Electronic Supplementary Material (ESI) for Nanoscale.

Ultra-high sensitivity infra-red detection and temperature effects in graphene – tellurium nanowire binary hybrid: (Supplementary Information)

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S1. Growth and synthesis technique of the TeNWs:

The synthesis of TeNWs was carried out using a reported procedure [1]. In a typical synthesis, 89 mg of Na_2TeO_3 and 1.00 g of PVP (molecular wt. = 55,000) were dissolved in 35 ml de-ionized (DI) water. Then 1.65 ml hydrazine hydrate (N_2H_4. H_2O) and 3.35 ml NH_3 solution were added to the solution. Then the whole solution was transferred to a teflon-lined stainless steel autoclave, and heated at 180^0 C for 4 h. The resultant black product was extracted with acetone and was subjected to rigorous washing with warm DI water to remove the PVP from the nanowire surfaces.

The ultrathin TeNWs used for devices were fabricated via a wet-chemical technique through the following reaction, wherein hydrazine (N_2H_4) reduces the Te^{4+} in Na_2TeO_3 to elemental tellurium:

$$TeO_3^{2-} + N_2H_4 = Te + 2OH^- + H_2O + N_2$$

PVP used in the reaction acts as a capping agent, restricting the nanowire diameter. The large quantity of PVP present in the reaction medium ensures the formation of the thin nanowires [1–4].

S2. Structure and DFT calculation of the TeNWs:

Tellurium, being trigonal in the crystal structure, has a 3_1 screw axis along the *c*-axis. This results in an inherent anisotropy in the bulk structure along the *c*-axis. Consequently, Te prefers to grow in an one-dimensional morphology along this direction. An idealized structure of a TeNW is shown in Fig. S1(a). All the marked atoms (A, B and C) are located in different planes along the [0001] direction along the mentioned screw axis. Furthermore, given the NW has an ideal $\{11\bar{2}0\}$ faceting, it can be thought of constituting concentric hexagons on $\{0001\}$ planes.

The DFT calculation of the TeNWs is shown in Fig. S1(b), which gives a direct band gap of ≈ 0.65 eV for the nanowire. Both the figures S1(a) and S1(b) have been taken from [5].

S3. Dropcasting technique of the TeNWs over the substrate:

A special technique was developed in order to dropcast the TeNWs as uniform as possible over the graphene surface. At first a dispersion was made using TeNW and ethanol with a volume ratio of 1:5, followed by an ultrasonication for about 5 mins. The ultrasonication

power broke the heavy clusters of TeNWs which were conglomerated together initially. After the ultrasonication, the whole dispersion became uniform in colour (almost like a perfect solution). This solution was centrifuged with 10,000 rpm for about 10 mins in order to get rid of the thicker TeNWs. Once the whole solution got centrifuged, the cleaner part of the solution was separated out and used for dropcasting on the sample or on a substrate. In order to keep the dropcasting as uniform as possible, we took the help of spin coater. The sample was rotated in the spin coater with 4,000 rpm for about 30-40 secs, when 1-2 drops of the solution were dropcast. And this process was repeated several ($\sim$ 10) times. By this method, we finally achieved a very thin and uniform coating of TeNWs of graphene layer or on the substrate. Fig. S2(a) shows the uniform coverage of the dropcast nanowires on a blank substrate in the optical image, whereas the corresponding SEM image has been shown in Fig. S2(b).

S4. HRTEM image of a single TeNW:

The high resolution transmission electron microscopy (HRTEM) image of a grown single TeNW has been shown in Fig. S2(c), which clearly establishes the high single crystalline nature of it. The image also shows a typical diameter of the nanowire $\approx$ 7 nm.

S5. Speed of graphene - TeNW photodetector:

The relaxation time (τ) associated with the change in the photocurrent (I_P) as a function of time, once the optical illumination was switched on, has been extracted in Fig. S3. The gate voltage (V_G) was -2 V and the optical power density P was kept at 7741 fWμm^{-2}. The corresponding decay in I_P has been fitted with an exponential function ($\sim$ 1 - exp($-\frac{t-t_0}{\tau}$)), with $t_0 \approx$ 121 s, the time when optical illumination was switched on.

The extracted relaxation time or decay time (τ) $\approx$ 700 msec, is consistent with the lock-in amplifier parameters (time constant = 300 msec at the roll-off of 24 dB/octave), which indicates that measurement electronics is the speed limiting factor.

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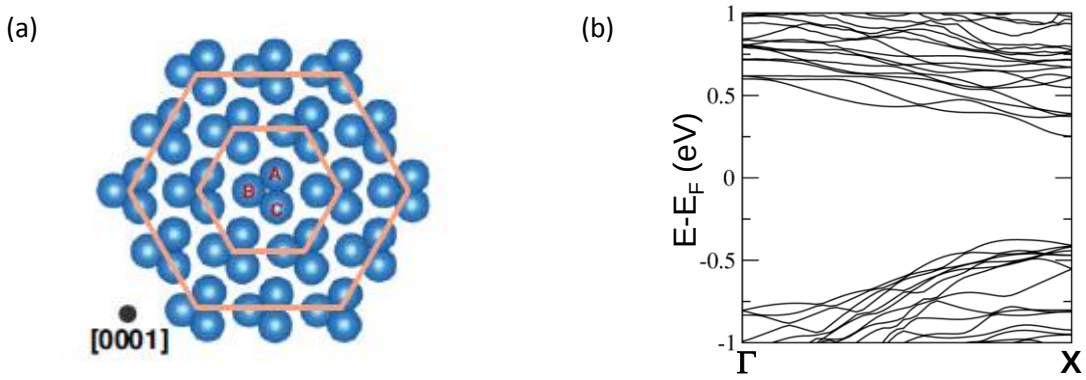

Figure S1: (a) [0001]-projection of the TeNW trigonal atomic structure. (b) DFT calculation of the TeNW, showing a direct band-gap ≈ 0.65 eV at X point.

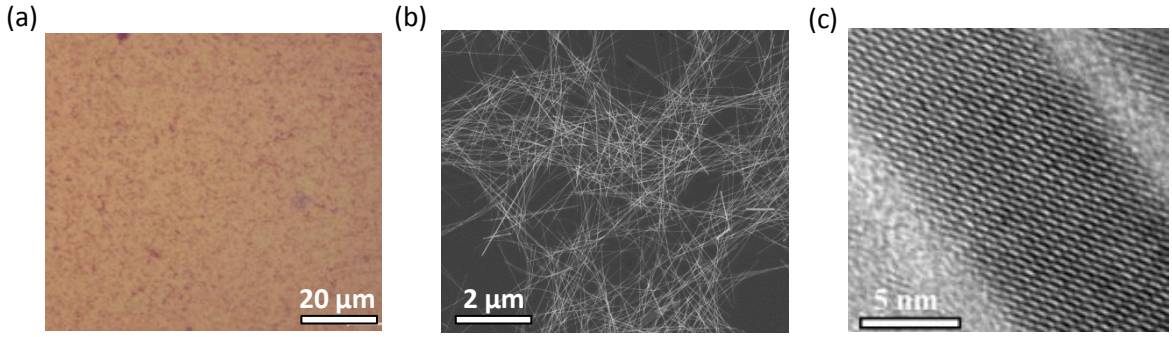

Figure S2: (a) Optical image of the dropcast TeNWs on a blank substrate. (b) SEM image of the same dropcast TeNWs shows a very thin and uniform coverage over the substrate. (c) HRTEM image of a single TeNW shows its high quality single crystalline nature as well as a diameter ~ 7 nm.

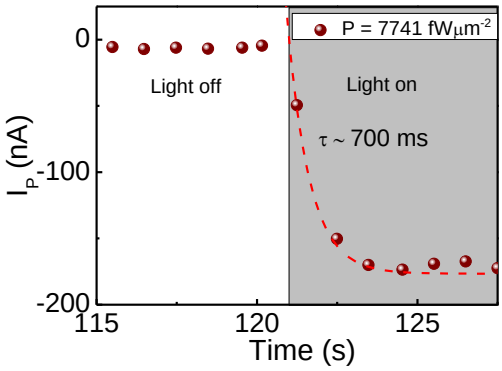

Figure S3: The relaxation time (τ) estimation from an exponential fit of the decay in photo-current (I_P) at $V_G = -2$ V and $P = 7741$ fWμm^{-2}. We get $\tau \sim 700$ msec from the fit.

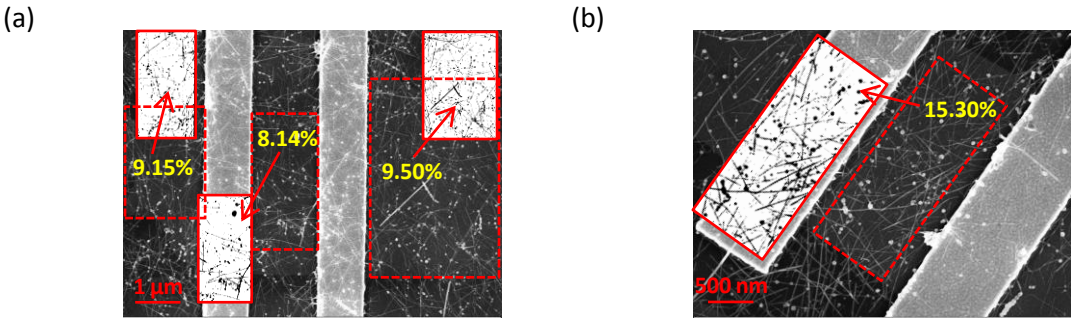

Figure S4: (a) Area fraction calculation of TeNWs on graphene from SEM image. The scanned area is shown with red border, along with the contrast mapping (inset). The value of the area fraction has been mentioned in yellow. (b) Area fraction shown in an image (of a similar device) with increased magnification. Overall we get an area fraction $\sim 10 - 15\%$.