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Optical Properties of Tantalum Doped Zinc Oxide Thin Films Prepared by DC Plasma Sputtering

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In this study, a thin film of tantalum doped zinc oxide (ZnO:Ta) with a thickness of 50 nm was deposited on a glass substrate using dc plasma sputtering under on argon atmosphere, at a room temperature and with a target-to-substrate distance of 5 cm. Two films were prepared at different sputtering powers: the first at 70W and the second at 80W while keeping the deposition time constant at 5 minutes. The aim of this research was to evaluate the effect of plasma parameters on the optical properties of the deposited films. The results showed that the film deposited at 80W exhibited the highest absorbance, while its transmittance was lower compared to the film deposited at 70W. Furthermore, the reflectance of the prepared films demonstrated a sharp decrease in the 80W sample showing the lowest reflectance among the studied conditions.

Keywords: ZnO:Ta; Plasma sputtering; Thin films; Optical properties

1. Introduction

Thin films represent one of the most important technologies that have significantly contributed to the development and investigation of semiconductors. They have provided clear understanding of numerous properties that are difficult to observe in materials in their bulk from thin films are characterized by their extremely small thickness, typically not exceeding a few micrometers. This is due to the fact that the film layer is deposited as a thin coating on various substrate materials, which may include glass, silicon or metals [1]. Zinc oxide (ZnO) is an example, which has attracted considerable attention in recent research due to its remarkable optical and photonic properties [2,3]. Zinc oxide is a transparent semiconductor material characterized by a wide energy band gap ranging in 3.2-3.3 eV with high optical transparency, and intrinsic n-type electrical conductivity [4]. Due to its natural abundance, relatively low cost [5], chemical inertness and enhanced stability of the compound make ZnO more attractive, while its fundamental conductive properties emerge predominantly at low temperatures, particularly below 200 °C [6-8]. These properties qualify it as an ideal candidate for use in solar cells. Additionally, it is utilized as a nanomaterial in the treatment of cancer and peptic ulcers due to its role as a carrier for pharmaceutical agents. Furthermore, it is employed for fruit preservation as it is considered a non-toxic material [9,10]. There are several methods for the preparation of thin films including both chemical and physical techniques among the physical methods, plasma sputtering stands out due to its flexibility and simplicity. This technique allow species Control over deposition rate and film thickness [11]. The electrical resistance of ZnO in influenced by doping level and the deposition conditions [12].

The researchers found that undoped zinc oxide (ZnO) thin films exhibit high electrical resistance. However, doping with tantalum (Ta) leads to a reduction in resistance, which is attributed to tantalum's good chemical stability, relatively high refractive index, and lower absorption rate in visible region [13].

The aim of studying the optical properties of tantalum-doped zinc oxide thin films prepared by dc plasma sputtering is to explore their potential for various applications, particularly in the fields that require high corrosion resistance.

2. Experimental Part

Tantalum-doped zinc oxide (ZnO:Ta) thin films were prepared using the dc plasma sputtering technique inside a high-vacuum deposition chamber with a basic pressure of approximately 10^{-5} torr. A high-voltage power supply was utilized to generate the plasma. Glass substrates were employed as deposition platforms and were meticulously cleaned using an ultrasonic bath to eliminate any surface contaminants or impurities that could affect the quality of the film deposition. Two groups of ZnO:Ta samples were prepared using a zinc oxide target doped with 10% tantalum in an argon atmosphere. In one group (ZnO:Ta9), one sample was deposited at a power of 70W in an argon atmosphere, while another sample was deposited at a power of 80W under the same argon atmosphere. The distance between the target and the substrate was 5 cm, the substrate temperature was maintained at 27°C and the deposition time was controlled at 5 minutes to achieve a film thickness of 50 nm.

3. Results and Discussion

The optical measurements of the ZnO:Ta thin films deposited by dc plasma sputtering revealed clear variations with deposition power for the sample prepared at 80W. The film deposited at 70W indicates that the tantalum doping leads to a modification in the electronic structure and an increase in charge carriers as a result of the substitution of Zn atoms by Ta dopants. As shown in Fig. (1), the absorbance was found to increase with higher doping levels. Since the introduced impurities create additional energy states within the band gap, these localized states facilitate electron transitions from the valence band to the conduction band much more efficiently.

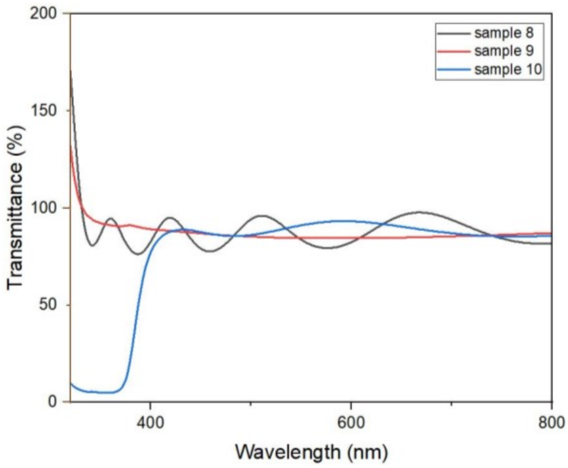

Fig. (1) Transmission spectra as a function of wavelength for ZnO thin films prepared by DC plasma sputtering

In contrast, the optical transmittance of the films decreased for the sample deposited at 80W compared with the films deposited at 70W, as shown in Fig. (2). Furthermore, reflectance measurements in Fig. (3) showed a significant reduction for all films, with the lowest reflectance observed in the 80W sample.

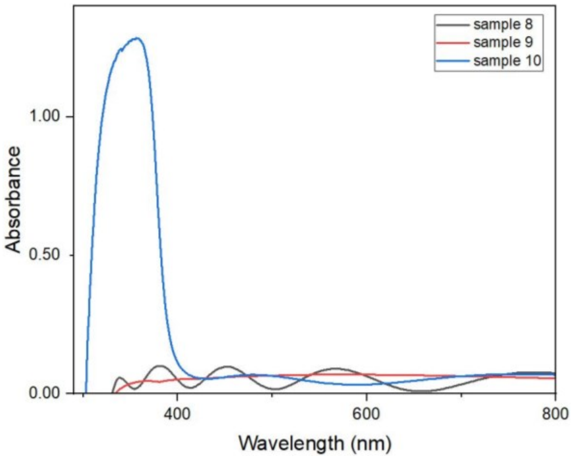

Fig. (2) Absorption spectra as a function of wavelength for ZnO thin films prepared by DC plasma sputtering

4. Conclusion

The optical studies of zinc oxide (ZnO) thin films deposited by DC plasma sputtering at two different sputtering powers (70 W and 80 W) revealed that increasing the sputtering power led to significant enhancement in the absorption. This behavior can be attributed to changes in the electronic structure and the formation of new localized energy levels induced by tantalum doping. Consequently, the optical transmittance decreased noticeably, while the lowest reflectance was observed for the film deposited at 80W. These findings are consistent with previous studies [14-16], which reported that tantalum doping in ZnO thin films introduces new energy states within the band gap and increases carrier concentration. Overall, the results confirm that sputtering power is one of the most critical plasma parameters for controlling the optical properties of ZnO:Ta thin films, making them promising candidates for optical, electronic, and biological applications.

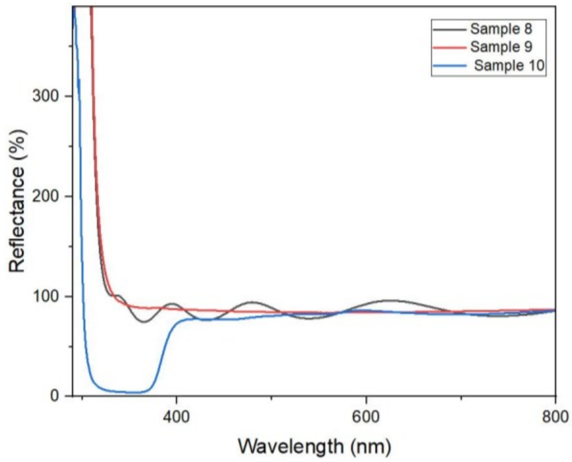

Fig. (3) Reflection spectra as a function of wavelength for ZnO thin films prepared by DC plasma sputtering

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