SUPPORTING INFORMATION

Silicon Nanomembrane-based Near Infrared Phototransistor with Positive and Negative Photodetections

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1. Statistics of various nanogroove structures by AFM measurement

The statistics of depth, width, and period constant of various nanogroove structures are obtained from AFM measurements, and the results are summarized in Fig. S1(a). The groove depth and period constant for all designed nanogrooves are maintaining around 180 and 500 nm, respectively. The width of nanogrooves varies from 325 to 470 nm. The corresponding AFM images of all fabricated nanogrooves are shown in Figure S1(b).

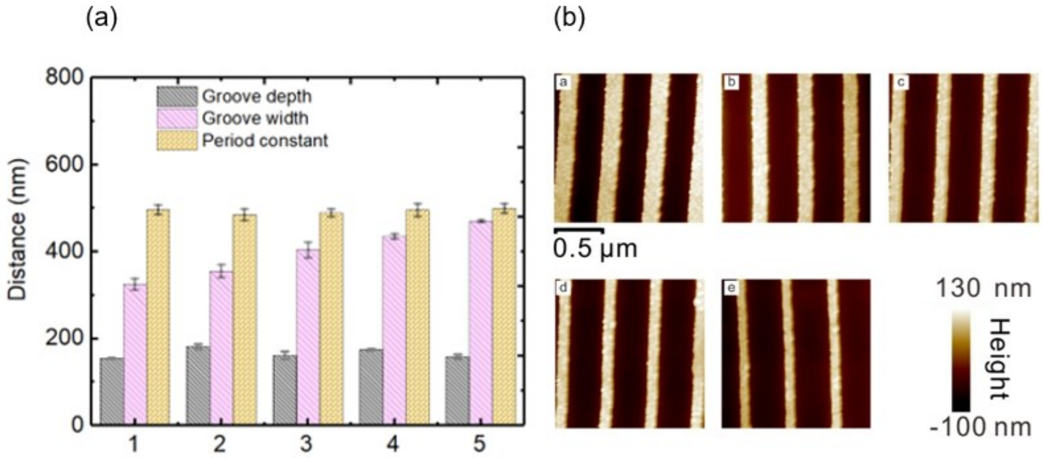

Fig. S1 (a) Statistics of depth, width, and period constant of various nanogroove structures. (b) AFM images of fabricated nanogrooves for height information. T

2. Reflectance and transmittance spectra of various nanogroove arrays

We experimentally investigated the reflectance and transmittance spectra of nanogroove arrays with different widths, as shown in Figs. S2(a) and S2(b), by micro area FTIR. The widths of nanogrooves are 325 nm, 355 nm, 404 nm, 435 nm, and 470 nm.

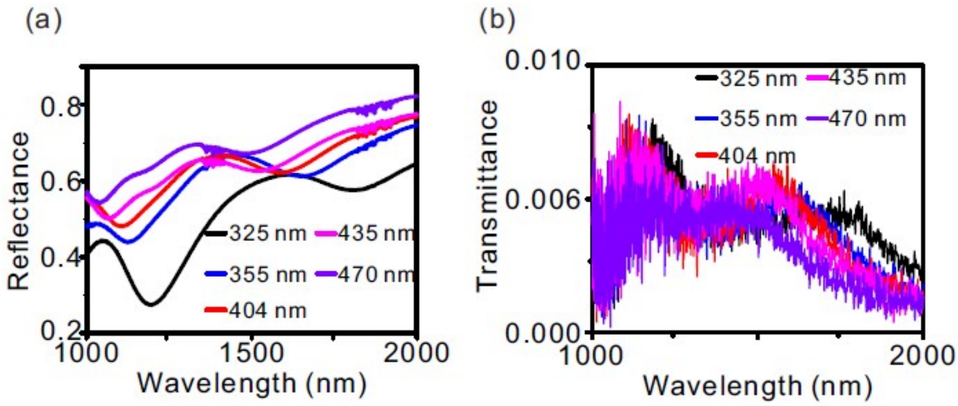

Fig. S2 Reflectance (a) and transmittance (b) spectra obtained from nanogrooves with different widths.

3. Photocurrent of nanogroove patterned photodiode with various widths

All devices are illuminated with a 1550 nm laser, and the power density is set as 0, 41, and 168 mW/cm^2. All devices are measured without a gate bias, i.e., with a floating gate.

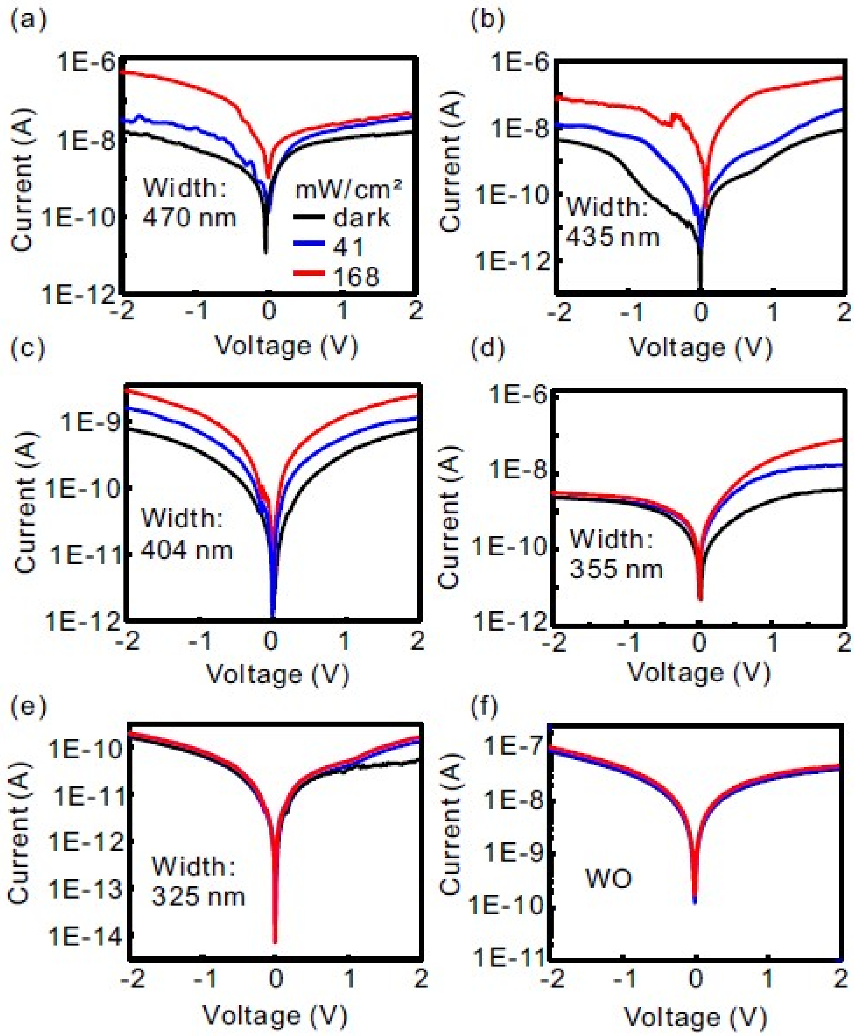

Fig. S3 Photocurrent of nanogroove patterned photodiode with various widths: (a) 470 nm, (b) 435 nm, (c) 404 nm, (d) 355 nm, and (e) 325 nm. (f) demonstrated the result from Si nanomembranes without nanogroove.

4. The response speed

Four on-off response cycles with different incident powers are depicted in Fig. S4(a). With incident power increasing, the on-state step gradually rising up (blue line), which is due to the thermal effect under large power intensity. And each rising and falling time of corresponding incident power was shown in Figs. 3(b) and 3(c), respectively. The average rising and falling times are ~59.3 and ~78.9 ms respectively, and are corresponding to hot holes injection and carriers recombination, respectively.

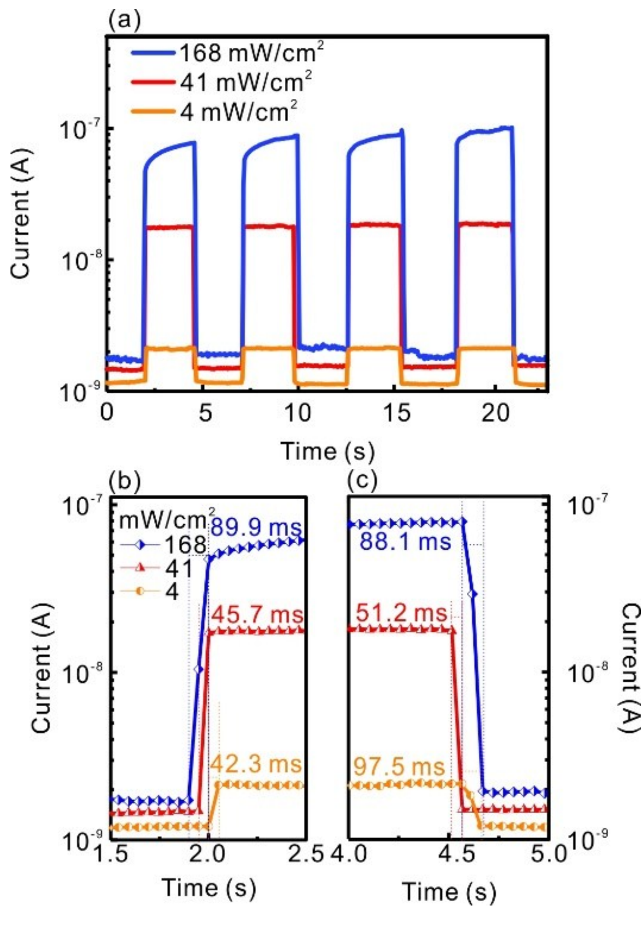

Fig. S4 Response time characterization of the device at V_{DS} = 2 V. The illumination power is from 4 to 168 mW/cm^2.

5. The comparison between different subwavelength structures based on Si near

infrared photodetection.

Table S1 Comparison of the responsivities and I_{on}/I_{off} ratios obtained from different types of SPP induced Si-based photodetectors.

Structure	Materials	Wavelength	Responsivity	I_{on}/I_{off} ratio	Response speed	Year	Reference
Au nano gratings	Au/bulk Si	1450 nm	600 μA/W	/	/	2013	[2]
Si QDs	Graphene/Si QDs	1450 nm	10^9 A/W	10^2★	3.4 s	2017	[3]
Au gratings	Au/$SrTiO_3$/Si	1350 nm	80 μA/W	10^1★	Dozens ms★	2018	[4]
Au resonance wires	Au/MoS_2/Si	1070 nm	5.2 A/W	About 40★	1 s★	2015	[5]
Au nanoparticles	Au/n-Si	1250 nm	10 μA/W	/	/	2011	[6]
Au gratings	Au/ n-Si	1550 nm	17.5 μA/W	/	/	2016	[7]
Au nanoparticles	Au/Graphene/Si	1550 nm	10^2 A/W	10★	600 ns	2017	[8]
Nanogrooves	SiNM	1550 nm	7 mA/W	10^2	59.3 ms	2019	This work
Nanogrooves phototransistor	SiNM	1550 nm	812 mA/W	6×10^2	/	2019	This work

The data have been extracted from the references as indicated. ★Data calculated using the reference material.

6. Calculation of channel mobility

It is known that the carrier mobility can be calculated from the following function,[4]

$$\mu_{eff} = \frac{\partial I_{DS}}{\partial V_{DS}} \frac{L}{W C_{ox}(V_{GS} - V_{TH} - 0.5V_{DS})}$$

where $\frac{\partial I_{DS}}{\partial V_{DS}}$ is the slope of I_{DS}-V_{DS} curves in the linear region under the certain gate bias (V_{GS}), C_{ox} is the capacitance of the gate dielectric per unit gating area, V_{TH} is the threshold voltage, and L and W are the channel length and width, respectively. According to the above equation, the channel mobility was calculated.

7. Transfer curve of nanogroove-structured Si nanomembrane-based phototransistor in dark condition with on/off ratio of ~10^5.

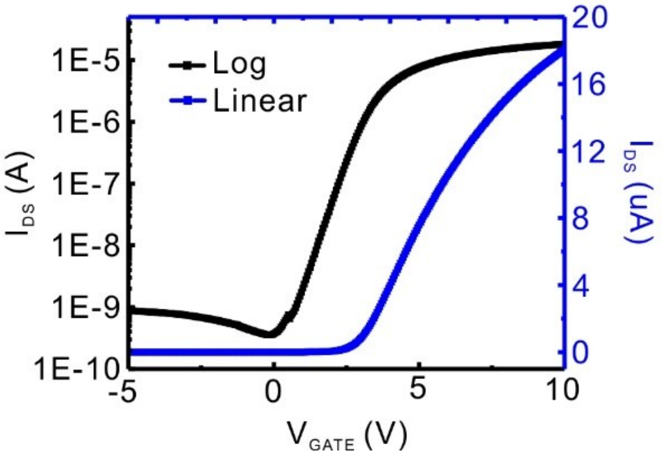

Fig. S5 Transfer curve of phototransistor in both semi-logarithmic and linear coordinate under dark at a V_{DS} of 2 V with on/off ratio of ~10^5.

8. Transfer curves of nanogroove-structured Si nanomembrane-based phototransistors with different widths.

All Si nanomembrane based phototransistors with different nanogroovewidths are measured under 1550 nm light illumination. During the measurement, the power density is tuned from 0-86 mW/cm^2, and the V_{DS} is set as 2 V. Transfer characteristics of all devices are extracted, as shown in Fig. S6.

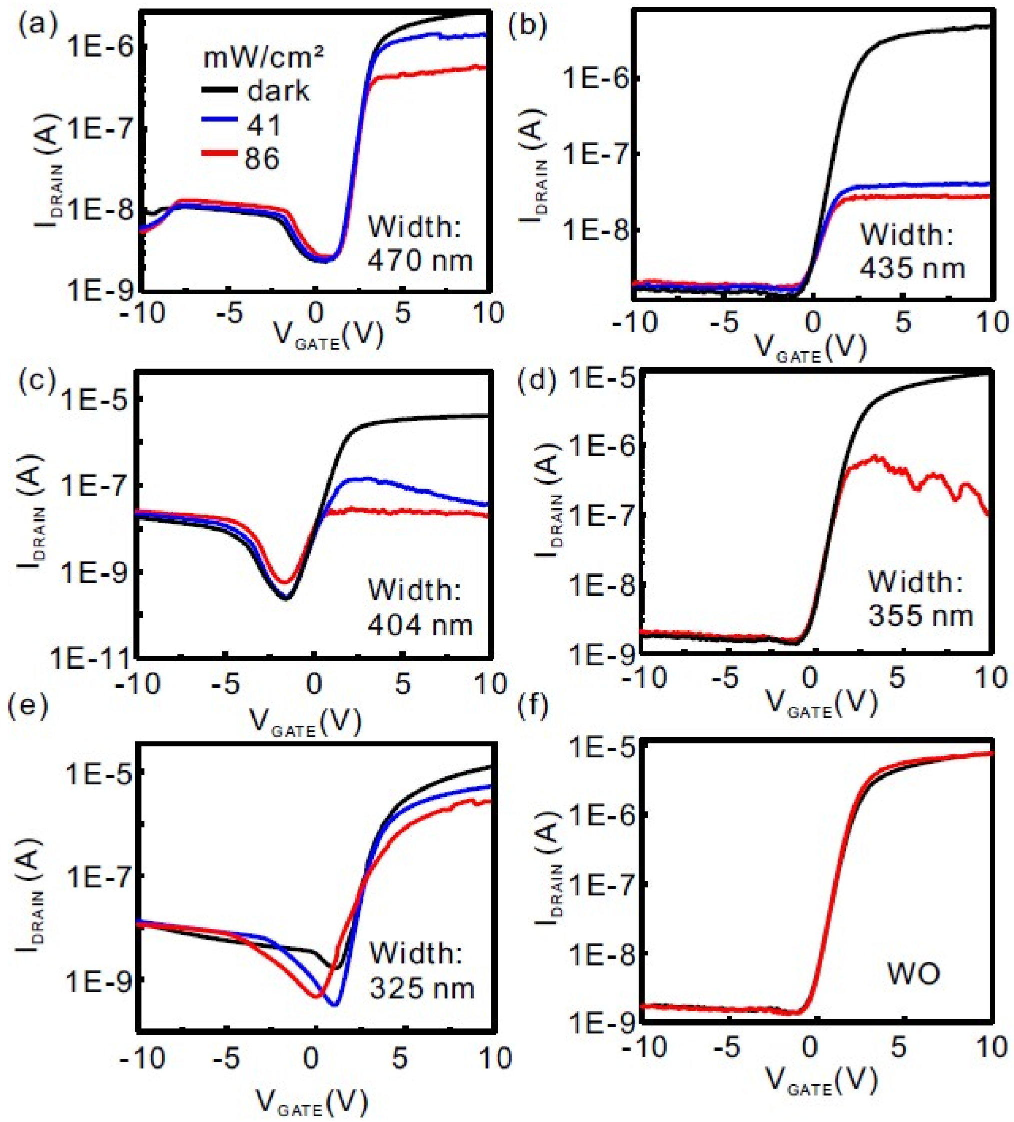

Fig. S6 Transfer characteristics of Si nanomembrane-based phototransistors with different nanogroove widths: (a) 470 nm, (b) 435 nm, (c) 404 nm, (d) 355 nm, and (e) 325 nm. (f) demonstrated the result from Si nanomembranes without nanogroove.

9. The threshold voltage shift vs incident light power

The reduced threshold can be estimated by the equation: $\Delta V_{Th} = (\Delta N_h \times e)/C_i$, where C_i is the capacitance per unit area of the dielectric layer, ΔV_{Th} is the shift of the threshold voltage, ΔN_h is reduced hole concentration, and e is the elementary charge. Under NIR illumination, hot hole injection has been demonstrated. While, under positive gate voltage, the electrons were driven to the interface between channel and gate dielectric layer, i.e. interface of SiNM/SiO_2. There would be a dramatic recombination between hot holes and electrons. ΔN_h is negative indicating the decreasing of hole concentration. Since ΔV_{Th} is proportional to $\Delta N_{h,}$ the threshold voltage shouldl decrease with such carrier recombination and holes concertation decreases. Hence, threshold voltage gradually decreases with the reduced hole concentration, as depicted in Fig. S7.

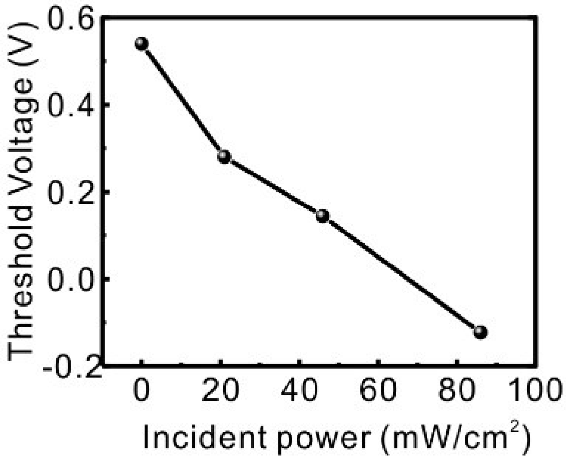

Fig. S7 Threshold voltage as a function of the incident light power.

Notes and references

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