Bull. Mater. Sci. (2022) 45:227
https://doi.org/10.1007/s12034-022-02804-3

Structural, morphological, optical and electrical properties of Ni-doped SnO_2 thin films by pneumatic spray pyrolysis method

SABRINA ROGUAI[1,2,*] and ABDELKADER DJELLOUL[1,2]

[1]LASPI2A Laboratory of Structures, Properties and Interatomic Interactions, Abbes Laghrour University, Khenchela 40000, Algeria

[2]Science of Matter, Abbes Laghrour University, Khenchela 40000, Algeria

*Author for correspondence (rog.sabrina@yahoo.fr)

MS received 11 April 2022; accepted 12 July 2022

Abstract. In this study, we used a pneumatic spray pyrolysis technique at 450°C to deposit $Sn_{1-x}Ni_xO_2$ thin films ($0.0 \leq x \leq 0.10$) on glass substrates. The influence of doping content on the films structural, morphological, optical and electrical properties was investigated. Structural characterization by X-ray diffraction indicated that the rutile phase of SnO_2 is present in all thin films, and crystallite sizes are estimated to be in the range of 27–47 nm. Furthermore, structural and microstructural analyses revealed that at $x = 0.05$, there is a solubility limit for (Ni/Sn) in the SnO_2 matrix. The optical bandgap energy increases from 3.83 to 4.01 eV as the dopant content increases according to the Burstein-Moss effect. Resistivity is affected by doping and the thickness of thin films. The figure-of-merit calculated for all samples showed significant differences in the Ni–SnO_2 thin films. There was a difference between the doped thin films depending on the thickness. The lowest resistivity of 1.32×10^{-2} Ω cm and the maximum conductivity of 75 Ω^{-1} cm^{-1} was found at a Ni content of 2%. Seebeck coefficient of all the thin films developed had n-type conductivity, and the values of 76, 71, 133 and 69 μ V/K for Ni-doped SnO_2 thin films at 0, 2, 5 and 10 at.%, respectively, were found to improve the thermoelectric properties of SnO_2 by Ni doping.

Keywords. Ni-doped SnO_2 thin films; pneumatic spray pyrolysis; Seebeck coefficient; optical properties.

1. Introduction

As a result of their unique structural (suitable textured morphology), electrical (relatively low resistivity, on the order of 10^{-15} Ω sq^{-1}), and optical (high optical transmittance) characteristics, transparent semiconductor oxide (TCO) thin films have been the subject of intense research for several years [1,2]. These materials are very important from a technological point of view, and their applications are extremely diverse; they are found in sectors such as electronics [3], silicon solar cells [4], optoelectronics [1] and photovoltaic conversion [5]. Tin oxide is one of these chemicals (SnO_2).

Tin dioxide is the most common tin ore. It crystallizes in a rutile-like structure in its native state (as casseterite). It has the following lattice parameters: $a = b = 4.74$, $c = 3.19$ [6]. SnO_2 is a wide bandgap energy semiconductor. It is transparent in the visible light. The gap of tin oxide in thin films varies between 3.6 and 4.2 eV. Its variances are due to the procedures that were used for its development. On the other hand, this bandgap energy is sufficiently large not to allow activation of the carriers at high temperatures, a process that strongly decreases the Seebeck coefficient. In this regard, inexpensive, environmentally friendly, non-toxic, and high-performance thermoelectric materials are extremely requested, such as SnSe [7], $SnSe_2$ [8], and SnTe [9].

The tin oxide bandgap is of direct type, the valence band and conduction band extrema are on the same axis. Electrons transitions from the valence band to the conduction band are vertical, and free electron concentrations in tin oxide range from 10^{19} to 10^{20} cm^{-3}. It can be doped to improve its electrical properties. Antimony (Sb), niobium (Nb), indium (In), fluorine (F) or chlorine (Cl) doping can improve the conduction characteristics of tin oxide [10].

SnO_2 is an n-type semiconductor [11]. The electrical conductivity of this material is mainly due to the non-stoichiometry of this material deposited in thin films, which causes oxygen vacancies to appear during the synthesis of these thin films. These gaps increase the conduction because they create levels under the conduction band that ionize. Tin oxide has a first ionization energy of 30 meV below the conduction band. Interstitial atoms also participate in the conduction of undoped TCO. This type of doping is done by replacing metal or oxygen atoms. Such doping depends on the size of the dopant and its solubility in the transparent conducting oxide lattice [12]. The doping of tin oxide is possible with elements such as fluorine (F), antimony (Sb),

Published online: 16 November 2022