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PAPER

Improving the multi-step fabrication approach of copper nanofiber networks based transparent electrode for achieving superb conductivity and transparency

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Abstract

Transparent Conductive Electrode (TCE), as an essential part of the optoelectronic devices, has become popular owing to its unique properties such as high optical transmittance and conductivity. Among utilized materials for fabrication of TCE, copper nanofibers (NFs)-network have been attracting much attention due to its extraordinary properties such as low sheet resistance, the scalable manufacturing and low-cost fabrication method. However, many challenges exist in the way of multi-step fabrication of network to increase the NFs continuity and consequently, improvement of their electrical conductivity as TCE. Herein, we report a deep investigation of the effective parameters on diameter and the continuity of network by tracing the impact of variations in spinning voltage, polymer concentration of electrospinning solution, temperatures and heating rates of heat treatment processes. The FESEM results demonstrated that the proper diameters of fibers could be gained using the optimized spinning voltage and a polymer concentration of 12 kV and 8 wt%, respectively. Also, the FESEM images indicated the most proper heating rates of calcination and reduction processes are 4 °C min^{-1} and 2 °C min^{-1}, respectively. In addition, the results of other analysis such as XRD, TGA, DTA and FTIR determined the appropriate temperatures of calcination and reduction are 500 °C and 300 °C, respectively, to the formation and stabilizing of continuous (NFs)-network. Using these values resulted in the formation of a perfect NFs network having required fused junctions with 20 Ω sq^{-1} sheet resistance and 81% transparency.

1. Introduction

Nowadays, due to the significant increase in application of the displays in the new electronic instruments and the ever growing use of the renewable solar energy, producing a high performance/cost-effective transparent conductive electrodes (TCEs) have gained particular importance [1–3]. TCEs have been employed as indispensable part of various optoelectronic devices such as solar cell, organic light emitting diode (OLED) and smartphone due to having the combination of low sheet resistance (R_s) and excellent transparency (T) [4–8]. However, their mechanical stability and flexibility are challenges which might adversely affect the usage of the traditional TCEs [9, 10].

Indium Tin Oxide (ITO), the most practical material used in TCEs, had a high proportion of the whole TCE' market in 2013 (approximately 93%) [4]. High transparency and low sheet resistance are the main reasons for this reputation [5, 11]. Also, the capability of controlling the thickness and concentration of doped materials can be considered as another appealing feature [12]. Due to this characteristic, ITO-based TCEs are produced with different electrical resistances which make them potentially useful in a wide range of optoelectronic devices [4]. However, ITO' drawbacks cannot be neglected. For instance, ITO is intrinsically brittle and cannot tolerate bending positions, so it would not be an ideal candidate for flexible optoelectronic devices [13]. Another equally