Unit-Cell Design of a Force Sensor Based on Vertical Piezoelectric Nanowires

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Summary

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PART I: INTRODUCTION
Large-scale integration of nano-objects

Context: Systems Integration and miniaturization
Development of a high performance force sensor based on functional nanomaterials

Piezoelectric response impacted by nanowires characteristics (Hinchet et al., IEDM 2012)

3D reconstruction of the force / deformation applied on the sensor via strain-stress field mapping
PART I: STARTING POINT
Starting Point

Static FEM simulation
NW Dimensions: $R=25\text{nm}$, $L=600\text{nm}$
Applied force: $F_y=80\ \text{nN}$

$V_{\text{max}} \approx 300\ \text{mV}$

(Y. Gao et al., Nano Letters 2007)

- Enables electrical contact positioning
- Missing surrounding environment of NW (pixel)
PART II:
STATIC FEM SIMULATIONS OF A PIXEL
FEM approach for sensing-device design

Multi-physics static finite element simulations: exploit the piezopotential reverse region for contacting

The piezopotential inversion region hosts the highest values in our configurations
FEM approach for device design: 1\textsuperscript{st} case

Boundary Conditions:

**MECHANICAL conditions**
- External force
- Clamped base
- Elastic-electric metal contacts

**ELECTRICAL conditions**
- Grounded-contact
- Floating potential
FEM approach for device design 1\textsuperscript{st} case

Parametric study
Parameter: ZnO layer thickness ($e_{ZnO}$)

The location of the piezopotential maximum depends on the ZnO thickness
Thinner seed layer is preferred

Collection efficiency = $\frac{\Delta V_c}{V_{\text{max}}}$
FEM approach for device design 2\textsuperscript{nd} case

Parametric study
Parameter: ZnO layer thickness ($e_{ZnO}$)

\begin{align*}
V = f (e_{ZnO}) \\
V_{\text{max}} \quad \text{(Point A)} \\
V_{\text{contact}} \quad \text{(Point B)}
\end{align*}

Collection efficiency = $\Delta V_c / V_{\text{max}}$

Better potential outputs with thinner ZnO layers
Realistic cases: issues inherent to fabrication

Possible misalignment of contacts and NW

Inherent to device fabrication (contact deposition and NW growth) which introduce strong variability.
Investigation of technologically realistic parameters

Parametric study
Parameter: spacing $\delta$ ($e_{ZnO}=20$nm)

<table>
<thead>
<tr>
<th>Configuration ($e_{ZnO}=20$nm)</th>
<th>Displacement at free end (nm)</th>
<th>$V_{\text{max}}$ (mV)</th>
<th>$\Delta V_c$ (mV)</th>
<th>$\Delta V_c/V_{NW}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta=0$</td>
<td>124</td>
<td>1349</td>
<td>862</td>
<td>63.9</td>
</tr>
<tr>
<td>$\delta=3$ nm</td>
<td>136</td>
<td>1630</td>
<td>544</td>
<td>33.3</td>
</tr>
<tr>
<td>$\delta=12$ nm</td>
<td>136</td>
<td>1631</td>
<td>424</td>
<td>25.9</td>
</tr>
<tr>
<td>$\delta=18$ nm</td>
<td>136</td>
<td>1619</td>
<td>384</td>
<td>23.7</td>
</tr>
<tr>
<td>$\delta=21$ nm</td>
<td>136</td>
<td>1613</td>
<td>370</td>
<td>22.9</td>
</tr>
</tbody>
</table>

Significant drop of $\Delta V_c$ when physical contact is lost
But stabilization of $\Delta V_c$ for $\delta > 5$ nm.
Investigation of technologically realistic parameters

Influence of the electrode height ($h_{\text{contact}}$)

$\delta = 0$

$\delta \neq 0$ (18 nm)
Investigation of technologically realistic parameters

Influence of the electrode height ($h_{contact}$)

**$\delta = 0$**

$h_{contact} = 30$ nm

$\Delta V_c = 862$ mV

$V_{max} = 1349$ mV

$h_{contact} = 100$ nm

$\Delta V_c = 385$ mV

$V_{NW} = 1620$ mV

**$\delta \neq 0$ (18 nm)**

$h_{contact} = 30$ nm

$\Delta V_c = 385$ mV

$V_{NW} = 1620$ mV

$h_{contact} = 100$ nm

$\Delta V_c = 775$ mV

$V_{NW} = 1169$ mV

For $\delta > 0$ nm there is no influence of $h_{contact}$
Conclusions

FEM simulations provide valuable insight for device design:

- The inversion region hosts the highest values of piezopotential, this is where the contacts should be placed.

- Piezopotential spreads continuously from the inversion region into the seed layer and (to a smaller extend) into the electrodes.

- Thinner seed layers are preferred.

- Although the piezopotential values drops dramatically when $\delta > 0\text{nm}$, it is still exploitable.

Microfabrication can be anticipated by studying the influence of different parameters that are inherent to device fabrication.
Thank you for your attention

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