Supporting Information

Superior Phototransistors Based on A Single ZnO Nanoparticle with High Mobility and Ultrafast Response Time

Linh-Nam Nguyen,[1,*] Wen-Hao Chang,[2] Chii-Dong Chen,[3,*] Yann-Wen Lan,[4,*]

[1]*University of Technology and Education, The University of Danang, Danang 59000, Viet Nam*

[2]*Deparment of Physics, National Taiwan University, Taipei 106, Taiwan*

[3]*Institute of Physics, Academia Sinica, Taipei 115, Taiwan*

[4]*Deparment of Physics, National Taiwan Normal University, Taipei 106, Taiwan*

**Corresponding author. Email: nlnam911@yahoo.com, chiidong@phys.sinica.edu.tw, ywlan@ntnu.edu.tw*

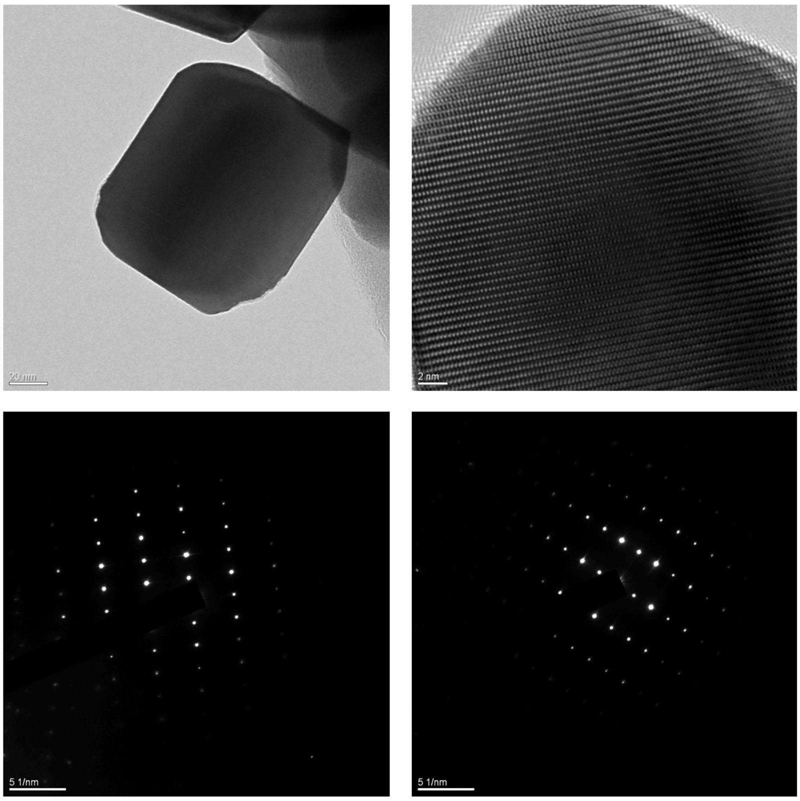

Figure S1. The TEM images and its diffraction pattern of the whole ZnO nanoparticle indicating a highly crystalline structure.

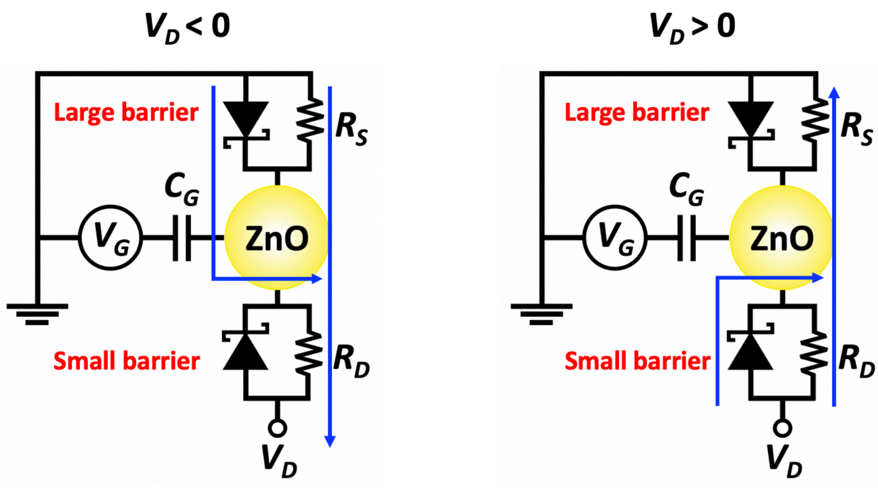

Figure S2. Routes of current passing through the device indicated as blue arrows while applying negative bias ($V_D < 0$) and positive bias ($V_D > 0$), respectively. Since the Schottky barrier at the interface between ZnO and drain electrode is smaller, the gate modulation of I_D-V_D curves is not changed too much compared to the one with larger Schottky barrier at the interface between ZnO and source electrode.

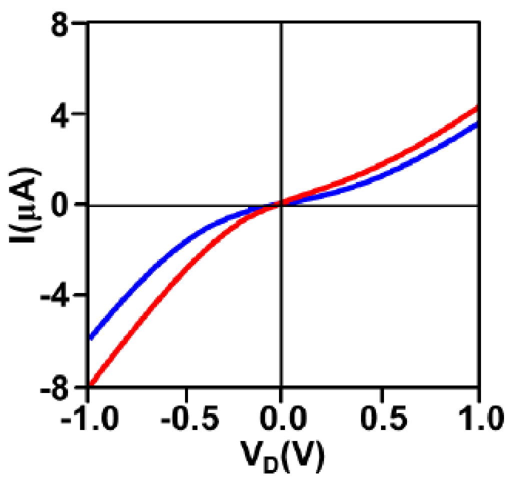

Figure S3. I-V_D characteristics at different V_G of 0 V (blue curve) and 0.8 V (red curve). The measurements are performed at 300 K for device B. At $V_G = 0.8$ V, the transconductance reaches 2.7 μS.

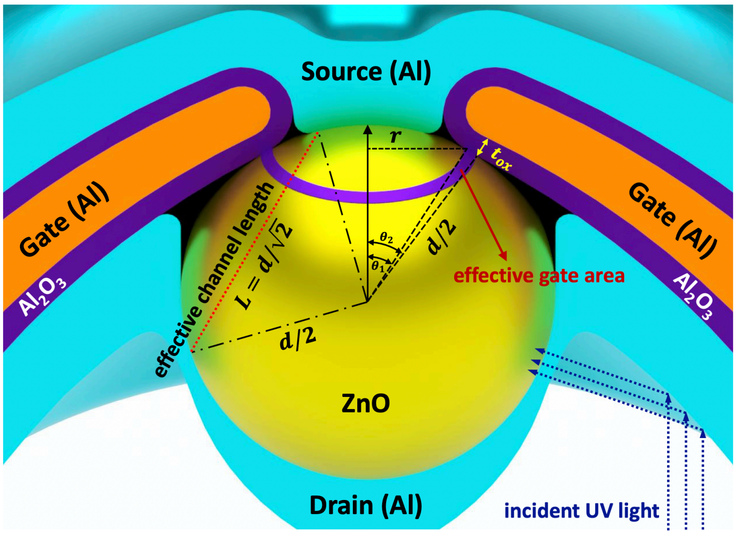

Figure S4. Illustration of effective channel length and effective gate oxide area between the Al gate electrode and ZnO nanoparticle.

Electron mobility calculation

From equation, the drain current can be rewritten as:

$$I = \frac{\frac{\mu C_G}{L^2}(V_G - V_{TH})V_D}{1 + \frac{\mu C_G}{L^2}(V_G - V_{TH})R_C}$$

We estimate the drain conductance ($g_d = dI/dV_D$) and transconductance ($g_m = dI/dV_G$) as:

$$g_d = \frac{dI}{dV_D} = \frac{\frac{\mu C_G}{L^2}(V_G - V_{TH})}{\left[1 + \frac{\mu C_G}{L^2}(V_G - V_{TH})R_C\right]}$$

$$g_m = \frac{dI}{dV_G} = \frac{\frac{\mu C_G}{L^2}V_D}{\left[1 + \frac{\mu C_G}{L^2}(V_G - V_{TH})R_C\right]^2}$$

In order to eliminate the contact resistance, we take $g_d/\sqrt{g_m}$:

$$\frac{g_d}{\sqrt{g_m}} = \sqrt{\frac{\mu C_G}{L^2}\frac{1}{V_D}}(V_G - V_{TH})$$

The electron mobility can be evaluated as:

$$\mu = \frac{(g_d)^2}{g_m}\frac{L^2}{C_G}V_D\frac{1}{(V_G - V_{TH})^2}$$

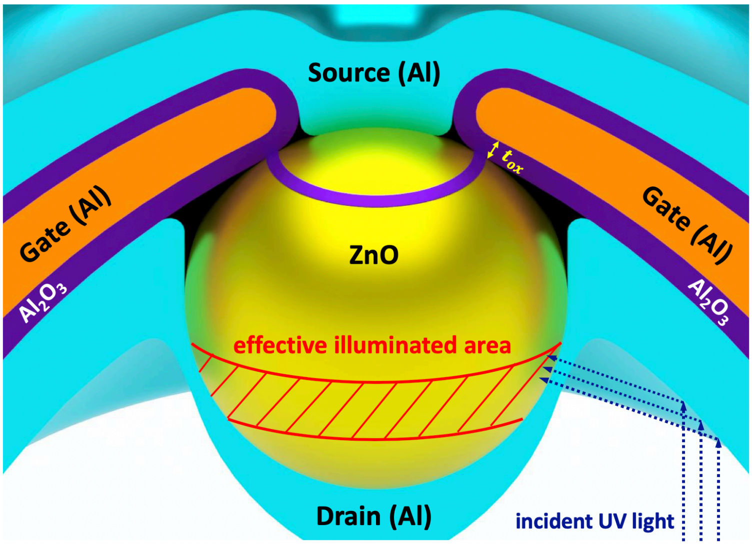

Figure S5. Effective illuminated area indicated as red region. This area is estimated from the consideration that incident UV light can penetrate the side-wall where it is thinner than the penetration depth of aluminum.

Penetration depth of aluminum under UV light calculation

$$\delta \approx \frac{1}{\sqrt{\pi \frac{c}{\lambda} \mu \sigma}} = \frac{1}{\sqrt{\pi \cdot \frac{3\times10^{8}\ m/s}{365\ nm} \cdot 1.257\times10^{-6}\ \Omega s/m \cdot 3.77\times10^{7}\ 1/\Omega m}} \approx 2.86\ nm$$