Carbon 105 (2016) 244–247

Contents lists available at ScienceDirect

Carbon

journal homepage: www.elsevier.com/locate/carbon

Letter to the editor

An electromechanical behavior of reduced graphene oxide fiber

A B S T R A C T

An electromechanical response of the chemically reduced graphene oxide (rGO) fiber is reported. The rGO fiber has a tensile strength of 159 MPa, and an electrical conductivity of 170 S/cm. When a current is applied, an immediate load-drop, up to 82% of the original loading, can be observed. Such a load-drop is partially reversible when the current is withdrawn. Higher current density (5–20 mA) and higher relative humidity (40%–80%) result in larger load changes. Joule heating induced dynamic absorption and desorption of water molecules, which further induce the rGO sheet sliding and elastic deformation are responsible for this actuation.

Since the discovery of aqueous liquid crystal forms of graphene oxide (GO), significant progress has been achieved in graphene-based macroscopic structures, including fibers, films and aerogels [1–3]. Particularly, one-dimensional graphene-based fibers with both high mechanical properties and electrical/thermal conductivities have attracted extensive interest all over the world [4]. Although GO fibers should be further reduced to improve electrical conductivity, both GO and reduced GO (rGO) fibers have demonstrated great potentials in functional applications. For example, GO fibers show volume change in response to humidity variation via water absorption/desorption [5], and rGO fibers can be magnetically activated when incorporated with Fe_3O_4 nanoparticles [6]. In this letter, we report for the first time the observation of a rapid and obvious mechanical response of rGO fibers upon applying an electric current, which opens the door for future development of functional rGO fibers in fields of actuators and sensors.

The rGO fibers were synthesized by wet-spinning of GO fibers and then chemical reducing with hydriodic acid (Fig. S1). Fig. 1a shows a typical rGO fiber with an irregular cross-sectional shape, which is similar to both wet-spun and hydrothermally synthesized graphene-based fibers [4,6]. Insider the fiber, wrinkled rGO sheets aligned along the axis in a layered structure, and perpendicular to the fracture surface (Fig. 1b). This would be favorable for water molecules being trapped between the layers [7]. The nominal diameter d, which is about 38 μm, of the irregular-shaped rGO fiber is defined as the diameter of an equal area (A) circle, and calculated by: $d = \sqrt{4A/\pi}$. The tensile strength and electrical conductivity of the rGO fiber are measured as 159 ± 8 MPa and 170 S/cm, respectively.

Fig. 2 shows that the rGO fiber has an immediate and significant mechanical response when an electric current is applied (See Fig. S2 for the measurement set up). As shown in Fig. 2a and b, when currents of 5, 10, 15 and 20 mA are applied at the tensile loading of 20 mN, load-drops of 1.3, 5.8, 9.9 and 14.8 mN appear immediately. After the current withdrawal (lasting for 5 s), instant load-jumps are also observed (Fig. 2b), and the corresponding values are calculated to be 1.2 (5 mA), 3.7 (10 mA), 5.9 (15 mA) and 7.5 mN (20 mA), respectively.

Fig. 2c–f demonstrate more remarkable mechanical responses when the current is applied at higher tensile loadings of 50 and 80 mN. All the corresponding load-drop and jump values are summarized in Fig. 2g and h, respectively. The load-drop increases with the current at certain tensile loadings, indicating that the larger the current, the more the load-drop will be. For instance, at the constant external loading of 80 mN, responsive load-drop increases by 61 mN (from 4.5 mN to 65.5 mN) when current changes from 5 mA to 20 mA. However, the load-jump value is relatively small (Fig. 2h), which is 8.9 mN at 20 mA, and is only 7.6 mN higher than that at current of 5 mA. One can further notice that at a certain current, load-drops increase significantly with the external tensile loading, while the load-jumps have only a slight difference. Taking the current of 20 mA as an example, when the loadings are 20, 50 and 80 mN, the load-drops are 14.8, 38.2 and 65.5 mN, while the corresponding load-jumps are 7.5, 8.5, and 8.9 mN, respectively.

This electromechanical response would mainly triggered by the collect effect of electrothermal induced rGO sheets sliding and elastic deformation. Since the rGO fiber was synthesized by reducing a GO fiber with hydriodic acid, the remaining oxygen-containing groups in rGO sheets readily absorb or desorb water molecules that makes the rGO structure swells or shrinks [8–10]. While water content variation causes the GO sheet sliding and changes its assembly structure greatly, relative humidity (RH) [9] and temperature [10] both can be the stimuli. With regard to the rGO fiber in the present study, the water content is 2.6% (RH = 40%, Fig. S3), and the current on or off induced temperature

http://dx.doi.org/10.1016/j.carbon.2016.04.037
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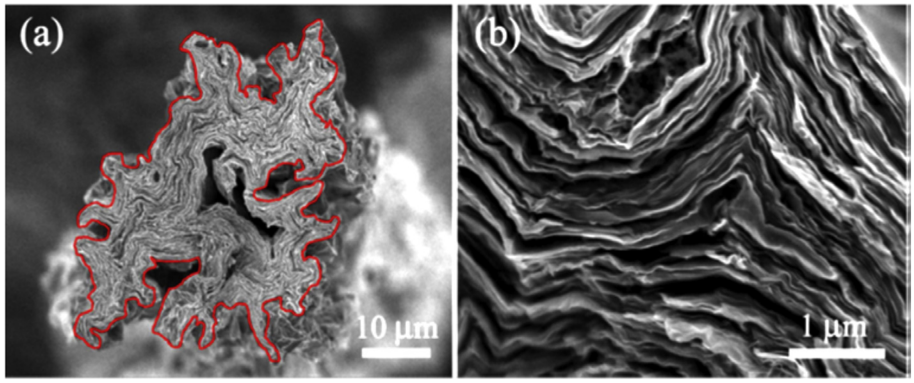

Fig. 1. Cross-sectional images of an rGO fiber with different magnifications. The red borderline around fiber cross-section in (a) is used to determine a same area circle for fiber nominal diameter calculation. (A color version of this figure can be viewed online.)