Using Dielectrophoresis to Separate Silicon Nanowires Based on Their Electronic Properties

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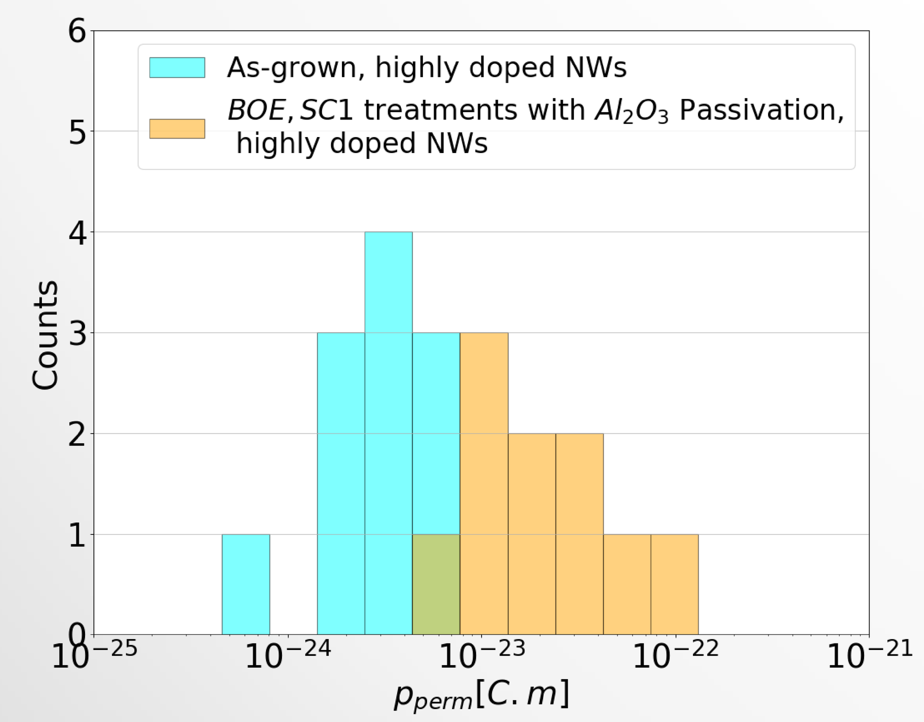
Abstract

Silicon nanowires are on the forefront of technology as their relatively easy manufacturing process allows electronic devices to be grown in labs, without the need for billion-dollar semiconductor fabs. In this work, we will focus on PN diode nanowires, which are one of the simplest complete nanodevices. From previous experiments we have confirmed that PN nanowires grown from the same batch show significantly different electrical conductivities and permanent dipoles, largely due to variation in surface quality. Because of the permanent dipole formed by opposite charges at the PN junction, as well as the induced dipole formed by nanowire polarization under external fields, each wire will experience different dielectrophoretic (DEP) forces when subjected to a spatially non-uniform electric field. Thus, by introducing the electric field inside a microchannel, we can flow fractionate dispersions of Si PN wires based on their electrical properties. We are fabricating microfluidic channels by sandwiching glass and plastic slides with an array of electrodes on one side. By applying a direct current (DC) electric field, the nanowire diodes can be separated by the strength of their permanent dipole, while an alternating current (AC) field will separate nanowires by their conductivity. We provide a proof-of-concept demonstration of the ability to separate the wires by their electronic properties and "filter" them for the best performance.

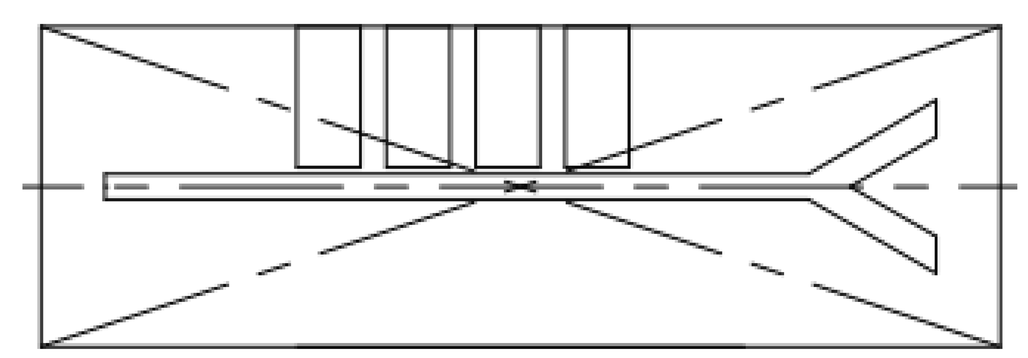
Background

- Semiconducting nanowires have a great potential in many different applications such as nanoelectronics, photovoltaics, photocatalysis, energy, etc.
- Nanowires grown from the same substrate can have a high variability in surface quality, which leads to variations in electrical/electronics properties.
- Our aim is to separate hundreds of nanowires into different subgroups that have the same electrical properties, using field-flow fractionation. The process can be very fast, high-throughput and useful for future applications.



Materials and Methods

Nanowire separation is achieved using a microchannel, electrodes, and a syringe pump. The nanowires are suspended in a conductive mineral oil solution that is pumped into the microchannel. The channel has one inlet and two outlets and can be seen below. The electrodes on the walls of the channel apply a DC or AC electric field.

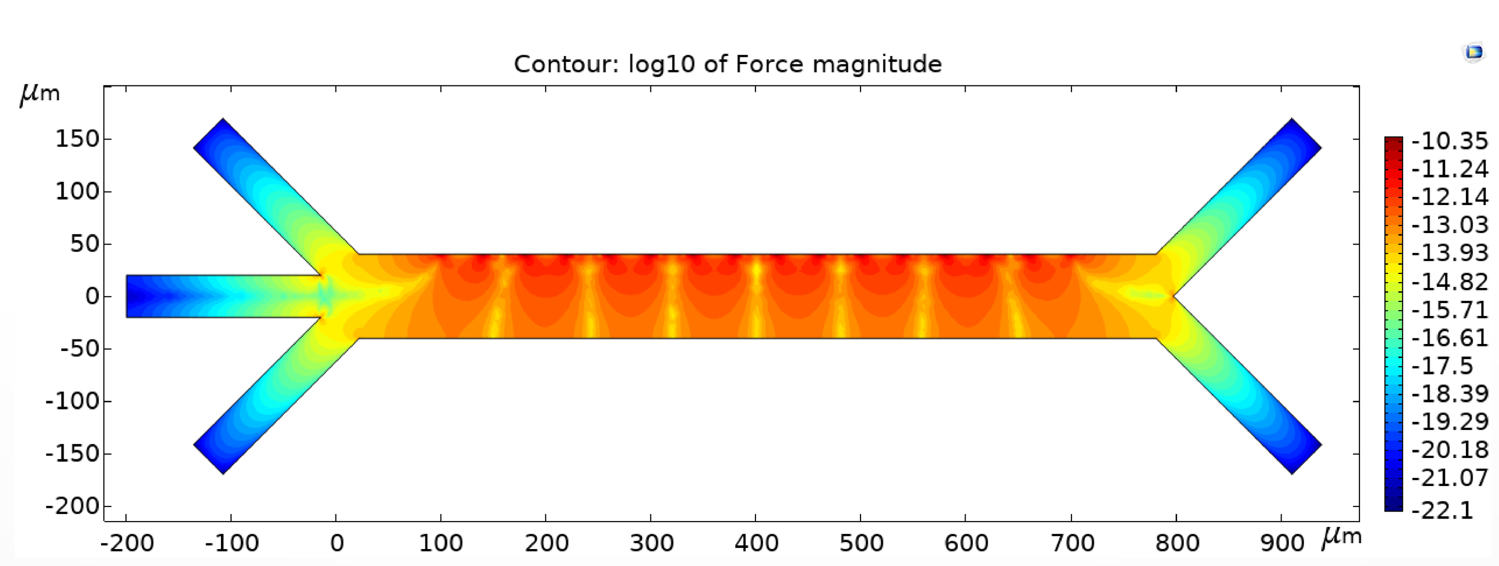


The fields are non-uniform and create a gradient which is pertinent to achieve dielectrophoresis. Dielectrophoresis is when the wires experience a force due to the non-uniform electric field. The equation below is the dielectrophoretic force. P_{perm} is the permanent dipole and β is the polarizability. When separating by electrical conductivity, the gradient needs to be large as the dielectrophoretic force goes with the square of the gradient. Also when applying an AC field, the second term is related to the conductivity of the wire.

$$F_{dep} = P_{perm}{}^{\Delta E} + \beta\Delta_{E}{}^{2}$$

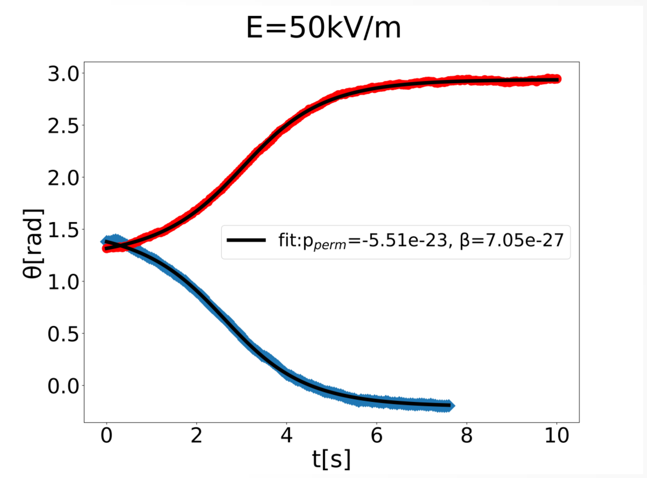
The wires of with higher polarizability are drawn to the electrodes whereas the wires with the weaker polarizability stay in the center of the channel. Once the wires reach the end of the channel, the ones that were attracted to the electrode will exit via one outlet and the others will exit the other.

To optimize the performance of the experiment, we are creating a simulation of the channel in COMSOL. COMSOL allows us to recreate the conditions the channel will experience when we apply the field. By doing this we can optimize the electric field orientation for the strongest DEP force.



Results

- Being able to measure the P_{perm} of wires allows for verification of the separation of the technique
- The channel has been tested by being sandwiched between a glass slide and plastic slide with different electrode configurations
- Once more results are available we can collect the wires at the outlets and measure the properties for verification



Conclusion

Our progress has been slowed down due to COVID-19 but we are still making strides to continue the research. We are moving to working on simulations that can be done remotely so once we are back in the labs we can advance the experiments. Separating silicon nanowires in this fashion has not been done before and we believe this procedure can be used in the engineering industry to selectively categorize nanowires based on electrical properties. By creating more coherent batches of wires we can create more precise nanodevices that can be used in cutting edge technology.

Future Direction

- Through more experimentation and collecting more results, we believe that we can fine-tune our process to make it more efficient.
- After finishing simulations we can create the most effective field inside of the channel
- We can also improve the specificity of separation that we wish to achieve.

Acknowledgments

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