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# Impact of thin metal layer on the optical and electrical properties of indium-doped-tin oxide and aluminum-doped-zinc oxide layers

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ABSTRACT

The distinguished transparent conductive oxide (TCO) layers like indium-doped-tin oxide (ITO) and aluminum-doped-zinc oxide (AZO) layers were prepared in different combinations with and without thin Ni metal layer. The optical and electrical properties of prepared samples were analyzed and compared with the objective to understand the role and influence of the Ni layer in each TCO combination. The highest transmittance value of 91.49% was exhibited by prepared AZO layers. Even though if the transmittance of Ni inserting TCO layers was marginally reduced than that of the ordinary TCO samples, they exhibited balanced optical properties with enhanced electrical properties. Carrier concentration of indium doped tin-oxide and aluminum doped zinc oxide (ITO/AZO) bilayer sample is increased more than double the times when the Ni layer was inserted between ITO and AZO. Thin layer of Ni in between TCO layers reduced sheet resistance and offered substantial transmittance, so that the figure of merit (FOM) value of Ni embedding TCOs was greater than that of TCOs without Ni layer. The ITO/Ni/AZO combination provided optimum results in all the electrical properties. As compared to other TCO/metal combinations, the overall performance of ITO/Ni/AZO tri-layer combination was appreciable. These results show that the optical and electrical properties of TCO layers could be enhanced by inserting a Ni layer with optimum thickness in between them.



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## 1. Introduction

The implementation of TCO layers in Si based solar cells is an important breakthrough in the ongoing progress of photovoltaic research. They serve as ohmic contacts, rectifying junctions, anti-reflectors and passivation layers in an effective manner. TCO layers provide higher metallic conductivity and complete transparency in a broad range of wavelength due to their wide optical band gap ($E_g$) which is higher than 3 eV. These qualities made TCOs as promising materials which can improve the efficiency of the photoelectric devices [1]. Among all TCOs, ITO and AZO layers are widely used in commercial applications such as displays, solar cells and photovoltaic devices, because ITO is well known for its excellent electrical conductivity and AZO for its enhanced optical transparency and thermal stability [2–5]. Many results were reported in explaining the efficient roles of ITO and AZO layers in photovoltaic devices [6–8]. Yun et al. reported that the bilayer structure of TCOs exhibited higher optical transparency and electrical conductivity than those of single layer ITO and AZO films [9]. Therefore, it was realized that overall functionalities of bilayer TCO structures were better than single layer TCOs. However, TCO layers offer relatively high resistivity and low transmittance at room temperature and as a result, the charge carrier generation and separation process is lagging behind and thereby degrading the photoresponse and the rectification property of the devices [10]. In order to solve this problem, thin metal layers such as Ni, Au, Ag, Al were embedded with TCO layers and annealed at different temperatures depending upon the TCO/metal combination. The metal embedding TCO layers with optimum thickness can reduce the reflection from metal layer and thus achieving selective transparency in visible region [11]. Moreover, when a light is incident on the Ni inserted TCO materials, the free electrons available in the metal layer speed up the light transportation from the top to the bottom of the device. Also, the metal layer helps to thrust up the separated charge carriers swiftly to the top electrode. Different combinations of TCO/metal/TCO structures such as ITO/Ni/ITO [12], AZO/Ni/AZO [13], ITO/Au/ITO [14], AZO/Al/AZO [15], AZO/Mo/AZO [16], TCO/Ag/TCO [17], AZO/Ag/AZO [18], AZO/Ag/FTO [19] and AZO/Au/AZO [20] were analyzed and reported by the researchers. Each combination has its own individuality in enhancing the overall performance of the devices. The suitable metal layers increase the carrier concentration without degrading transmittance of the devices. For most of the photovoltaic applications, Ni is the suitable material. Ghosh et al. [21] presented in their studies that the optical properties of Ni compete with the optimum conditions which are necessary to be employed in photoelectric devices, compared to the noble metals Au and Ag. Moreover, Ni possesses lower reflectivity than Au and Ag, so that increasing quantum efficiency, which relates to absorption of photons [22]. In this innovative period of photovoltaics, it is necessary to report all the conceivable and improved combinations of TCO layers with optimized thin metal layer in a single stroke.

In this work, we presented a panoramic view of optical and electrical properties of ITO, AZO layers, their bilayer combination (ITO/AZO) and how does a thin layer of Ni improve the entire characteristics of these TCO materials. Three kinds of TCO layers, namely ITO, AZO and ITO/AZO (further, referred in the text as S1, S2 and S3) were prepared without any metal insertion and characterized. Afterwards, similar combinations, but with embedding thin Ni layer of 5 nm thickness such as ITO/Ni/ITO, AZO/Ni/AZO and ITO/Ni/AZO (further, referred in the text as S4, S5 and S6) were prepared. The optical and electrical properties of all the prepared samples were characterized and compared. The peculiar properties exhibited by the prepared samples were explained with relevant interpretations. It was identified that the electrical properties of metal inserting TCO layers were enhanced compared with ordinary TCO layers, whereas ordinary TCO layers dominated in optical transmittance. And, it is reported that the mobility, carrier concentration, conductivity and figure of merit (FOM) of Ni embedding TCO samples were comparatively higher than those of ordinary TCO layers. This study provides a key idea for photovoltaic researchers and manufacturers to choose the better TCO combination according to their requirement.