# **Supporting Information**

# Tin Oxide Nanowire Sensor with

# Integrated Temperature and Gate Control

# for Multi-Gas Recognition

Eric N. Dattoli, \* Albert V. Davydov, and Kurt D. Benkstein

Material Measurement Laboratory, National Institute of Standards and Technology (NIST), 100

Bureau Drive, MS 8362 Gaithersburg, MD 20899-8362

\* eric.dattoli@nist.gov

Nanowire Material Characterization



**Figure S1.** X-ray diffraction (XRD)  $\omega$ -2 $\theta$  scan of SnO<sub>2</sub> nanowires grown on Si (100) substrate. All indices correspond to the tetragonal tin oxide phase (P42/*mnm*; PDF#88-0287) with lattice parameters *a*, *b* = 0.4737 nm and *c* = 0.3186 nm.



**Figure S2.** Scanning electron microscopy (SEM) image of  $SnO_2$  nanowire (a) with corresponding Electron Backscatter Diffraction (EBSD) patterns for  $SnO_2$  (b) and for the Au cap (c). The simulated crystallographic orientations of the  $SnO_2$  and Au unit cells are shown in insets. According to the EBSD indexing, the NW is elongated along the [101] axis, which is consistent with previous reports on similarly grown  $SnO_2$  nanowires.<sup>1</sup>



**Figure S3.** Optical Image of a NW-Sensor Device on a Suspended Membrane. Note that the device shown in this figure was fabricated under comparable conditions (in the same batch) as the device detailed in the main text. That specific device was not used for imaging since it suffered membrane cracking during additional testing that was conducted following the sensor experiment detailed in this work. Also note that the color gradient (red to green) that is visible on the outer areas of the membrane is believed to be a result of thickness non-uniformities in the upper spin-on-glass layer. Additionally, a few particulates are visible on the surface of the membrane, which are likely silicates that stuck onto the membrane surface during the KOH etching procedure. These particulates were not present in the central sensor area for the devices examined in this work and are not believed to have affected sensing results.

# Microhotplate Thermal/Electric Simulation

A three-dimensional thermal-electric finite element simulation of the membrane microhotplate/sensor structure (as displayed in Figure 1c) was performed using Ansys 12.0.1.\* As noted in the text, the simulation was performed to gain insight into the temperature distribution at the surface of the microhotplate during typical operating conditions. Due to uncertainty in the thermal characteristics of the utilized spin-on-glass (SOG) layer and the effect of unaccounted for parasitic resistances, the included simulation results are meant to be an estimate, not a perfectly matched model, of the heating characteristics of the tested microhotplate device.



Figure S4. Schematic of Tested Microhotplate / Nanowire Sensor Device

Specifically, a steady-state thermal/electric simulation was performed. The geometric design of the simulated structure was chosen to closely match the tested device's fabrication parameters. An exploded view of the fabricated structure is shown in Figure S1 and a detailed list of fabrication parameters is included below.

Device Stack Information:

- The sensor itself comprised an electrode pair serving as top contacts to bridging  $SnO_2$  nanowires. The nanowires were neglected in the thermal simulation. The electrodes consisted of a 20 nm Ti / 200 nm Pt film. The electrode layer was simplified to a single 200 nm thick Pt film in the simulation.
- Sandwiched between the sensor and the heater layer were insulating layers of Spin-on-Glass (SOG) and SiN<sub>x</sub>. The SOG layer was 160 nm thick and was utilized as a planarizing and adhesion layer. The SiN<sub>x</sub> layer was 300 nm thick.
- The Pt meander heater structure consisted of a 20 nm Ta / 200 nm Pt stack, this layer was simplified to a 200 nm thick Pt film in the simulation.
- The bottom nitride membrane (closest to the underlying Si substrate) consisted of a 300 nm thick SiN<sub>x</sub> layer.

The simulation included modeling of the following physical effects:

- Heat generation via Joule heating of the embedded platinum thin-film serpentine heater.
- Heat losses by conduction through the nitride membrane and platinum thin-film into the silicon substrate surrounding the nitride membrane
- Heat loss by convection to the surrounding air environment. Convection coefficients for a typical air medium were approximated to be 125 W/(m<sup>2</sup>·K) and 60 W/(m<sup>2</sup>·K) for the top and bottom membrane surfaces, respectively, according to simulations previously carried out on a similar microhotplate structure in ref. 3.

The temperature-dependent values for the platinum material properties, specifically thermal conductivity and resistance, were obtained from experimental studies of similarly deposited platinum films.<sup>2</sup> The TCR for platinum utilized from ref. 2 was 2.0 x  $10^{-3} \Omega/(\Omega \cdot K)$ . The silicon nitride thermal conductivity was assigned as 6.4 W·(m·K)<sup>-1</sup> as determined from prior studies.<sup>3</sup> The temperature of the microhotplate silicon frame was fixed at 23 °C. Since the thermal conductivity of the 160 nm thick spin-on-glass layer was not known to us, it was estimated as 2.0 W·(m·K)<sup>-1</sup>, which is in the range of other glasses.<sup>4</sup>

Simulation Details:

- 9361 elements
- Sparse matrix direct solver

### Thermal Simulation vs. Experimental Results

Parameter	Simulation Result	Experimental Result
Applied Power	14.7 mW	24.3 mW *
Temperature of Heater Area	264 °C to 332 °C	average of 300 °C over entire heater area

\* Note about power consumption of the fabricated heater:

The cited value for the actual heater power consumption includes the power consumed by the two Pt electrodes that are used to bias the central serpentine heater (these electrodes are visible in Figure S3). Based off of geometric considerations, these Pt lines are estimated to account for  $\approx$  20  $\Omega$  of the 90  $\Omega$  total room-temperature heater resistance. The simulation did not model the effect of this parasitic resistance and thus underestimates the actual heater power consumption.

Although the power consumption of the microhotplate was not modeled in its entirety, i.e., including the consumption by parasitic resistances, this deficiency in the simulation was not believed to affect the accuracy of the predicted thermal profile at the surface of the microhotplate. This thermal profile is primarily determined by convection and conduction heat losses that were believed to be modeled accurately in this simulation.



#### Nanowire Diameter Distribution in Sensor Device

**Figure S5.** Diameter Distribution of Nanowires Employed by Sensor. A total of 23 nanowires were found to bridge the sensing electrodes. Their diameters were measured by scanning electron microscopy (SEM) imaging. The mean and standard deviation of the distribution were 51.4 nm and 21.3 nm, respectively.



# Response of the Sensor when Operating at Fixed Conditions

**Figure S6.** Response of the Sensor to Stepped Ethanol Exposures at a Fixed Operating Condition,  $V_{gs} = 0$  V and  $T_{heater} = 245$  °C. The sensor was operated in a dry air background for this measurement. Note, these plots consist of raw measurements; no signal processing or extraction was performed in preparation of this figure.



Transient Response of the NW Sensor to Step-Changes in Temperature or Gate Bias

**Figure S7.** Transient Sensor Conductance Behavior in response to Operating Condition Changes. (a) Conductance of the sensor while  $T_{\text{heater}}$  is stepped through the range of operating temperatures and  $V_{\text{gs}}$  is fixed at 0 V. (b) Response of the sensor as a result of stepped changes to  $V_{\text{gs}}$ , when the operating temperature was fixed,  $T_{\text{heater}} = 373$  °C. The sensor was operated in a dry air background for both measurements. Note, these plots consist of raw measurements; no signal processing or extraction was performed in preparation of this figure.

The conductance of the NW sensor was observed to respond in a transient manner in response to step-shaped changes in  $T_{\text{heater}}$  and  $V_{\text{gs}}$  conditions. Figure S7 displays conductance measurement traces when either  $T_{\text{heater}}$  or  $V_{\text{gs}}$  were individually varied while the other parameter was held fixed. Although the figure only displays conductance transients for two fixed conditions ( $V_{\text{gs}} = 0$  V and  $T_{\text{heater}} = 373 \text{ °C}$ ) similar transient behavior was observed for the entire range of sensor operating conditions, i.e.,  $V_{\text{gs}} = -5$  V to 5 V and  $T_{\text{heater}} = 192 \text{ °C}$  to 373 °C.

The transient nature of the sensor's response in both cases has been described as a result of slow changes (occurring on the time scale of seconds, minutes) in the concentration of adsorbates at the surface of the MOX material.<sup>5-6</sup> Additionally, changes in the bulk oxygen vacancy concentration of MOX materials have been suggested to play a role.<sup>7</sup>

With respect to temperature modulation, it is important to note that the microhotplate was expected to possess fast thermal characteristics as a result of its low thermal mass. Thermal transient studies on similar microhotplate devices have characterized these thermal transients to be on the order of  $\approx 5$  ms.<sup>8</sup>

# Analyte Recognition Statistical Analysis Technique

#### (a) Signal Extraction and Preprocessing Procedure



#### (b) Pattern Training/ Recognition Analysis



**Figure S8.** Procedural Data Flow Charts Displaying an Overview of the Signal Extraction / Preprocessing and Pattern Training/Recognition Techniques.

# Mitigation of Sensor Drift in the Pattern Recognition Procedure

A noticeable amount of drift in the sensor baseline conductance level occurred during the tens of hours long analyte exposure/recognition test, see Figure 2. Such drift has been observed over comparable time scales in other SnO<sub>2</sub> nanowire sensors.<sup>10</sup> In order to mitigate the effect of this drift in the pattern recognition procedure, rescaling of the sensor conductance measurements was carried out in the procedure's Preprocessing stage, see Figure S8a. In particular, two rescaling procedures were used, range scaling followed by mean centering. Similar drift correction techniques have been used in previous studies of chemiresistive sensors and are detailed below.<sup>11</sup>

$$x_{i}^{(k)} = x_{i}^{(k)} - \text{mean}[x_{i}] \qquad \text{mean centering}$$
(S1)  
$$x_{i}^{(k)} = \frac{x_{i}^{(k)} - \min[x_{i}]}{\max[x_{i}] - \min[x_{i}]} \qquad \text{range scaling}$$
(S2)

where  $x^{(k)}$  denotes the conductance value of the sensor at operating condition *i* and at sample *k*.

Although the deleterious effect of drift on the pattern recognition procedure was successfully mitigated using these scaling procedures, a detailed examination of the sensor drift behavior is out of the scope of this paper due to the use of modulated operating conditions which makes analysis of this drift prohibitively complex.

# Linear Discriminant Analysis (LDA) - based Pattern Recognition Analysis Procedure

The analyte training/recognition stage of the sensor data analysis (Figure S8b) consisted of the use of a pattern recognition algorithm, linear discriminant analysis (LDA), followed by a classification algorithm, the *k*-nearest neighbor method.

However, to begin this stage of the analysis, an *n*-element subset of the extracted signals (where  $n \le 384$ ) was first selected. This set of extracted signals was chosen to serve as the input to LDAbased pattern recognition procedure. Specifically, this set of signals corresponded to measurements that were conducted at certain sensor operating conditions (i.e.,  $T_{\text{heater}}$ ,  $V_{\text{gs}}$ ) of interest and was chosen with the purpose of examining the effects of operating conditions on sensor selectivity. The recognition accuracies that were obtained from use of differently-chosen sets of signals in the recognition procedure are examined in the main text. LDA was used for purposes of calculating a transform of the training phase data such that the separation between data recorded during different analyte conditions was maximized and the variation between measurements of the same analyte condition was minimized. In mathematical terms, LDA finds a transform consisting of the eigenvectors of  $S_W^{-1}S_B$  where  $S_W$  and  $S_B$  are the within and between condition covariance matrices.<sup>9</sup>

Subsequently, classification analysis was carried out on LDA-transformed validation phase measurements using the non-parametric *k*-nearest neighbor method (k = 1). Similar recognition accuracies were obtained for *k* values ranging from 1 to 5; k = 1 was used for the sake of simplicity. Note that recognition of analyte concentration levels was not examined in this work. Moreover, measurements that occurred during modulation cycles that overlapped an analyte change event were omitted from the entire analysis.

# **Complete Recognition Results**

Analyte Predicted				
	Dry Air	Acetone	Ethanol	MEK
Analyte Exposed				
	0.996 (445)	0.002 (1)	0.002 (1)	0.000 (0)
Dry Air	· · · ·			
	0.000 (0)	1.000 (54)	0.000 (0)	0.000 (0)
Acetone				
	0.149 (7)	0.106 (5)	0.723 (34)	0.021 (1)
Ethanol				
	0.346 (18)	0.077 (4)	0.000 (0)	0.577 (30)
MEK	, , ,		. ,	, , , , , , , , , , , , , , , , , , ,

Table S1.	Confusion Matr	ix for Figure 3a	$V_{\rm gs} = 0  \rm V$	$T$ , $T_{\text{heater}} =$	192 °C to	373 °C
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Average Analyte Recognition Rate: 76.7 %,

Table S2.	Confusion Mat	ix for Figure 31	$V_{\rm gs} = -2.5$	V, 0 V and	$T_{\text{heater}} = 192 ^{\circ}\text{C} \text{ to}$	373 °C
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Analyte Predicted				
	Dry Air	Acetone	Ethanol	MEK
Analyte Exposed				
	0.996 (445)	0.002 (1)	0.000 (0)	0.002 (1)
Dry Air				
	0.000 (0)	0.981 (53)	0.000 (0)	0.019 (1)
Acetone				
	0.000 (0)	0.000 (0)	0.957 (45)	0.043 (2)
Ethanol				
	0.000 (0)	0.000 (0)	0.000 (0)	1.000 (52)
MEK				

Average Analyte Recognition Rate: 98.0 %,

The quantities contained in the above confusion matrices are fractions which represent the number of modulation cycles (76.8 s long subdivisions of the analyte exposure test) where a certain analyte was recognized per the number of modulation cycles where that analyte was exposed. The quantity in parenthesis is just the number of modulation cycles where that test gas was identified.

The quantity termed "Average Analyte Recognition Rate" is defined in this report as the mean of the recognition rates for Acetone, Ethanol, and MEK analytes with equal weighting given to each analyte; dry air only exposures are excluded from this quantity.

Sensor Measurements used in Training / Recognition Task							Rec	ognition Res	ults					
	$V_{gs}$ conditions (V) $T_{heater}$ conditions (°C)				$T_{\text{heater}}$ conditions (°C)									
-2.5, 0	-5 to 0	-2.5	0	2.5	-5 to 5	2.5, 5	192 to 373	219 to 350	245 to 309	280	192	Avg. Mahal. Dist.	Avg. Analyte Recog. Rate (%)	Total Recog. Rate (%)
>							$\succ$					7.81	98.0	99.2
	$\times$						$\succ$					7.93	94.1	98.0
		$\succ$					$\succ$					7.47	77.3	93.8
			$\succ$				$\succ$					4.74	76.7	93.8
				$\succ$			$\times$					4.27	55.1	87.7
					$\succ$		$\succ$					6.19	55.8	88.2
						$\succ$	$\ge$					4.46	37.8	81.0
$>\!$								$\succ$				6.44	92.1	97.8
$\ge$									$\ge$			5.70	85.1	95.8
$\geq$										$\succ$		5.22	69.4	92.0
$\ge$											$\succ$	4.44	38.3	79.7

# Table S3. Classification Results Depending on Sensor Conditions

The effect of differently chosen subsets on the obtained recognition accuracy was examined in separately run classification/recognition analyses. Such measurement subsets corresponded to different measurement conditions and certain conditions were shown in this work to be more useful for achieving higher recognition accuracies than others. The results of this analysis are contained in Table S3.

Table S3 was generated using the data processing and analyte recognition procedures already detailed in the main text, i.e., LDA data dimension reduction and 1-nearest neighbor classification methods. The utilized data for these rows are represented by checkmarks in the appropriate field. The means for determining the "Average Analyte Recognition Rate" were discussed in the preceding section. The "Total Recognition Rate" is defined as the mean of the recognition rates for all the analytes and additionally the dry air background exposures.

The column labeled "Avg. Mahal. Dist." contains the average Mahalanobis distance between the analyte clusters contained in the classification plots generated from validation phase data (i.e., Fig 3a,b). The value was generated using the method utilized in a similar gas sensor selectivity study.<sup>12</sup> The Mahalanobis distance is a special measure of distance which takes into account the variance between variables in a data set. It is used in this instance as a measure of cluster separability, i.e., how well similar analyte points are clustered together and how well different analyte points are separated in the classification plots. Cluster separability directly impacts the gas discrimination capability of a sensor system.

# Discussion of the Usefulness of Transient Sensor Signals for VOC Recognition Purposes

As is shown in Figure S7, the NW sensor responded in a transient manner to changes in both  $T_{\text{heater}}$  and  $V_{\text{gs}}$ . Sequential measurements were conducted, 200 ms apart, during sensor operation to capture these induced transient changes in the sensor conductance. In particular, four of these measurements were conducted during each 0.8 s long step in  $V_{\text{gs}}$ . Using the comparative analysis approach that is outlined in the main text, the usefulness of the 4 separate signals that were extracted from these sequential measurements at each  $V_{\text{gs}}$  step were evaluated in terms of the obtained VOC recognition accuracy. Results of this comparative analysis, shown in Figure S10, reveal that optimal VOC recognition was obtained using all 4 of the sequentially conducted measurements during each  $V_{\text{gs}}$  step.

From this result, we conclude that the transient sensor conductance changes of the sensor contained analyte-dependent information that assisted the VOC recognition analysis. Such conductance transients, as have previously been obtained due to temperature modulation, have been used for similar analyte discrimination purposes in at least one other report.<sup>5</sup>



**Figure S9.** Effect of utilized sensor data on the average analyte recognition rate. Sensor data recorded when  $T_{\text{heater}} = 192 \text{ °C}$  to 373 °C and  $V_{\text{gs}} = -2.5 \text{ V}$  and 0 V. The highest recognition rate is obtained when all four, sequentially performed measurements during a single  $V_{\text{gs}}$  step are utilized rather than any one individual measurement.



#### **Current-Voltage Characteristics of Nanowire Sensor**

**Figure S10.** I-V sweeps at a static 192 °C Heater Temperature. (a)  $V_{ds} - I_{ds}$  sweep for different  $V_{gs}$  biases. (b)  $V_{gs} - I_{ds}$  sweep at  $V_{ds} = 0.3$  V. The threshold voltage ( $V_{th}$ ) of the sensor FET is - 63.4 V as determined by linear extrapolation of the graph.

The linear behavior of the  $I_{ds}$ - $V_{ds}$  curves (Figure S11a) is evidence of ohmic contacts to the SnO<sub>2</sub> nanowires. This behavior was consistent for all temperatures examined in this report (192 °C to 373 °C). Only the  $I_{ds}$ - $V_{ds}$  measurement conducted at 192 °C heater temperature is reported since in general Schottky contacts are more evident at lower temperature due to a reduced amount of thermally generated carriers and lower rates of thermionic emission at the contact barriers.<sup>13</sup>

# **2-D Electrostatic Gating Simulation**

# Simulation Details:

The 2-D finite element electrostatic simulation shown in Figure 5 was carried out using Maxwell 2D 9.0 Student Version.\* The simulation mesh consisted of 9860 triangles and a direct matrix solver was used. The relative dielectric constant for the  $SiN_x$  dielectric was specified as 7 as has been experimentally determined in other reports.<sup>14</sup> The  $SnO_2$  nanowire and Pt gate were approximated as being perfect conductors during the simulation. This approximation is likely to be inaccurate for the semiconducting  $SnO_2$  nanowire when it is modified to be in a high-resistance state, i.e., as a result of highly negative gate voltages or the presence of oxidizing gases. Previous simulation work on NW-FETs, however, has shown that this approximation is appropriate for  $V_{gs}$  significantly greater than  $V_{th}$ .<sup>15</sup> In addition, this simulation assumed that the nanowire in the sensor active region was separated by at least 0.25 µm from any neighboring nanowires.

### Calculation of Capacitance between each of the NW surfaces and the Gate:

In order to calculate the amount of mutual capacitance between the back-gate and each of the four surfaces of the  $SnO_2$  nanowire examined in the simulation, the following computation approach was utilized. Note that these surfaces are labeled in Figure S12. This approach utilized the electric-field profile that is shown in Figure 5 of the main text and that was obtained from the above-described simulation.



**Figure S11.** Electrostatic Simulation Overview. (a) Cross-sectional schematic of the NW-gate structure used in the electrostatic simulation. (b) Diagram displaying the four different nanowire surfaces (a bottom, a top, and two side surfaces) that possess different amounts of capacitance with respect to the back-gate.

To elaborate, this approach was used to determine the amount of capacitance present between each of the nanowire surfaces and the back-gate. First, the amount of surface charge per unit length that was present on each nanowire surface was found using (Equations S4 and S5).

$$\sigma_{face}(x, y) = \varepsilon_0 \varepsilon_r E_{n, face}(x, y)$$
 calculation of surface charge using Gauss's Law (S4)

where  $E_{n,face}$  is the normal component of the electric-field (found in the FEM simulation) with respect to the nanowire surface of interest (units of V/m),  $\varepsilon_0$  is the permittivity of free space,  $\varepsilon_r$  is the relative dielectric constant of the dielectric that is contact with the nanowire surface. Air is assumed to possess  $\varepsilon_r = 1$  and SiN<sub>x</sub> is assigned  $\varepsilon_r = 7$ .

$$Q_{face} = \int \sigma_{face}(x, y) dx dy$$
 total amount of surface charge per unit length at a (S5)  
NW face

where  $Q_{\text{face}}$  possesses units of C/m since integration was only performed on a 2-D cross-section of the nanowire, i.e., integration over the z-dimension was not performed.

Once  $Q_{\text{face}}$  was found, the amount of capacitance present between the surface of the NW of interest and the back-gate, termed  $C_{\text{face-gate}}$  and which has units of F/m, was calculated using Equation S6.

$$C_{face-gate} = \frac{Q_{face}}{V_{gs}}$$
 capacitance calculation using the definition of capacitance (S6)

The results of this calculation for each of the surfaces of the NW are presented in Table S4.

Surface(s) of Nanowire	C <sub>face-gate</sub> (F/m)	Percent of Total Gate-NW Capacitance
Top Surface	$3.16 \times 10^{-12}$	5.43 %
Side Surface (Left)	$5.64 \times 10^{-12}$	9.67 %
Side Surface (Right)	$5.64 \times 10^{-12}$	9.67 %
Bottom Surface	$4.37 \times 10^{-11}$	75.2 %
All Surfaces	$5.82 \times 10^{-11}$	100 %

Table S4. Capacitance of Various Nanowire Surfaces with respect to the Gate

In order to verify the capacitance results contained in Table S4, the total gate-NW capacitance (abbreviated as  $C_{\text{gate-NW}}$ ) was compared to a capacitance value that was determined by the Maxwell 2D simulator using a different calculation method. Specifically, this alternate method provided by the simulator utilized the electrostatic energy relation and is given in Equation S7. Using this method,  $C_{\text{gate-NW}}$  was found to be  $5.84 \times 10^{-11}$  F/m. Note that this value closely agrees with the total of  $5.82 \times 10^{-11}$  F/m that was found using the previously described method that was used to generate Table S4. The minor discrepancy between these two values is likely a result of the different computational approaches that were used in order to calculate these values.

$$\frac{1}{2}C_{gate-NW} \cdot V_{gs}^2 = \int \frac{1}{2}\varepsilon_0 \varepsilon_r \left[\nabla \vec{V}(x,y)\right]^2 dxdy \qquad \text{total gate-NW capacitance found from the} \\ \text{electrostatic energy relation} \tag{S7}$$

where  $V_{gs} = 1$  V (according to simulation parameters),  $\varepsilon_r$  is the relative dielectric constant of the dielectric that is contact with the nanowire surface. Air is assumed to possess  $\varepsilon_r = 1$  and SiN<sub>x</sub> is assigned  $\varepsilon_r = 7$ . Lastly, V represents the electrostatic potential as determined by the simulation.

As a further check, the value of  $C_{\text{gate-NW}}$  was calculated using an analytical equation that is commonly used to estimate the capacitance of the back-gate NW-FET structure (Equation S8). Using this equation,  $C_{\text{gate-NW}}$  was approximated as  $5.98 \times 10^{-11}$  F/m which agrees fairly closely with the value as determined from the electrostatic simulation.

$$C_{gate-NW} = \frac{2\pi\varepsilon_0\varepsilon_r\alpha}{\cosh^{-1}((R+h)/R)}$$
 total gate-NW capacitance found from the  
analytical metallic cylinder-plane system (S8)

where *R* is the nanowire radius (25 nm), *h* is the silicon nitride gate dielectric thickness (300 nm),  $\alpha$  is a correction factor that accounts for the fact that nitride does not fill the entire space around the nanowire as that analytical model assumes. The value  $\alpha = 0.5$  is used in this work since it has been shown to provide a reasonable approximation for the back-gate NW-FET geometry examined in this work.<sup>15</sup>  $\varepsilon_r$  is the relative dielectric constant of the nitride dielectric and is assigned to  $\varepsilon_r = 7$ .

\* Certain commercial equipment, instruments or materials are identified in this report to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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