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Synthesis of silicon carbide nanoparticles by using electronic waste as a carbon source



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ABSTRACT

Around the world the amount of electronic waste is growing exponentially and considered to be an important environmental and health issue. The environmental friendly and resource recovery methodology is critically required for existing scenario to recycle electronic waste. In this paper, a novel approach to synthesise silicon carbide (SiC) nanoparticles by using electronic waste compact discs (CDs) char as a carbon source is reported. The synthesis is based on carbothermal reduction at 1550 °C using waste CD char as the carbon source and silicon dioxide as the silicon source. FTIR, Raman and XPS results confirm the formation of SiC particles and XRD signifies the major phases of 3C-SiC. The size of synthesised SiC particles was in the range of 40–90 nm and was mainly composed of sphere shaped nanoparticles. This innovative approach of using electronic waste CDs as the carbon source for synthesising SiC nanoparticles will reduce the volume of waste in landfills and also the dependency of industries on traditional raw materials.

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1. Introduction

Silicon carbide (SiC) is a refractory material with outstanding thermal, chemical and mechanical properties. It has high mechanical strength, high thermal conductivity, low thermal expansion coefficient, large band gap, low density, high hardness and excellent corrosion resistances [1–3]. Nanostructured SiC materials can be used in the field emission displays, nanosensors, nanoscale electro-devices, light emitting devices and also as biological labels [4–6]. The simple and economical carbothermal reduction process is widely used in industries to synthesise SiC nanoparticles [7]. In addition, other methods such as sol–gel [8], plasma [9], mechanical [7] and microwave radiation [10] technologies are also employed to synthesise SiC nanoparticles. For all the methods, the choice of carbon is one of the crucial factors for SiC production. Currently, the carbon source is limited to carbon black, coke, phenolic resin and other materials. Therefore, an alternative carbon source is required to develop an efficient and economical process to synthesise SiC nanoparticles.

Due to rapid advancement in technology and urbanisation, electronic waste (e-waste) is the fastest-growing waste stream around the world. E-waste is growing three times faster than normal municipal solid waste [11]. Waste compact discs (CDs) are

widely used and have contributed significantly to the total e-waste. Twelve billion units of CDs were produced in the year 2003 around the world, and have increased significantly in the recent years. Waste CDs are difficult to recycle due to their heterogeneous combination of multi-layer metal coating and polymer.

In our group, we have made an extensive effort to replace coke in a steelmaking process by various plastics and agricultural wastes [12,13]. Recently, we reported the utilisation of waste glass and plastic as silicon and carbon sources for synthesising ferrosilicon alloy [14]. In the literature, only few studies have made an attempt to replace conventional carbon source to synthesise SiC [15]. In this work, we report the use of electronic waste CDs as a carbon resource to synthesise SiC nanoparticles. Recently, we proclaimed the generation of highly valuable carbon with good crystallinity from waste CDs [16].

In this study, a novel approach to synthesise SiC nanoparticles by using electronic waste CDs char as the carbon source is reported. The composition and morphology of synthesised SiC nanoparticles have been investigated in detail by using various analytical techniques. This approach can be an economical route to produce SiC nanoparticles and also effective in reducing waste CDs in landfills.

2. Experimental

The carbon source from waste CDs was generated by performing pyrolysis at 700 °C for 20 min in an argon atmosphere.

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The obtained char was characterised by an X-ray diffractometer (XRD, PANalytical X'Pert Pro multipurpose) and a Raman spectrometer (Renishaw inVia) to determine carbon structure. The morphology and carbon content of char were analysed by using a Scanning Electron Microscope (SEM, Hitachi 3400-I) and a carbon (LECO CS-444) analyser.

Silicon dioxide (SiO_2 , ~99%, 0.5–10 μm , Sigma-Aldrich) and obtained char from waste CDs were used as silicon and carbon sources. SiO_2 and char were used in a stoichiometric ratio and mixed by using a ring mill for 2 h and were transferred to pellets. The carbothermal reduction reaction for synthesising SiC nanoparticles was conducted by placing pellets into a horizontal tubular furnace at 1550 °C for 1 h in the argon atmosphere. The synthesised SiC nanoparticles were identified by XRD, Fourier transform infrared spectrometer (FTIR, Perkin-Elmer Spotlight 100), XPS (Thermo ESCALAB250i) and by Raman spectrometer. SEM was also used to study the morphology of synthesised SiC nanoparticles.

3. Results and discussion

The crystalline size, amorphous content and porosity of carbon source are significant factors for synthesising SiC particles. The waste CD char produced at 700 °C showed a very high surface area of 330 m^2/g . A XRD pattern of char shows (002) and (100) carbon phases, with crystalline size of 0.8 nm. The existence of γ -band indicates the presence of amorphous structure in char [16]. Two bands i.e. G- (~1590 cm^{-1}) and D-band (~1350 cm^{-1}) were observed in Raman spectra of char. I_V/I_G (I_G – intensity of G-band and I_V – intensity of a valley between G and D bands) is 0.58, which specifies the presence of structural defects, sp^2 carbons and amorphous content [16]. The SEM image clearly signifies that char is highly porous. The less crystalline size, amorphous content, and porosity of char clearly indicate that waste CD char can be a good source of carbon for synthesising SiC particles [17]. The percentage of carbon in char was around 89% and remaining 11% was majorly composed of silica [16] (Fig. 1).

The synthesised SiC powder was grey green in colour, which was similar to the colour of SiC obtained in industries using petroleum coke as the carbon source. A representative SEM image of synthesised SiC nanoparticles is shown in Fig. 2, which evidently appears that the product is mainly composed of sphere shaped nanoparticles with diameter of 40–90 nm (Fig. 2a). In a high magnification SEM image (Fig. 2b), it is clearly observed that SiC particles are aggregated into chainlike nanostructures and branches on chains are also noticed.

The XRD patterns of reactant SiO_2 and synthesised SiC nanoparticles are shown in Fig. 3a. A typical XRD spectrum was observed for SiO_2 with maximum intensity of (011) peak. For

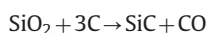
synthesised SiC, the spectrum shows various sharp peaks, which indicates crystallinity. The peaks appeared correspond to (111), (200), (220), (311) and (222) phases of 3C-SiC (JCPDS no. 29-1129) and the peak denoted as 'SF' is due to stacking faults in SiC structure [18]. No peak which is attributed to SiO_2 was observed in the SiC spectrum, which signifies complete transformation.

Fig. 3b shows the Raman spectra (200–2000 cm^{-1}) of reactant SiO_2 and synthesised SiC nanoparticles. The typical Raman spectrum was observed for SiO_2 with two strong peaks at ~200 and 464 cm^{-1} , and corresponds to A1 external modes. For synthesised SiC, two main peaks exist at ~779 and 954 cm^{-1} which are attributed to the characteristic transverse mode (TO) and longitudinal mode (LO) of 3C-SiC. A little frequency shift was observed in TO and LO modes which are due to the presence of stacking fault in structure and size confinement effect. The absence of SiO_2 peaks in the SiC spectrum indicates complete transformation.

FTIR absorbance spectra of reactant SiO_2 and synthesised SiC nanomaterial are shown in Fig. 3c. The two major peaks were observed at ~1045 and 700 cm^{-1} in a SiO_2 spectrum, which attributes to Si–O–Si and Si–O stretching vibrations. In the SiC spectrum, the strong peak at 790 cm^{-1} exists which corresponds to the stretching mode of Si–C bond and in turn indicates the TO phonon of stoichiometric SiC crystal. The disappearance of Si–O bonds in the SiC spectrum demonstrates that there is no existence of SiO_2 in synthesised SiC nanoparticles.

XPS analysis was carried out to study the chemical state of synthesised SiC particles. Fig. 4 shows the high resolution XPS spectrum of Si and C regions. The XPS spectrum of Si2p region shows two peaks, the strong peak at 100.4 eV corresponds to Si2p in SiC nanoparticles. The less intense peak at 101.9 eV corresponds to Si2p in silicon oxycarbide. The XPS spectrum of C1s region shows four peaks, major one at 282.3 eV corresponds to C1s in SiC. The other three less intense peaks at 285, 286.5 and 289 eV correspond to outer carbon layers, adsorbed carbon dioxide and some other organic molecules containing carbonyl groups [19]. The spectrum of O1s shows one peak at 531.6 eV which corresponds to Si–O–C bond in silicon oxycarbide. So the spectral decomposition of Si2p, C1s and O1s regions confirms that the outer surface of synthesised SiC nanoparticles is contributed majorly by Si–C and to lesser extent by silicon oxycarbide.

Here we propose the growth of SiC nanoparticles by vapour-solid mechanism [19]. The reduction of SiO_2 by waste CDs char follows the reaction



Similar type of nanochain structures was observed during the synthesis of SiC by Xi et al. The mechanism of formation of nanochains may be due to the presence of carbon deposit over SiC nanoparticles [19]. These results demonstrate that waste CD

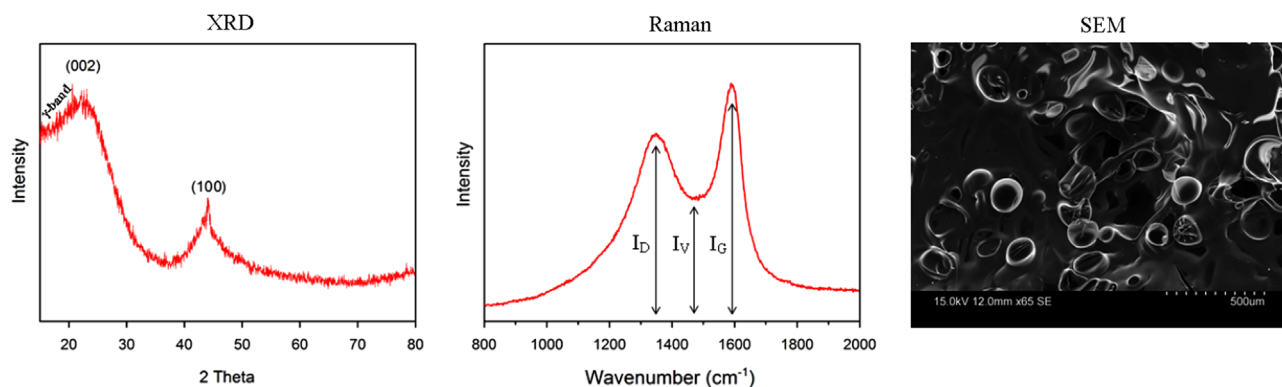


Fig. 1. XRD pattern, Raman spectra and SEM image of produced char from waste CD.

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