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Structural, optical and electrical properties of sol–gel prepared mesoporous Co_3O_4/SiO_2 nanocomposites

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ABSTRACT

Structures, optical and electrical properties of Co_3O_4/SiO_2 nanocomposites are reported. Well crystalline Co_3O_4 nanoparticles embedded in an amorphous SiO_2 matrix is formed, and confirmed by XRD and FTIR measurements upon calcination of gel precursors up to 800 °C. The obtained nanocomposites have high surface area ~126–312 $m^2\ g^{-1}$, and the Co_3O_4 particle size was ~7–15 nm. The optical properties of the Co_3O_4/SiO_2 nanocomposites indicate the presence of two energy gaps; both of them are smaller than those reported for the Co_3O_4 bulk phase. The first is varied from 1.32 to 1.44 eV and the second one is varied from 1.76 to1.87 eV depending on the particles size. DC conductivity was measured in the temperatures range 300–673 K. The activation energy for DC conduction varies with particle size. The conduction mechanism was suggested to be through small polarons and variable range hopping mechanisms, at high and low temperatures respectively.

1. Introduction

The interest in nanocomposite materials fabrication arises from the combination of the unique properties of the guest phases and host matrices. Nanocomposites can have different functionalities depending on the nature of the matrix, and size and distribution of the dispersed materials. Recently, synthesis of nanoscale Co_3O_4 has received extensive attention because of its thermal stability, chemical and magnetic properties [1,2]. Cobalt oxide/silica nanocomposites have been used as catalytic [3–5], gas and humidity sensing [6–9], optical [10,11], magnetic [12,13] and electrical [14,15] materials in various technological applications.

Synthesis routes play a crucial role in preparing the target product and determining its properties [16]. Various methodologies and routes have been used for synthesis and fabrication of these materials such as sol–gel [3,6,16–18], citrate-gel-Pechini [9], surface organic modification [4] and wet impregnation [5] techniques. The advantages of the sol–gel process are good composition, size control and homogeneity, low processing temperature and low cost [3,16].

Optical absorption studies on the multi-valence spinel tricobalt tetraoxide, Co_3O_4, has shown that it exhibits multiple band gap energies 2.28 eV ($O^{-2} \rightarrow Co^{+2}$) and 1.57 eV ($O^{-2} \rightarrow Co^{+3}$) [14,19]. The distribution of cations on spinel Co_3O_4 is shown to be $Co^{+2}[Co_2^{+3}]O_4^{-2}$: where the cations inside parentheses are octahedral and those outside are tetrahedrally coordinated with oxygen ions [20]. Moreover, the electrical conduction in these p-type semiconducting materials normally occurs by the hopping of small polarons between two different valency states of the cobalt ions [15]. The basic conduction mechanism is due to transfer of electrons between cobalt ions in different valence states. The current carriers are highly localized in the matrix. The strong electron–lattice interaction results in the formation of small polarons which were described by the small–polaron theory [21].

In this paper, we report on sol–gel synthesis of Co_3O_4/SiO_2 nanocomposites. Chemical composition, phase analysis, porosity, particle size, pore size distribution and specific surface area results are discussed and compared. The optical and electrical properties; and the conduction mechanism of these nanocomposites were also investigated.

2. Experimental procedures and techniques

2.1. Sample preparation

Co_3O_4/SiO_2 nanocomposites having different weight content of Co varied from 0 to 50 wt% were prepared by sol–gel method. Co-gelation process starting from alcoholic solution of cobalt nitrate and TOES was performed. The route is similar to that described in our previous work [16]. The formed gel was centrifuged, dried at 80 °C for 24 h and calcined at 400 °C to obtain Co_3O_4 crystallites embedded in

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