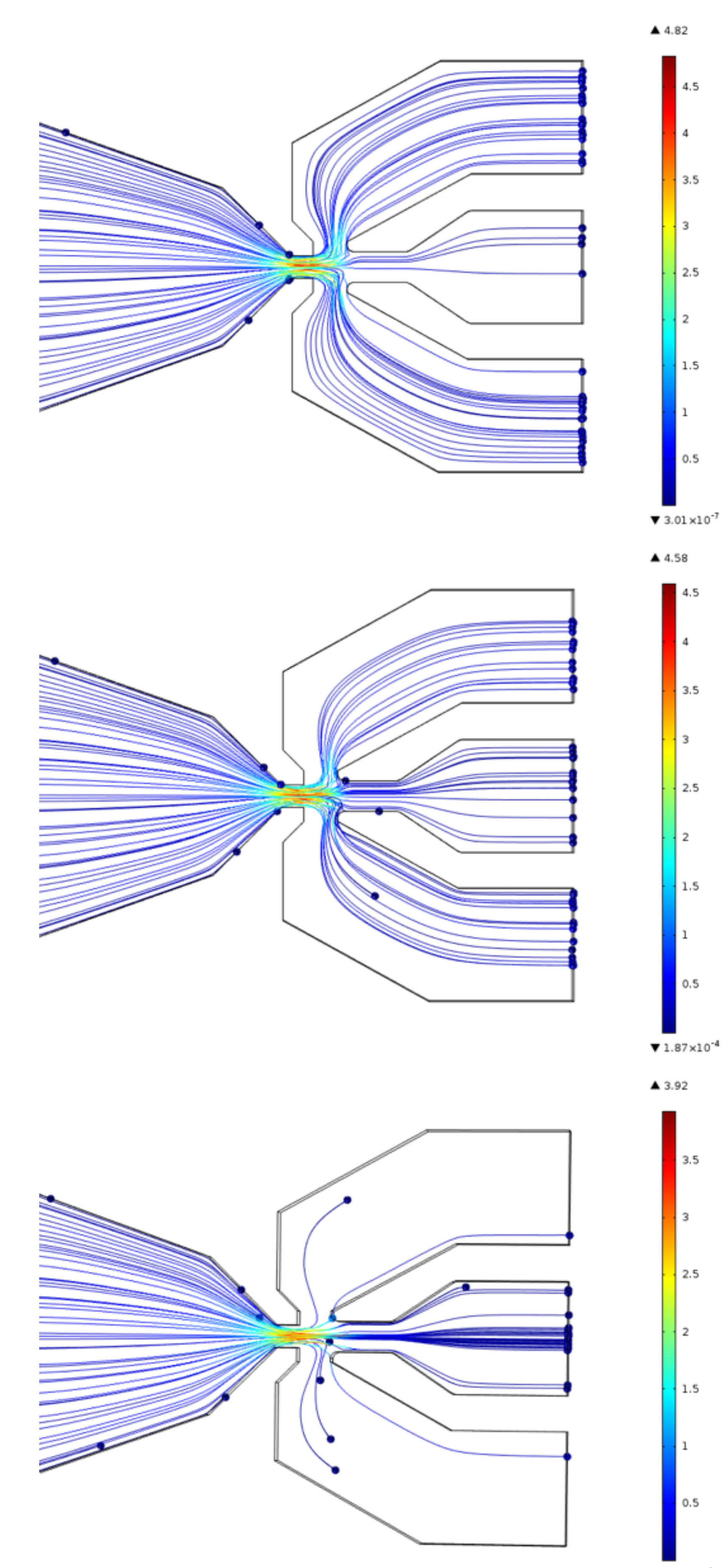
OPTICAL GRAVIMETRY

Particles are collected on filters both up- and downstream of the microfluidic channels. The filters are then imaged and analyzed algorithmically to measure particle number, with the goal of measuring the size selectivity of the VI.



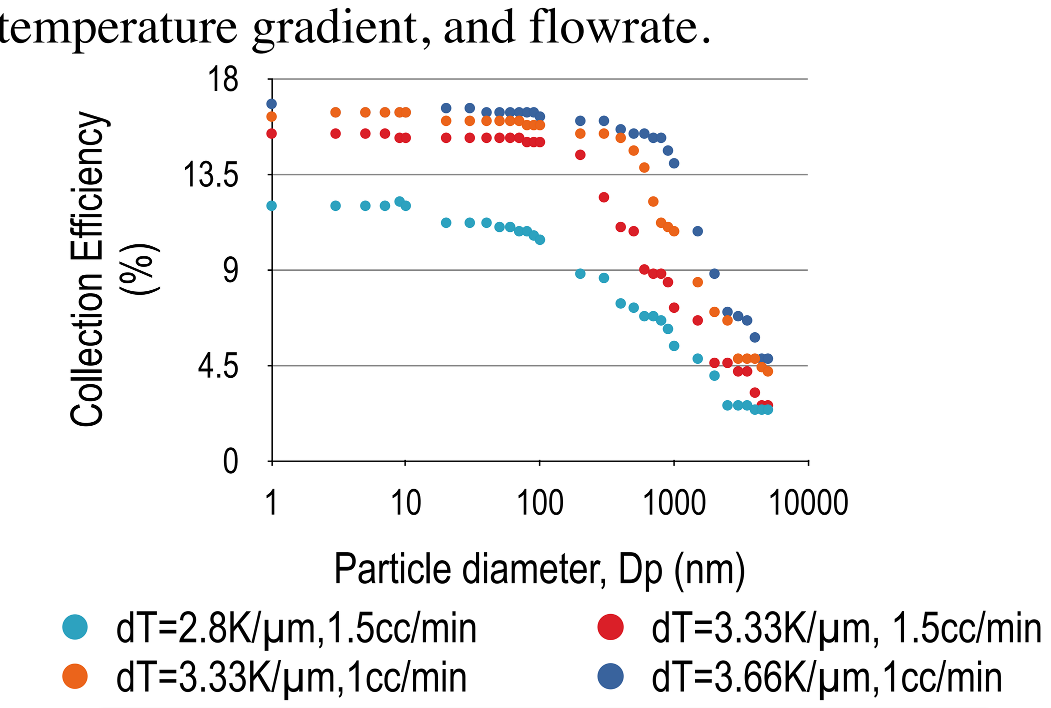
MODELING DATA

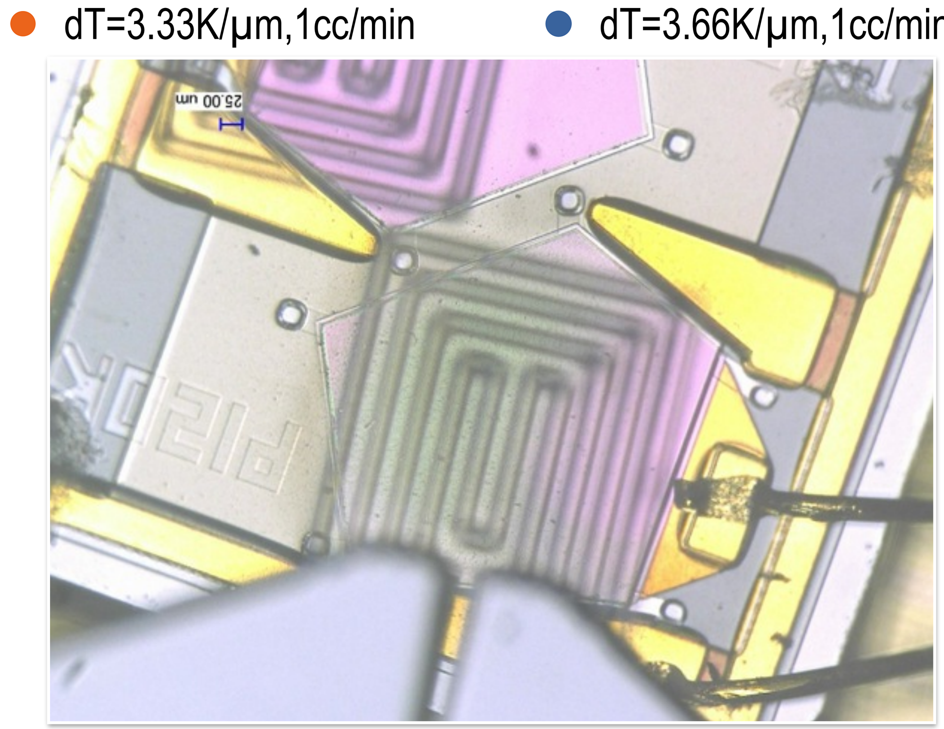
Finite Element Analysis modeling (using COMSOL) shows the trajectories of 1 µm (top), 2.5 µm (middle), and 5 µm (bottom) particles in the virtual impactor (VI shown on the left).



THERMOPHORESIS

A heater placed directly above the FBAR creates a temperature gradient, which drives particles away from the heater. A fraction of the particles deposit on the resonator, dependent upon particle size, temperature gradient, and flowrate.





Deposition (green) on the FBAR (pink) under the heater (silver).

ACKNOWLEDGMENTS

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