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Full Length Article

As-pyrolyzed sugarcane bagasse possessing exotic field emission properties

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ABSTRACT

The present study aims to demonstrate the application of sugarcane bagasse as an excellent field emitter. Field emission property of as-pyrolyzed sugarcane bagasse (p-SBg) before and after the plasma treatment has been investigated. It has been observed that electronic nature of p-SBg transformed from semiconducting to metallic after plasma treatment. Maximum current and turn-on field defined at 10 $\mu A/cm^2$ was found to be 800 $\mu A/cm^2$ and 2.2 V/μm for as-pyrolyzed sugarcane bagasse (p-SBg) and 25 $\mu A/cm^2$ and 8.4 V/μm for H_2-plasma treated p-SBg. These values are found to be better than the reported values for graphene and activated carbon. In this report, pyrolysis of bagasse has been carried in a thermal chemical vapor deposition (Th-CVD) system in inert argon atmosphere. Scanning electron microscopy (SEM), X-ray Diffraction (XRD), High-resolution transmission electron microscopy (HRTEM) and X-ray photoelectron spectroscopy (XPS) have been used to study the structure of both pre and post plasma-treated p-SBg bagasse's sample. HRTEM study reveals that carbonaceous structures such as 3D-nanographene oxide (3D-NGO), graphite nanodots (GNDs), carbon nanotubes (CNTs), and carbon onions are present in both pre-treated and plasma-treated p-SBg. Hence, we envision that the performed study will be a forwarding step to facilitate the application of p-SBg in display devices.

1. Introduction

Despite, being a promising raw material for various products such as generation of electric power [1], pulp and paper production [2], nanocellulosic fiber [3], carbon tubules [4], carbon quantum dots (CQDs) [5] and for products based on fermentation such as glucose, xylose and biofuel (ethanol) [6–8], sugarcane bagasse is generally considered as an environmental hazard due to emission of greenhouse gasses during its burning either in agriculture fields or in sugar/jaggery plants for generation of power and heat, respectively [1]. Moreover, recently sugarcane cultivation has assumed great importance for the world economy, especially due to large demand for ethanol production, although it presents a high risk impact for environment. In recent report, about 279 million metric tons (MMT) of bagasse production annually throughout the world was mentioned by Anuj K. Chande *et al.* in 2011 [9] and it is causing severe pollution in the environment due to effluent greenhouse gases as well as emission of aerosols and nano-sized carbon particulates in the atmosphere during its burning. So, in future its proper utilization is highly desirable.

Structurally, sugarcane bagasse (SBg) is composed mainly of cellulose and lignin [9]. Hence, it might be a promising resource for production of as-pyrolyzed and post chemically treated activated carbon (AC). This could offer the combined benefits to diminish emissions of greenhouse gasses as well as offers high commercial value by producing activated carbon. It is reported that activated carbon (produced from agricultural waste) has high carbon and low ash contents, high adsorption capacity, high density and considerable good mechanical strength which is highly required to create porous structures in the activated carbon matrix [10].

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Recently, many interesting applications of bare SBg have been reported, for example, Elisabeth Arif *et al.* [11] demonstrated that ash left over after burning of bagasses can be utilized in geo-polymer or zeolites production as well as in cements or mortars as a filler material without any further treatment depending on burning temperature (e.g. ashing at 550 °C). Ganaie *et al.* [12] reported that bare SBg is the most promising substrate for excellent growth and adequate production of fructosyltransferase (FTase). In further advances, bagasse was used in waste water treatment and for adsorption of chromium (VI). Cronje *et al.* [13] have reported that under optimal process parameters high removal i.e. up to 87% can be achieved. The optimal process parameters include the optimum adsorbent dose, temperature, initial concentration of Cr(VI) and initial pH of the Cr(VI) solution which in this case were found to be 6.85 g/L, 40 °C, 77.5 mg/L, and 8.58 respectively. Similarly, Jaguaribe *et al.* [14] also reported that activated carbon produced from bagasse can remove chlorine from water. Santos *et al.* [15] reported that by chemically modifying sugarcane bagasse using carboxylic groups can be used for lead adsorption from aqueous medium. In further advances, Tan, *et al.* [16] reported that carbon nanodots (CNDs) can be synthesized by laser ablation of bagasse in ethanol where femtosecond laser was used. These CNDs with tunable band gap, without any further functionalization exhibit strong optical limiting response to fs laser pulses with an optical limiting threshold of 74 mJ/cm [16]. Alves *et al.* [17] reported that bagasse can be used as a feedstock for carbon nanotube growth on SS substrates. Recently, Lisunova *et al.* [18] reported that screen-printed activated carbon which was made of coal exhibited the highest emission current density (J) of ~350 ($\mu A/cm^2$) and with the lowest threshold electric field (E_{th}) ~ 4.2 (V/μm) defined at 10 $\mu A/cm^2$.

Previously, field emission properties of various carbonaceous materials [19,20] such as graphite [21], carbon nanotubes [19,22], graphene [23,24], nanodiamond [25,26] and nanoporous carbon [27,28] have been studied. These materials have proven to be excellent field emitters due to their promising properties which includes low electron affinity, high chemical, emission stability and low turn-on electric field [29]. Soin *et al.* [23] compared emission properties of pristine FLGs and N_2 plasma-treated FLGs and found that significant improvement in field emission characteristics by lowering the turn-on field (defined at 10 $\mu A/cm^2$) from 1.94 to 1.0 V/μm. Field emission current was found to be increased from 17 $\mu A/cm^2$ at 2.16 V/μm for pristine FLGs to about 103 $\mu A/cm^2$ at 1.45 V/μm for N-doped FLGs. In present work, maximum current and turn-on field (defined at 10 $\mu A/cm^2$) was found to be 800 $\mu A/cm^2$ and for 2.2 V/μm as-pyrolyzed sugarcane bagasse (p-SBg) and 25 $\mu A/cm^2$ and 8.4 V/μm for H_2-plasma treated p-SBg. The observed turn-on field (defined at 10 $\mu A/cm^2$) 2.2 V/μm for p-SBg was found to be in range of 1.94–6 V/μm reported for few layer graphene [30]. This has been reprted that turn-on field were restricted by the orientation distribution of graphene sheet and conductivity of substrate as well.

In present work, we have demonstrated the application of p-SBg as highly efficient field emitter and found that it possess superior emission properties than those reported for graphene [23] and activated carbon [18]. It has been observed that semiconducting nature of p-SBg transformed into metallic after plasma treatment. In order to analyze the observed exotic field emission behavior, we have compared the crystal structure, surface morphology and chemical structure of both un-treated and plasma-treated p-SBg which were examined using XRD, HRTEM and XPS, respectively. We forsee that in future performed studies could be a forwarding step to facilitate the application of p-SBg in display devices. It might also be helpful to develop value added applications to improve economic condition of agriculture sector.

2. Experimental details

Pyrolysis of SBg was carried out in thermal chemical vapor deposition (thermal CVD) technique at 550 °C in inert atmosphere. Schematic of the process is demonstrated in Fig. 1. During heating until temperature reaches the set point (550 °C), the quartz reactor was placed in such a manner that quartz boat containing bagasse will be at room temperature and argon/hydrogen gas mixture in the ratio of 2:1 with total flow of 1500 sccm was used to create inert atmosphere. Once desired temperature is achieved, tube was dragged inside the hot zone in such a manner that the boat remains at 550–600 °C. After completion of the pyrolysis process system was cooled down naturally in inert atmosphere and

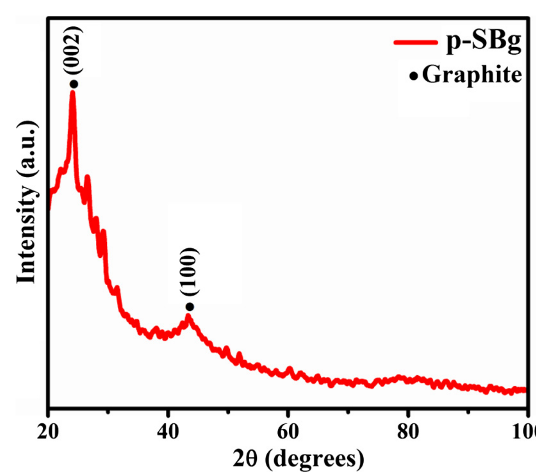

Fig. 2. XRD pattern of as-pyrolyzed sugarcane bagasse.

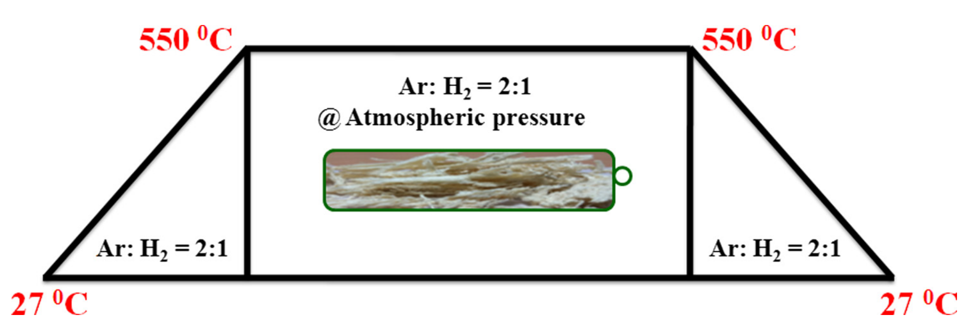

Fig. 1. Schematic of experimental condition of pyrolysis of sugarcane bagasse.