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Supporting Information

The tunable electrical properties of graphene bridge

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S1: Synthesis of GO films.

GO was prepared via the modified Staunedmaier method.[1] Firstly, a piece mixture of sulfuric acid (36 mL) and nitric acid (18 mL) was slowly poured into a reaction flask containing a magnetic stir bar and cooled by immersion in an ice bath followed by stirring. Natural graphite (2 g) was added under energetic stirring to avoid agglomeration. After the graphite powder was well dispersed, potassium chlorate (22 g) was added slowly over 30 min to avoid sudden increase in temperature. The reaction flask was allowed to stir for 96 h at room temperature. Also we used sodiun hydroxide solution to absorb the generated chlorine from the reaction mixture in order to avoid environment pollution. Secondly, the mixture was slowly poured into deionized water under stirting and then filtered after stratification. The products were dissolved in deionized water and washed in a solution of 5% HCl twice in order to remove sulfate ions. The color of the solution turned into brown-black from dark green after reduction of chloride ions. Thirdly, the brown-black solutions were diluted in deionized water and ultrasonicated for 30 min to achieve further exfoliation, and then centrifuged at 8000 r/min for 10 min in order to clean up the residual graphite. The collected supernatant was brown-yellow GO solution with homogeneous dipersion.

S2: Spectroscopic ellipsometry using Lorentz model fitting

The spectroscopic ellipsometry parameters of GO tanΨ and cosΔ are measured by ellipsometer in visible range (260-800 nm) at the incidence angle of 75°. We set up a three phase model substrate SiO_2/rGO/ambient to fit the ellipsometric spectrum. Lorentz oscillator model is added to characterize the dielectric function of GO described as follows:

$$\varepsilon=\varepsilon_1+i\varepsilon_2=\varepsilon_\infty(1+\sum_i \frac{A_i^2}{C_i^2-E^2-jv_iE}) ,$$

where ∞ is the light-frequency dielectric constant, Ai, Ci and vi are the amplitude, center energy, and damping coefficient of each oscillator in eV, respectively. The Ai value also represents the percentage contribution of oscillator i in the whole system. Also film thickness (d) is another unknown parameter in the fitting process and we define them as variables. These oscillators in fitting GO are defined as same as in our previous work.[2] The calculated ellipsometry spectrum show good accordance with experimental spectrum in Fig S1. The calculated thickness of GO is 7.3 nm. As we know, the thickness per GO layer is approximately 1 nm,[3] so our GO is estimated to be about 7 layers.

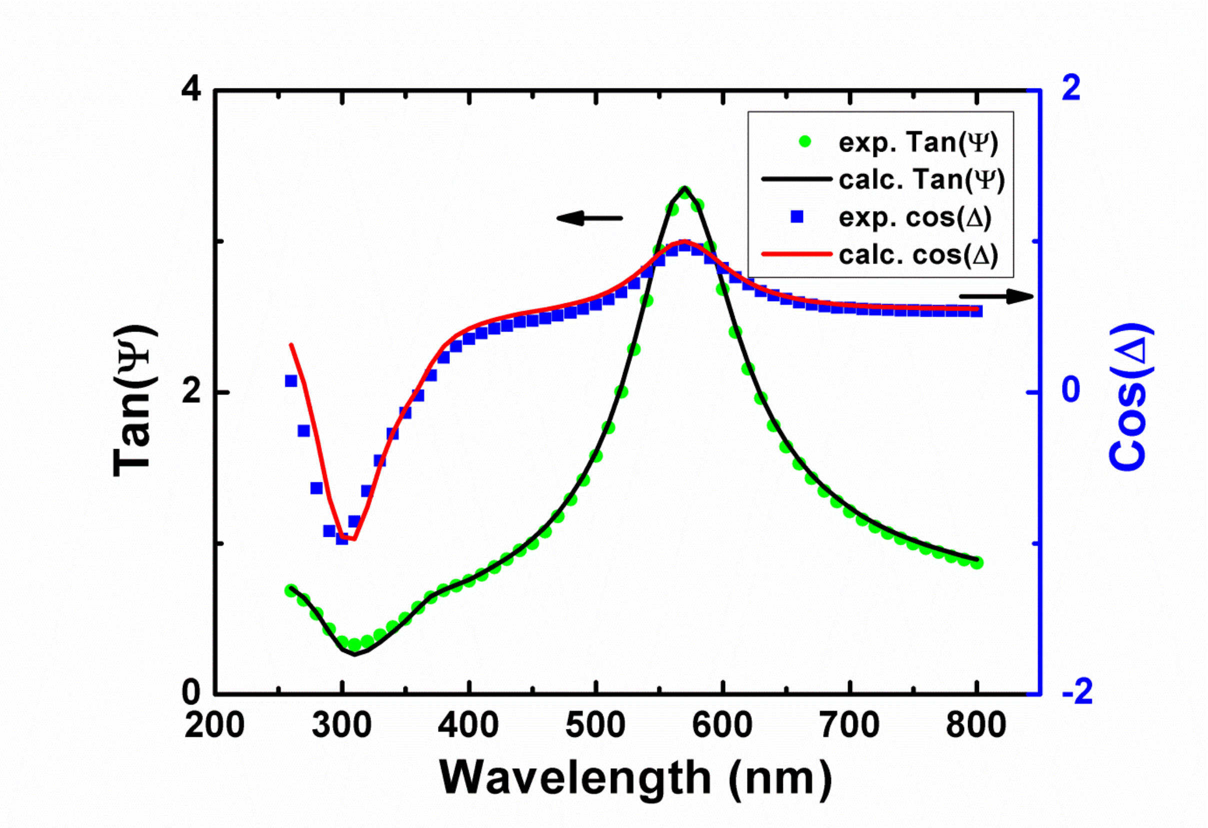

Fig S1. The experimental and calculated spectrum of ellipsometric parameters tanΨ and cosΔ of GO.

S3:The tunable bandgap with different reduction level by chemical method

We made one GO film and four other RGO films with different reduction level and we call them 1 (G), 2, 3, 4 and 5 (GO) in order which the larger number means less reducing time.

The reduction process may induce the variation of coverage, and different coverage state represents different electronic density of state[4]. Three main coverage of combination of oxygen and hydroxyl at 100%, 75% and 50% have the electron gap of approximately 2.8, 2.1 and 1.8 eV, respectively. The calculated band-gap energy descends in order from 2.0 to 0.02 eV from sample 5 to sample 1 as shown in Fig S2. It is obvious that the bandgap shift appears with different reduction level by chemical method. Therefore, we believe that the tip-induced electrochemical reduction of graphene oxide also has the tunable bandgap with elevated reduction bias.

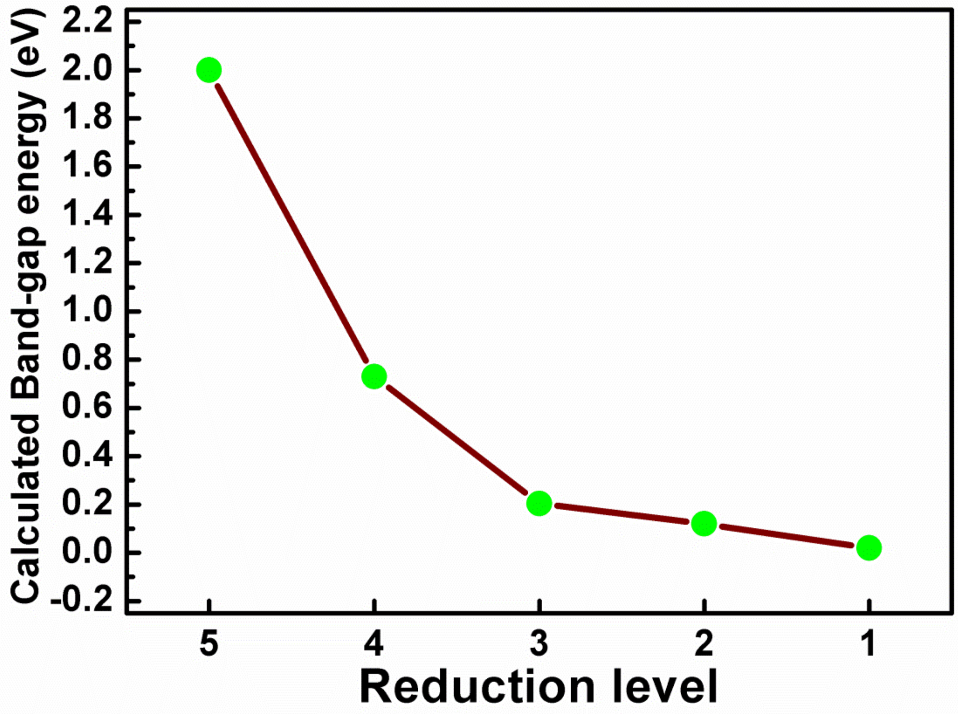

Fig S2. The experimental and calculated tunable bandgap of reduced GO with controllable reduction level by chemical reduction method.

S4:Device fabrication process and measurement method

Back-gated reduced GO transistors were fabricated with RGO as channel. First, GO films was carried out by vacuum filtration of the dispersion using a mixed cellulose ester membrane filter and spin-coated onto a heavily doped silicon substrate capped with a 300 nm layer of thermally grown oxide. Next, the source and drain electrodes made of Au metal (70 nm) were fabricated by e-beam lithography and liftoff. Finally, RGO channels were patterned by applying negtive bias voltages -8 V and -7 V between the Pt/Ir coated tip and one of the two electrode pads and scanning the tip between the two electrod pads in the contact mode.

Electrical characterization was performed using a Micromanipulator 450PM Manual Probe Station. An Agilent B1500A semiconductor analyzer software was used to source voltages and collect data.

S5: Mobility calculations

Field-effect mobilities were calculated using the formula $\mu = \left(\frac{\mathrm{d}I_{\mathrm{DS}}}{\mathrm{d}V_{\mathrm{BG}}}\right)_{\max} / \left(C_{\mathrm{BG}}\frac{\mathrm{W}}{\mathrm{L}}V_{\mathrm{DS}}\right)$. Here C_{BG} was taken to be the ideal value for 300 nm SiO_2 (the value of C_{BG} is 11.5 nF/cm^2). $\left(\frac{\mathrm{d}I_{\mathrm{DS}}}{\mathrm{d}V_{\mathrm{BG}}}\right)_{\max}$ is the maximum of the differential change in source drain current per differential change in back-gate voltage (V_{BG}) and they are 4.87×10^{-2} μA/V for holes and 2.79×10^{-2} μA/V for electrons,respectively. W/L is 0.4/10.5 here for this device.

Reference

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