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Supporting Information

Demonstration of low power high–speed graphene/Silicon heterojunction near–infrared photodetector

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1. Transferred graphene on patterned SiO_2/Si substrate

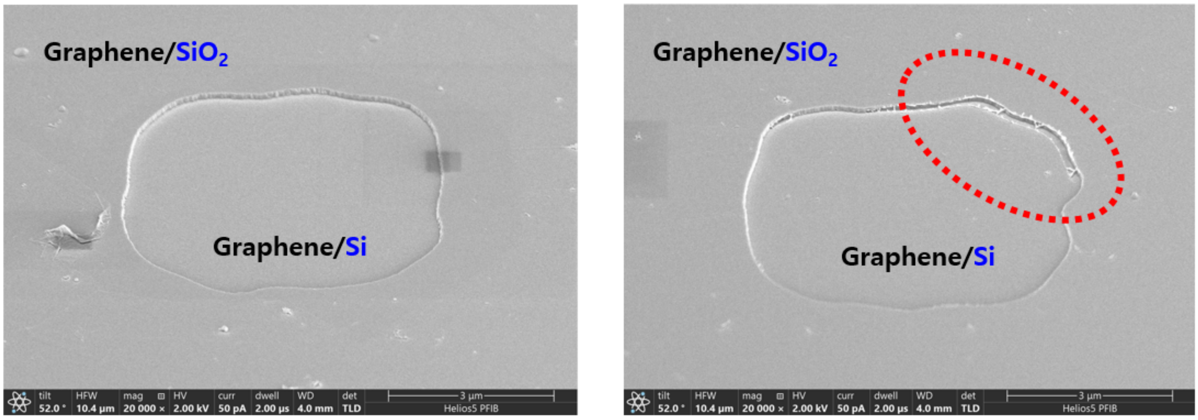

Fig. S1 (a) SEM image of SiO_2/Si substrate with partially etched Si (b) Graphene image with some damage (red circle area)

2. Setup for measuring the photocurrent characteristics

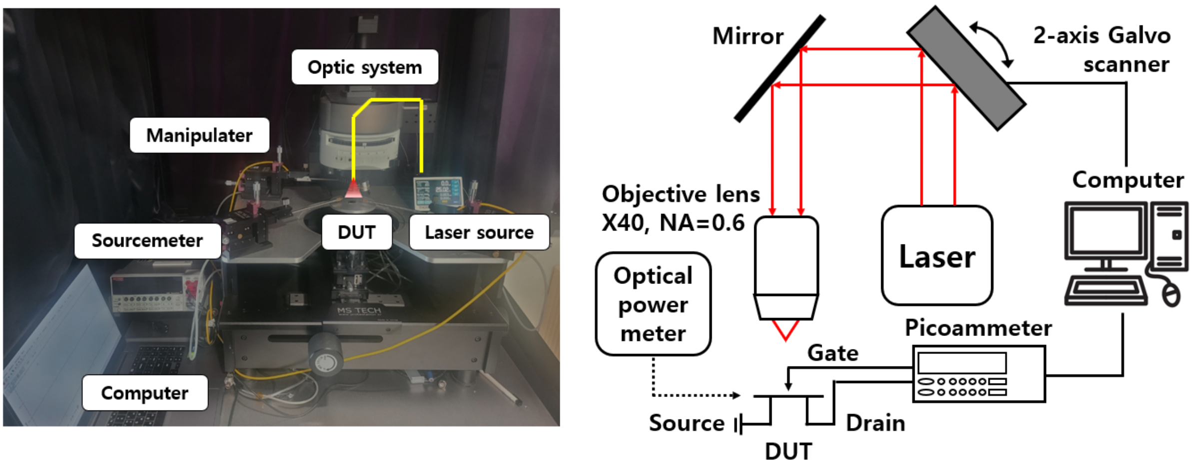

Fig. S2. (a) The measurement setup for photocurrent characteristics (b) Diagram of the photocurrent measurement setup

A continuous–wave laser beam of 850 nm wavelength from the solid–state laser diode and controller (Thorlabs LP850–SF30) was focused onto the sample through a 40× objective lens (Olympus LUCPlanFLN, 40×, NA=0.6). Electrical measurements were performed using the Keithley Model 4200 parameter analyzer. The Newport Model 1918–C hand–held optical power meter and 919P–003–10 thermopile sensor were used to measure the optical power. All measurements were performed under ambient conditions (T = 300 K, P = 1 atm) in the air.

3. Dirac voltage of graphene

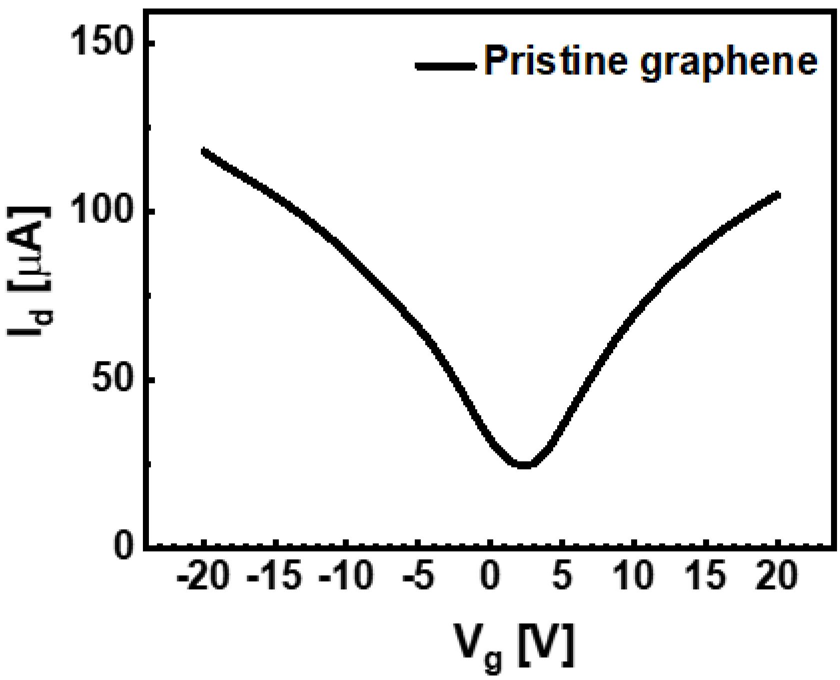

Fig. S3: Dirac voltage of the graphene

Dirac voltage at the graphene FET used to fabricate the devices. The Dirac point exists between approximately 2 and 3 V.

4. Device parameters used to extract the Schottky barrier height

Parameter	Value
Temperature [K]	300
Si carrier concentration [cm^{-3}]	10^{18}
Si Richardson constant [A/cm^2K^2]	120
Device area (Graphene channel) [μm^2]	50×50

Table S1. Our device parameters used to extract the Schottky barrier height at I–V curve

The Schottky barrier height of our device was calculated using the reverse saturation current by I–V characteristics at a fixed temperature. Equation (1) in the text can be expressed as the equation below, and ln(I_S) allows the calculation of the Schottky barrier height.[1,2]

$$I = AA^*T^2 exp\left(-\frac{q\Phi_b}{kT}\right)\left[\exp\left(\frac{qV}{nkT}\right) - 1\right], \quad (1)$$

$$\ln\left[\frac{I}{1 - \exp\left(-\frac{qV}{kT}\right)}\right] = \ln I_S + V\left(\frac{q}{nkT}\right),$$

Where I_S is the reverse saturation current of the Schottky diode, A is the device area, A* is the Richardson constant of Si.

$$\varphi_b = \frac{kT}{q} ln\left(\frac{AA * T^2}{I_S}\right)$$

5. Calculation of carrier collection time in bulk Si–based photodetector

Under illumination conditions, a photocarrier is formed, and photocurrent flows as the generated carriers move to the electrode. In general, photocarriers are generated in the depletion region of the graphene/Si junction, but in the case of a graphene/bulk Si photodetector, additional gain can be obtained by forming carriers far away from the Si substrate.[3] To calculate the approximate photocurrent rise time of the Graphene/bulk Si photodetector, the equations and parameters below were used.

$$v = \mu E, \quad \text{(Carrier velocity = mobility} \times \text{electric field)} \tag{2}$$

$$E = -\frac{qN_D}{\varepsilon_S}W \quad \text{(Electric field)}$$

$$W = [\frac{2\varepsilon_S}{qN_D}(V_{bi} - V_a)]^{1/2} \quad \text{(Depletion width)}$$

Parameter	Value
Donor density, N_D [cm^{-3}]	$10^{17} \sim 10^{18}$
Si permittivity, ε_S [F/m]	$11.8 \times 8.85 \times 10^{-12}$
Elementary charge, q [C]	1.602×10^{-19}

Table S2. Our device parameters used to calculate the rise time

Rise time was calculated using the carrier velocity obtained above. Not all parts of the bulk Si substrate were considered (it was assumed that photocarrier generation would be minimal in areas too far away), and it was assumed that carriers were collected up to the boundary of the drain electrode. As a result, the rise time was calculated to be approximately 11 to 22.1 μs, which was consistent with the actual measured value (12.6 μs).

References

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2 E. H. Rhoderick and R. H. Williams, *Metal–Semiconductor Contacts*, Clarendon press, Oxford, 1988.
3 K. E. Chang, T. J. Yoo, C. Kim, Y. J. Kim, S. K. Lee, S–Y. Kim, S. Heo, M. G. Kwon and B. H. Lee, *Small*, 2018, **14**, 1801182.