Enhancement of Solar Power Conversion Efficiency by an Active Dual Thin Layer of Ga-Zno For EV Applications

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**Abstract.** The development of electric vehicles (EVs) is the future transportation that makes the environment green. In this, various research activities were executed and found solar is the prominent source that availed from natural sunlight radiations. Solar power enhancement is the main theme. The gallium (Ga) and zinc oxide of 30nm layer thickness was formed above the SiNx layer via a vacuum-assisted chemical vapour technique maintained at 100ºC. The formed Ga-ZnO layer structure was examined via SEM, and its range was noted by X-ray diffraction technique. The structure showed the equal distance of Ga layered with ZnO and found a homogenous distribution. It found higher (0.51 W/mK) thermal conductivity, high drain current of 2.4x10-3 amps, and increased photocurrent density of 2.7mA/cm2. The developed electrical power is stored in a lithium-ion battery and utilized for EV applications.

# Introduction

Day to life, the utilization of transport was important and operating as different modes like roadways, waterways, and airways. Road transport mostly facilitates connecting the intercity with the economy. In future aspects, renewable energy will contribute major shares. It makes a pollution-free environment economical and efficient compared to non-natural energy [1]. Amid various sources of energy, the energy from solar gained significance in various households, heating/cooling applications, electrical production, EVs applications, etc., [2]. Most recently, EVs were in the coming decades to fulfil the energy demand in transportation. Many researchers investigated solar power with the modification of solar film [3]. The impact of solar on self-heat thermal conditions was examined through system software [4].

Ga co-doped ZnO thin films used to solar cells and study their characteristics. The reduced band gap increases solar conversion efficiency by 2.43% superior to conventional solar cell system [5-8]. The Ga-zinc oxide (ZnO) film layer was prepared by vacuum annealing for antenna applications. The optoelectronic behaviour of the synthesized layer showed high optical transparency, reduced band gap, and good thermal conductivity from solar sources [9-12]. Al, Ga, and ZnO doped film layer was made by sol-gel technique, and its solar characteristics were studied and compared. ZnO combination with Ga found superior solar behaviour with a high current rating compared to others [13-17]. Al, Ga, and ZnO doped film layer was made by sol-gel technique, and its solar characteristics were studied and compared. ZnO combination with Ga found superior solar behaviour with a high current rating compared to others [8]. Similarly, the composites were noted to have good thermal behaviour [18-22]. Moreover, the biochar recovered and utilized for thermal storage systems has high thermal stability [23-25].. The zinc oxide-based semiconductor layer found a good self-heating effect, and its results improved current [26]. It was economical and efficient compared to copper and silicon dope materials [27-30].

The attention of solar renewable energy in EVs applications and its technology was addressed in detail. The enhancement of solar power was made with ZnO thin film. This work presents the twin layer of Ga-ZnO offered good solar thermal behaviour, resulting in improved thermal conductivity, drain current and photocurrent density.

# Materials and Methods

Gallium/ zinc oxide (Ga/ZnO) have been strategically selected as superior coating materials to enhance the silicon nitride (SiNx) layer on a glass substrate. A precision-crafted thin film, just 30 nm thick, was produced through an advanced vacuum aided chemical vapor deposition process. When compared to copper, Ga and ZnO deliver remarkable benefits, such as enhanced thermal conductivity, significant weight reduction, and impressive cost-effectiveness. This innovative choice not only optimizes performance but also positions the project for greater efficiency and sustainability [31-34].

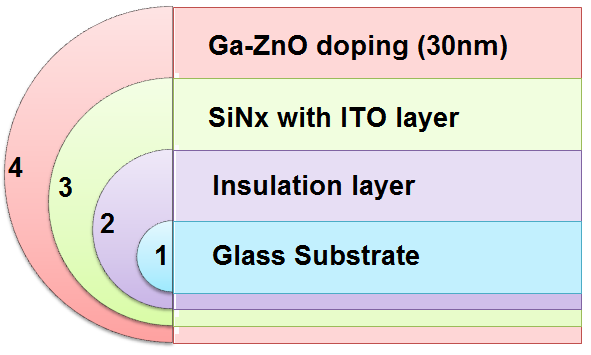


Fig. 1 Operation layout for layer formation on Ga-ZnO doping

Fig. 1 shows the operation layout for the Ga-ZnOdopping system over the SiNx/ ITO layer. Before this, the glass substrate was to be covered with an insulator, and then the SiNx layer was formed in an ITO. In the first stage, the required amount of Ga/ZnO was kept over the SiNx layer & involved to a CVD process with an applied 100ºC temperature under a 0.1 bar vacuum bar [35-38]. The thin layer formed by low temperature with vacuum pressure enhances particle sharing and reduces the space between the particles. The CVD process was more efficient and economical than others. The actual setup of CVD is indicated in Figure 2.

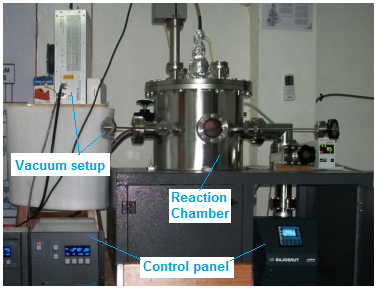


Fig. 2Vacuum -chemical vapour deposition for Ga-ZnO doping setup

During the process, 0.1 bar pressure (vacuum) was adopted with low heat, which helped increase particle dispersion and significantly reduced particle gap. It leads to enhancing solar power conversion.

The low temperature formed Ga/ZnO layer has good solar behaviour, & its photocurrent was measured. Moreover, the coated material improved solar irradiance [39-42]. The deposited Ga-ZnO layer is presented in Figure 3.

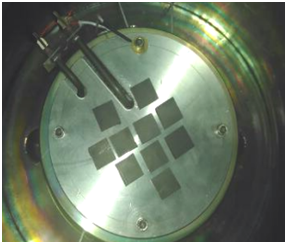


Fig. 3 Ga-ZnO doping layer with SiNx phase

The ZESIS model SEM helped to find the internal layer structure for the developed Ga-ZnO layer, and XRD analyzed its various peaks.

# Results and Discussion

## SEM microstructure of Ga-ZnO thin film layer

Fig. 4 indicates the SEM microstructure of the zinc oxide layer taken at 3000x magnification for 100nm. It showed uniform particle distribution with increased optical trace space. This results in increased absorption capacity [43-45]. While combined with Ga, a thin layer is illustrated in Figure 5.

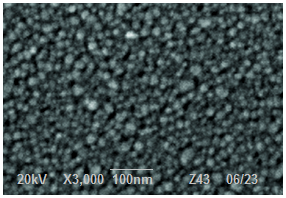


Fig. 4 Microstructure of Un-doped ZnO layer

The layer of Ga was uniformly placed over the layer of ZnO and treated as a second thin layer merged thickness of 30nm. It was noted from Fig. 5 that the Ga particles were speared evenly over the ZnO layer and showed increased optical space as of a reduced band gap. It results in an increased self-heat effect [46-47]. It was due to low-temperature deposition.

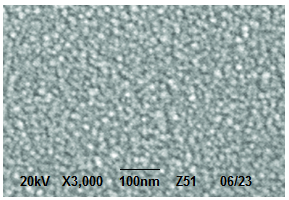


Fig. 5 Microstructure of Ga-doped ZnO layer

Due to the conditions for space between the particles, the impact of self-heat was improved [10]. The low-temperature chemical vapour deposition found increased particle distribution with low band gap results [48-50]. However, the layer of Ga/ZnO was framed over the SiNx layer through CVD with 0.1 bar applied vacuum pressure.

## X-ray diffraction analysis for the Ga-ZnO layer

XRD of Ga/ZnO layer are presented in the Figure 6 (a) and vary concerning the impact of deposition. It was recorded as Ga (002) and ZnO (100). The 3rd layer showed the X-ray peaks on ZnO thin film without doping material. The 4th layer is shown in Ga doped Ga-ZnO thin layer. Layer 4 of the X-ray diffraction image shows the Ga peak at 34.5º and ZnO at 44.3º. Figure 6 (b) mentions the detailed cross-sectional SEM microstructure.

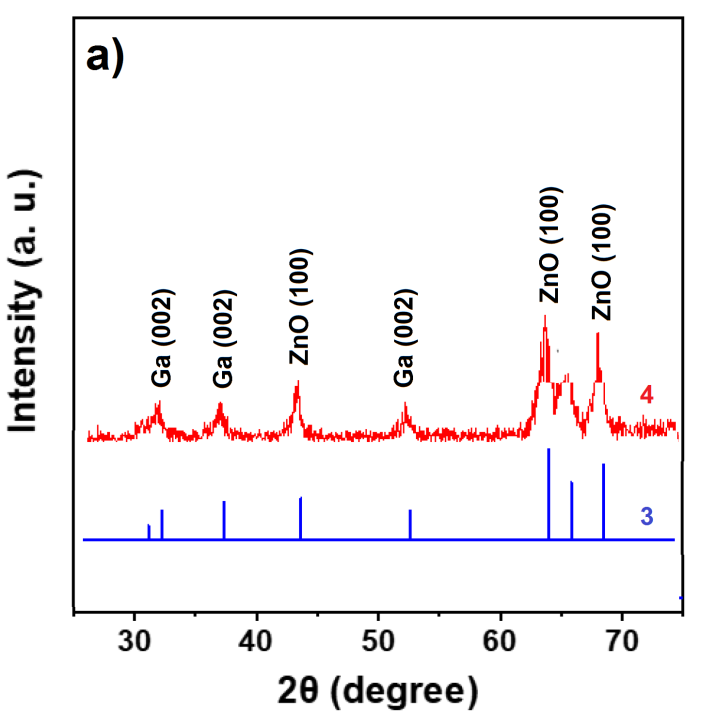


Fig. 6 (a) X-ray diffraction peaks on ZnO and Ga-ZnO thin film

Their Ga and ZnO presence in thin film was proven and showed an even distribution distance. It was noted from Fig 6 (a). mentioned above that the Ga-ZnO layer was formed above the SiNx layer with good interfacial bonding.

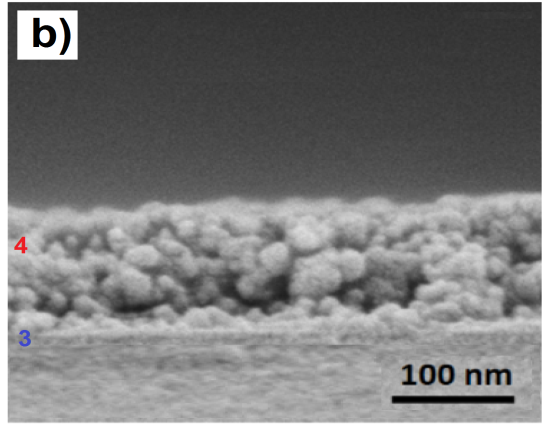


Fig. 6(b) Cross-sectional view of doped Ga-ZnO layer formed with SiNx layer

The intermediate gap of the Ga-ZnO particle found maximum optical transference during the thermal race absorption. The low-temperature deposition makes an effective Ga-ZnO layer bonding, improving the self-heating effect. A similar tendency was noted in past literature on Ga-ZnO thin film [51].

## Thermal conductivity of thin film solar cell

Fig. 7 illustrates the thermal conductivity of the SiNx embedded with Ga-ZnO layer evaluated from morning to evening (6.00 am to 6.00 PM). During this period, the temperature of the Ga-ZnO was noted by thermo couple and calculated its thermal conductivity of solar cell. It showed that the thermal conductivity of Ga-ZnO was increased from 0.47W/mK to 1.97W/mK with a gained temperature of 24ºC to 48ºC.

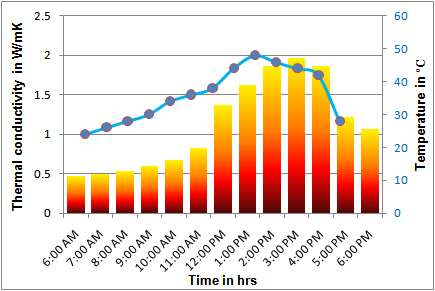


Fig. 7 Thermal conductivity of Ga/ZnO doped solar cell.

The Ga-ZnO thin layer thermal condutivity was improved gradually with an increase from 6:00 AM to 2:00 PM after it fell gradually. The maximum thermal conductivity of 1.97W/mK was noted at 46ºC from 2.00 to 3.00 PM. It was due to the self-heating effect of zinc oxide. Moreover, the ZnO has high thermal performance and, combined with Ga, found better thermal conductivity [12].

From Fig. 7, the film layer for thin Ga-ZnO gained significance in solar thermal absorption, resulting in improved temperature and thermal conductivity.

## Drain current vs. Drain voltage

Fig. 8 indicates the drain current vs. voltage of the SiNx layer without and with Ga-ZnO.

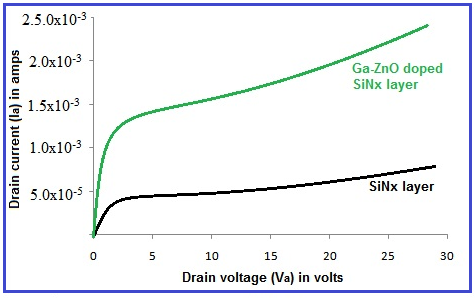


Fig. 8 Drain current vs. drain voltage during evaluating SiNx & Ga/ZnO embedded SiNx layer

The drain current of the Ga–ZnO thin film was found to be significantly higher than that of the SiNx layer. In the SiNx solar cell, the drain current increased slightly from 0 to 4 × 10⁻⁴ A at 30 V, which was attributed to the thermal absorption characteristics of the SiNx layer. Silicon-based thin films typically exhibit good thermal stability and heat absorption [9]. In contrast, the Ga–ZnO thin film deposited over the SiNx layer demonstrated a substantial improvement in drain current, reaching 2.4 × 10⁻³ A. This represents an approximately 80% increase compared to the SiNx layer alone. The ZnO coating exhibited higher thermal conversion efficiency than conventional solar cell layers [10]. As illustrated in Fig. 8, the green and black curves represent the drain currents of the Ga–ZnO and SiNx solar cell layers, respectively. The results clearly indicate that the Ga–ZnO layer deposited on SiNx enhances the drain current [52, 53].

## Photocurrent density

Figure 9 illustrates the photocurrent density-voltage characteristics of the SiNx layer, both without and with the Ga–ZnO thin film. The results indicated that the Ga–ZnO-coated SiNx solar cell exhibited a higher photocurrent density compared to the SiNx layer on its own. The Ga–ZnO thin film demonstrated a significant self-heating effect, which contributed to improved solar power conversion. Zinc oxide is known for its good thermal properties, and when combined with gallium (Ga), it enhances thermal conductivity [11].

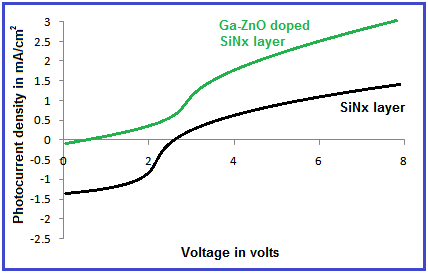


Fig. 9 Photocurrent density Vs. Voltage during evaluating SiNx and Ga-ZnO doped SiNx layer.

At 0.1 V, the photocurrent density for the SiNx solar cell was measured at -1.54 mA/cm², while the Ga–ZnO-doped thin layer showed -0.99 mA/cm². By 8 V, there was a notable increase in photocurrent density, with the Ga–ZnO-doped SiNx solar cell outperforming the SiNx layer alone. This improvement is attributed to the presence of the thin Ga–ZnO film and its superior thermal properties. The higher photocurrent density recorded for the Ga–ZnO-doped SiNx solar layer was 2.7 mA/cm² at 8 V, which is nearly double that of the SiNx layer.

# Conclusion

The SiNx solar cell's performance has been remarkably enhanced through Ga–ZnO doping, utilizing an innovative vacuum-assisted, low-temperature chemical vapor deposition technique. This advanced Ga–ZnO structure features a uniform particle distribution and a reduced band gap, which significantly boosts solar power conversion efficiency. X-ray diffraction analysis not only confirms the presence of Ga–ZnO within the SiNx layer but also reveals consistent particle spacing, further validating the quality of this enhancement. At a measured thermal conductivity of 1.97 W/m·K at 46 °C during the peak afternoon hours of 2:00 to 3:00 PM, this Ga–ZnO-doped SiNx thin layer demonstrates superior performance. The drain current capacity has soared to 2.4 × 10⁻³ A, marking an impressive 80% increase compared to the traditional SiNx layer. Even more compelling, the enhanced photocurrent density has nearly doubled, setting a new benchmark for efficiency. These groundbreaking improvements position Ga–ZnO-doped SiNx solar cells as a highly promising solution for energy storage applications, particularly in the rapidly evolving electric vehicle (EV) market. By harnessing this cutting-edge technology, we can pave the way for a more sustainable and efficient energy future.

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