Temperature coefficient of resistance of reduced graphene oxide

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The influence of technique parameters on the temperature coefficient of resistance (TCR) of reduced graphene oxide (RGO) films is studied. These technique parameters include the ultrasonic time, solution concentration, and heat treatment temperature. Results show that, the best technique parameters are ultrasonic time of 14 h, solution of 0.12 ml, and annealing temperature of 800 ℃, and on this point, TCR value of RGO is from −0.67% to −1.36% at the different film thicknesses.

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Graphene is two-dimensional (2D) electronic systems with a honeycomb lattice structure, and a large number of research both theoretical and applied aspects is attracted since the successful preparation. Temperature coefficient of resistance (TCR) of reduced graphene oxide (RGO) is less discussed because more research work focus on the tensile properties, stress performance, hydrothermal performance, and other properties[1]. It is very significant to study TCR of RGO for studying the infrared-sensitive materials, optical information storage materials, un-cooled infrared focal plane arrays, infrared modulator, and so on[2]. In this letter, RGO has been prepared under different conditions, and the relationships between TCR and technique parameters were obtained.

Firstly, three bottles of solution with the concentration of 0.2×10^{-3} g/ml were prepared, and its solute was the solid graphene oxide (GO), its solvent was de-ionized water. Secondly, three bottles of samples were respectively under ultrasonic treatment for 11, 14, and 17 h with ultrasonic power of 60% and ultrasonic temperature of 25°. The upper solution was used to manually coat on the JGS1 quartz substrate. The solution volume smeared on a quartz substrate was restricted as 0.08, 0.1, and 0.12 ml to control the film thickness. The film sample was placed in the drying oven of 70° for 5 min, and the samples were marked GO/SiO_2. Finally, GO/SiO_2 samples were annealed at 600 ℃, 700 ℃, and 800 ℃, respectively for 90 h in RTP-500, and these samples were marked RGO/SiO_2.

The resistances of samples were measured using the four-probe measuring instrument[3]. The measurement temperatures change from 10° to 40°, and its step-size is 2 ℃. TCR is calculated according to the tested resistance-temperature curve using[4]

$$\mathrm{TCR} = \frac{1}{R}\cdot\frac{\mathrm{d}R}{\mathrm{d}T}, \quad (1)$$

where $\frac{\mathrm{d}R}{\mathrm{d}T}$ is the differential sign and R is the resistance.

Figure 1 shows the relationship between the resistance and the temperature at the annealing temperature of 800 ℃ and the solution of 0.12 ml.

According to Eq. (1), TCR values of RGO are −0.68%, −0.95%, and −0.81%, respectively, corresponding to ultrasonic time of 11 h, ultrasonic time of 14 h, and ultrasonic time of 17 h. TCR value increases slowly with the ultrasonic time increasing[5]. It can be seen from Fig. 1 that the resistance decreases with the temperature increases and TCR value varied with the ultrasonic time. Three micrograms of ultrasonic time of 11, 14, and 17 h were respectively shown in Figs. 2(a), (b), and (c). The sheet structure is difficult, as shown in Fig. 2(a), there are more distinct sheet structure and stratification

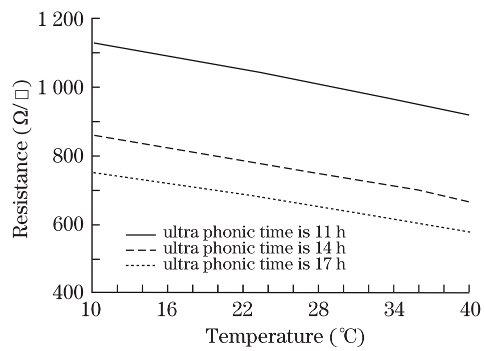

Fig. 1. Resistance-temperature curve under different ultrasonic time.

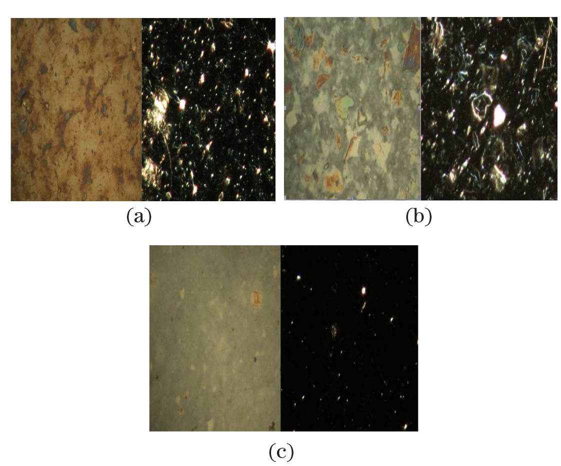

Fig. 2. Samples microgram in light and dark under ultrasonic time of (a) 11 h, (b) 14 h, and (c) 17 h.

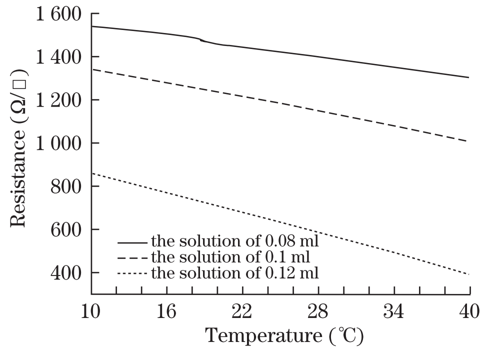

Fig. 3. Resistance-temperature of RGO film under different thicknesses.

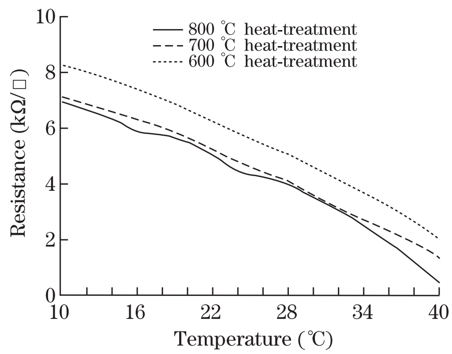

Fig. 4. Resistance-temperature curve of RGO under different annealing temperatures.

in Fig. 2(b) than Fig. 2(a), similarly, there are less and smaller sheet structure in Fig. 2(c) than Fig. 2(b). With the increase of ultrasonic time, there are more obvious sheet structures on substrate because the solid GO will dissolve fully in the de-ionized water and the outside shock improves the probability of molecular collision, thus the structure of GO became denser, and it is sensitive to the outside temperature[1,6]. However, the ultrasonic time is too long, GO sheet structure may be smaller, and the density of sheet structure is less.

Figure 3 is the measured resistance-temperature chart of RGO film at the ultrasonic time of 14 h and heat treatment temperature of 800 ℃.

According to Eq. (1), TCR values of samples are −0.67%, −0.88%, and −1.2%, respectively, corresponding to the solutions of 0.08, 0.1, and 0.12 ml. TCR absolute differences of two adjacent film thicknesses is 0.22 and 0.32. The result obtained from TCR absolute difference shows that TCR value changes quickly with the film thickness increasing[6]. It can be seen from Fig. 3 that each curve decreases with the temperature increasing. TCR of RGO varied with film thickness. The increasing film thickness leads to RGO sheet structure more evenly spread on the quartz substrate, and the sheet lapped together with tight structure[1,7]. Thus, RGO will be more sensitive to the change of outside temperature, and TCR value of 0.12 ml sample is biggest.

Figure 4 is the measured resistance-temperature curve with ultrasonic time of 14 h and solution of 0.12 ml.

According to Eq. (1), TCR values are −1.36%, −0.87%, and −0.69%, respectively, corresponding to the heat treatment temperatures of 800 ℃, 700 ℃, and 600 ℃. The TCR absolute differences of two adjacent annealing temperatures are 0.49 and 0.18. The result shows that TCR value changes slowly with the treatment temperature increasing[5]. It can be seen from Fig. 4 that, the resistance decreases with the temperature increasing. The reason may be that, the molecular bond adsorbing the water in the interlamination ruptured, and C-O-C,-COOH, -OH functional groups decomposed with the annealing temperature increasing[6]. As a result, RGO resistance changed quickly with the distance of RGO film layer reduced, and the structure got denser. What's more, C-C bond length in the plane expands rapidly, and C-C bond length between the layers shranks with the increase of temperature[1,2,7]. C-C bond contraction extent in the same layer is greater than the thermal expansion of the interlamination. Thus, the electron current increased fast, and the resistance changed quickly.

In conclusion, RGO is prepared under different technique parameters, and the influence of technique parameters on TCR of RGO is studied. The maximum TCR absolute differences of each situation are 0.27, 0.32, and 0.49, so the annealing temperature has a greater influence than the others. The ultrasonic treatment time of 14 h, annealing temperature of 800 ℃, and film thickness corresponding to the volume of 0.12 ml solution are the best technique parameter, and under this condition, the maximum TCR value is up to −1.36%.

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