The operating mechanism of Schottky-gate nanosensors

Yun-Ju Lee[1], Hsien-Chin Tung[1], Wen-Wei Wu[2] and Ping-Hung Yeh[1]*

[1]Department of Physics, Tamkang University, 151, Ying-chuan Road, Tamsui, Taipei, Taiwan 251
[2]Department of Materials Science and Engineering, National Chiao-Tung University, Hsinchu, Taiwan 300
E-mail: phyeh331@mail.tku.edu.tw

Abstract

The highly sensitive nanowire-based Schottky-gate nanosensors for detecting UV, bio-molecules, and gas sensing were demonstrated. The operating mechanism of the Schottky-gate nanosensors is totally distinct from the conventional Ohmic contacted nanosensors. The Schottky–gated device (SGD) has a few merits in comparison to the conventional Ohmic contacted device (OCD). First, it needs no bio-probe to detect molecules; rather, it depends on the absorption of the charged molecules to the junction region. Second, as for the same type of nanowires, such as ZnO, the sensitivity of the SGD is much higher than that of OCD, because a few molecules at the junction region can change the "gate" that effectively tunes the conductance. This Schottky-gate-modulation based sensing principle can be applied to other materials and sensing systems.

Keywords: Schottky contact, Zinc oxide, nanowire and sensor

Introduction

In recent year, nanodevices based on one-dimensional (1D) nanostructures, including nanobelt, nanotube, and nanowire,[1-12] have attracted many attention because of their advantageous of large surface to volume ratio and finite, readily manipulative charge carrier flow of the confined charge transport channel. The two contact ends of the device are usually designed to form Ohmic contacts to have the obvious conductance variations from the NW and minimize the contacted resistances, because the mechanism of the conventional sensor is about the conductance variations of the device once it is exposed to the species to be detected, which are expected to change the surface conductance of the NW due to modification of the surface charge and states, change in local band alignment, disturbance the gate potential, and/or permittivity. For gas sensing, past research efforts in improving the sensitivity have been focused on surface modification of the functional material with polymer or nanoparticles,[13-16]new material growth processes,[17-18] and networking of the functional material.[19-20]

In conventional devices, the Schottky contacted avoidance is an inveterate idea for the current signal detection. Recently, a new operating mechanism device was designed for achieving highly sensitive and fast-response nanosensors by using the non-symmetrical Schottky contact. The key idea is that the current passing through the Schottky barrier formed at the contact area is dominantly controlled by the barrier characteristic, which is very sensitive to the environment around this small area, such as light irradiation, molecule adsorption, etc. [21-24]

Result and discussion

The Schottky contacted device which shown in Fig. 1(a) is composed of a single ZnO nanowire mounted on Pt electrodes with one end in Ohmic contact and the other end in Schottky contact; the (conventional) Ohmic contacted device shown in Fig. 1(b) composed of a single ZnO nanowire mounted on Pt electrodes with two ends in Ohmic contact.

The electrons can pass the schottky barrier height (SBH) at high temperature (250˚C) due to the thermal effect. The SBH modulation is the main idea of schottky-gate nanosensor. There are several parameters will affect the SBH, like the interface state, positive/negative charged molecules and the thermal effect. The current-voltage characteristic curve of the Schottky diode and the theoretical band diagram which worked under different temperature are shown in Fig. 2 (a) and (b), respectively. The Schottky contacted device exhibited Ohmic characteristic under high temperature condition (250°C) due to high carrier energy which allowed carriers pass through the Schottky barrier easily. The current output of Schottky contact can be approximately estimated via the classic thermionic emission-diffusion theory by the following equation[25]:

Forwards bias: $$I = I_s \exp\left(\frac{qV}{\eta kT}\right)\left[1-\exp\left(\frac{-qV}{kT}\right)\right] \text{.........(1)}$$

$$I_s = (area)A^{**}T^2 \exp\left(\frac{-q\psi_{b0}}{kT}\right) \text{.......(2)}$$

Reverse bias: $$I = (area)A^{**}T^2 \exp\left(\frac{-q\phi_{eff}}{kT}\right) \text{.............(3)}$$

V is the forward bias, k is Boltzmann constant), ψ_{b0} is zero bias barrier height, ϕ_{eff} is effective barrier height, A^{**} is effective Richardson constant, η is ideality factor. The parameters can be calculated by using the above equations, like effective barrier height and ideality factor. The effective barrier height will readily manipulate the current output at reverse bias, which will be gigantic enhanced for UV, charged Bio-molecule and gas nanosensors [21-24]. But the ideality factor will be the other important effect for nanosensing devices. Analyzing the ideality factor can give us more information to find optimum condition for different sensing devices.

The band diagrams of the schottky contact at reverse bias are shown in Fig. 3. The SBH is functioned as a "gate" which controls the current passing through the metal/semiconductor interface or not. Positive or negative charged molecules absorption, the SBH will be reduced or increased as the gate is open or closed, respectively. The operating mechanism of the Schottky-gate nanosensors is modulating the variations of SBH, but uncertainty will affect the SBH, like temperature influence and the metal/semiconductor interface absorbed situation.

Conclusion

Schottky-gate sensing mechanism has been demonstrated for ultrahigh sensitive nanosensing devices, this Schottky-gate-modulation based sensing principle can be applied and extended to other materials and sensing systems. The operating mechanism could be effective toward single molecule detection, because the adsorption of a few molecules at the junction region could significantly change the local barrier height.

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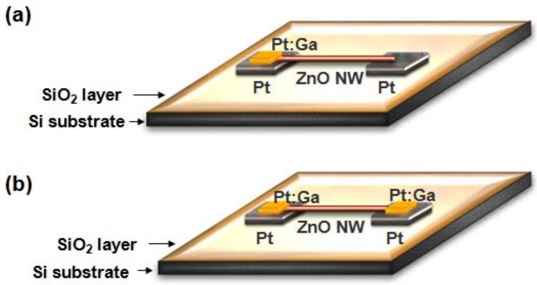

Fig. 1 (a) Schematic of the Schottky contacted device (SCD). (b)Schematic of the Ohmic contacted device (OCD). For OCD, a single crystal ZnO NW was placed on a Pt electrode pattern, and then Pt-Ga was deposited on the both sides of the NW to form Ohmic contacts using a focus ion beam (FIB) system. For the SGD, a ZnO NW was placed on a Pt electrode pattern, the natural contacts of which are mainly Schottky-type. By using a FIB to deposit Pt-Ga at a localized region at one end, a local Ohmic contact is achieved.

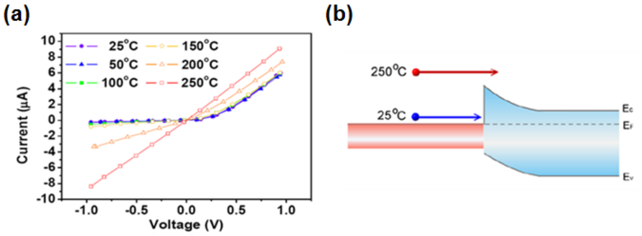

Fig. 2 (a) The current-voltage (I-V) characteristic curve of the Schottky diode at various temperature conditions. The current-voltage characteristic become to ohmic-like I-V characteristic, no more schottky I-V characteristic at high operating temperature (250˚C). (b)The theoretical band diagram. The electrons will pass through the SBH due to the high thermal effect.

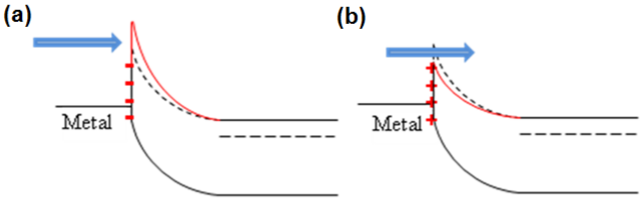

Fig. 3 Charged molecule absorbed on the metal/semiconductor interface will vary the Schottky barrier height. (a)Negative charged absorption will increase the SBH and turn the Schottky-gate off, stop the current flow. (b)Positive charged absorption will reduce the SBH and turn the Schottky-gate on, let the current flow.

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