Chemically-modified graphene sheets as an active layer for eco-friendly metal electroplating on plastic substrates

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A R T I C L E   I N F O

Available online 3 November 2011

Keywords:  
Graphene  
Graphene oxide  
Electroplating  
Metalization  
Eco-friendly plating

A B S T R A C T

Eco-friendly nickel (Ni) electroplating was carried out on a plastic substrate using chemically modified graphene sheets as an active and conductive layer to initiate electroplating without using conventional pre-treatment or electroless metal-seeding processes. A graphene oxide (GO) solution was self-assembled on a polyethylene terephthalate (PET) film followed by evaporation to give GO layers (thickness around 6.5 \( \mu \)m) on PET (GO/PET) film. Then, the GO/PET film was chemically and thermally reduced to convert the GO layers to reduced graphene oxide (RGO) layers on the PET substrate. The RGO-coated PET (RGO/PET) film showed the sheet resistance of 100 \( \Omega \) per square. On RGO/PET film, Ni electroplating was conducted under the constant-current condition and the entire surface of the PET film was completely metalized with Ni without any voids.

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1. Introduction

Metal electroplating is one of the most widely used techniques in a variety of fields ranging from the fabrication of printed circuits in electronic devices to the decoration of consumer products [1]. Especially, in industry, polymers or plastics have frequently been used as a substrate, since they provide many advantages in the manufacturing of products, such as lightness, ease of design, and low cost of production [2,3]. The surface properties of polymers can be improved or changed by incorporating metal components through electroplating, e.g., their reflectivity, abrasion resistance, conductivity, and a variety of decorative effects [4,5]. However, non-conductive substrates need several pre-treatment processes before they are subjected to electroplating, which usually includes etching, activation, acceleration and electroless plating steps to secure an electrical path, unless electroplating, which usually includes etching, activation, acceleration and electroless plating steps to secure an electrical path, unless electroplating can be performed on non-conductive substrates [6]. The etching process is employed to improve the adhesion between the substrates and the metal layers and to cause catalysts to be embedded on the surface of the substrates [7]. For this process, hazardous and toxic chromic acid is most commonly used [8], which contains hexavalent chromium. Since hexavalent chromium can cause cancer, the European Union has greatly limited its use by the Restriction of Hazardous Substances Directive [9,10]. In addition, catalytic metals should be introduced onto the substrates through several processes, in order to initiate electroless plating, in which expensive noble metals, usually palladium (Pd), are employed as catalysts [11]. Thus, there is a considerable demand for eco-friendly and cost saving electroless plating techniques which can reduce the number of pre-treatment steps before electroplating. Numerous attempts have been made to develop eco-friendly plating techniques such as the use of chromium-free etching solutions [12], ion-assisted laser treatment [13], plasma modification [14], and excimer UV laser treatment [15]. These studies were mainly focused on the development of an alternative etching process by changing the components of the etching solution or by adopting existing surface modification methods. However, they were neither efficient in obtaining sufficient adhesion compared to chromic acid etching, nor did they decrease the number of processing steps. Hence, more efficient pre-treatment techniques should be developed to overcome these problems.

Recently, graphene, which consists of a monolayer of sp\(^2\)-bonded carbon atoms packed in a honeycomb crystal lattice, has attracted a great deal of attention for its unusual mechanical (Young’s modulus—1 TPa) [16], electronic (charge-carrier mobility = 250,000 cm\(^2\) V\(^{-1}\) s\(^{-1}\)) at room temperature, conductivity up to 6000 S/cm) [17,18], and optical properties [19]. Especially, it has been considered as a promising candidate for flexible electrodes in electronic devices, due to its high conductivity, transparency, flexibility, and stability [20,21]. Moreover,