Responses of AlGaN/GaN Heterojunction Field Effect Transistors to DNAs

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In AlGaN/GaN heterostructures, the polarization-induced two-dimensional electron gas (2DEG) at AlGaN/GaN interface is extremely sensitive to ambient. Any polarity change on the surface by gases, polar liquids, and charge-carrying biomolecules affects the surface potential and modulates the 2DEG density.[1] In this paper, the response of un-gated AlGaN/GaN heterojunction field effect transistors (HFETs), whose cross-sectional view is shown in Fig. 1, exposed to different concentrations of λ-DNA solutions is described and a model is discussed.

Figure 2 shows that the device channel current is quantitatively modulated by the concentration of DNAs in buffer solutions. The current decreases as the increase of λ-DNA concentration. The ATLAS (Silvaco) software was used for modeling the device behavior and the extraction of parameters from the measurements. The 2DEG is simulated by a thin and heavily doped layer of carriers under the AlGaN/GaN interface. A simple Fermi model is adopted for the simulation of device I-V characteristics. By simulating the current at a bias of 30 V, the 2DEG density was extracted which behaves an exponential dependence to the DNA concentration, as shown in Fig. 3. The last term for the exponential expression is the sheet carrier concentration under equilibrium. The coefficient of the first term is decided by the device response to the buffer and the coefficient in the exponential term is decided by the device sensitivity. One also can see that the sensitivity in the low concentration region is really high. To distinguish the responses of HFETs to DNA solutions and to ionic solutions, the Gouy-Chapman-Stern model is adopted to simulate the applied surface potential on the AlGaN surface by assuming the 2DEG carriers near the AlGaN/GaN interface is decided by the surface donors. The calculated change in 2DEG due to the change of ionic solution concentration is shown in Fig. 4. The change of current based on simulation is in the same range of the reported experimental results of GaN-based HFET ion sensors,[2] which is much smaller than the change of current in DNA solutions. As shown in Fig. 1, at the DNA concentration of 30 ng/ml or ~1.0 pM, the device is close to cutoff, indicating a much higher sensity considering each λ-DNA carries < 10^5 electron charges.

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1 J. Song, and W. Lu, Appl. Phys. Lett., **89**, 223503 (2006).

2 B. S. Kang *et al*, Appl. Phys. Lett. **86**, 173502 (2005).

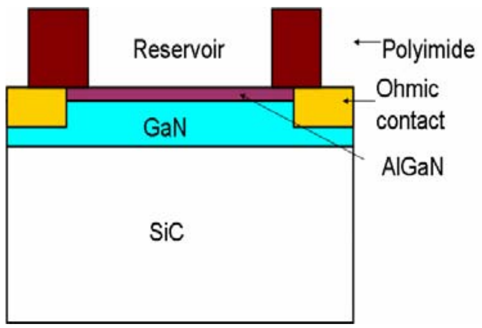

Fig. 1. Cross-sectional view of HFET sensor devices.

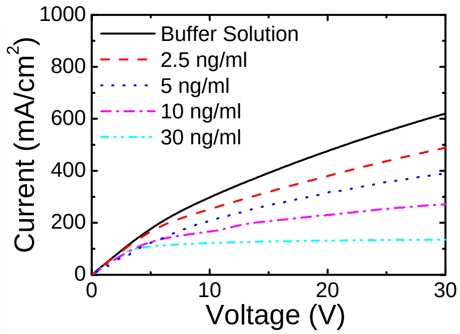

Fig. 2. The drain current density of un-gated AlGaN/GaN HFETs as a function of drain bias by exposure to λ-DNAs in buffer solution at different concentrations.

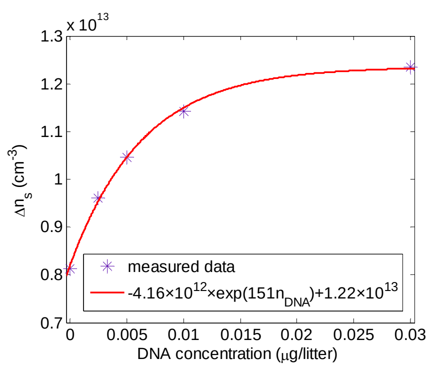

Fig. 3. The extracted change of 2DEG vs λ-DNA concentration.

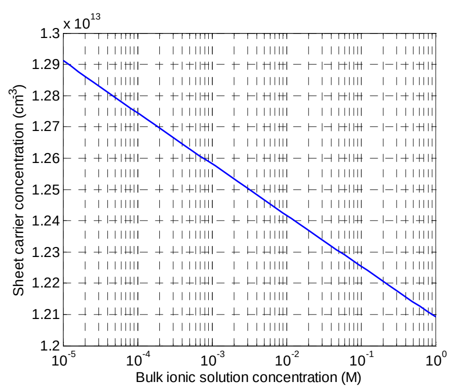

Fig. 4. The simulated change of sheet carrier concentration vs bulk single-valence ionic solution concentration.