PRODUCTION AND CHARACTERIZATION OF SILICON NANOSTRUCTURES FOR THE ADVANCEMENT OF NOVEL ENERGETIC FORMULATIONS

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ABSTRACT

This paper details the synthesis and characterization of Silicon (Si) nanostructured powder with a wide variety of morphologies such as nanoparticles, nanowires, nanotubes etc produced by DC plasma arc discharge route. These nanostructures were synthesized by controlling the synthesis parameters such as current, voltage, catalyst, gas pressure etc. The structural, morphological and vibrational properties were investigated using X-ray diffraction, transmission electron microscopy, scanning electron microscopy, nitrogen adsorption-desorption isotherms and Raman Spectrometer. Both bright and dark field imaging were performed in order to study the morphological characteristics of the nanostructures. These images confirm the formation of high aspect ratio nanostructures of Si with diameters of up to 15 nm and lengths in the range of 500 – 1000 nm. Diffraction patterns were recorded to identify the number of phases formed and determine the crystal structure of the observed phases. The BET surface area of Si nanoparticles and high aspect ratio Si nanostructures (nanowires and nanotubes) are about 60 m^2/g and 360 m^2/g respectively. Raman spectrum of nanostructured Si showed both shift in the peak position and broadening of the Raman peak.

1. INTRODUCTION

In recent years, there is a renewed interest on the development of nanostructured silicon (Si) to advance the preparation of next generation energetic formulations. Two significant achievements that spurred this interest were the demonstration of (i) the preparation of a explosive composite based on porous Si filled with gadolinium nitrate ($Gd(NO3)_3$) in 2002. [Mikulec et al, 2002] and (ii) explosive reaction of nanoporous silicon immersed in cryogenic oxygen discovered in 2001. [Kovalev et al, 2001]. The growing interest in porous silicon is attributed to its high reactivity with oxygen owing to high internal surface area and higher energy of the exothermic reaction of silicon and oxygen than that of the most common carbon-based explosives. [Clément et al, 2005] Therefore, it is envisaged that the energetic compositions based on silicon will be extremely useful in several applications including in microarray analysis, as a smart ignition system for conventional explosives or as a propulsion system for microelectromechanical systems (MEMS) Moreover the energetic mixture prepared with silicon nanostructures is thermally more stable because of its higher melting point as compared to Al. The energetic formulation based on nano Si is also relatively more ESD insensitive.

These scientific developments motivated us to produce silicon nanostructured powder in our laboratory. In this paper, we report the preparation and characterization of silicon nanostructured powder using DC arc-discharge system, in particular, with an emphasis on the production of high aspect ratio Si nanostructures such as nanowires and nanotubes. Silicon nanotubes and nanowires with large surface area and high mechanical strength are likely to be a better choice of fuel compared to porous silicon and silicon nanoparticles. In this work, iron was used as a metal catalyst to prepare nanowires and nanotubes.

2. EXPERIMENTAL

2.1 Materials

Silicon wafers were crushed into powders and used as a precursor in the synthesis process. Iron powder with particle size less than <10 μm and purity of 99.9+ % obtained from Sigma Aldrich (product number: 267953) was used as the catalyst.

2.2 Synthesis of Si Nanostructured Powder

An attempt to grow high aspect ratio Si nanomaterials is described below. This was accomplished through the use of the plasma arc discharge reactor similar to those used for fullerene and nanotube synthesis.