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Electronic Supplementary information

Upconversion nanoparticles enhanced Graphene/GaAs self-driven near-infrared photodetector

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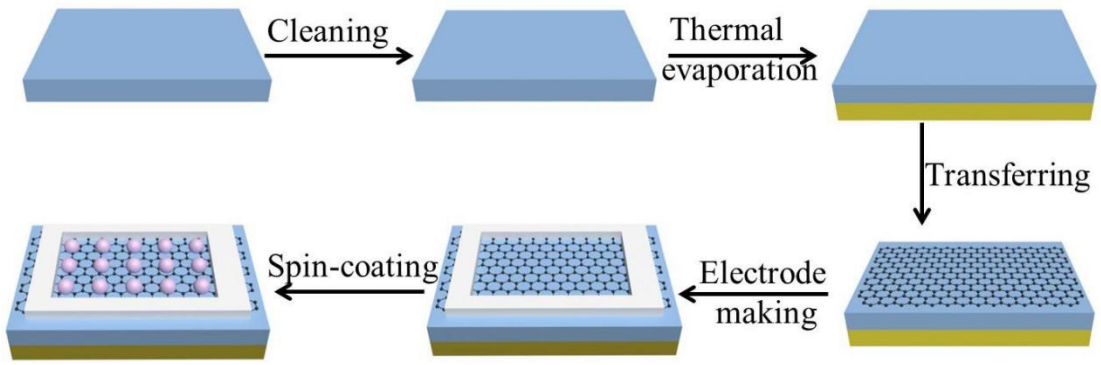

Fig. S1 The detailed fabrication process for UCNPs/graphene/GaAs heterojunction photodetector. After soaking in dilute hydrochloric acid for 3 min, GaAs is thermal evaporated of Au in order to construct back electrode. Trilayer graphene is transferred onto passivated GaAs. PMMA on the surface of graphene is removed by acetone. Subsequently, front rectangular electrode is constructed by silver paste. Eventually, UCNPs is dropped on the active area to promote the sensing characteristics of near infrared light at the wavelength of 980 nm.

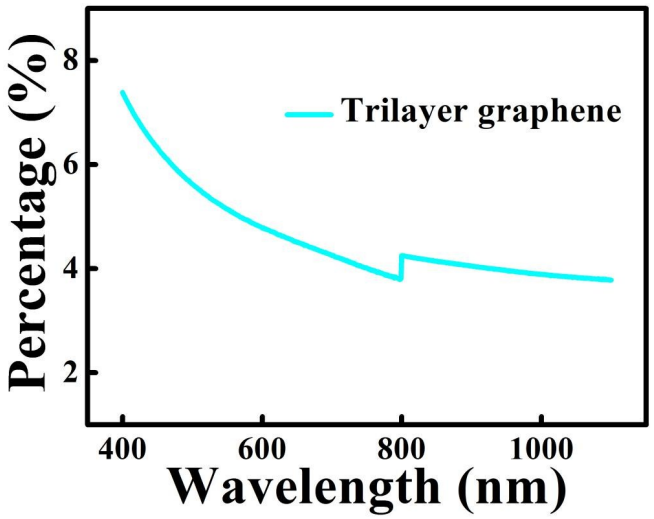

Fig. S2 Absorption spectrum of the trilayer graphene. It can be seen that graphene sheet exhibits good absorption characteristics from 400 nm to 1100 nm. Multilayer graphene sheet, therefore, can work as photoactive material in near infrared region.

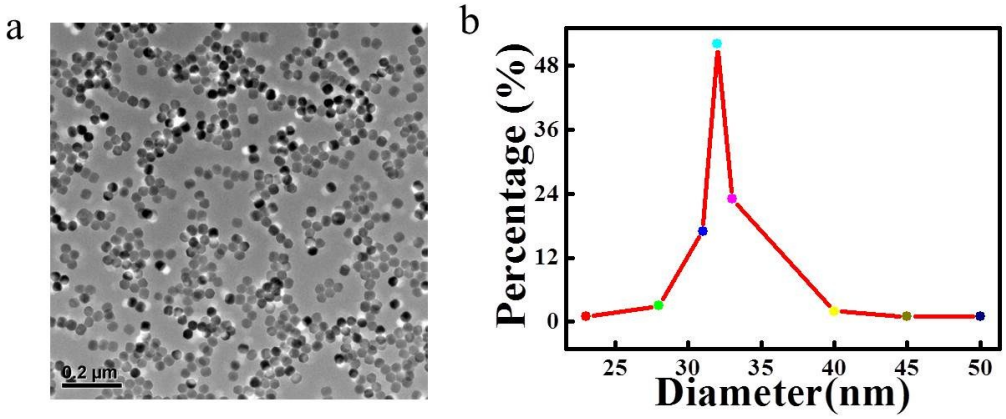

Fig. S3 Characterization of $NaYF_4$:Yb^{3+},Er^{3+} upconversion nanoparticles (UCNPs). (a) Low-magnification transmission electron microscope (TEM) image of UCNPs. (b) Size distribution of UCNPs. The average diameter value is about 33 nm.

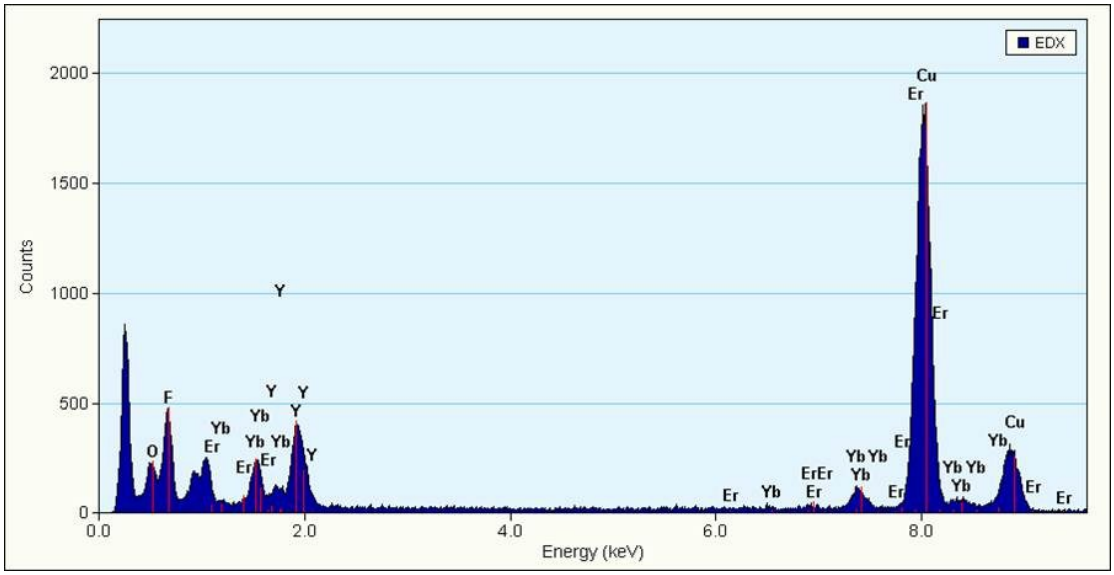

Fig. S4 EDX of UCNPs. The peak of Cu element completely derives from Cu grid and O element may be attributed to solvent and oxidized Cu.

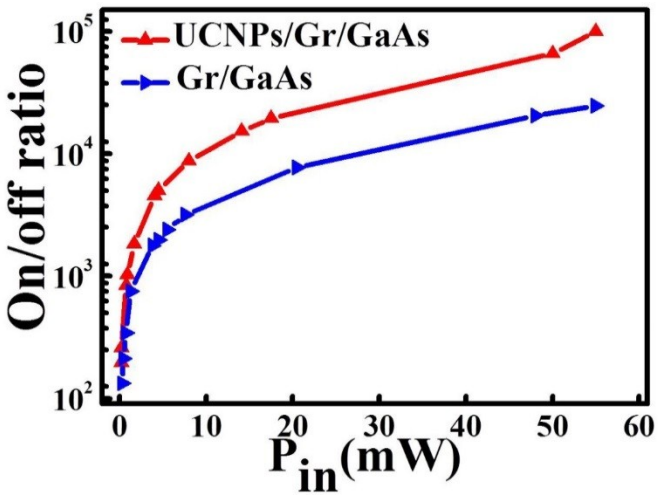

Fig. S5 On/off ratio (OFR) values of the NIRPDs without and with UCNPs under illumination of 980 nm. The value of OFR is deduced from the ratio of I_p and I_d.

$$OFR = \frac{I_p}{I_d} \tag{1}$$

The values of OFR for the device with UCNPs are several times higher than those without UCNPs, resulting from the enhancement of photocurrent.

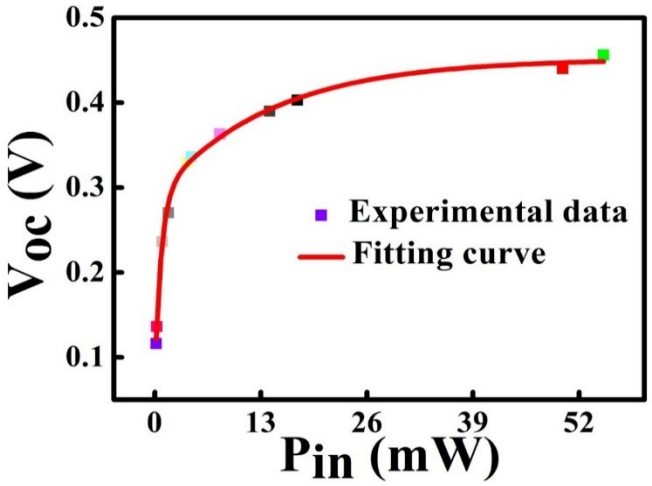

Fig. S6 Experimental data and fitting curve of V_{oc} with different incident light power.

The relationship between V_{oc} and incident light power can be expressed in an exponential mathematical function as follows:

$$V_{oc} = -0.21 \times \exp\left(-\frac{4P_{in}}{3}\right) - 0.16 \times exp(-\frac{P_{in}}{13.9}) + 0.45 \quad (2)$$

The model shows a great agreement between the experimental data and the fitting results.

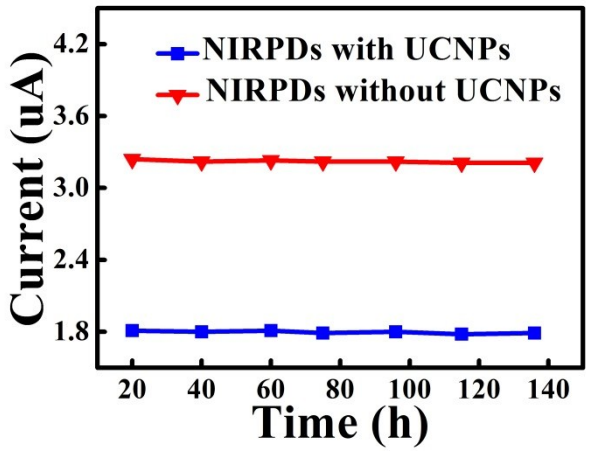

Fig. S7 Stability of graphene/GaAs NIRPD with and without UCNPs. As shown in in Figure S7, current degradation is as low as 1.1%, indicating good stability for sustained operation of these devices.

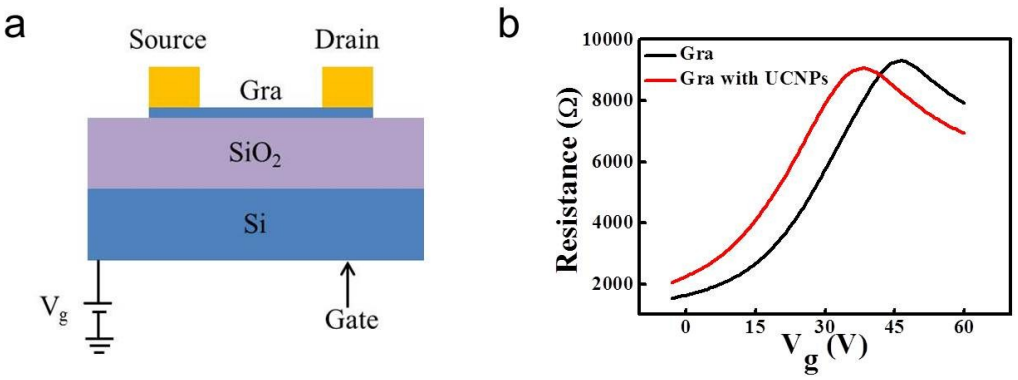

Fig. S8 (a) Field effect transistor based on graphene. (b) Resistance as a function of back-gate voltage for graphene with and without UCNPs. The change of graphene resistance results from the doping of UCNPs.