# Characterization of Si-Nanowires for Biosensor Applications

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## Abstract and Introduction:

Silicon nanowire field effect transistors (Si NW FETs) are promising structures for the development of new biosensors due to their ability to directly translate interactions with target molecules into readable signals [1]. They are highly sensitive and selective and capable of real-time response and label-free detection. However there are challenges with stability and reproducibility in the development of such sensors due to the property changes over time of the thin gate dielectric when exposed to an electrolyte, low signal to noise ratio due to the small size of the NWs, and an increased role of surface effects.

In order to develop and to find the optimal dielectric passivation for Si NW sensors this project is focused on the investigation of the influence of an electrolyte liquid gate on the physical and electrical properties of the NW FETs covered with a thin silicon dioxide ($SiO_2$) passivation layer. Noise spectroscopy was employed to characterize the performance of the devices in the electrolyte and without it. This technique provides a number of advantages. Noise measurements allow for the determination of various kinetic parameters from experimental data gathered without time-varying external excitation.

In addition, data extracted from noise spectra contains information about structure performance, and quality of the samples, making noise spectroscopy a powerful tool for monitoring device state. Noise spectra were measured and analyzed for Si NW FETs of 500 nm width and a variety of lengths (2-16 $\mu$m) with a thin $SiO_2$ passivation layer (10 nm thickness) in air and phosphate buffered saline (PBS) at different liquid gate and back-gate voltages. Parameters of interest include the effects on threshold voltage and charging time of the device gate dielectric.

## Methods:

Drain voltage spectral density was measured for samples of varying nanowire length (2-16 $\mu$m) over a range of different applied back-gate voltages; first in air, then in PBS. A constant source-drain voltage of 100 mV was applied to the samples to ensure linear regime of operation. The noise spectra of the device were registered using a HP Spectra Analyzer after the output signal from the sample was passed through a low-noise

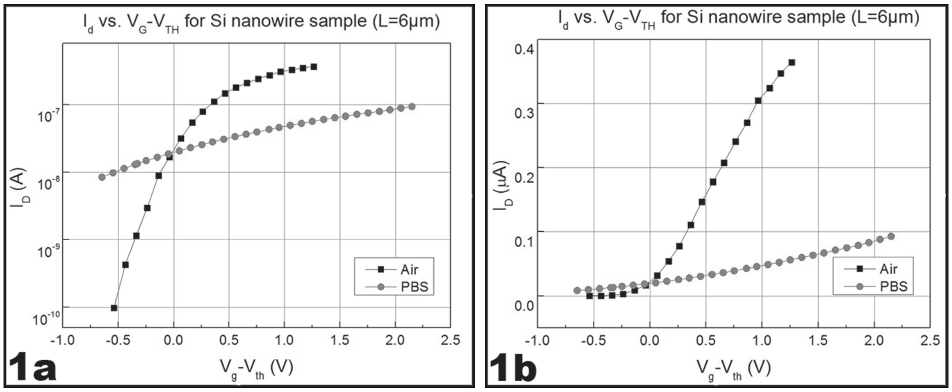

*Figure 1: Drain Current vs. $V_{GATE}$-$V_{THRESHOLD}$ for a 6 µm sample shown in (A) semi-log and (B) linear scale.*

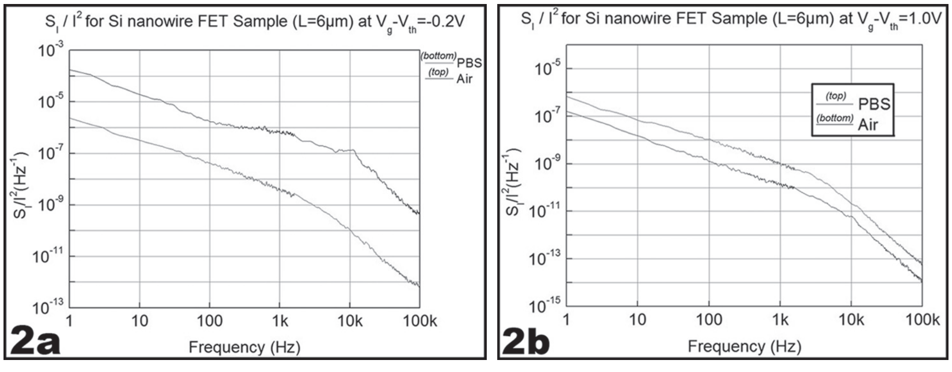

*Figure 2: Normalized Current Noise Spectral Density measured for a 6 µm sample in (A) the sub-threshold region and (B) above threshold voltage region.*

homemade amplifier with gain 100 dB. A custom program was designed to measure the drain current and spectra data. This data was then analyzed using OriginLab software to determine the effects of PBS on threshold voltage and the noise spectra. The current spectral density, $S_I$, was calculated using the measured voltage spectral density and the equivalent resistance of the measurement scheme.

## Results and Discussion:

The first parameter of interest of our device was the effects that PBS had on the samples' threshold voltages. Drain current in the samples was measured over a range of backgate voltages, and the transfer characteristics of the FETs were then plotted. Threshold voltage was calculated by applying a best fit approximation to the linear region of the curves. Figure 1 shows typical transfer characteristics measured for a sample of length 6 $\mu$m in (A) semi-log and (B) linear scales. From Figure 1A, it can be seen that the addition of PBS affects the sub-threshold current of the sample, and thus facilitates exchange between interface traps of the top dielectric with the channel of the Si NW FET in the sub-threshold region. Therefore, the interaction of the electrolyte with the nanowire FET structures results in changes of the state of the interface traps. Also, an increase in threshold voltage is registered when the sample is exposed to PBS, indicating a change in surface charge of the NW transistor.

Figure 2 shows normalized current spectral density, $S_I / I^2$, at (A) sub-threshold backgate voltage, $V_{bg} - V_{TH} = -0.2V$ and (B) above threshold voltage, $V_{bg} - V_{TH} = 1.0V$, measured in air and PBS. In the sub-threshold region, the normalized current spectral density of fluctuations in the device decreased when PBS was introduced to the sample. This decrease can be explained by the changing of the surface charge due to PBS and thus the charge state of traps in the sample's top dielectric and partly by increases in the sub-threshold current without a corresponding increase of the noise (Figure 1A).

Above the threshold voltage, submerging the sample in PBS appears to increase the amount of fluctuations in the sample. The lower value of the current at $V_{bg} - V_{TH} = 1.0V$ in PBS (see Figure 1B) only partially explains this behavior. If change in the number of charge carriers was the only cause, then the ratio of currents in air to PBS and the ratio of $S_I / I^2$ in PBS to air would be similar.

Figure 1B shows that the current in air is three times higher than the current in PBS at this voltage. However, $S_I / I^2$ at 100 Hz, is ten times greater in PBS than in air. Thus, the change in number of carriers is not the only factor influencing the change in noise level. We suggest that another component of this variation is a change in the mobility of the charge carriers due to a change in the behavior of the traps at the interface between the semiconductor and the top dielectric caused by the PBS.

## Conclusions and Future Directions:

It was shown that the exposing the nanowire samples to PBS not only affects the number of charge carriers, but also most likely results in a change in mobility of charge carriers. Further experiments need to be done to determine what other factors affect the stability and reliability of the samples working with the liquid gate. The next step will be to compare the properties of the Si NW FET samples passivated with different thin film dielectric layers in air and in PBS. Measurements will also be performed after exposing the samples to cell media for the development of neuron-nanowire FET hybrid structures.

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## References:

[1] "Silicon nanowire field-effect transistor-based biosensors for biomedical diagnosis and cellular recording investigation"; Chen, K; Li, B; Chen, Y; Nanotoday (2011) 6, 131-154.