Supporting Information

A Novel Solution-Gated Graphene Transistor Biosensor for Ultrasensitive Detection of Trinucleotide Repeats

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Working mechanism of SGGT sensors

The channel current I_{ds} of a SGGT at fixed V_G and V_{DS} is given by the following equation [1,2]:

$$I_{ds} = \frac{q\mu p_0 tW}{LV_P}\left(V_P - V_G^{eff} + \frac{V_{DS}}{2}\right)V_{DS} \quad (\text{when } |V_{DS}| << |V_P - V_G^{eff}|) \tag{1}$$

$$V_P = \frac{qp_0 t}{c_i} \tag{2}$$

$$V_G^{eff} = V_G + V_{offset} \tag{3}$$

Where q is the electronic charge (1.602×10^{-19}), t is the thickness of the active layer, μ and P_0 are the hole mobility and initial hole density of the channel, respectively. V_P and V_G^{eff} are the pinch-off voltage and effective gate voltage of the transistor, respectively. V_{offset} is the offset voltage at the interfaces. W and L are the width and length of the graphene channel of SGGT device, respectively. C_i is the effective gate capacitance which is related to the capacitances of C_{GE} and C_{EC}.

$$V_G = V_{GE} + V_{EC} = (1 + \frac{C_{EC}}{C_{GE}})V_{EC} = (1+\gamma)V_{EC} \tag{4}$$

$$V_{GE} = -2.30\frac{kT}{2q}log[W_{DNAzyme}] + C_1 \tag{5}$$

$$V_{EC} = V_G + 2.30\frac{kT}{2q}log[W_{DNAzyme}] - C_1 \tag{6}$$

$$V_G^{eff} = 2.30(1+\gamma)\frac{kT}{2q}log[W_{DNAzyme}] + C_2 \tag{7}$$

$$I_{DS} \propto \alpha log[W_{DNAzyme}] + constant \tag{8}$$

$\gamma = C_{EC}/C_{GE}$; C_1 and C_2 are constant, and $W_{DNAzyme}$ is the amount of DNAzyme modified on the gate. T and K are the room temperature and Boltzmann constant.

Because the immobilization and hybridization of DNA on the gate electrode show little effect on C_{GE}. According to the Equation (3), the change of transfer curve could be ascribed to the V_{offset}. The V_{offset} is also related to that two interfaces. Due to the DNA is immobile on the gate，

$$C_i = \frac{C_{EC}C_{GE}}{(C_{GE}+C_{EC})S}$$

(10)

$$\Delta V_{offset} = \frac{nQ_{DNA}}{\varepsilon_t \varepsilon_0} t_{DNA} \tag{11}$$

where n is the density of DNA molecules on the surface, Q_{DNA} is the pure charges for one DNA molecule, S is the area of graphene active area. Immobilization and hybridization of the DNA on the gate electrode has a small effect on the gate capacitance [3]. ε_t is the relatively dielectric constant of DNA layer, ε_0 is the dielectric permittivity of the free space, and t_{DNA} is the thickness of the DNA layer.

Step of wet transfer of graphene

Glass flakes as the substrate of the device needed to be etched by hydrofluoric acid and DI water mixture solution (v: v=1: 7) for 1min to make sure the surface irregularity first. Then, the glass flakes were thorough ultrasonically cleaned in acetone (5 min), ethanol, and DI water respectively, followed by N_2 drying. Chromium and gold were deposited on the substrate using a thermal evaporator through a shadow mask. Chromium layer was deposited before gold layer for gold better adhering. The copper (Cu) foil having a graphene layer on both sides was cut into a suitable size (3×3mm). A layer of polymethyl methacrylate (PMMA) was spin coated onto the front side graphene/Cu sheet and cured at room temperature for 10 minutes. The oxygen plasma etched back side graphene and the patterned glass flakes to change the surface from hydrophobic to hydrophilic to facilitate the transfer of graphene. Subsequently, $Fe(NO_3)_3$ solution was chosen to dissolve the copper substrate for 2~3h.The formed PMMA/graphene was transferred to the modified-flakes after it was rinsed with DI water for 3 times to remove residual $Fe(NO_3)_3$. After drying naturally, modified-flakes covered with PMMA/graphene layer were heated on stirring hot plate at 90 ℃for half an hour and placed in acetone solution at 60 ℃ for 3 hours to remove the layer of PMMA. Finally, these were stored in the glove box for further use.

Polyacrylamide gel electrophoresis experiment

A 15% native polyacrylamide gel was prepared using 10 x TBE buffer, TEMED, Acry/Bis 40% solution (19:1), APS and ultrapure water. By mixing 7 μL of DNA sample and 3 μL of 6×loading buffer as loading buffer, and placing it for 3 minutes, it was then injected into a polyacrylamide gel. Gel electrophoresis was carried out in 1 x TBE buffer at 120 V for 60 minutes, then the gel was removed and soaked for 5 minutes at a concentration of 0.1% Gel-Red dye. Finally scanned with Molecular Imager Gel Doc XR.

Table S1. DNA sequence used in the experiment.

Name	From 5'→3'
Capture DNA	Bio-$(CH_2)_6$ -TGGAGCGCTTCTCTGAGT
Target DNA	GAAGAAGAAGAAGAAGAAGAAGAAGAAGAAACTCAGAGAAGCGCTCCA
Reporter DNA	TTCTTCTTCTTCTTCAAAGGGTTGGGCGGGATGGGC
TGG	TGGTGGTGGTGGTGGTGGTGGTGGTGGACTCAGAGAAGCGCTCCA
ATT	ATTATTATTATTATTATTATTATTATTACTCAGAGAAGCGCTCCA
CAG	CAGCAGCAGCAGCAGCAGCAGCAGCAGACTCAGAGAAGCGCTCCA
CTG	CTGCTGCTGCTGCTGCTGCTGCTGCTGACTCAGAGAAGCGCTCCA
CCG	CCGCCGCCGCCGCCGCCGCCGCCGCCGACTCAGAGAAGCGCTCCA
CGG	CGGCGGCGGCGGCGGCGGCGGCGGCGGACTCAGAGAAGCGCTCCA

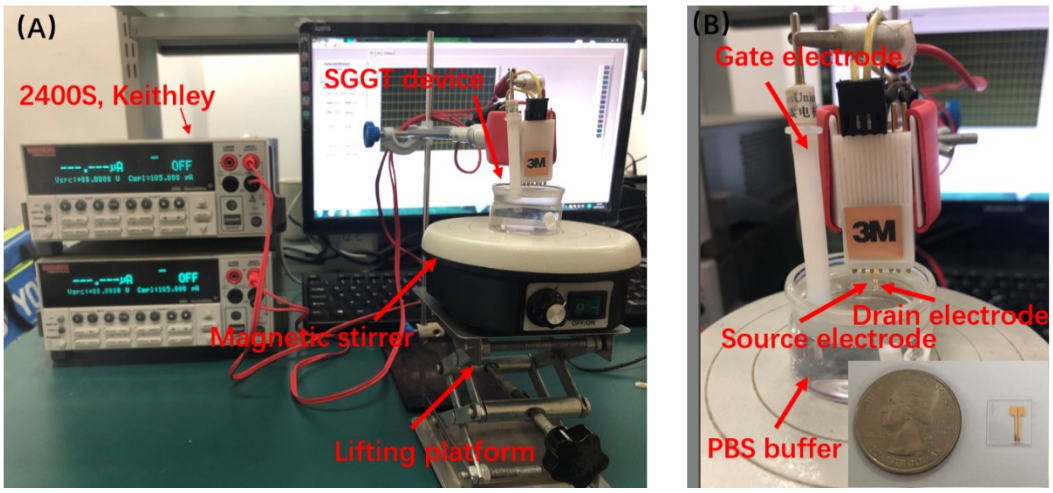

Fig. S1. (A) Actual test photo of the device. (B) structure photo of the device. Inserted image displayed that the real size of the chip compared with Quarter Dollar.

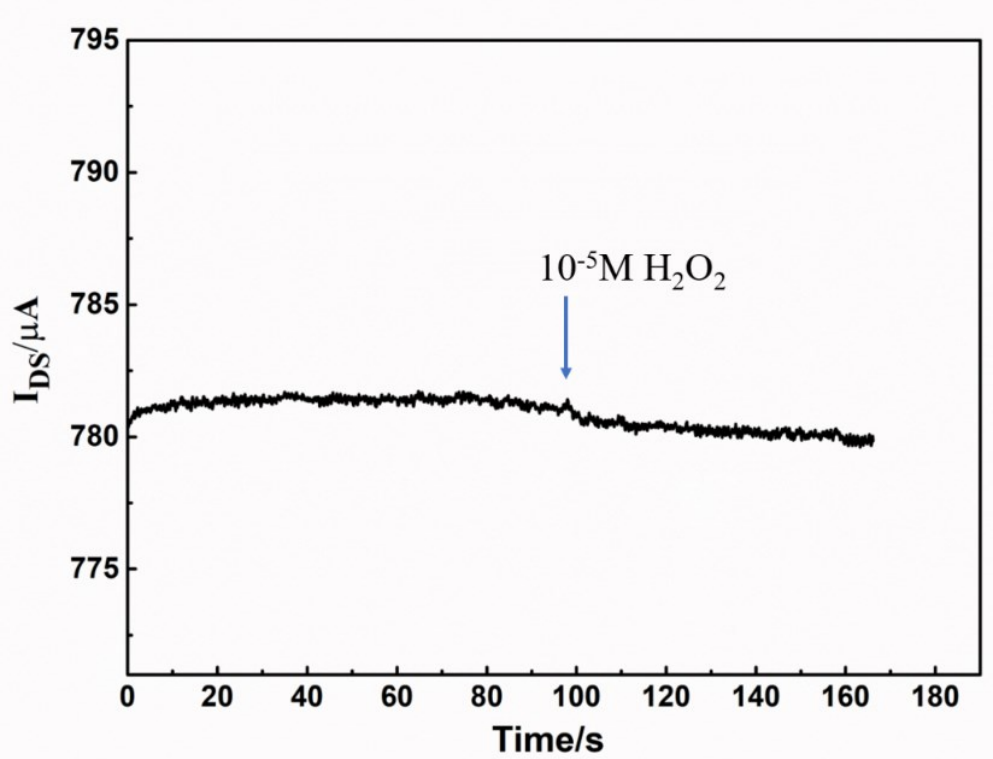

Fig. S2. The channel current response after adding 10^{-5} H_2O_2 to the electrolyte. (Ag/AgCl reference electrode is used as the gate electrode)

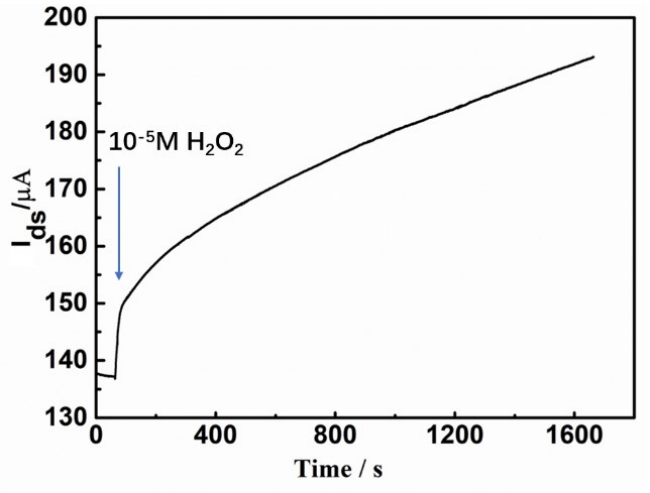

Fig. S3. The channel current responses of sensor to the addition of H_2O_2 at the operational voltages of V_G= 0.6 V and V_{DS}= 0.05 V on the broken graphene.

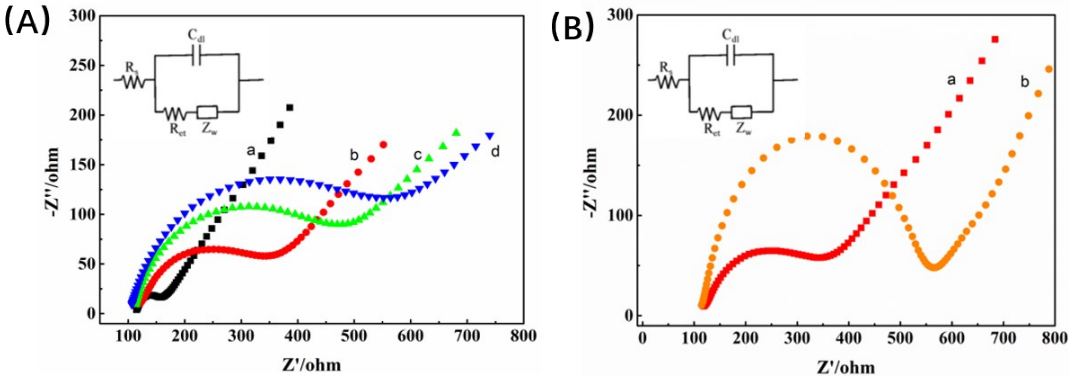

Fig. S4. (A) EIS (potential of 0.175 V, frequency range of 0.1 Hz to 100 kHz, alternating potential of 5 mV) of for the progressively modified gate electrodes, the points correspond to the (a)bare GCE (b)CHIT-SA/PANI/GCE (c)Bio-DNA/CHIT-SA/PANI/GCE(M-gate) (d)Hemin/Rep-DNA/T-DNA/M-gate.(T-DNA,100pM). (B) Nyquist plots of (a) CHIT-SA/PANI/GCE (b) CHIT-SA/GCE.

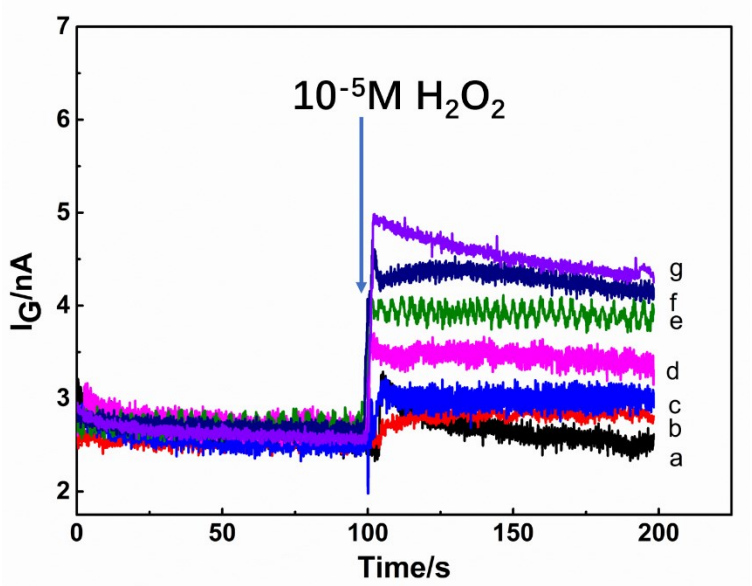

Fig. S5. Gate current of the SGGT during the additions of GAA TNR with different concentrations ((a) 0.1 pM; (b) 1 pM; (c) 10 pM; (d) 100 pM; (e) 1 nM; (f) 10 nM; (g) 100 nM).

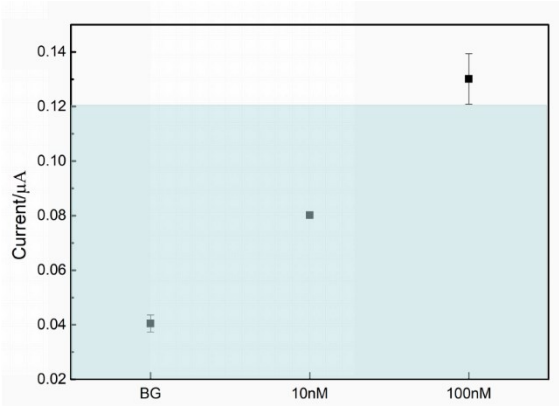

Fig. S6. A scatter plot of different concentrations of target DNA when DNAzyme-modified gate electrode was used as work electrode in traditional three-electrode electrochemical platform. The blue region indicates that a signal to noise ratio are less 3. The number of test samples for each set of data is 3.

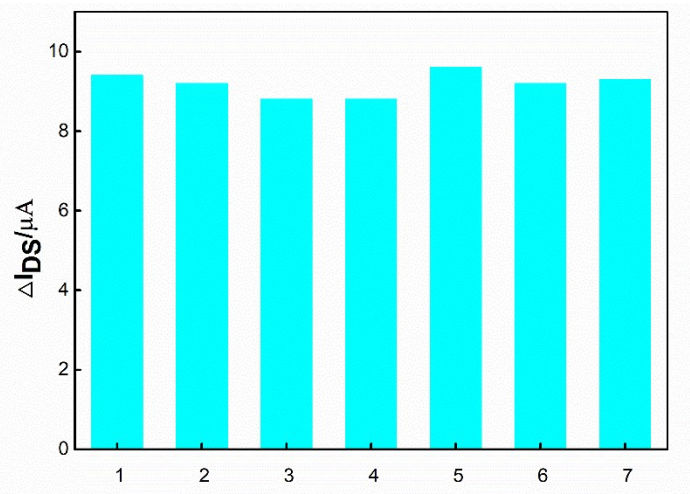

Fig. S7. The repeatability of the proposed sensor for the detection of target GAA TNR (10pM).

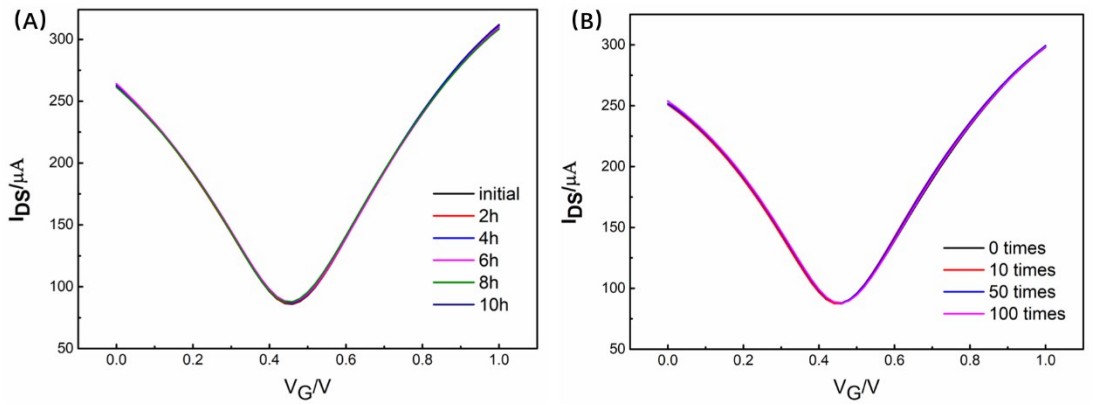

Fig. S8. The transfer characteristics of SGGT measured in PBS solution (A)from initial to 10h. (B) from 0 times up to 100 times.

Reference:

1. M. Zhang, C. Liao, Y. Yao, Z. Liu, F. Gong, F. Yan. High-performance dopamine sensors based on whole-graphene solution-gated transistors. *Adv. Funct. Mater.*, 2014, 24(7),978-985.
2. F. Yan, M. Zhang, J.H. Li. Solution-gated graphene transistors for chemical and biological sensors. *Adv. Healtic. Mater.*, 2014, 3(3), 313-331.
3. P. Lin, X. Luo, I.M. Hsing, F. Yan. Organic electrochemical transistors integrated in flexible microfluidic systems and used for label-free DNA sensing. *Adv. Mater.*, 2011, 23(35),4035-4040.