Applied Surface Science 458 (2018) 236–244

Contents lists available at ScienceDirect

Applied Surface Science

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

Full Length Article

A facile approach to fabricating silver-coated cotton fiber non-woven fabrics for ultrahigh electromagnetic interference shielding

Yan-Jun Tan[a], Jie Li[a], Yuan Gao[b], Jiang Li[b], Shaoyun Guo[b], Ming Wang[a,*]

[a] Key Laboratory of Applied Chemistry of Chongqing Municipality, School of Chemistry and Chemical Engineering, Southwest University, Chongqing 400715, PR China
[b] State Key Laboratory of Polymer Materials Engineering, Polymer Research Institute of Sichuan University, Chengdu 610065, PR China

ARTICLE INFO

Keywords:
Cotton fiber
Non-woven fabrics
Silver
Electrical conductivity
Electromagnetic interference shielding

ABSTRACT

Electromagnetic radiation pollution has become a serious threat to human health. Wearable materials with high electromagnetic interference (EMI) shielding are highly desirable to protect people far from electromagnetic radiation. In this study, we prepared flexible and wearable materials with ultrahigh EMI shielding via a facile wet electroless deposition of Ag on surface of cotton fibers (Ag@CFs) in non-woven fabrics. High conductivity of ~3333 S/m and excellent EMI shielding effectiveness (SE) of ~71 dB were achieved by only costing the wet deposition time of 10 s with 1.61 vol% Ag coating layers, which was far more than the requirement for common commercial EMI SE of 30 dB. The EMI SE of the materials could reach ~111 dB when the Ag plating time was 3 min. The ultrahigh EMI shielding performance was ascribed to cell-like configuration, which is the abundant interfaces and porous structure in the Ag@CFs non-woven fabrics, and the voids in Ag layers. The electromagnetic radiation, which was reflected at the interfaces and then absorbed in the composites, was hard to escape from the cell-like configurations. Moreover, the prepared Ag@CFs films could also maintain high EMI SE by suffering dozens of washing times or one thousands of bending times. For example, there were only reduction of a few dB in the EMI SE for the non-woven fabrics with the coating time of 3 min after washing 20 times or bending 1000 times. Therefore, this work gave a new strategy for fabricating wearable materials with high-performance EMI shielding.

1. Introduction

Mobile communications and electronic devices have become the necessities for people to communicate and learn new knowledge in the modern world. In contrast, the electromagnetic radiation generated from the electronic products threat to our health and safety [1–5]. Besides, the electromagnetic radiation, which is also harmful to the normal work of electronic equipment, makes high risk in precise equipment without any shielding [6–8]. Nowadays, electromagnetic pollution has also become a more important concern [9–11]. The wearable materials or flexible films with high electromagnetic interference (EMI) shielding have drawn many attentions to protect people and surroundings from radiation pollution. Generally, metal films with high electrical conductivity and shallow skin depth were used to attenuate electromagnetic radiation. However, it is very difficult to prepare lightweight and flexible materials with high EMI shielding effectiveness for wearable applications because of the nature heavy weight and brittleness of metals [12–14]. Recently, conductive polymer composites (CPCs) have become a popular alternative for EMI shielding due to their easy processability, flexibility, corrosion resistance, and low density [15–21]. Except for EMI shielding application, CPCs can also be used as antistatic materials, strain sensors, and conductors [22–27]. However, the CPCs with high-performance EMI shielding effectiveness (EMI SE) usually require high filler loadings and large shield thickness, which results in the scarification of the flexibility and durability, and thus restriction for their wearable applications [28–31]. Developing flexible wearable materials with high-performance EMI shielding is still a great challenge.

Generally, reflection, absorption and multiple reflection of electromagnetic wave happen in materials to attenuate electromagnetic radiation. The total EMI SE (SE_T) is usually the sum of three attenuations [32]. The SE_T of 30 dB indicates the attenuation of 99.9% incident microwave energy, which is the target value for the commercial application in EMI shielding devices [33]. Reflection of EMI shielding is mainly ascribed to the charge carriers directly contacting with electromagnetic fields which to reflect radiation [11,34–36]. Absorption of EMI shielding is that the electric and/or magnetic dipoles interact with the radiation [37–39]. Multiple reflection is a positive or negative

* Corresponding author.
E-mail address: mwang@swu.edu.cn (M. Wang).

https://doi.org/10.1016/j.apsusc.2018.07.107
Received 17 April 2018; Received in revised form 5 July 2018; Accepted 14 July 2018
Available online 17 July 2018
0169-4332/

correction term induced by the reflecting waves inside the shielding barrier [40]. In most cases, the high conductivity is helpful to improve the absorption and reflection of electromagnetic wave [41]. However, conductive fillers are usually random dispersion in a polymer matrix, which requires high loadings to reach high conductivity. High content of conductive fillers will bring high melt viscosities, low economic affordability and limited application. Optimizing the distribution of conductive fillers in a polymeric matrix was a key factor to obtain high electromagnetic attenuation at low filler loadings, such as double percolation structures [42–45] and segregated structures [46–52].

Besides the conductivity, the morphology of CPCs is also very important to the high performance EMI shielding. Layer-by-layer [53] and cell-like [49] configurations have been well demonstrated to enhance the EMI shielding [49]. Multiple reflections within and between the cell-like or layer-by-layer configurations enhance interactions between the shielding material and EM waves. Furthermore, most of the multiple reflections can be further absorbed if the absorption is higher than 10 dB [53–58]. For one example, an alternating multilayer structure with MWCNTs distributed in the continuous and parallel layered spaces of a poly (vinyl chloride) matrix has found to improve the microwave absorption because of the multi-reflection of microwaves between the layered interfaces [53]. Another example, the EMI SE was abruptly enhanced by the formation of the segregated structure, where the cell-like configuration formed with dense highly conductive filler layers surrounding. The microwaves were efficiently attenuated by the multiple reflection at the interfaces in the cell-like configurations and then absorption in the composites [59–62]. Therefore, the controlling distribution of the conductive fillers in polymer matrix to form multiple interface was another important factor to improve EMI shielding.

Recently, the silver filled polymer composites was found to efficiently improve electrical conductivity and EMI shielding because of the high conductivity of silver phase. It was found that the EMI SE values of the polyethylene terephthalate film coated with a thin silver layer could reach 60.5 dB at 0.1 GHz and 54.7 dB at 1.0 GHz [63]. The cellulose papers coated with 0.53 vol% silver nanowires (AgNWs) exhibited electrical conductivity of 67.51 S/cm and EMI SE of ~48.6 dB at 1 GHz [64]. The segregated poly(lactic acid)/silver nanocomposites with 5.89 vol% sliver particles possessed the remarkable electrical conductivity of 254 S/m and outstanding EMI SE of 50 dB at 8.2–12.4 Hz [65]. The polypyrrole filled with AgNWs could obtain the electrical conductivity of 1206.72 S cm^{-1} and the EMI SE of 48.4 dB (8.0–12.0 GHz, X-band) with 50 wt% AgNWs [66]. The ultralight waterborne polyurethane and polyimide foams with AgNW showed the ultrahigh surface specific EMI SE of ~1087 dB cm^3/(g mm) at X-band and 1210 dB·g^{-1}·cm^3 at 200 MHz, respectively [67–69]. The extremely large conductivity mismatch between the silver and polymer matrix was thought to provide much enhanced polarization and charge accumulation at the interfaces, boosting the absorbing capability of the composites [70].

In addition, cotton fiber fabrics have become more and more popular substrate to prepare the wearable and flexible high EM shielding materials because the fiber network has many interfaces that can reflect radiation many times. The low density of cotton fibers as the matrix overcame the deficiency of the heavy weight metal, hence, metal wrapping cotton fiber network due to the depositing metal layer in the fabric possessed high dielectric loss can get more attention and further application than bulk metal [71–76]. Herein, we prepared flexible and high-performance EMI shielding non-woven fabrics by using Ag wet electroless depositing on surface of cotton fibers. The EMI shielding performance of the Ag coated non-woven fabrics was excellent because of the cell-like configurations, which were porous structure in the non-woven fabrics and the voids in Ag layers. The mechanism of the high-performance EMI shielding, as well as the effect of Ag content, was also discussed in this work.

2. Experimental

2.1. Materials

Non-woven cotton fibers (CFs) with a density of 0.44 g/cm^3 were obtained from Guangdong Jielisi Co., Ltd., China. $AgNO_3$ (≥99.8%) was purchased from Tianjin Ruijinte Chemicals Co., Ltd., China. $NaKC_4H_4O_6{\cdot}4H_2O$, $NH_3{\cdot}H_2O$ (25.0–28.0%), HCl (36.0–38.0%) and ethanol (≥99.7%) were all offered by Chongqing Chuandong Chemicals Co., Ltd., China. α-D-(+)-glucose (≥99%, [α] 20 + 52.5–53.0°) and NaOH (≥99.5%) were provided from Chengdu Kelong Chemicals Co., Ltd., China.

2.2. Preparation

Before electroless depositing, the non-woven cotton fibers (CFs) were cleaned by using water and ethanol with assistance of ultrasonication. The cleaned CFs were immersed in the solution of 0.1 M tin (II) chloride ($SnCl_2$) and 0.1 M hydrochloric acid (HCl) for 10 min with assistance of ultrasonication to make the nuclei (Sn^{2+}) on the CFs surface. After that, the sensitized CFs were washed with distilled water, and immersed in the Tollen's reagent and reducing solution with stirring to achieve Ag deposition, as shown in Fig. 1. The Tollen's reagent was prepared by adding excessive $NH_3{\cdot}H_2O$ to 2.0 wt% $AgNO_3$ solution with stirring until precipitate subside. The reducing solution was composed of 5.0 g potassium sodium tartrate ($NaKC_4H_4O_6{\cdot}4H_2O$), 0.5 g NaOH, 0.7 g glucose ($C_6H_{12}O_6$) and 50 mL deionized water. The deposition amount of Ag particles was controlled the depositing time. Here, the depositing times of 10, 20, 30, 40, 60, 120, and 180 s, which were named as Ag@CFs-10, Ag@CFs-20, Ag@CFs-30, Ag@CFs-40, Ag@CFs-60, Ag@CFs-120, and Ag@CFs-180 for convenience,

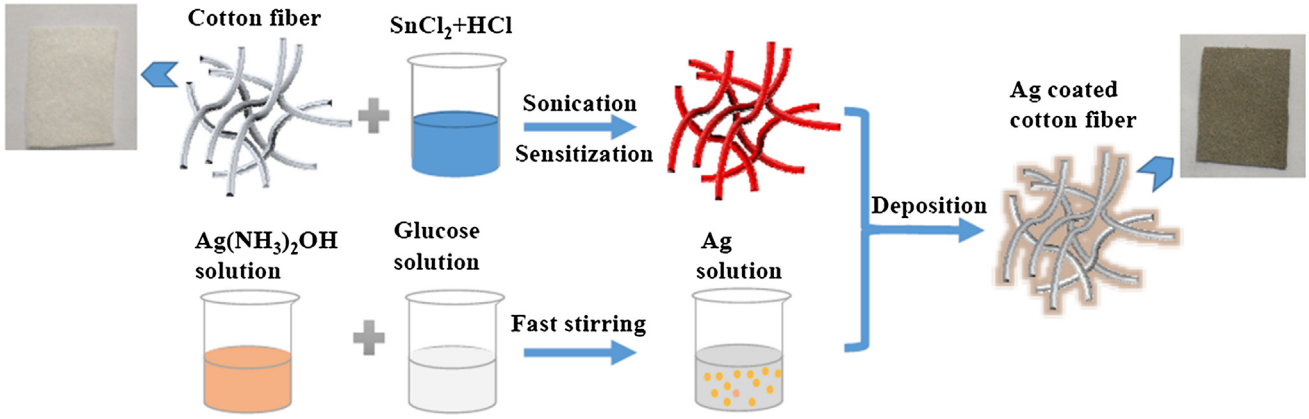

Fig. 1. The schematic diagram of the processing procedures of Ag@CFs non-woven fabrics.