Explicit Gain Equations for Single Crystalline Photoconductors

(Supplementary Information)

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Section S1: Four-probe and two-probe measurements

Fig.S1. Current-electric field curves for the 150 nm wide nanowire photoconductor by two-probe and four-probe measurements.
Section S2: Simulated potential profile for nanowires with a continuous channel

Fig. S2. Valence band of the 80 nm wide nanowire with a continuous channel. (a) 2D valance band (b) extracted valence band along the nanowire radial direction.

Two-dimensional simulations were performed using Silvaco Atlas software. The p-type nanowire is 5 μm long and 80 nm wide. The boron doping concentration is $1 \times 10^{18}/\text{cm}^3$. The negative fixed charge density at the surface is set at $3 \times 10^{12}/\text{cm}^2$. To distinguish the effect of the surface charges, only part of the nanowire surfaces is set with fixed charges (Fig. S2a). We extracted the potential profile along the nanowire radial direction as shown in Fig. S2b. The depletion regions are formed near both side surfaces of the nanowire. The nanowire channel remains continuous. Under light illumination, the barrier height between the surface and the channel decreases. The channel width expands, which is consistent with our experimental results.

Section S3: FDTD simulation

In order to calculate the ratio of the photons absorbed to the incident light intensity by the nanowire, we employed FDTD simulations using the Lumerical FDTD software packages. The schematic of the simulation is shown in Fig S3. The silicon nanowire 200 nm thick and 150 nm wide is on the top of the SiO$_2$ layer. We analyze the absorption and the generation rate in the nanowire. The light source is a plane wave launched perpendicularly from the top. The periodic boundary condition is applied on the two planes vertical to the nanowire axis, while perfectly-matched-layer (PML) boundary
conditions are used in the other four planes. The values of the power absorbed normalized by the light illumination intensity of the whole simulation region that is extracted from the software for different wavelength. According to the simulation results, we can easily calculate the value of $\alpha$, the ratio of photons absorbed by the nanowire to photons incident on the nanowire.

$$\alpha = \frac{\text{Simulated ratio} \times \text{area of Simulation region}}{\text{area of the absorbed region}}$$

For $\lambda=460\text{nm}$, $\alpha = \frac{0.03202 \times 2\mu m \times 2\mu m}{170\text{nm} \times 1\mu m} = 0.8539$

![Fig.S3. Schematic of the FDTD simulation. The red rectangle refers the silicon nanowire.](image)

![Fig. S4. Ratio of photons absorbed by the nanowire to photons incident on the nanowire.](image)
Section S4: Simulated potential profile for nanowires with a pinched-off channel

Fig. S5. Valence band profile for the 50nm wide nanowire with a pinched-off channel. 
(a) 2D valence band in darkness. (b) 2D valence band under illumination. (c) Valence band profile along the nanowire axis (the dashed line in panel a) with (red) and without (black) illumination, (d) Valence band profile along the nanowire radial direction (the dashed line in panel b) with (red) and without (black) illumination.

For the nanowire 50 nm wide, the channel is pinched off by charged surface states, creating a potential barrier $\varphi_{sd}$ between the source and drain. We extracted the potential profile along the radial and axis direction of the nanowire. Panel d shows that the potential profile along the radial direction simply shifts up under light illumination, indicating no change in surface depletion region width. It means that the assumption $\Delta \varphi_{sd} = \Delta V_{bi}$ is correct.