Comparative and Investigational Studies of Solar Cell Featured for Modern Electric Vehicle Applications

M Naveen Kumar1, K Arthanareswaran1, S Sakthivel1, T T Rameshkumar Raja2, M Elango3,a),R Venkatesh 4, M Ramamurthy5,M Senthil Kumar6, Jonnala Subba Reddy7

1Department of Mechanical Engineering, K.S.Rangasamy College of Technology,

Tiruchengode, 637215, Tamil Nadu, India.

2 Department of Mechanical Engineering, Sengunthar Engineering College, Thuduppathi,

638057, Tamil Nadu, India.

3 Department of Mechanical Engineering, Erode Sengunthar Engineering College, Thuduppathi,

638057, Tamil Nadu, India.

4 Department of Chemistry, Sona College of Technology, Salem, 636005, Tamil Nadu, India.

5 Department of Mechanical Engineering, Academy of Maritime Education and Training, Deemed to be University

Kanathur, Chennai – 603112, Tamil Nadu, India.

6 Department of Mechanical Engineering, Centre for Research and Development, Vinayaka

Mission's Kirupananda Variyar Engineering College, Salem, Vinayaka Mission's Research

Foundation, (Deemed to be University) Salem,Tamil Nadu, India.

7Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Andhra Pradesh, 521230, India.

**Corresponding author:** a)[elango3088@gmail.com](mailto:elango3088@gmail.com)

**Abstract:** Electric vehicles (EV) provide better performance and are advantageous over internal combustion engines. Solar-featured EVs have gained significance in the automotive field, are eco-friendly, and are designed with iridium tin-oxide (ITO) because of high optical transparency, better electrical conductivity, and durability. However, its performance is limited by increased surface area, and the limited availability of indium leads to minimize the functional properties of solar EVs. The present study enriches the functional properties of the ITO layer featured with magnesium-zinc oxide (Mg-ZnO) thin film coating (20nm)/ aluminium-zinc oxide (Al-ZnO) through the sol-gel method. Influences of thin film processing and actions of Al-ZnO & Mg-ZnO on surface morphology and functional properties are studied. SEM (Scanning electron microscope) and XRD (X-ray diffraction) provide better particle dispersion, and its contribution peaks ensure the contributions of Al/ZnO & Mg/ZnO in the ITO layer. However, the Mg-ZnO coated ITO solar layer found better functional characteristics like improved current density (2.1mA/cm2), better optical absorptance and transmittance behaviour, which are better than the uncoated ITO layer. The Mg-ZnO thin film featured ITO solar cell is suggested for EV applications.

# Introduction

Solar renewable energy is used for a variety of applications and is the fastest-growing segment in the energy sector [1-3]. Recently, it has been widely adopted for electric vehicle usage due to its simplicity, efficiency, and cost-effectiveness compared to conventional fuel sources [4-6]. Additionally, solar energy is applied in household, industrial, and other energy-related applications [7-11]. One of the advancements in solar energy is its potential for electron transport applications, which are environmentally friendly and economically viable, particularly for fuel-powered vehicles [12-15]. Recent studies on nano-sized thin film coatings have shown that they boost the behaviour of solar cell, demonstrating superior optical, electrical, and thermal characteristics compared to traditional solar cell systems [16-19]. Solar was the broad area. Researchers were focused on enhancing solar performance through solar collector modification, solar film modification, and thin film coating on solar transistors [20-22]. Moreover, the solar film was the significant choice for attaining maximum solar performance [23-24].

With the technology of the sol-gel method, zinc oxide coating formed over the fluorine layer featured with tin oxide layer. The influence of coating on optoelectrical behaviour is studied. The thin layer is exposed to better optical and electrical behaviour, and higher electrical efficiency is noted [25-27]. The cost-effective sol-gel technique is used for making thin film coating, which provides better antireflection coating and influences better electrical efficiency [28-30]. An optoelectrical properties of Al/ZnO & Cu/ZnO embedded solar cells was studied, and their microstructure reveals better doping of particles could be located as uniform. The results increased photoelectric efficiency and found 0.492% on Al-ZnO doped cell [31-33]. The cerium oxide-based film thin layer showed a good buffer level and 20% improved solar power conversion efficiency. Meantime, the absorption coefficient was increased to 20 to 26.59%, respectively [34-36]. Influences of Al/Mg on the surface morphology behaviour of ZnO nanoparticles featured electron transport layers were analyzed for solar film applications. The sol-gel method forms the thin layer at 400ºC with 23 and 27nm. Its outcome results showed that the sol-gel developed ZnO layer has found uniform particle distribution with reduced space between the particles [37-40]. Optical/electrical (O/E) behaviour of Mg-doped with annealed temperature performed Al/ZnO mapped with and Mg/p-Si/Al hetero-junction was studied, and its results of the structure showed homogenous distribution with increased ZnO concentration, it results in superior O/E behaviour. The ZnO layer formed over the ITO via plasma chemical vapour deposition. It studied its structure O/E characteristics of solar thin film, and the co-doping ZnO layer found high thermal absorption. However, the sol-gel developed ZnO layer solar cell found good optical transmittance value, and its structure showed an even particle distribution with reduced particle space. With the attention solar renewable energy featured with EV is the trend and found to have better performance than conventional systems. This technology is featured with wireless charging and is cost-effective [41-44]. Thin film coating technology with an ITO layer is found to higher optoelectrical properties, which impacts the functional behaviour of solar cell EVs. This thin film coating is made via the physical vapour deposition method, which helps to enhance the particle distribution & leads to higher optoelectrical properties of solar cells.

Current study correlated to past references is studied & discussed above. The ITO solar layer found hiked optoelectrical properties. However, its behaviour is reduced with increased surface area, and the limited availability of indium leads to reduced functional characteristics. This research is to overcome the above disputes. It enhances the functional behaviour of the ITO layer coated with Al-ZnO and Mg-ZnO electron transport layer (ETL) via the sol-gel method. The impacts of treating on the structural and functional behaviour of ITO coated with Al-ZnO and Mg-ZnO layers (20nm) are studied, and its outcomes are compared with the significance of 20nm Mg-ZnO ETL layer over the ITO layer expected to better microstructural, optical and electrical properties.

# Materials and Methods

According to [45-46], the sol-gel parameters like spin speed and time are chosen as 1200rpm for 30sec. Likewise, the 0.5% concentration of zinc nitrate precursor solution is chosen, and its viscosity is followed by 5 centipoise. Fig. 1 represents the sol-gel technique developed for the Al-ZnO thin film doping flow process. Initially, the precursor solution (0.5% concentrations of zinc nitrate) was kept in a beaker, and the required amount (1wt%) of Al nanoparticles (50nm) was deposited into the solution. The ageing process controlled the process. The controlled Al doping agent was positioned to sol and dipped over the ZnO surface under the spin coating deposition technique. The actual sol-gel setup is presented in Figure 2.

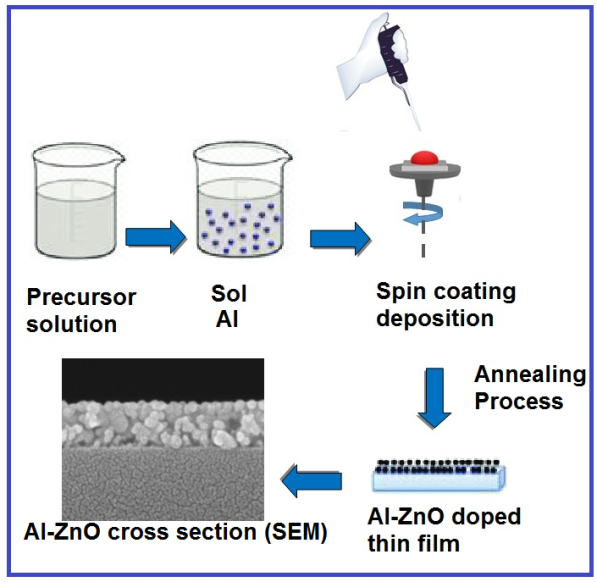


Figure 1 Flow process diagram for doping of Al-ZnO thin film via sol-gel route.

During the sol-gel processing, a high spin speed of 1200 rpm is followed for 30sec influences to uniform spreading of the solution, which leads to making an efficient thin film layer over the ITO. Higher spin speed leads to thin layer formation, which is potential for nano thickness coating reported [47]. Before the annealing process, the layer is involved at 100⁰C for 10 min, which helps to reduce the moisture and enhance the surface quality [48]. The complete sol (Al) covered ZnO layer was kept in the annealing process with an applied temperature of 450ºC for 60 minutes. The annealing process offered good bonding between Al and ZnO with increased coarse grains. The developed Al surface over the ZnO overlap excess layer was removed in the next step, and the effective wall crystallization was formed. The Al-ZnO doped cross-section layer is indicated in the above Figure 1. A similar modulation has to be repeated for Mg-ZnO thin film formation over the ITO. Moreover, this has to be effective and right for making a thin film layer nano thickness. The developed Al-Zno and Mg-ZnO structure was analyzed using a ZESIS model scanning electron microscope with 3000x magnification, and its peaks were noted by X-ray diffraction.



Figure 2 Sol-gel setup.

Equation (1) [48] describes transmittance.

(1)

The J-V Curve, showed in equation (2) [48] which relates applied voltage to current density.

(2)

To find the test significance, the test hypothesis of the present experiment is made three times and its average value is considered.

# Results and Discussion

Fig. 3 (a-b) depict the SEM images of the Al-ZnO doped solar layer and the cross-sectional microstructure view of Al-ZnO doped over the ITO solar layer. It was revealed from Fig. 3(a) that the Al particles over the ZnO showed uniform particle distribution with reduced particle distance, which leads to fine grain boundaries and resulting better optical properties. It was due to even spin coating over the ZnO. Moreover, the 50nm of Al particle influences to increase more number of nucleation sites, which leads to an increase in bonding strength between the Al and ZnO layer, resulting in improved functional behaviour. In addition, the solar cell film doping material quality was varied because of the sol process. Moreover, the solar absorption behaviour was improved with increased optical absorptance behaviour. However, the homogenous dispersion of filler leads to better optoelectrical properties. The cross-sectional microstructure of the Al-ZnO doped layer is displayed in Figure 3 and proves the Al presence over the ZnO layer. It was noted by a 3000x magnification range with a 50nm scale. In the cross-sectional view of Al-ZnO, we found good bonding.

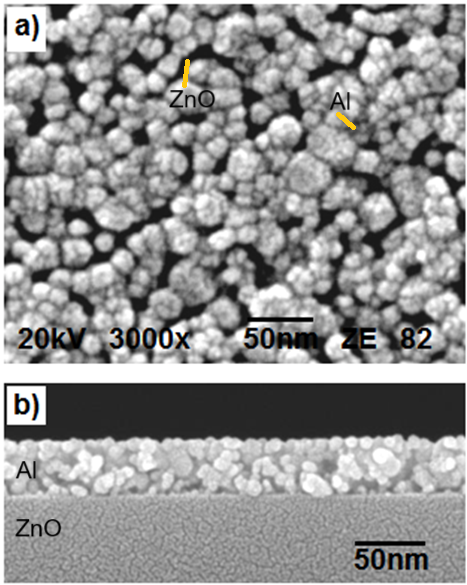


Figure 3 SEM images of a) Al-ZnO layer b) cross-sectional view of Al-ZnO.

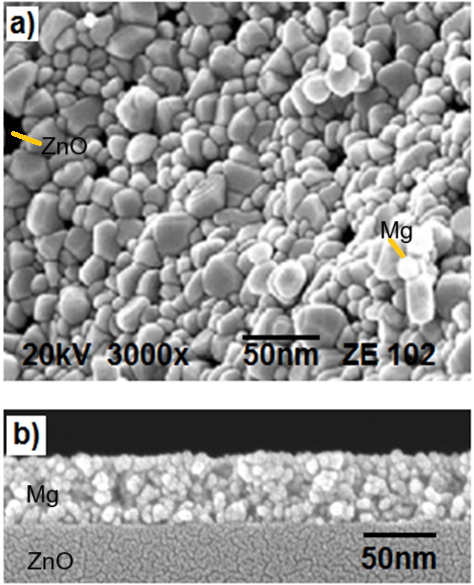


Figure 4 Surface morphology of a) Mg-ZnO layer b) cross-sectional view of Mg-ZnO.

Figure 4(a) illustrates the SEM surface morphology of the Mg-ZnO doped solar layer gathered from the Mg-ZnO thin layer with a 300x magnification range at a 50nm scale. It showed enhanced particle distribution with reduced space between the particles and increased occupational area. It results in an increased surface to absorb the heat from solar radiation. The effect of sol-gel formation leads to thin film formation, and applied processing temperature has fixed the particle distribution. Moreover, selecting precursor solution and sol formation was important for obtaining the thin film. It was noted from Fig. 4 (b) above that the cross-sectional illustration of Mg-ZnO showed the Mg thin layer over the ZnO layer. It has doped effectively because of the annealing process. In addition, the particle band gap increased with reduced particle space distance. It results in improved self-heat of solar cells [12 and 15]. However, the Al and Mg sol-gel doped ZnO showed uniform particle distribution with improved coarse grain structure. The effect of Al & Mg-doped ZnO solar cell XRD (X-ray diffraction) was addressed in the next section.

Figure 5 illustrates the X-ray diffraction (XRD) peaks of the ZnO, Al-ZnO, and Mg-ZnO layers. According to the contribution of sol-gel processing, the Al-ZnO and Mg-ZnO layers peaks are compared with ZnO peaks. The peaks of (intensities) 100, 001, and 010 are represented by oxide, Al and Mg, and Zn layer, which lies on 7.8 degrees (2θ), 37 degrees (2θ), and 61.2 degrees (2θ). During the analysis, the zinc oxide is found like zinc and oxide, which is represented in the peaks of 010 and 100, respectively. Initially, the XRD peaks for ZnO showed micro variations and its oxide concentration was attained as the level of peaks, and it was the major peak rather than other peaks. Similarly, the Al and Mg-doped ZnO layers showed minor variations. In the red curve from Fig. 5, the magnesium was recorded at 37º, and the oxide combination was formed at 7.8º. The sol-gel formation and its process parameters enhanced the particle distribution. Moreover, the XRD pattern of Mg-ZnO compared with the ZnO layer showed equal particle distribution and even particle distribution distance. It results in a superior self-heat effect found to have good photocurrent density. Recently, the Al and Mg-doped ZnO layer found high solar cell performance. However, an effective spin speed influences thin layer formation and finds uniform peaks, which leads to better optical properties.

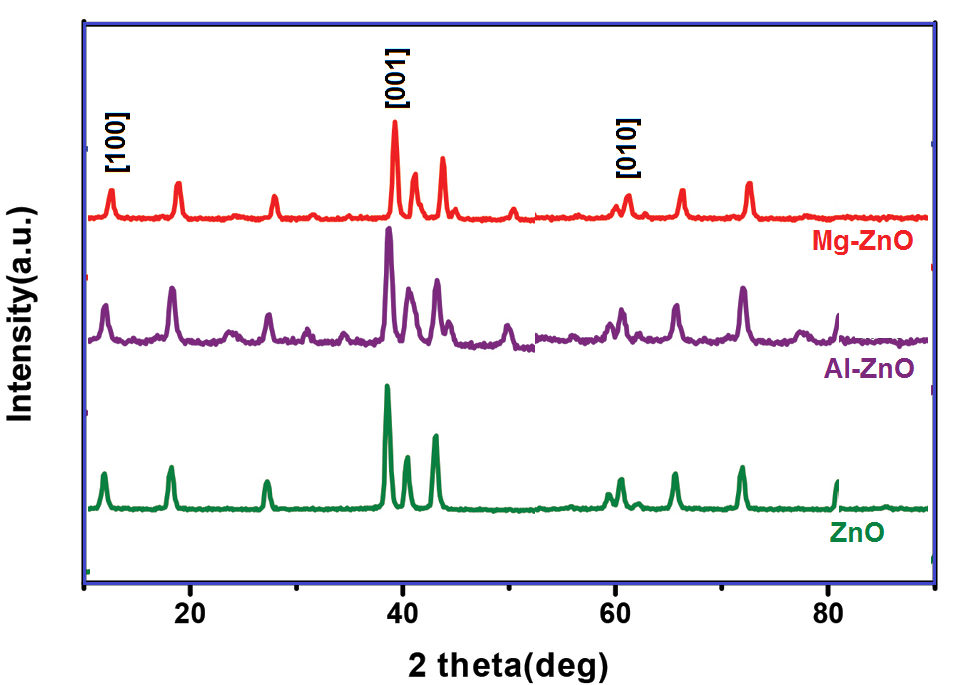


Figure 5 XRD analysis of ZnO, Al-ZnO, and Mg-ZnO layer.

The interfacial bonding between the Al-ZnO layer and the Mg-ZnO layer could be obtained by higher optical transmittance with enhanced solar behaviour [14 and 32]. . Controlled lattice contraction and flaws are linked to improved electrical conductivity and optical transparency with even peaks of Al-ZnO. Although Mg inclusion results in reduced gap tuning in the Mg-ZnO layer, excessive doping can introduce MgO phases and damage crystallinity.

Figure 6 presents the current density of the ZnO, Al-ZnO, and Mg-ZnO layers made by the sol-gel route. The current density of doped ZnO is much larger than the undoped ZnO. The current density of ZnO was increased gradually by an increased voltage and 0.6mA/cm2 as the maximum. While ZnO doped with Al showed larger than the ZnO current density of 1.7mA/cm2 on improved voltage. It was due to improved self-heat effect during the solar radiation. The aluminium was found to have superior thermal conduction [33-35].. The Mg-ZnO layer's current density was 2.1mA/cm2, higher than the others. It was improved 2.5 times compared to ZnO later without dope material. It was due to Mg's higher thermal conductivity of 0.48W/mK. However, the Mg-doped ZnO found superior current density due to coarse grain structure with reduced particle space. Moreover, the sol-gel developed Al-ZnO and Mg-ZnO layers are found to increase nucleation sites, which leads to coarse grain boundaries to better electrical behaviour and enhances the conductivity performance of solar cells.

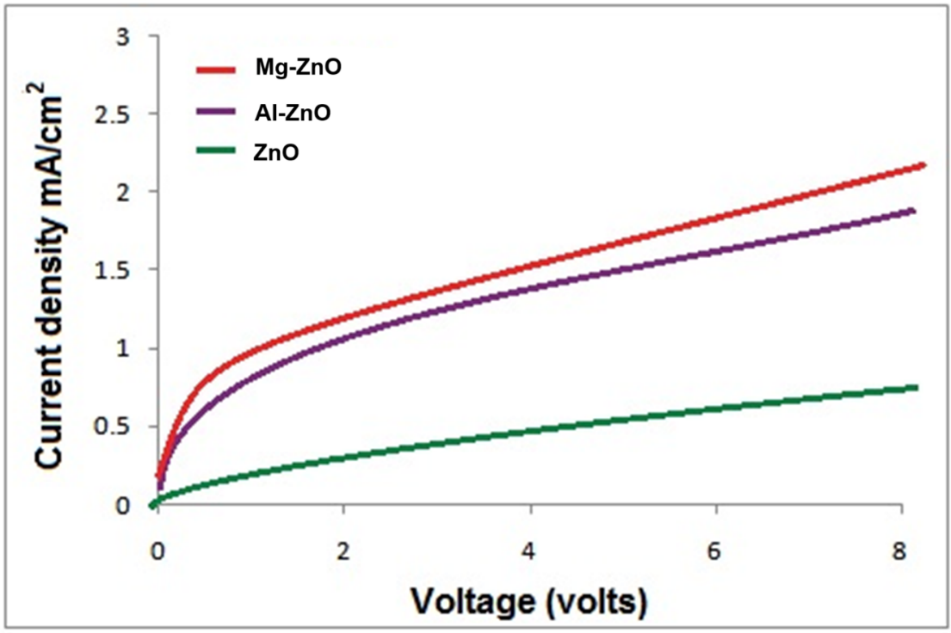


Figure 6 Current density behaviour of ZnO, Al-ZnO, and Mg-ZnO layer.

However, the current density of the Al-ZnO and Mg-ZnO layer is the ability to enhance the overall performance with improved electron transport behaviour due to enriched carrier behaviour. Solar radiation directly influences to carrier effect, which leads to better current density. According to the film thickness, the current density is varied and optimum current density is found on Mg-ZnO combinations. It is due to the impact of the Mg2+ carrier introducing optimum bandgap increases the free carrier concentration and reduces the mobility to lattice distortions. Moreover, the Al-ZnO and Mg-ZnO layers offered high transparency efficiency behaviour, which is 83 and 86%, respectively. However, Mg-ZnO doped ITO layer under normal solar energy, bandgap widening modestly lowers current density by reducing overlap with the visible spectrum. Defect-related scattering decreases the efficiency of charge transport by reducing carrier mobility [22].

Figure 7 (a) shows the optical behaviour of the un-doped and Al and Mg-doped ZnO layers, while Figure 7 (b) shows the absorptance, which increased gradually with improved wane length (200-600 nm). The Mg-ZnO layer showed a superior absorptance percentage compared to others, with the absorptance percentage of ZnO decreasing from 80% to 19% with improved wavelength (100 nm to 1200 nm) due to the reduced thermal behaviour of the layer, while the Al-doped ZnO was larger than the value of ZnO due to the presence of the Al layer over the ZnO.

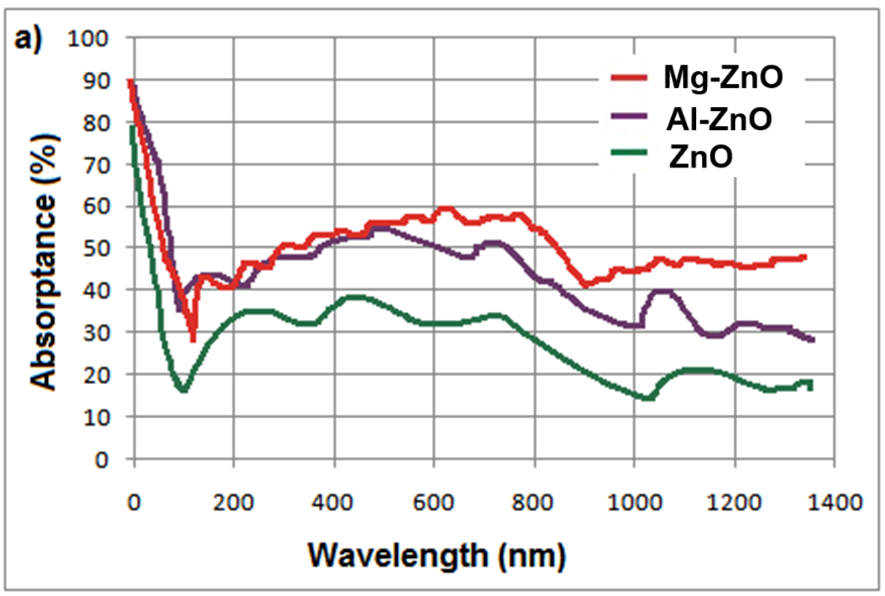


Figure 7 (a) Absorptance properties of ZnO, Al-ZnO, and Mg-ZnO layer

Figure 7(b) expressions of the transmittance percentages of ZnO and Al and Mg-doped ZnO layer measured with different wavelengths. It was identified, Fig. 7(b) that the Mg-ZnO doped solar cell found an enhanced transmittance range and improved by 89%. The transmittance behaviour of ZnO is found to be 35% (800-1000nm wavelength), and the layer coated with Al (20nm) is found better enhancement in transmittance behaviour. It is due to the concentration of aluminium influences to enriching the absorption and optical behaviour, resulting in enhanced transmittance behaviour, and its value is 55% (800-1000nm wavelength) and 61% (more than 1000nm wavelength), which is 74% better than uncoated ZnO ETL layer. However, the Mg-ZnO coated ETL layer has found optimum transmittance behaviour of 89%, which is 154% and 46% better than the uncoated ZnO and Al-ZnO coated layer. The higher transmittance percentage was due to identifying the Mg layer over the ZnO, which performed a higher current density of 2.1mA/cm2. Uniform dispersion of Mg and higher thermal absorption behaviour of Mg are the reason for enhanced transmittance behaviour [49-50].

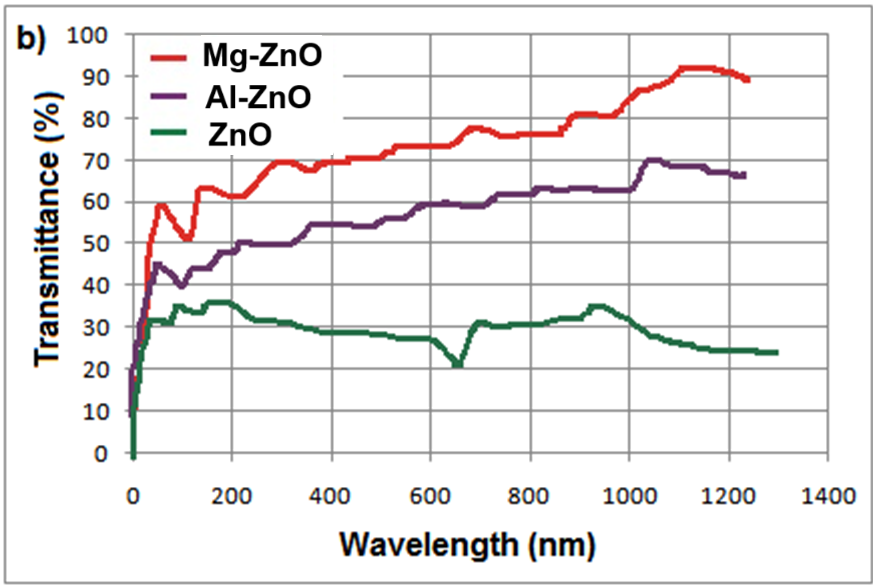


Fig. 7 (b) Transmittance properties of ZnO, Al-ZnO, and Mg-ZnO layer

Because of the absorption of free carriers at higher temperatures, self-heating may influence lower transmittance. Compared to Al-ZnO, Mg-ZnO exhibits more stable transmittance under self-heating, especially in the visible spectrum; nonetheless, thermal activation of flaws may cause degradation in UV transparency. Heating causes bandgap shrinking, this results in a tiny redshift that slightly lowers UV transparency but has no discernible effect on the absorption of visible light. Because of Al-ZnO's high carrier mobility, increased free carrier absorption at higher temperatures can marginally reduce transmittance. Mg's stabilizing actions result in minimal optical deterioration under self-heating, allowing for continued performance even in hot conditions.

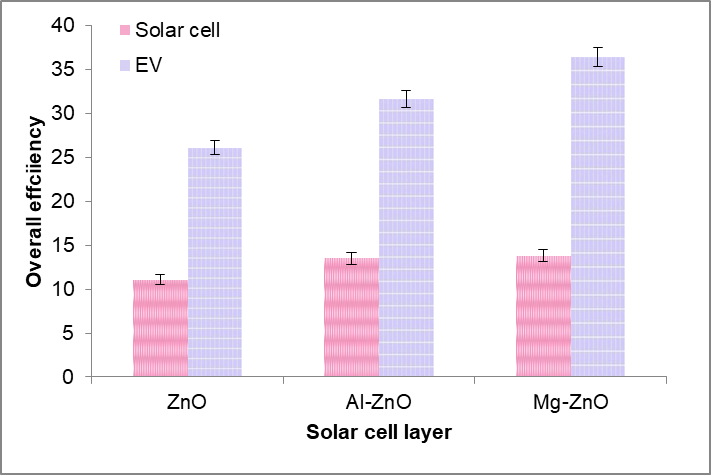


Figure 8 Overall efficiency (solar and EV) for different solar cell layers.

Figure 8 illustrates the overall solar and EV efficiency behaviour of ZnO, Al-ZnO, and Mg-ZnO layers. The solar cell layer of the ZnO ETL layer is found to have 11.1% and 13.8% of overall solar and EV efficiency properties, which is lower than the Al-ZnO and Mg-ZnO coated ITO solar cell layer. The solar cell featured with 20nm of Al-ZnO layer is observed by 13.5 and 31.6% of overall solar and EV efficiency behaviour, which is higher than the ZnO layer. However, the solar cell featured with Mg-ZnO ETL layer over the ITO is found to have an optimum overall solar and EV efficiency, and its values are 13.8 and 36.4%, respectively. The significance of the Mg-ZnO ETL layer on the ITO is uniform and coarse grain boundaries lead to better optical and electrical properties.

# Conclusion

Present investigations of ITO layer featured with Al-ZnO and Mg-ZnO layer of 20nm thickness is made via sol gel technique for solar EV application. The effect of sol-gel processing on microstructural and its intensities are analyzed via X-ray diffraction (XRD) and scanning electron microscope (SEM). Additionally, the actions of the ETL layer coated with Al-ZnO and Mg-ZnO on the functional behaviour of solar cells are evaluated, and important conclusions are summarized below.

* Microstructural studies revealed uniform particle distribution favours to enhance the absorption behaviour, and XRD peaks conform to the intensities of Al, Mg and ZnO contribution. This study provides a cross-section view that conforms to the multilayer and influences better optoelectrical behaviour to the ZnO ETL layer of the ITO solar cell.
* Among the various layers, the Mg-ZnO-coated Ito solar cell is establish to have best current density behaviour and 250%, and 23% better than the Uncoated ZnO and Al-ZnO coated solar cell layer.
* Likewise, the absorptance and transmittance behaviour of Mg-ZnO coated solar cells is found to be 83%/34% (absorptance) and 154% and 46% better than uncoated ZnO and Al-ZnO coated solar cell layer.
* The overall solar cell performance (efficiency) of Mg-ZnO-coated solar cells is increased by more than 40%. As suggested for modern solar-assisted EV applications and the future, the layer is configured with a multi-TL layer for achieving better solar cell performance.

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