Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information for

Ultrafast, superhigh sensitivity visible-blind UV detector and optical logic gates based on nonpolar a-axial GaN nanowire

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Figures S1-S3

Supplementary Discussion: the transport characterization of MSM GaN NW PD.

Figure S1

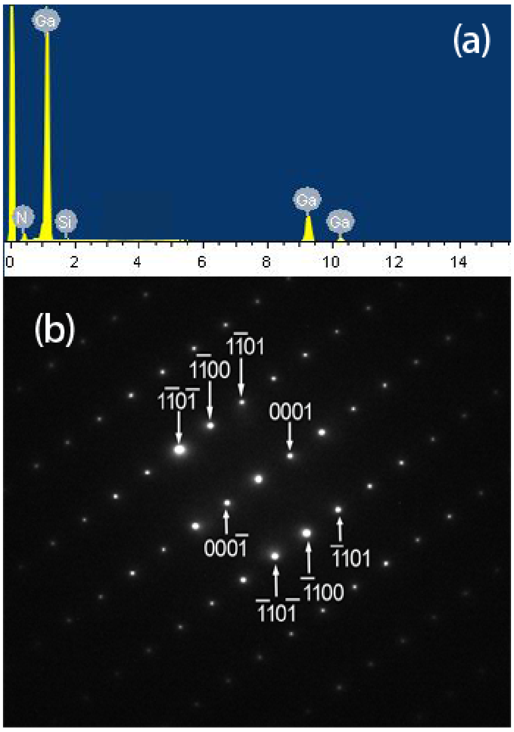

Figure S1. (a) EDS data of a single GaN NW grown on patterned Si; (b) the electron diffraction data with the electron beam perpendicular to the axis of a typical GaN NW.

Figure S2

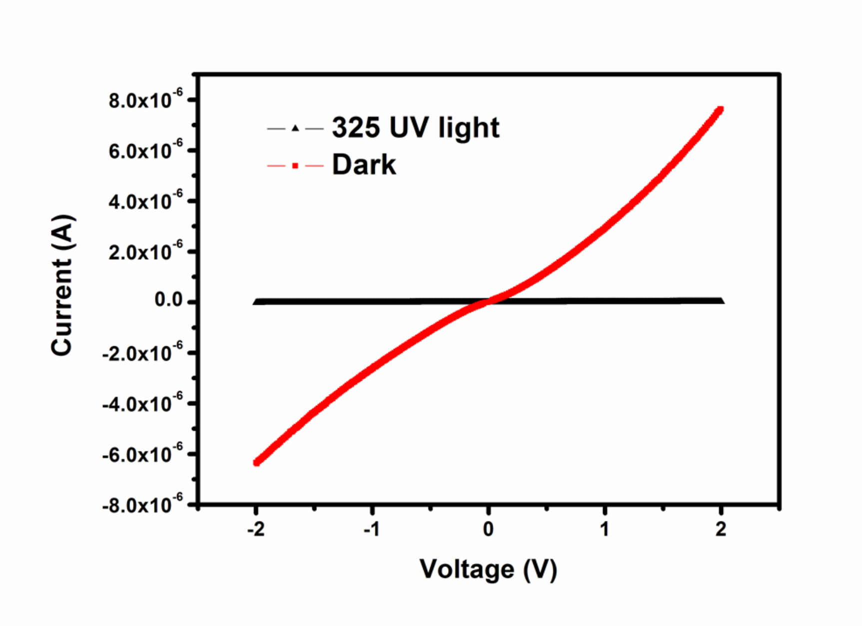

Figure S2a. typical linear scale I-V characteristics of the fabricated GaN NW PD both in the dark (black curve) and upon 325 nm UV light illumination with power density of 1 mW/cm^2 (red curve).

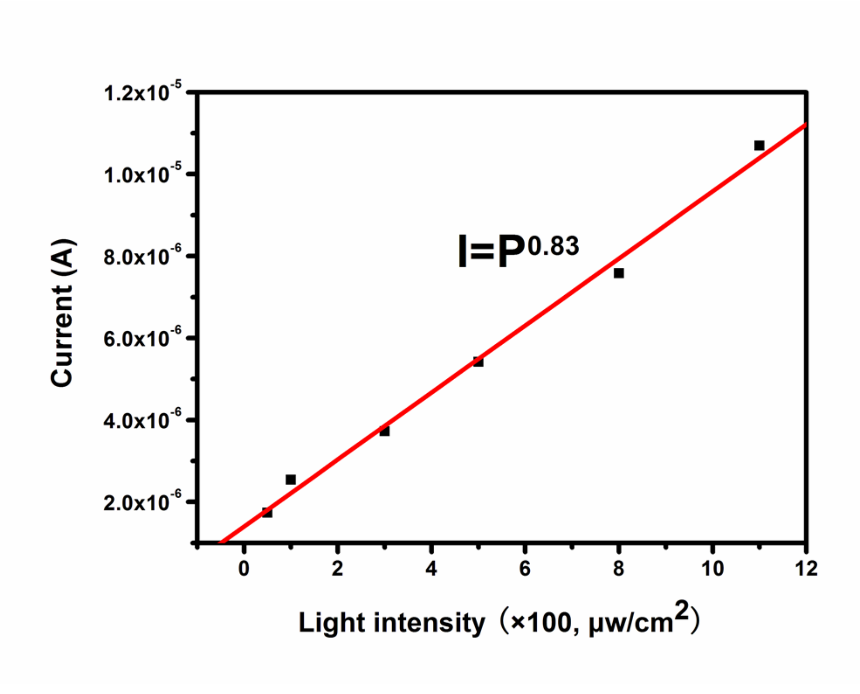

Figure S2b. light density dependent photocurrent curve at a voltage of 1 V

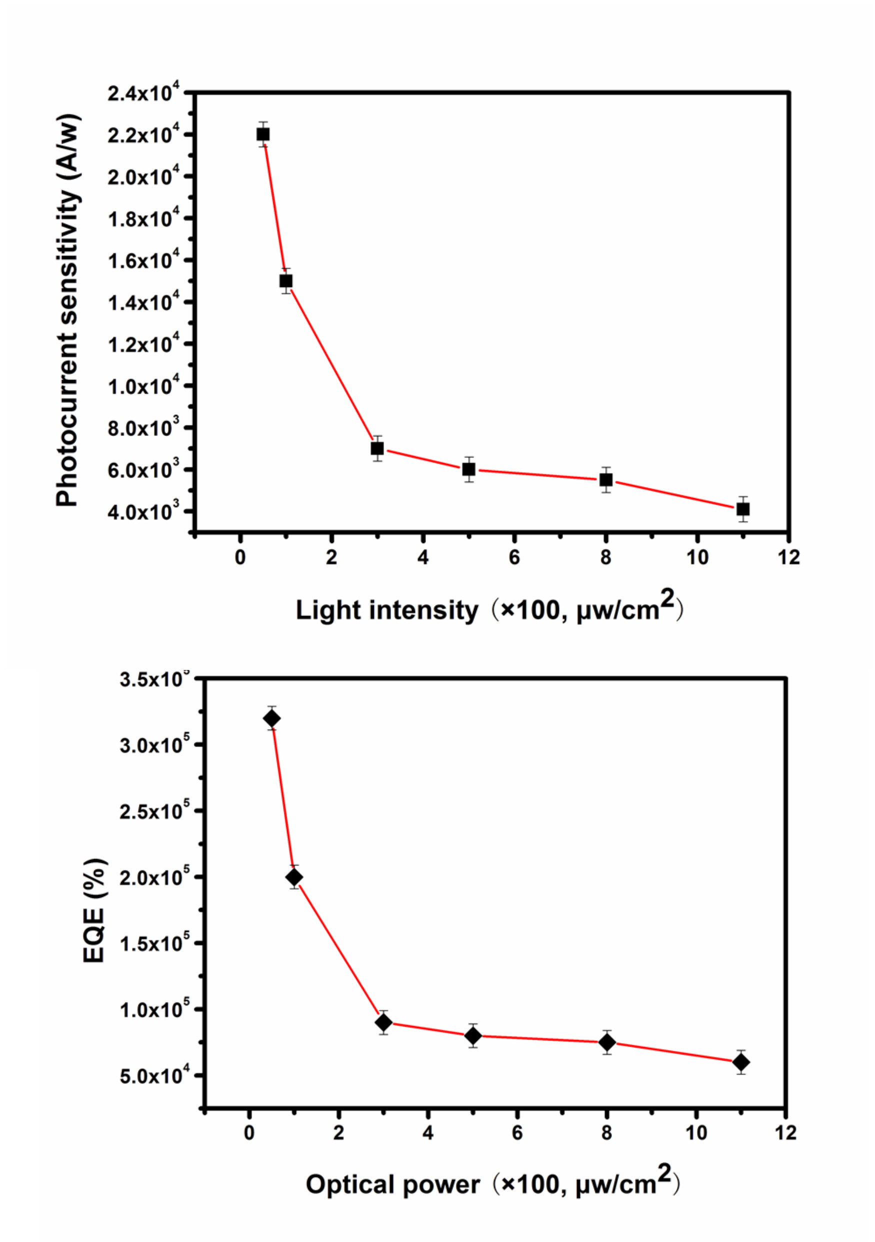

Figure S2c and d. the light density dependent spectra responsivity (R_λ) at a voltage of 1V (c). the light density dependent external quantum efficiency (EQE) at a voltage of 1 V (d).

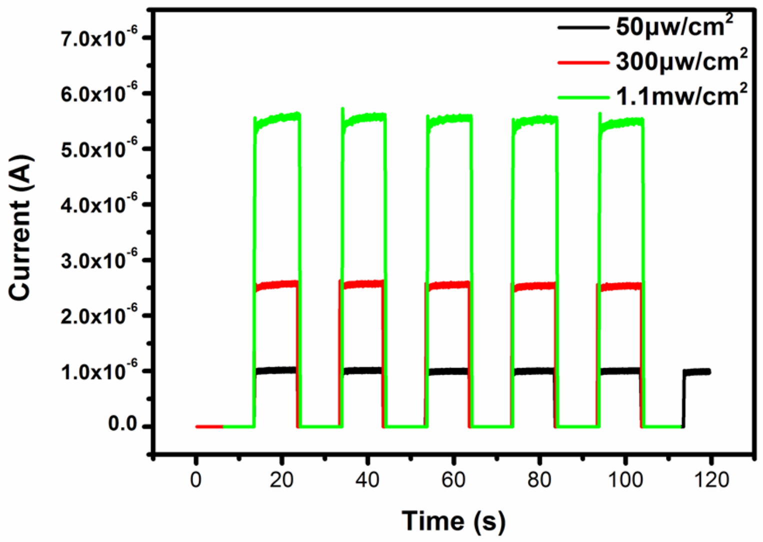

Figure S2e. Time dependent photocurrent response of the GaN PD device in the light density of 50, 300 and 1100 μw/cm^{2}^{0} when the UV light turned on and off with a period of ~10 s (at a bias of 1 V).

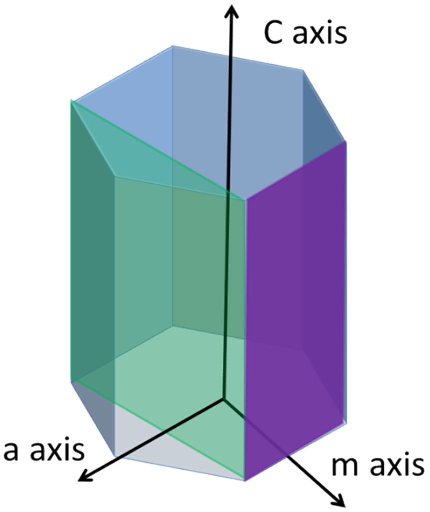

Figure S3. schematic diagram of polar (c-axis) and non-polar (m and a axis) crystal orientation in wurtzite structure GaN.

Supplementary Discussion:

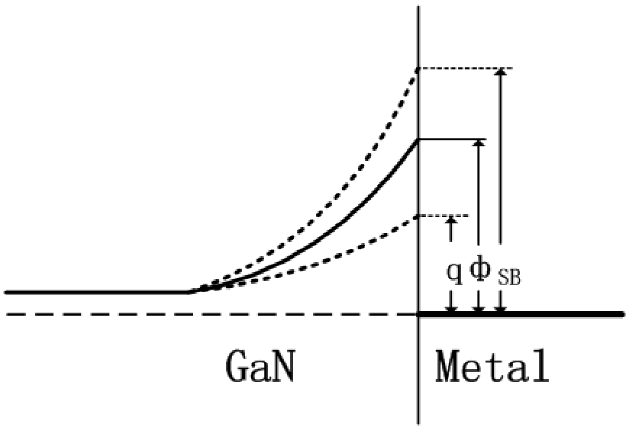

Figure S4. the energy-band diagram for the Schottky barrier that is formed at the metal-GaN interface.

The back-to-back MSM GaN NW PD can be regarded as a nanowire connected with a forward-biased SB diode and a reverse-biased SB diode in series. **Fig. 3d** in the main text shows the energy-band diagram for the GaN NW PD device. The reverse biased SB height (Φ_R) is much higher than that of forward biased (Φ_F), The reverse biased Schottky contact area is the bottleneck for the current transport in the device. **Fig.S3** shows the energy-band diagram for the Schottky barrier that is formed at the metal-GaN interface. The original SB height Φ_{SB} is determined by the work-function difference between the metal and GaN, and the interface states. As for the forward-biased SB diode, the current passing through this barrier can be described by the thermionic-emission (TE) theory. The total current density is given by:[1, 2]

$$
\begin{aligned}
J_{\mathrm{n}} &= \left[A^{*}T^{2}\exp\left(-\frac{\mathrm{q}\phi_{SB}}{\mathrm{kT}} \right) \right] \left[\exp\left(\frac{\mathrm{q}V}{\mathrm{kT}} - 1 \right) \right] \\
&= J_{TE}\left[\exp\left(\frac{\mathrm{q}V}{\mathrm{kT}} - 1 \right) \right]
\end{aligned}
\tag{1}
$$

Therefore,

$$I_{TE} = SA^{*}T^{2}\exp\left(-\frac{\mathrm{q}\phi_{SB}}{\mathrm{kT}} \right) \tag{2}$$

and

$$A^{*} = \frac{4\pi \mathrm{q}\mathrm{m}^{*}\mathrm{k}^{2}}{\mathrm{h}^{3}} \tag{3}$$

in which S is the area of the Schottky contact, A* is the effective Richardson constant, T is the temperature, q is the unit electronic charge, k is the Boltzmann constant, and V is the applied voltage. And for the reverse-biased SB diode, the current can be described by the thermionic-emission-diffusion theory (for V»3kT/q ~77 mV) as:[1, 2]

$$I_{TED} = SA^{**}T^{2}\exp\left(-\frac{\mathrm{q}\phi_{SB}}{\mathrm{kT}} \right)\exp\left(\frac{\sqrt[4]{\mathrm{q}^{7}N_{D}\left(V + V_{\mathrm{bi}} - \mathrm{k}T/\mathrm{q}\right)/8\pi^{2}\xi_{\mathrm{s}}^{3}}}{\mathrm{kT}} \right) \tag{4}$$

and

$$V_{\mathrm{bi}} = \Phi_{SB} - \left(E_{\mathrm{C}} - E_{F}\right) \tag{5}$$

in which A** is the effective Richardson constant, N_D is the donor impurity density, V_{bi} is the built-in potential, and ε_S is the permittivity of GaN. The depletion layer formed at the SB area has a width of:

$$W_D = \sqrt{\frac{2\xi_S}{\mathrm{qN}_D}\left(V_{\mathrm{bi}} - V - \frac{\mathrm{k}T}{\mathrm{q}}\right)} \tag{6}$$

Considering Equation 2 , 4 , and 6 we can conclude that the current passing through the Schottky contact is very sensitive to the Schottky barrier height and barrier width, especially under reverse-bias conditions. Therefore, the photocurrent transport characteristics of the M-S-M structure-based PD devices are mainly dictated by the reverse biased Schottky diode.

Reference

1. Hu, Y. F.; Zhou, J.; Yeh, P. H.; Li, Z.; Wei, T. Y.; Wang, Z. L. Supersensitive, Fast-Response Nanowire Sensors by Using Schottky Contacts. *Adv Mater* 2010, **22**, 3327-3332.
2. Sze, S. M. Physics of Semiconductor Devices. Wiley, : New York, NY, 1981.