소자의 구부러짐에 따른 ZnO 나노선 FET 의 특성 분석
Analysis of Bending Responses of ZnO Nanowire Field Effect Transistor

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INTRODUCTION

As size of devices decreases, the electronic components also should be sized down. But current technologies with top-down approaches using lithography are facing limitations to reduce a pattern size to less than 20 nm. However, new approaches based on bottom-up technologies can fabricate a component of which size ranging from few nm to hundreds nm. So it would be very useful to use components such as nanowires(NWs) to constitute a device. Fortunately, several devices using NWs have shown exceeding performances compared to conventional devices [1]. That shows possibilities of NW-based future electronic devices.

But the problem is that the reduction in size would bring some negative effects on several properties of devices. One of these is piezoelectric effect when ZnO NW is used as a component. Atoms in ZnO with wurtzite structure can easily be displaced by external forces, results in electrostatic potentials [2]. By so-called piezopotential, mobile charge carriers from one side will move to the other side of NW, and the resulting charge redistribution would influence to the effective pathway of electrons in NW when bias is applied.

EXPERIMENT

The potential in NW can be described by an equation (1), which was derived from series of equations including mechanical equilibrium, constitutive, geometrical compatibility and Gauss equation of electric field [3].

$$\varphi(r,\theta) = \frac{1}{8\kappa_\perp}\frac{f_y}{I_{xx}E}\left[2(1+\nu)e_{15} + 2\nu e_{31} - e_{33}\right]\left[\frac{\kappa_0 + 3\kappa_\perp}{\kappa_0 + \kappa_\perp}\frac{r}{a} - \frac{r^3}{a^3}\right]a^3 \sin\theta \quad (1)$$

where f_y is an external force applied at the end of NW in y-direction, 2a is a dimension of a cross-section of a square NW, κ_0 is a vacuum permittivity, $\kappa_\perp$ is a permittivity of $E \perp c$ direction and equal to 7.77 κ_0 for ZnO, ν is a poisson ratio with a value of 0.349 and piezoelectric constants are e_{15}=-0.45C/m^2, e_{31}=-0.51C/m^2, e_{33}=1.22C/m^2. The potential map was obtained by Matlab and indicated in Figure 1 at different f_y values.

And then gate-all-around n-type ZnO (100) NW FET was simulated at 300K. The longitudinal and transverse effective mass was set to 0.21m$_0$ and 0.24m$_0$, band gap was 3.3eV and permittivity was 8.91κ_0. NW was surrounded by SiO_2 with well-known dielectric constant of 3.90 and thickness, width of 1nm. Source-to-drain distance, channel length and gate length were set to 10nm. The channel thickness and width were chosen by considering the dimension of cells consisted of only few ZnO unit cells. The values of channel cross-sectional dimension were shown in Table 1. Lastly, charge carriers were assumed to be accumulated in the dotted region in Figure 1. That means, channel was doped with 1.0x10^{-16} cm^{-3} originally but carriers will be gathered in dotted line. Source and drain were heavily doped with 1.0x10^{-20}cm^{-3} of dopant. Dotted region was defined as a zone of which voltage was higher than 0.1789V. The value corresponds to an equilibrium voltage between ideal p-n junctions which has 1000 times difference in the dopant concentration.

DISCUSSION

From Figure 2, we could see current significantly decreases with the applied force. That is detrimental to a device for working properly. Figure 3 indicates an abrupt increase in threshold voltage above certain values. Subthreshold swing was relatively constant with respect to the forces and around 60meV/decade.

As a size of NW decreases, an effective mass and a band gap increases by quantum confinement

effect. To evaluate this effect, I conducted band structure analysis of ZnO NW with various radii ranging from 0.5nm to 5nm using Atomistix toolkit and obtain band gap and effective mass values as presented in ref [4]. But as reported in many journal papers, DFT(LGA and GGA) result gave the band gap of 0.7~1eV [5] and Extended Hückel method resulted in metallic behavior. At this time, these misleading results were not considered but later the modified band gaps will be considered in the simulations. Also, since local carrier concentration was overestimated, it would be more precise to replace dopant concentration above to that of equation (3).

$$n_{dopant} = \int_{-a}^{-a}\int_{-a}^{-a} n(x,y)dxdy \quad (2)$$

$$< n > = \frac{\int_{y_0}^{y_1}\int_{x_0}^{x_1} n(x,y)dxdy}{\int_{y_0}^{y_1}\int_{x_0}^{x_1} dxdy} = \frac{\int_{y_0}^{y_1}\int_{x_0}^{x_1} A\exp(\varphi(x,y))dxdy}{\int_{y_0}^{y_1}\int_{x_0}^{x_1} dxdy} \quad (3)$$

CONCLUSION

The results obtained from simulations would be useful to predict the effect of bending on the performance of flexible devices. In this paper, we observe a potential change by charge distribution with respect to the external force applied. When a device is bended, current flow decreases significantly and threshold voltage increases, and the device would not work. These results would give some intuitions in select the material and design a device properly in the future electronics.

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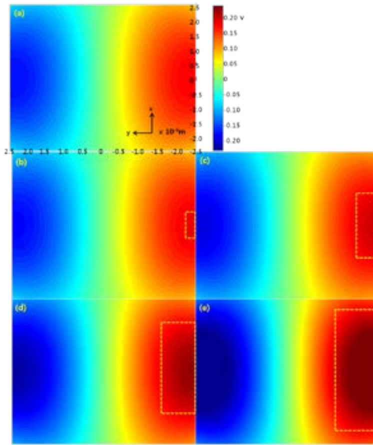

Figure 1. Top view of NW indicating the potential map at various forces applied. (a) 5nN (b) 5.1nN (c) 5.55nN (d) 6.3nN (e) 7.7nN

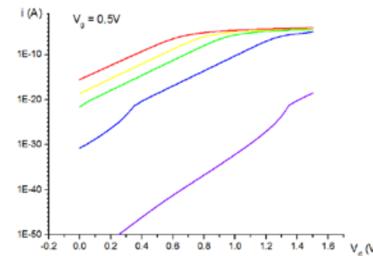

Figure 2. I_d-V_g curve of ZnO NW FET. Drain voltage was fixed to 0.5V and gate voltages were swept from 0 to 1.5V.

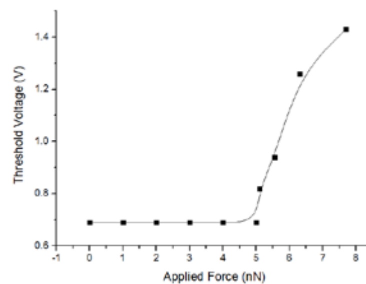

Figure 3. Threshold voltage with applied forces.

Table 1. Exerted forces and their corresponding channel thickness and width.

Force(nN)	Channel thickness (nm)	Channel width(nm)
7.7	0.32495	1.04138
6.3	0.64990	2.08276
5.55	0.97485	3.12414
5.1	1.29980	4.16552
0 ~ 5	2.50000	5.00000