Engineering a Nanofluidic Pressure-to-Potential Conversion System

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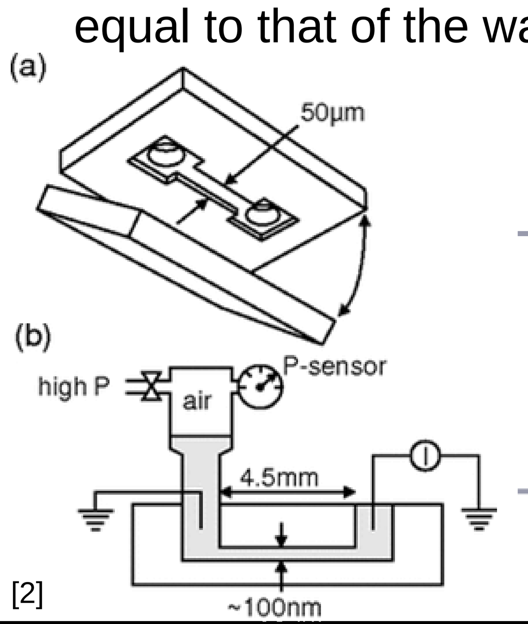
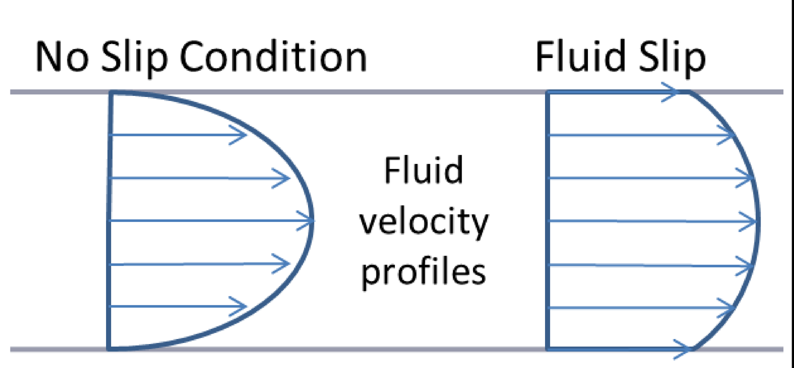
Objectives

- Conduct case studies to assess the feasibility of nanofluidic pressure-to-potential (nanoP2P) converters for real-world applications
- Design and construct a sealed testing system for nanofluidic devices
- Test reliability of the system with various micro- and nanofluidic devices

Background Information

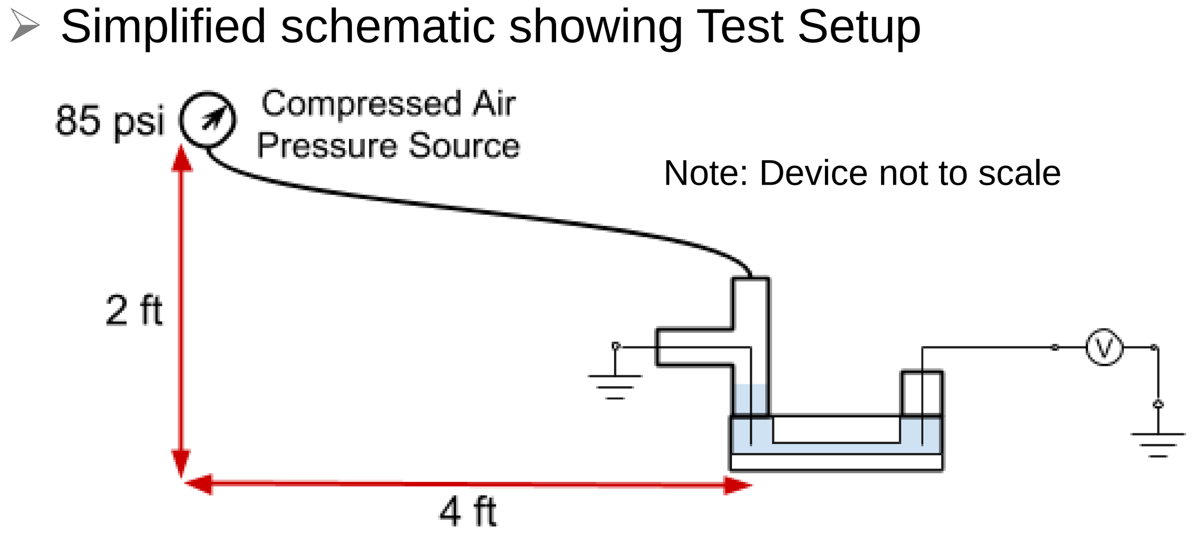
- In 2013, the United States generated 4 trillion kilowatt-hours of electricity, 67% coming from fossil fuels [1].
- A nanoP2P converter utilizes pressure-driven flow of an ionic solution through a nanochannel or bank of nanochannels to generate a streaming potential [2].
- A nanochannel is defined as a conduit for passage of fluid with at least one dimension characteristic to the flow in the 1–100 nm range [3].
- The generated streaming potential can be collected and used to perform electrical work.
- Fluid slip and surface charge density of the substrate enhance the power conversion efficiency of the device.
- Fluid slip occurs when the velocity of the fluid is not equal to that of the wall at the boundary.





Approach

- Two Case Studies Analyzed:
  1. LED Lighting
     - Incandescent halogen bulbs are being replaced by brighter and more efficient LED bulbs throughout US cities [5]
     - A nanoP2P converter could collect pressure from cars moving through intersections
     - Streaming potential could be used to power traffic and/or street lights
  2. Personal Devices
     - A nanoP2P converter could be embedded in a shoe to collect pressure from walking and running
     - Streaming potential could be used to power mobile devices
- Simplified schematic showing Test Setup

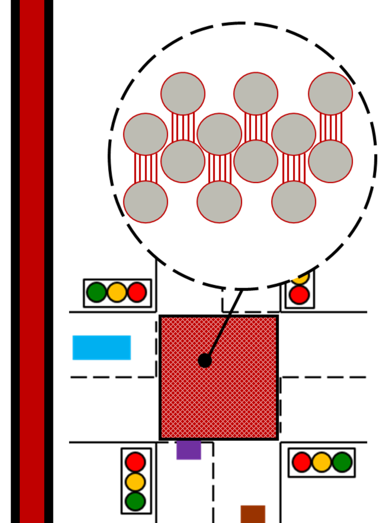


Case Study Analysis

LED Lighting

- Estimated 300,000 traffic lights and 26 million street lights in the US [4,5]
- Assume each traffic light has equivalent of one 15 W LED bulb lit 24/7, consuming **131 kW-hr** annually
- Assume each street light has one 25 W LED bulb lit 4100 hours per year, consuming **102.5 kW-hr** annually

Our Device



- Consider a 16.25 m wide square intersection with **12 traffic lights,** consuming **1,572 kW-hr** annually
- Each device collects **590 psi** from moving cars on average
- Fluid slip increases flow rate and power generation

Traffic Lights — No Slip

ε	Consumption of 12 Traffic Lights (kW-hr/yr)	Power Output of Devices (kW-hr/yr)	% Light Consumption
30%	1572	2.85	0.18
50%	1572	4.75	0.30
70%	1572	6.65	0.42

Traffic Lights — Slip

ε	Consumption of 12 Traffic Lights (kW-hr/yr)	Power Output of Devices (kW-hr/yr)	% Light Consumption
30%	1572	19.95	1.27
50%	1572	33.24	2.12
70%	1572	46.54	2.96

Street Lights — No Slip

ε	Consumption of 1 LED Street Light (kW-hr/yr)	Power Output of Devices (kW-hr/yr)	% Light Consumption
30%	102.5	2.85	2.78
50%	102.5	4.75	4.63
70%	102.5	6.65	6.50

Street Lights — Slip

ε	Consumption of 1 LED Street Light (kW-hr/yr)	Power Output of Devices (kW-hr/yr)	% Light Consumption
30%	102.5	19.95	19.46
50%	102.5	33.24	32.43
70%	102.5	46.54	45.40

Walking

ε	Consumption per Smart Phone (kW-hr/yr)	Power Output per Person (kW-hr/yr)	% Phone Consumption
30%	4.9	3.2×10^{-8}	0.66×10^{-6}
50%	4.9	5.4×10^{-8}	1.1×10^{-6}
70%	4.9	7.5×10^{-8}	1.5×10^{-6}

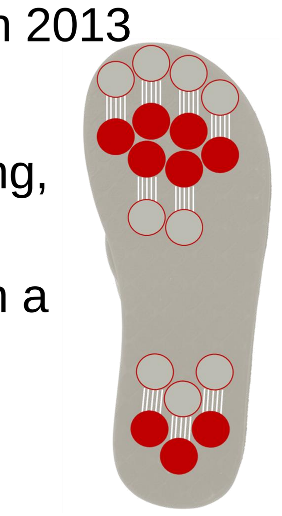
Running

ε	Consumption per Smart Phone (kW-hr/yr)	Power Output per Person (kW-hr/yr)	% Phone Consumption
30%	4.9	3.0×10^{-7}	0.62×10^{-5}
50%	4.9	5.0×10^{-7}	1.0×10^{-5}
70%	4.9	7.0×10^{-7}	1.44×10^{-5}

Personal Devices

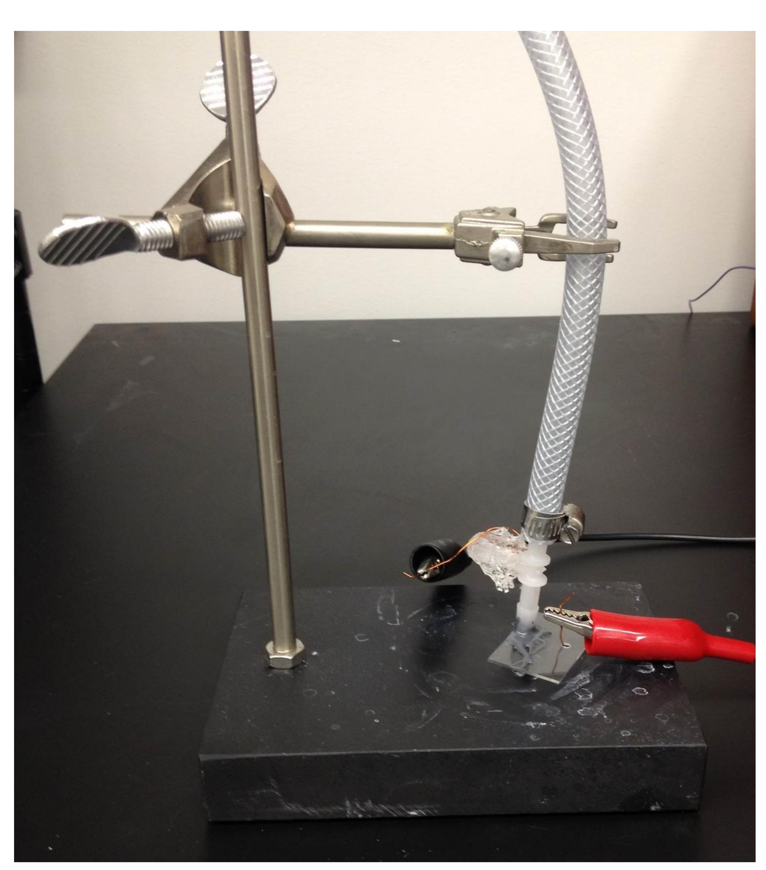
- Estimated 144.5 million smart phones in the US in 2013 [6]
- Each phone consumes about **4.9 kW-hr** annually from charging [6]
- Equaling ~0.018% of the electricity generated in 2013

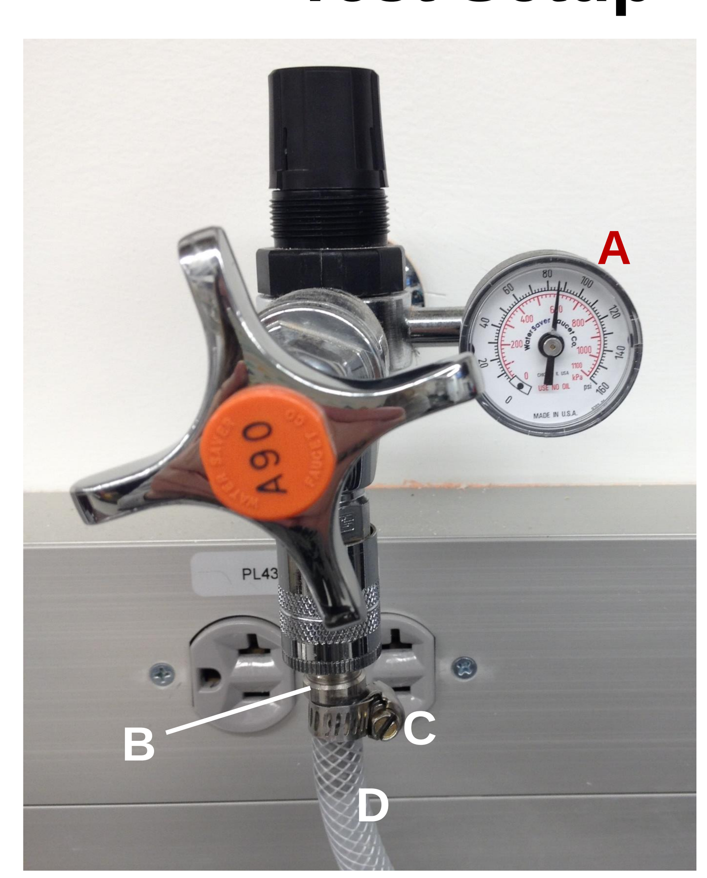
Our Device

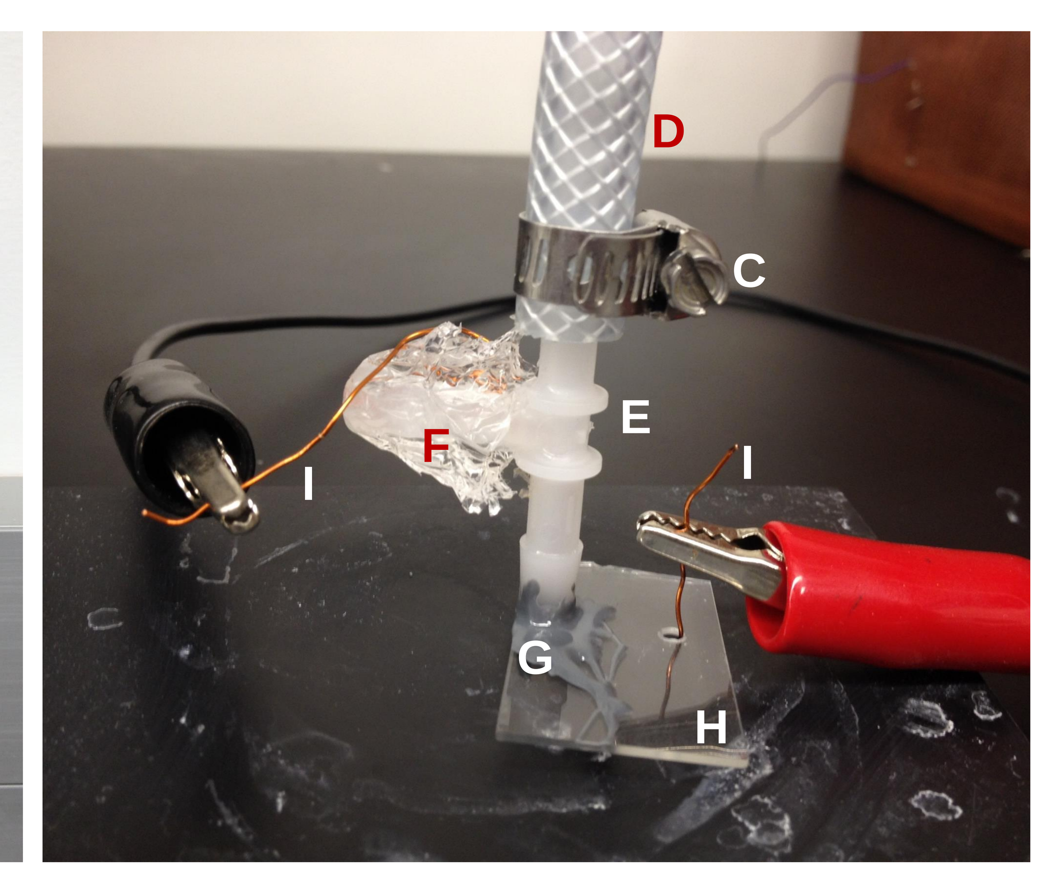


- Collect **72 psi** from the average adult walking, **144 psi** from running
- Pressure applied over the devices embedded in a running shoe
- Running generates more power than walking

Test Setup





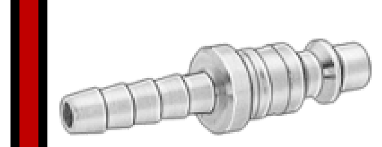


Compressed air at 85 psi is applied to the input reservoir and forces an ionic solution through the nanochannel or bank of nanochannels in the device. A pressure of 85 psi was selected to stay consistent with existing research in this field. The streaming potential, or voltage generated in the device, is measured across the channel. Data representing the relationship between pressure and potential will be presented in my defense.

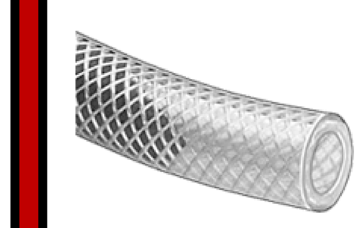
A. Compressed Air, 85 psi
B. Hose Coupling
C. Hose Clamp
D. Tubing, ID of ¼"
E. T-Connector
F. PDMS Plug
G. Double Bubble Epoxy
H. NanoP2P Device
I. Copper Wire

Test Setup Components

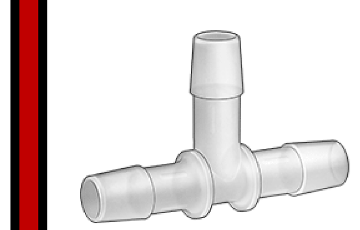
Leak-Free Connections



Stainless Steel Hose Coupling
- Max Pressure: 300 psi



High-Pressure Tygon PVC Tubing
- Max Pressure: 250 psi
- ID: ¼"



White PVDF Barbed Tube Fitting
- Max Pressure: 150 psi

Leak-Free Sealants

Breeze Mini Hose Clamps
- Secure pipe to connector at various joints

Polydimethylsiloxane (PDMS)
- Seal arm of T-connector with lead wire

Double-Bubble Epoxy, Orange Package
- Seal T-connector to device input reservoir
- Tensile Strength: 250 psi

Conclusions

- It is not feasible to pursue nanoP2P converters for charging personal devices
- NanoP2P converters are theoretically feasible for street lighting
- Connections are leak-free as tested with bubbles, will collect streaming potential data

References

[1] Unites States. Energy Information Administration. Independent Statistics and Analysis. *Total Energy Overview*. By EIA. N.p., 2014.

[2] Olthuis *et al*. "Energy from Streaming Current and Potential." *Sensors and Actuators B: Chemical* 111-112 (2005): 385-89.

[3] Li, Deyu. "Nanochannel Fabrication." *Encyclopedia of Microfluidics and Nanofluidics* (2008): 1409-414. *Springer US*.

[4] Greentech Efficiency, *"Cree Launches $99 LED Street Light"*

[5] Howstuffworks, *"Why are they replacing all of the traffic lights in my town"*

[6] Statista, *"Number of smartphone users in the U.S. from 2010 to 2018"*

Further Information

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