

# Review of nanostructured NiO thin film deposition using the spray pyrolysis technique

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## ARTICLE INFO

### Keywords:

Nickel oxide  
Nanostructured  
Solar cells  
Spray pyrolysis technique  
Thin film deposition  
Metal oxide

## ABSTRACT

This study reviews NiO film deposition using the Spray Pyrolysis Technique (SPT). Physical and chemical methods can be used to deposit NiO film. This review looks at different precursors and their characterization methods for spray deposition of NiO thin film. The usefulness of SPT emanates from this method being simple, low cost, and viable for mass production. It gives high product purity for metallic and non-metallic material deposition. Nickel chloride, nickel acetate, nickel nitrate, nickel hydroxide, nickel sulfate, and nickel formate are the major precursors for NiO thin film deposition. Nickel chloride and nickel acetate are the most used and highly available precursors. Unlike nickel acetate, nickel chloride precursors corrode the deposition equipment (spray gun). These precursors are relatively cheap compared to current materials used for solar panels (cells). SPT equipment consumes negligible power during deposition and none after usage. Various authors have investigated the physical, chemical, optical, structural characterization and properties of nanostructured NiO thin film. NiO films are p-type semiconductors and as such possesses direct band gap suitable for various applications. The film has been categorized as an excellent material for optoelectronic applications because of its tune-ability for optimization. The wide band gap is in the range of 3.25–4.0 eV. This review will be useful to researchers exploring solar photovoltaic potentials for solving electricity problems of developing countries.

## 1. Introduction

About one-fourth of earth's inhabitants lack access to electricity with little or no change of outlook since over forty year now [1]. Several developing countries in Africa and elsewhere are still struggling to deliver affordable and stable electricity [2]. Renewable energy is a viable solution to ending the global electricity problem as it exceeds world electricity demand [3]. Renewable energy includes solar, wind, geothermal, oceanic, hydro, biomass and other energy sources. Solar energy can be converted to useful direct current electricity using solar cells [4]. A major breakthrough in solar cell fabrication would be large scale production at affordable cost [5]. Currently, there is difficulty in scaling up existing method of solar cell fabrication. The major obstacles are the expensive nature of materials and the complexities involved in fabricating solar cells. The Spray Pyrolysis Technique (SPT) is widely used because of its simplicity and affordability [6]. The properties of spray deposited film depend on the substrate, substrate temperatures, spray rate and droplet sizes [7]. Droplet size depends on spray rate, nozzle diameter and carrier gas / carrier gas pressure [8]. Inorganic semiconducting materials are inexpensive, environmentally friendly and viable sources for solar cell fabrication [9]. Fabrication of

nanostructure metal oxide films has generated interest over the years due to their wide application [10–16]. They are used in radiation detectors, solar cells, semiconducting devices, laser materials, thermoelectric devices, and optoelectronic devices [17–20]. Nanostructured metal oxide is a promising option for thin film solar cells [21]. NiO is one such metal oxide with many suitable properties. Despite the promising properties of NiO, limited studies have been conducted on it when compared with ZnO and CuO.

### 1.1. NiO structural properties and applications

Nickel oxide adopts the rock salt form of NaCl, having octahedral Ni (II) and O<sup>2-</sup> sites (Figs. 1 and 2). As a binary metal oxide, the ratio of Ni:O deviates from 1:1 making it non-stoichiometric most times. NiO stoichiometry is shown by the colour variation [22]. NiO can either be a black or green crystalline powder. Density of NiO is 6.67 g/cm<sup>3</sup> and the melting point is 1955 °C [23]. Nickel chemical composition of NiO is 78.55% while oxygen is 21.40%. It has a molar mass of 74.6928 g/mol. It has magnetic susceptibility of +660.0·10<sup>-6</sup> cm<sup>3</sup>/mol. The refractive index of NiO is 2.1818. The toxicity of nickel oxide depends on the quantity inhaled [24]. It exists in various oxidation states. The states

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<http://dx.doi.org/10.1016/j.rser.2017.10.041>

Received 29 March 2017; Received in revised form 14 July 2017; Accepted 26 October 2017

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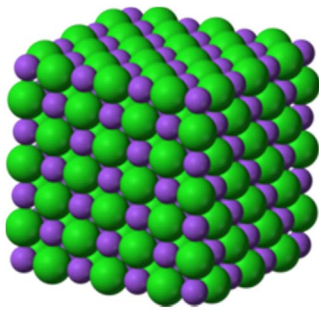


Fig. 1. Crystal structure of NiO [23].



Fig. 2. Pictorial view of NiO.

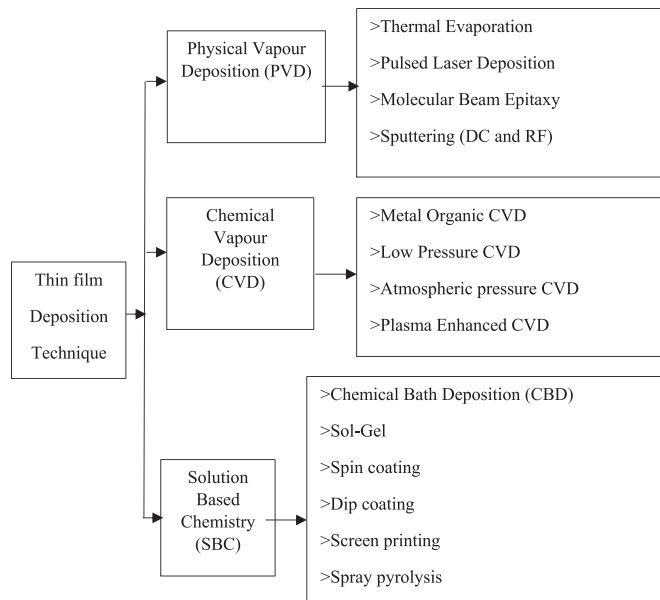


Fig. 3. Classification of thin film deposition methods.

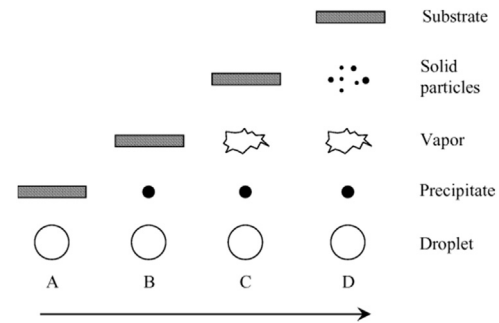


Fig. 5. Deposition processes initiated with increasing substrate temperature [67].

are nickel trioxide or sesquioxide ( $\text{Ni}_2\text{O}_3$ ), nickelous oxide ( $\text{NiO}$ ), nickel dioxide ( $\text{NiO}_2$ ), nickelous oxide ( $\text{Ni}_3\text{O}_4$ ), and nickel peroxide ( $\text{NiO}_4$ ).  $\text{NiO}$  has rhombohedral or cubic structure referred to as Bunsenite.  $\text{NiO}$  is a p-type semiconductor with a wide band gap between 3.5 and 4.0 eV [25].  $\text{NiO}$  finds useful application in solar cells [26] and UV photo-detectors [27] due to its high durability and excellent chemical stability. Other applications include electrochromic devices [28], anti-ferromagnetic layers [29], and chemical sensors [30].

Thin film deposition is divided into three groups by means of its nature of deposition as depicted in Fig. 3 [31]. However, this classification was done considering the physical or chemical processes involved. Chemical processes include gas-phase and solution deposition methods. Gas-phase methods include: chemical vapour deposition (CVD) [32], atomic layer epitaxy [33], and atomic layer deposition (ALD) [34]. Solution deposition methods include: spray pyrolysis [35], sol-gel [36], spin [37], and dip-coating [38]. Physical processes include: pulsed laser deposition [39], physical vapour deposition (PVD) [40], molecular beam epitaxy [41], and magnetron sputtering [42]. Other techniques include: chemical bath deposition [43], advanced reactive gas deposition [44], electron beam evaporation [45], vacuum evaporation [46], and anodic oxidation [47]. Different techniques have been employed to deposit nickel oxide thin films. The techniques are RF sputtering [48], electron beam evaporation [49], DC magnetron sputtering [50], and anodic electrodeposition [51]. Cathodic electrodeposition [52] and chemical vapour [53] can also be used for  $\text{NiO}$  deposition. This study will review  $\text{NiO}$  films deposited using SPT.

## 1.2. Spray pyrolysis technique

SPT is classified as a solution based chemistry based on the nature of the deposition. Solution based methods for films deposition are becoming more popular [54]. Solution based methods provide high purity products at low cost, starting from easily available materials. SPT is useful for depositing varieties of thin film. Using SPT, films of very thin

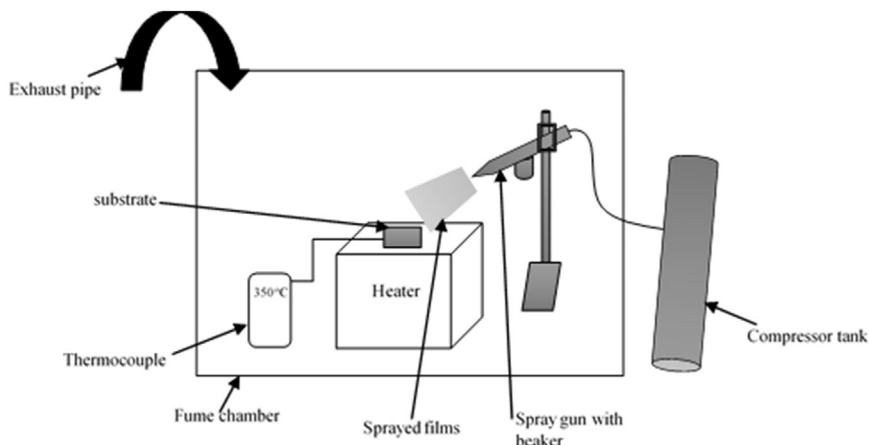


Fig. 4. Experimental set-up of spray pyrolysis technique.

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