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A NOVEL ELECTRICALLY CONDUCTIVE MATERIAL DERIVED FROM IN SITU SYNTHESIS OF SILVER NANOPARTICLES ON THE SURFACE OF BAMBOO TIMBER

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ABSTRACT

Bamboo timber with special performance such as conductive property becomes one of the research highlights in the field of functional materials. Highly conductive Ag/bamboo timber composites were in situ synthesized by reduction of $[Ag(NH_3)_2]^+$ complex on the surface of bamboo timber using D-glucose as a reducing agent. Scanning electron microscopy (SEM) images of the as-prepared bamboo timber showed that the compact Ag nanoparticles (Ag NPs) with sizes ranging from 100 to 300 nm coated on the bamboo timber surface, which rendered the intrinsic insulating bamboo timber highly conductive. Furthermore, the in situ synthesis mechanism of Ag NPs on the surface of bamboo timber was also discussed.

KEYWORDS: Bamboo timber; Ag nanoparticles; conductivity; surfaces; composite material.

INTRODUCTION

Bamboo is an abundant natural resource in Asia and South America. Generally, bamboo can be divided into three parts. The outer part where vascular bundles are dense is called bamboo green, while the inner part where vascular bundles are rare is called bamboo yellow. The layer between bamboo green and yellow is called bamboo timber (Chand et al. 2006). The bamboo timber is usually selected for use in the practical applications, such as construction timbers, floorings, boards, and raw materials for pulping and papermaking (Li et al. 2014). However, due to its natures like electric insulativity, the development of bamboo timber in the application of functional materials such as electronic circuits or devices is greatly limited.

As known as an excellent conductor of electricity, silver has been widely used since ancient times. Current methods employed for the preparation of Ag NPs include chemical reduction, reverse micelles, and electrochemical and sonoelectrochemical techniques have been developed (Sivaraman et al. 2009, Li et al. 2006, Raveendran et al. 2006, Sharma et al. 2009, Noritomi et al. 2010). Among these methods, the method of chemical reduction has the advantage over the others in easy control of the reaction process and production rate. The chemical reduction method is achieved by reduction of a metal ion salt solution, and is frequently applied for the preparation of Ag NPs (Xue et al. 2012). To our best knowledge, there are few reports published on endowing the intrinsic insulating bamboo timber with conductivity.

In this work, a novel electrically conductive material was in situ synthesized by reduction of $[Ag(NH_3)_2]^+$ complex on the surface of bamboo timber. The dense Ag NPs coating settled onto the surface of bamboo timber imparted the metallic feature to the bamboo timber rendering the composite highly conductive property.

MATERIAL AND METHODS

Synthesis procedure

All the chemical reagents were analytical grade and used as received. The bamboo timber specimens of 10 mm (longitudinal) × 10 mm (tangential) × 4 mm (radial) were ultrasonically rinsed in deionized water for 30 min and dried in vacuum at 60°C for 24 h. A typical procedure was described as follows. Firstly, bamboo timbers were treated with 1 M aqueous NaOH solution at 25°C for 10 min followed by rinsing with copious amount of distilled water. Secondly, ammonium hydroxide (28 wt. %) was added into a 0.5 M $AgNO_3$ aqueous solution dropwise with continuous stirring until a transparent colorless silver-ammonia complex solution was formed. The NaOH-treated bamboo timbers were immersed into the fresh silver-ammonia complex solution for 1 h, then transferred into a 0.2 M D-glucose stock solution. After 5 min, the residual silver-ammonia complex solution was poured into the D-glucose solution. The reaction was continued for 30 min. At last, the samples were rinsed in water and then dried at 60°C for 24 h.

Characterizations

The surface morphology of the samples was characterized using field-emission scanning electron microscopy (SEM, Quanta 200, FEI) operating at 12.5 kV in combination with EDS (Genesis, EDAX). The crystalline structures were identified by X-ray diffraction (XRD, Bruker D8 Advance, Germany) operating with Cu Kα radiation (λ = 1.5418 Å) at a scan rate (2θ) of 4°/min with an accelerating voltage of 40 kV and an applied current of 40 mA ranging from 5 to 80°. The electrical resistance was measured by a multimeter (Hewlett-Packard 3457A, USA). All the electrical resistance were determined by averaging 5 measured values on each sample surface.

RESULTS AND DISCUSSION

Fig. 1 showed the SEM images of the original and Ag NPs-coated bamboo timber. As shown in Fig. 1a, the original bamboo timber presented a clean and smooth surface.

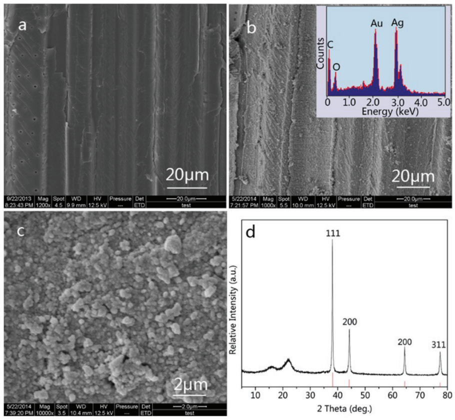

Fig. 1: SEM images of a) the original bamboo timber, and b, c) the Ag/bamboo timber composite at different magnification. EDS of Ag/bamboo timber composite as an insertion in Fig. 1b. d) XRD pattern of the Ag/bamboo timber composite.

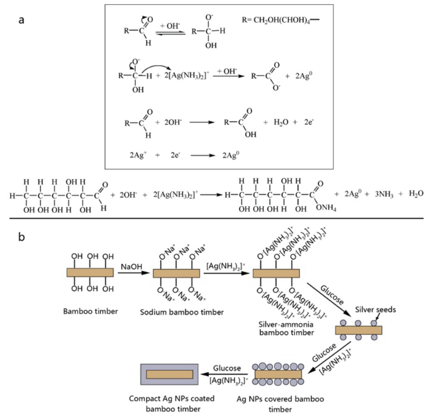

Fig. 2: a) The reduction reaction equation for the formation of Ag NPs. b) Illustration of the processes involved in the bamboo timber coated with Ag NPs.

After coated with Ag NPs, the nanoparticles with the sizes ranging from 100 to 300 nm were settled onto the surface of bamboo timber (Fig. 1b and c). The inset in Fig. 1b gave a typical EDS spectrum of the Ag/bamboo timber composite. Only C, O, Ag, and Au elements could be detected. The Au element was originated from the coating layer used for SEM observation, and the C and O elements were from the bamboo timber. Fig. 1d displayed the XRD pattern of the Ag/bamboo timber composite. The diffraction peaks at 16 and 22° represented the crystalline region of the cellulose of the bamboo timber (Li et al. 2011). Four obvious diffraction peaks at 38°, 44°, 64°, and 77° were attributed to (1 1 1), (2 0 0), (2 2 0), and (3 1 1) planes of silver crystal (JCPDS cards No. 04-0783), respectively. No characteristic peaks for the other impurities such as Ag_2O were detected, indicating that only high-purity silver crystals were existed.

The above results showed that the compact Ag NPs could be obtained through the reduction of $[Ag(NH_3)_2]^+$ using D-glucose as the reducing agent. D-glucose is a highly water-soluble compound with strong polarity. Although D-glucose is well known as a reducing sugar, it does have limited reduction ability at ambient temperature (Shervani and Yamamoto 2011). However, D-glucose can effectively reduce Ag^+ ions into Ag^0 in the presence of OH^- ions in the reaction solution (Raveendran et al. 2006). The reduction reaction equation shown in Fig. 2a clearly indicated that the OH^- ions was involved in the reaction to yield Ag NPs, where D-glucose behaved as an aldose.

When OH^- attacked aldehyde group, H^- was generated by the affinity reaction between OH^- and the aldehyde group. H^- reacted with OH^-, simultaneously, two e- were produced, which reduced Ag^+ into Ag^0 (Shervani and Yamamoto 2011). As mentioned above, when the Ag^+ was reduced and the Ag^0 was formed by D-glucose, the H^+ was also formed at the same time. As a result, the protons were neutralized and consumed by hydroxyl ions from silver-ammonia complex solution, which accelerated the reduction rate according to Le Chatelier's principle (Zhou et al. 2009). The mechanism of Ag NPs in situ synthesis on the surface of bamboo timber could be explained (Fig. 2b): Firstly, the bamboo timber was pretreated with NaOH making its surface negatively charged. After dipping the $NaOH^-$ treated bamboo timber into the silver-ammonia complex solution, the complexes of $[Ag(NH_3)_2]^+$ were easily absorbed on the surface of bamboo timber by ion exchange reaction with silver-ammonia complex solution on the basis of the high affinity of $[Ag(NH_3)_2]^+$ ions (Shateri Khalid-Abad and Yazdanshenas 2010).

After that the treated bamboo timber were transferred into the glucose solution, then $[Ag(NH_3)_2]^+$ would be reduced into silver seeds based on the surface of bamboo timber. With the addition of $[Ag(NH_3)_2]^+$ and glucose, more and more silver ions were settled onto the surface of bamboo timber and reduced into silver, and the silver seeds grew larger into Ag NP, attached to each other forming a compact Ag NP coating on the surface of bamboo timber.

Based on the XRD results, only silver crystals covered on the surface of bamboo timber and no other compounds existed, which imparted highly electrical conductivity to the Ag/bamboo timber composite with electric resistance as low as 3.2 Ω ± 1.4 Ω. In order to further prove the reliability of highly electrically conductive Ag/bamboo timber composite, a simple circuit was constructed. As demonstrated in Fig. 3a, the LED device was not lit, which is common sense that the dried bamboo timber is an insulator. By contrast, a blue LED device was lit by charging the two Ag/bamboo timber composite bridged with the LED device (Fig. 3b).

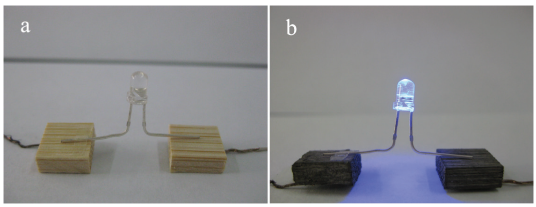

Fig. 3: Conductive photographs of a) the original bamboo timber and b) the Ag/bamboo timber composite.

All the obtained Ag/bamboo timber composite were able to light the LED device by randomly measuring the conductivity on the surface of bamboo timber. This result indicated that the Ag/bamboo timber composite existed an excellent conductivity. The novel electrically conductive material is expected to become a powerful platform for fabricating the electronic circuits or devices.

CONCLUSIONS

In summary, the highly electrical conductive Ag/bamboo timber composite have successfully in situ synthesized by reduction of the $[Ag(NH_3)_2]^+$ complex on the surface of bamboo timber using D-glucose as a reducing agent. The Ag/bamboo timber composite were characterized by XRD, which proved only high-purity Ag NPs were formed. The dense Ag NPs coating formed on the surface of bamboo timber imparted electrical conductivity to the bamboo timber.

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