Modeling of Directional Dependence in Nanowire Flow Sensor

A. Piyadasa[1,3] , P. Gao[1,2,3]

1. Department of Physics, University of Connecticut, Storrs, CT, USA

2. Department of Materials Science & Engineering, University of Connecticut, Storrs, CT, USA

3. Institute of Materials Sciences, University of Connecticut, Storrs, CT, USA

Introduction: Developing a reliable and robust micro scale gas flow sensor has proven to be an important requirement for future micro- and nano-electromechanical devices. Current study is focused on modeling a novel form of multi-directional gas flow sensor which is designed by utilizing a Si nanowire array and its piezoresistive properties to change conductivity upon flow pressure on the sensor material. Finite element analysis (FEA) model constructed using COMSOL Multiphysics® software has been used for modeling piezoresistive phenomena in the nanowire array. Figure-1 shows the nanowire array gas flow sensor with gas flowing through the channel.

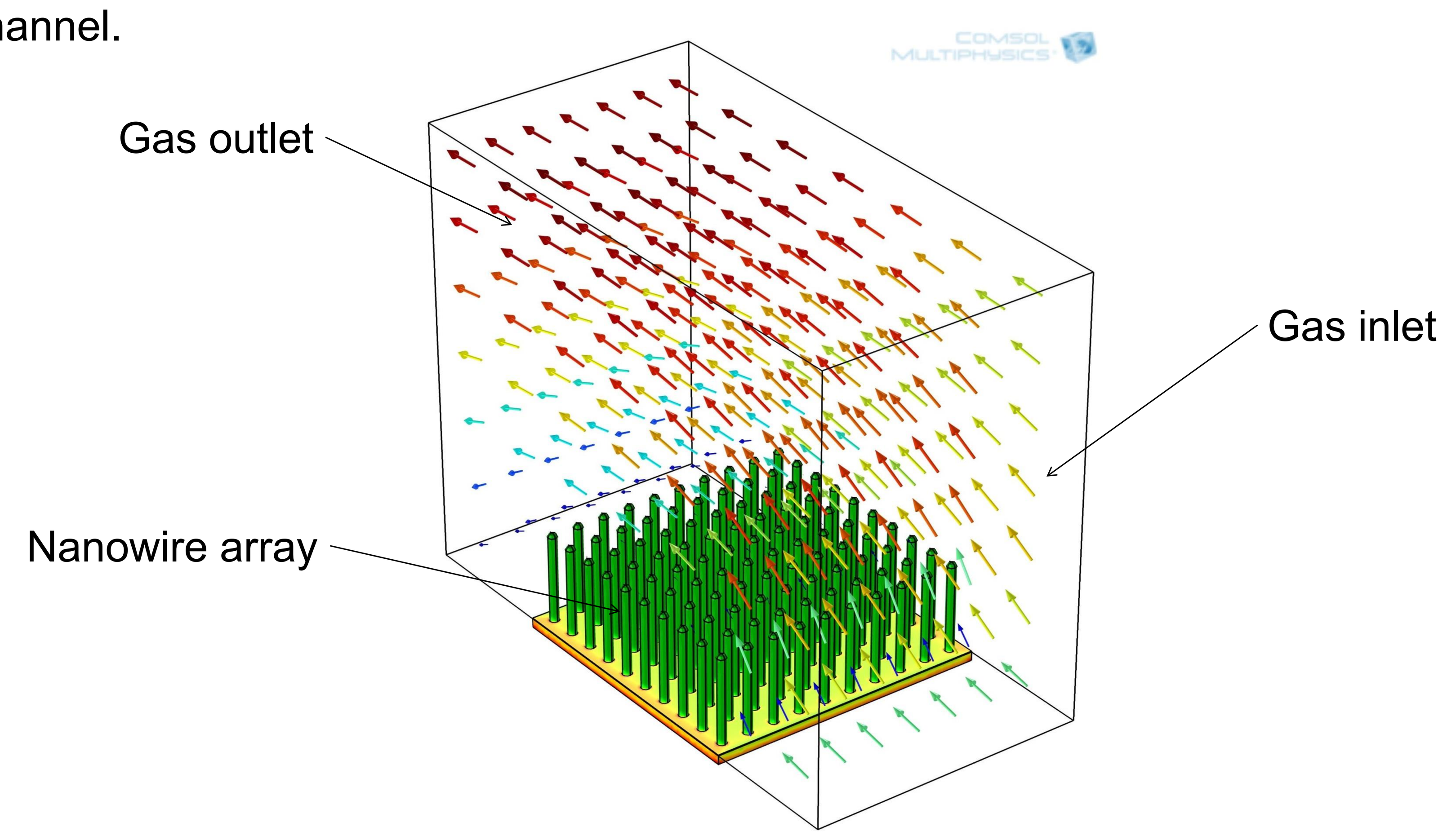


Figure 1. Nanowire flow sensor

Computational Methods: Single nanowire model (Figure 2) has been constructed using COMSOL Multiphysics® to test the piezoresistive phenomena and its directional dependence in the nanowire array. Constructed model consists of three types of physics coupled together, fluid flow and structural mechanics (Fluid Structure interaction) and piezoresistivity (MEMS module).

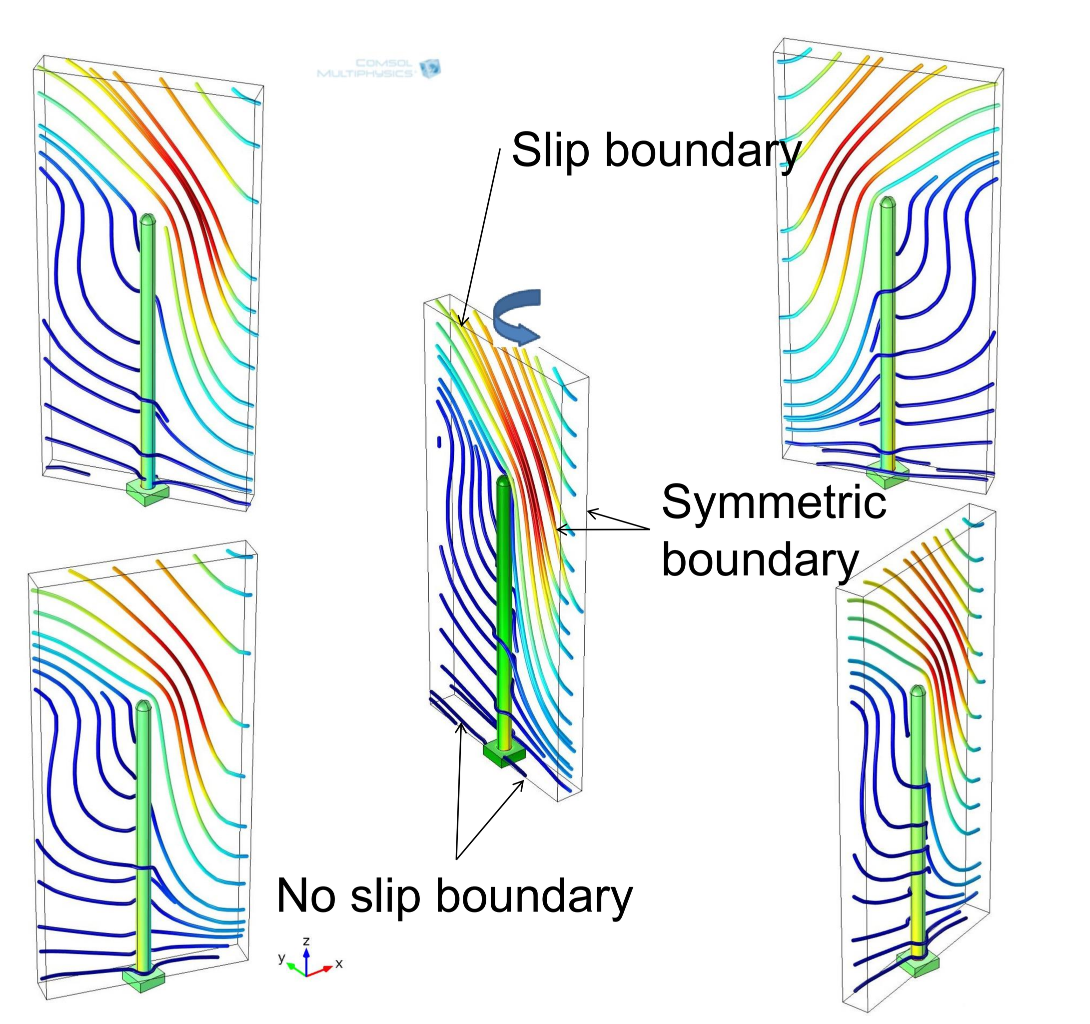
The fluid flow in the channel is described by the incompressible Navier-Stokes equations for the velocity field, u = (u, v), and the pressure, *p*

$$\rho\frac{\partial u}{\partial t} - \nabla\cdot[-pI + \eta(\nabla u + (\nabla u)^T)] + \rho\big((u - u_m)\cdot\nabla\big)u = F$$

$$-\nabla\cdot u = 0$$

The nanowire is fixed to the piezoresistive base (Figure 3) and all the other surfaces of the nanowire experience a load from the gas flow which is given by, (n is the normal vector to the boundary).

$$F_T = -n\cdot(-pI + \eta(\nabla u + (\nabla u)^T))$$



Parameter	Value
NW Length	8um
NW radius	200nm
Base thickness	300nm
Base side	800nm
Channel length	1.2um
Inlet velocity	0.05m/s
Input voltage	1E-6V

Figure 2. Single nanowire model and parameters

Electric field, E, and the current density, J, within a piezoresistor is:

$$E = \rho\cdot J + \Delta\rho\cdot J$$

where ρ is the resistivity and Δρ is the induced change in the resistivity which is related to the stress, σ and piezoresistive tensor Π by the constitutive relationship:

$$\Delta\rho = \Pi\cdot\sigma$$

For Silicon :

$$\begin{bmatrix}\Delta\rho_{xx}\\ \Delta\rho_{yy}\\ \Delta\rho_{zz}\\ \Delta\rho_{yz}\\ \Delta\rho_{xz}\\ \Delta\rho_{xy}\end{bmatrix} = \begin{bmatrix}6.6 & -1.1 & -1.1 & 0 & 0 & 0\\ -1.1 & 6.6 & -1.1 & 0 & 0 & 0\\ -1.1 & -1.1 & 6.6 & 0 & 0 & 0\\ 0 & 0 & 0 & 138.1 & 0 & 0\\ 0 & 0 & 0 & 0 & 138.1 & 0\\ 0 & 0 & 0 & 0 & 0 & 138.1\end{bmatrix} * 10^{-11} \times \begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{yz}\\ \sigma_{xz}\\ \sigma_{xy}\end{bmatrix}$$

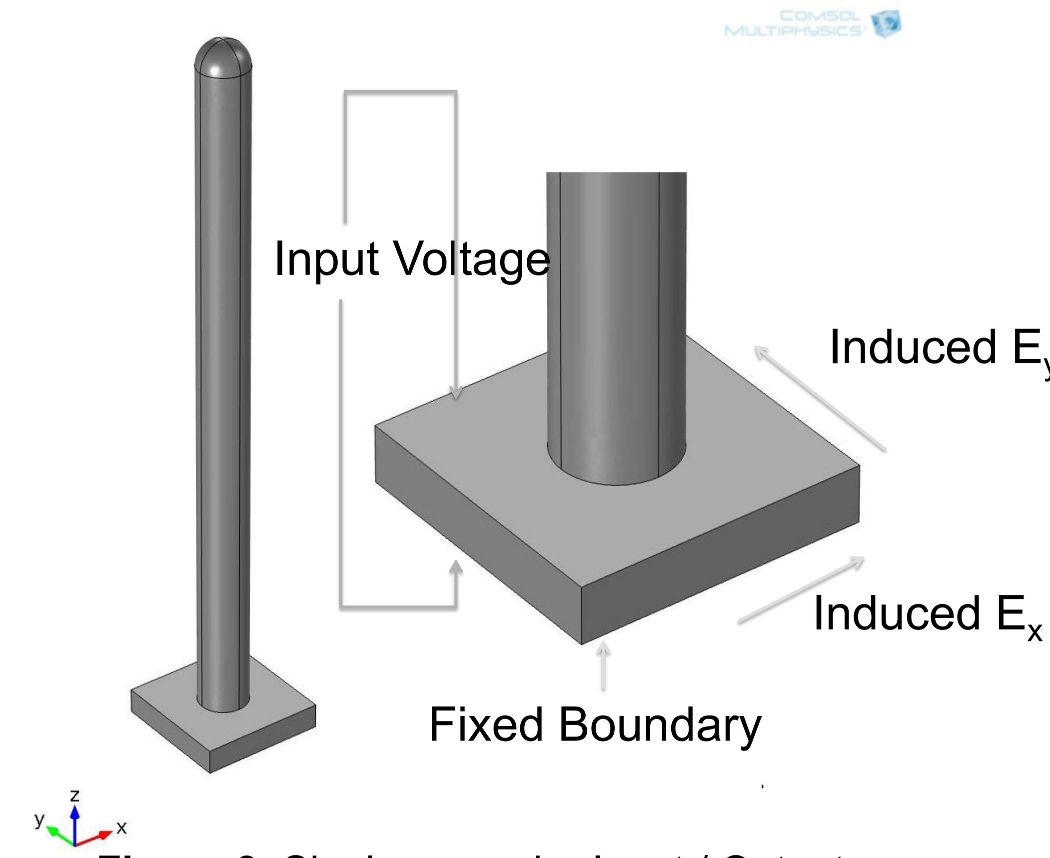


Figure 3. Single nanowire Input / Output

Induced voltage in nanowire base due to stress :

$$V_x = 138.1\times10^{-11}\times\sigma_{xz} \times\rho_0\times J_z\times X$$

$$V_y = 138.1\times10^{-11}\times\sigma_{yz} \times\rho_0\times J_z\times Y$$

$$V_z = (1 + (-1.1\cdot\sigma_{xx} - 1.1\cdot\sigma_{yy} + 6.6\cdot\sigma_{zz})\times10^{-11}) \times\rho_0\times J_z\times Z$$

Results: Average induced stress components σ_{xz} and σ_{yz} vs. flow direction is plotted in Figure 4 and change in resistivity components $\Delta\rho_{zy}$ and $\Delta\rho_{zx}$ vs. flow direction is plotted in Figure 5.

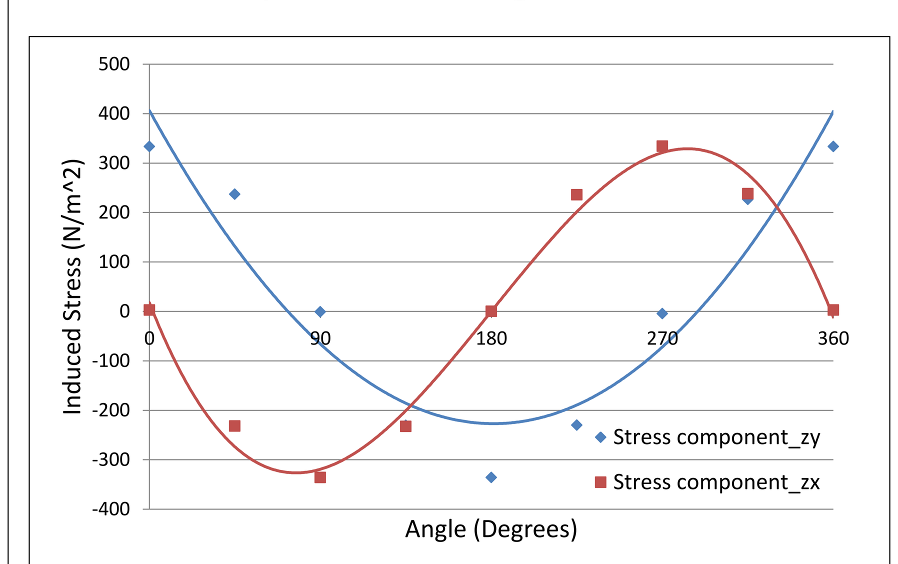


Figure 4. Induced stress vs. flow direction

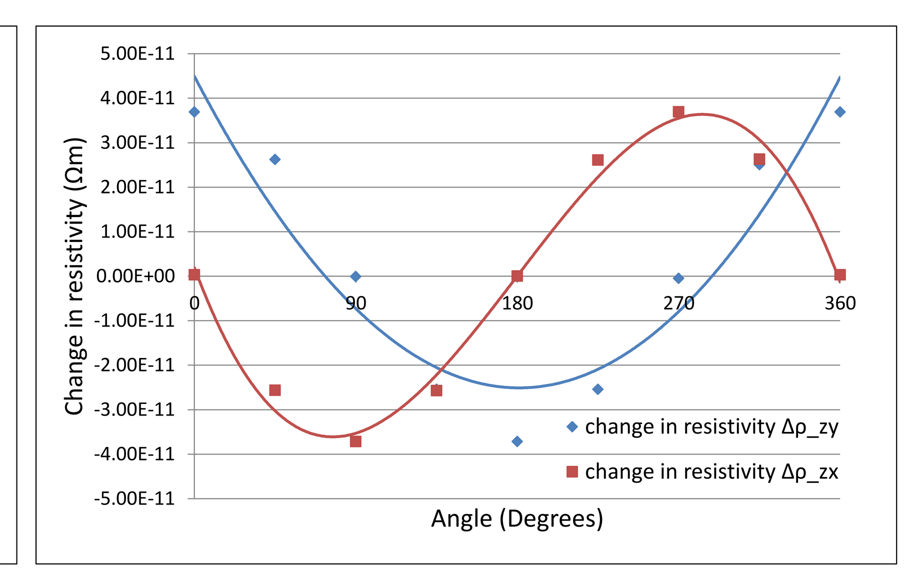


Figure 5. Resistivity change vs. flow direction

From Figure 6 it shows the change in induced electric field in the nanowire base with the varying flow direction in the channel.

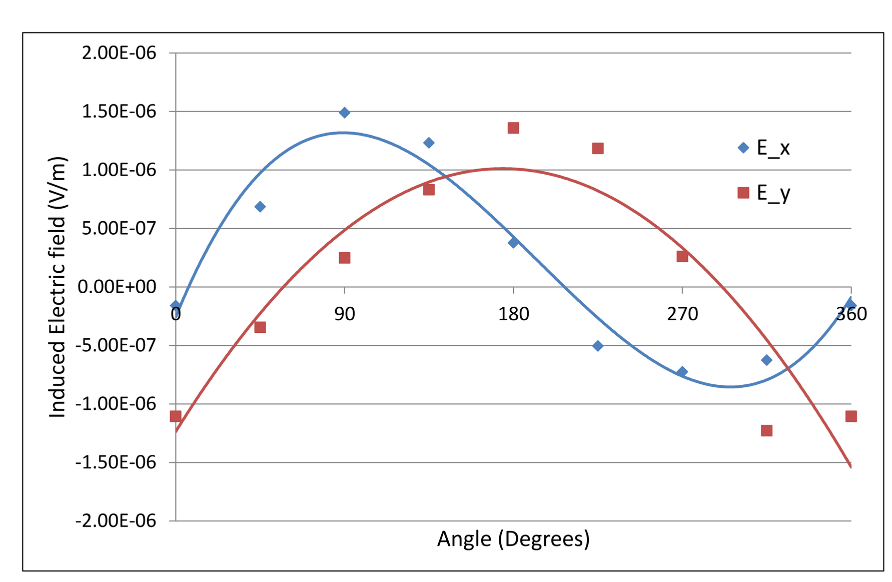


Figure 6. Induced electric field vs. Flow direction

Flow sensor can be used in determining the flow direction by analyzing the two voltage outputs from the sensor.

Flow in +y direction :- $E_x \approx 0$, $E_y \approx negative\ maximum$

Flow in - y direction :- $E_x \approx 0$, $E_y \approx positive\ maximum$

Flow in +x direction :- $E_y \approx 0$, $E_x \approx negative\ maximum$

Flow in - x direction :- $E_y \approx 0$, $E_x \approx positive\ maximum$

Conclusions: 3D model has been developed to test the directional dependence of nanowire gas flow sensor. Output of the nanowire flow sensor is directly proportional to the induced stress in the nanowire base. Average values of the stress components σ_{xz} and σ_{yz} varies with flow direction allowing the sensor to detect the gas flow direction inside the channel. Current results show that the anisotropic properties of the material can be successfully used in the gas flow sensor to differentiate flow components in different directions.

References:

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