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Epi-n-IZO thin films/⟨1 0 0⟩ Si, GaAs and InP by L-MBE—a novel feasibility study for SIS type solar cells

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Abstract

High quality epitaxial indium zinc oxide (heavily indium oxide doped) (epi-n-IZO) thin films were optimized by laser-molecular beam epitaxy (L-MBE) i.e., pulsed laser deposition (PLD) technique for fabricating novel iso- and hetero-semiconductor–insulator–semiconductor (SIS) type solar cells using Johnson Matthey "specpure"- grade 90% In_2O_3 mixed 10% ZnO (as commercial indium tin oxide (ITO) composition) pellets. The effects of substrate temperatures, substrates and heavy indium oxide incorporation on IZO thin film growth, opto-electronic properties with ⟨1 0 0⟩ silicon (Si), gallium arsenide (GaAs) and indium phosphide (InP) wafers were studied. As well as the feasibility of developing some novel models of iso- and hetero-SIS type solar cells using epi-IZO thin films as transparent conducting oxides (TCOs) and ⟨1 0 0⟩ oriented Si, GaAs and InP wafers as base substrates was also studied simultaneously. The optimized films were highly oriented, uniform, single crystalline approachment, nano-crystalline, anti-reflective (AR) and epitaxially lattice matched with ⟨1 0 0⟩ Si, GaAs and InP wafers without any buffer layers. The optical transmission T (max) $\geqslant 95\%$ is broader and absolute rivals that of other TCOs such as ITO. The highest conductivity observed is $\sigma = 0.47 \times 10^3\ \Omega^{-1}\,\text{cm}^{-1}$ (n-type), carrier density $n = 0.168 \times 10^{20}\ \text{cm}^{-3}$ and mobility $\mu = 123\ \text{cm}^2/\text{V s}$. From opto-electronic characterizations, the solar cell characteristics and feasibilities of fabricating respective epi-n-TCO/⟨1 0 0⟩ wafer SIS type solar cells were confirmed. Also, the essential parameters of these cells were calculated and tabulated. We hope that these data be helpful either as a scientific or technical basis in semiconductor processing.

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Keywords: Laser epitaxy; Semiconducting materials; Thin film structure and morphology; Buffer layer on InP; Solar cells

1. Introduction

At present, coatings of intrinsic and extrinsic varieties of zinc oxide thin films have been actively studied on a massive scale for solar cell, display and other opto-electronic devices. The optimum electrical conductivity and also superior optical transparency window is needed for current envisaged applications. Indium zinc oxide (IZO) is another promising transparent conducting oxide (TCO) candidate exhibits transport and optical properties rivaling those of many TCO's.

There are several deposition techniques which have been utilized for epi-n-IZO thin film growth including

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Nomenclature

I_{sc}	short circuit current, nA	v	pulse frequency, Hz
V_{oc}	open circuit voltage, mV	u	energy density, J/cm^2
P_m	maximum power output, μW/cm^2	E	pulse energy, mJ
P_{in}	input power, mW/cm^2	P	vacuum pressure, Torr
η	conversion efficiency, %	X_{st}	substrate to target distance, cm
σ	electrical conductivity, $\Omega^{-1}\,cm^{-1}$	t_s	substrate thickness, mm
n	carrier density, cm^{-3}	ρ	film resistivity, Ω cm
μ	mobility, cm^2/V s	A	cell area, cm^2
T (max)	maximum optical transparency, %	t_o	oxide layer thickness, Å
T_{sub}	substrate temperature, °C	R_{sh}	shunt resistance, MΩ
λ	wavelength, nm	R_s	series resistance, MΩ

electron beam evaporation, spray pyrolysis, metal organic chemical vapour deposition (MOCVD), molecular beam epitaxy (MBE) and pulsed laser deposition (PLD). Among these, PLD offers the attraction of in-situ growth under a variety of atmosphere and easy control of composition.

The present work describes the application of pulsed laser deposition technique to deposit high quality transparent conducting oxide thin films i.e., IZO thin films on ⟨1 0 0⟩ single crystal semiconductor substrates for iso- and hetero- semiconductor–insulator–semiconductor (SIS) type solar cells with the goals of studying the feasibility of these novel models, defining appropriate precursors, growth conditions, the role of dopant, the relationship of film processing on thin film quality, microstructures and what has been left from bulk studies.

On the basis of referred literature, we framed the chemical and thin film strategies for the development of high quality TCOs. Previously optimized epi-n-IZO thin films were highly oriented, uniform, single crystalline approachment, nano-crystalline, anti-reflective (AR) and epitaxially lattice matched with ⟨1 0 0⟩ silicon (Si), gallium arsenide (GaAs) and indium phosphide (InP) semiconductor single crystal wafers without any buffer layers.

Lattice matching in semiconductor device structure is important in the sense that lattice mismatch with lattice imperfection leads to dominant recombination loss associated with other interface losses. For example in solar cells, it causes a severe drop in conversion efficiency. Also, the optical transmission window of such obtained films i.e., T (max) $\geqslant$ 95% is broader than those of other valid TCOs such as indium tin oxide (ITO) and absolute rivals that of the most other TCOs. The highest electronic properties found for epitaxial IZO thin films were $\sigma = 0.47 \times 10^3\ \Omega^{-1}\,cm^{-1}$ (n-type), carrier density $n = 0.168 \times 10^{20}\ cm^{-3}$ and mobility $\mu = 123\ cm^2/V\,s$ (Ramamoorthy et al., 2000, 2001a,b,c, 2003a,b).

The high radiation resistance and optimum energy gap (E_g) for solar energy conversion of ⟨1 0 0⟩ Si, GaAs and InP give their suitability as valid promising base materials. The effects of substrate temperatures, substrates and heavy indium oxide incorporation on IZO thin film growth and opto-electronic properties with ⟨1 0 0⟩ Si, GaAs and InP were studied. As well as the feasibility of developing some models of iso- and hetero-structures using high quality epi-IZO thin films as TCOs and ⟨1 0 0⟩ Si, GaAs and InP wafers as base substrates was also studied simultaneously. The extra-mural study on the effect of heavy indium oxide incorporation in to the intrinsic ZnO thin film growth and on opto-electronic properties gives added advantages to the IZO work.

2. Experimental techniques

In the present study, pulsed laser deposition system is employed to deposit highly oriented, lattice matched epi-n-IZO ($In_2Zn_2O_5$) thin films on ⟨1 0 0⟩ Si, GaAs, InP semiconductor single crystal substrates held at room temperature (RT), 350 and 450 °C. n-Si, p-Si, n-GaAs, n-InP and p-InP single crystals having ⟨1 0 0⟩ orientation are used as substrates for the preparation of epi-IZO thin films. PLD technique is a good technique to produce crystalline quality and stoichiometric thin films. Pulsed laser deposition has been shown to be superior to sputtering and conventional MBE for growing highly pure and good crystalline metal oxide epitaxial thin films in combinatorial synthesis of materials. A critical step to achieving high quality thin films was the treatment of the substrate surface. ⟨1 0 0⟩ Si, GaAs, and InP single crystal wafers (grown at Hebei Semiconductor Research Institute (HSRI), Ministry of Informatics, Hebei, PR China) were lapped, polished with $HBr–K_2Cr_2O_7–H_2O$ solution. Also degreased, cleaned with trichloroethylene (3 min), acetone (4 min), methanol (3 min) and dried. Before 'metal oxide on semiconductor deposition', the deposition of IZO thin films was optimized with float glass substrates. The targets were made by Johnson Matthey 'specpure'- grade 90% In_2O_3 mixed 10% ZnO (commercial ITO composition) for indium zinc oxide thin film deposition. The powders were mixed with polyvinyl alcohol binder and hot water. Then stirred, slurred, crushed into powder, dye palletized, kept in furnace at 600 °C for 3 h, and sintered at 900 °C for 3 h for IZO targets. Then the targets were ablated with third harmonic of "Quantel, YG 980, France, Nd:YAG laser" ($\lambda = 355$ nm, pulse width = 6 ns, and $v = 10$ Hz) with energy density (u) of 5 J/cm^2. Throughout the experiment, the laser was set at pulse energy (E) of 250 mJ and repetition rate of 10 Hz. Deposition chamber was initially evacuated up to 1×10^{-6} Torr pressure (P) using a turbo macromolecular pump and O_2 was introduced during deposition and kept constant at 1×10^{-5} Torr. Substrate to target distance (X_{st}) was kept at 6 cm. Through out the deposition period, the target holder was rotated for uniform deposition of the ablated material. The optimum substrate temperature for epi-n-IZO thin films was found as 450 °C. Initially the epi-n-IZO thin film depositions were optimized using float glass plates and ⟨1 0 0⟩ p-InP wafers held at RT, 350 and 450 °C. Then the subsequent depositions of epi-n-IZO thin films on ⟨1 0 0⟩ oriented n-Si, p-Si, n-GaAs and n-InP wafers were carried out at $T_{sub} = 450$ °C.

To increase the performance, study the feasibility and give a contribution to the present day novel state-of-the-art of hetero-junction solar cells, opto-electronic properties of fabricated TCO/substrate iso- and hetero-structures have to be investigated. Photovoltaic or solar cell (opto-electronic) (I–V) characterizations were performed for the detailed study of opto-electronic properties of the epi-n-IZO thin films/⟨1 0 0⟩ wafers.

3. Results and discussions

3.1. Opto-electronic properties

SIS type solar cells nowadays attract photovoltaic field as a suitable and advantageous power source than other types. SIS type is an advanced type of hetero-structure. Our aim is to study the feasibility of PLD fabricated novel iso- and hetero-SIS type structures for solar cell field.

In SIS type solar cells, TCO plays an important role as a wide band gap material transparent to solar radiation, anti-reflection (AR) coating and conducting path for the charge carriers, thus it reduces the series resistance, surface recombination velocity and eliminates the necessity of fine grid pattern. In order to give some contribution to the present day state-of-the-art of iso- and hetero-type hetero-junction solar cells, we have developed some novel models of SIS type structures using high quality epi-IZO thin films as TCOs and ⟨1 0 0⟩ oriented Si, GaAs and InP semiconductor single crystal wafers as base substrates. The utilization of epi-n-IZO thin films is attractive because of their wide band gap and low resistivity.

Application of these structures can also be a challenging career in semiconductor device processing. Important advantage is that the InP substrates have high radiation resistance as well as have optimum band gap values for photovoltaic conversion. Properties of used single crystal semiconductor wafer substrates are Zn doped p-type, Sn doped n-type, cubic structured, ⟨1 0 0⟩ oriented, thickness (t_s) of 0.45 mm, carrier concentration of the order of $10^{16–18}$/cm^3 and resistivity of the order of 10^{-3} Ω cm. To the best of our knowledge, this is the first time that PLD deposited epi-n-IZO thin films on ⟨1 0 0⟩ wafers have been applied to solar cells. The solar cell characteristics were studied. In this paragraph, we have described a simple technique for measuring absolute solar cell efficiencies in the laboratory precisely as well as reproducibly. We have used this technique to study the feasibility of the fabricated iso- and hetero-SIS type structures for solar cells. The contacts were made by silver paste (ESL 590-G) being a single dot of 0.5 mm in diameter. The photoelectric current is measured by 'oriel' ammeter, the photovoltage is measured by 'keithley' voltmeter. The incident illumination was calibrated by CEL suryamapi. The measurement of solar power conversion efficiency also requires the measurement of open circuit voltage (V_{oc}) and fill factor (FF). Using a solar illuminator consisting of a halogen lamp, we measured V_{oc}, I_{sc} and FF with an illumination of $P_{in} = 100$ mW/cm^2 at room temperature. The solar cell conversion efficiency (η) of SIS type multi-junction solar cells is defined as

$$\eta = P_m/P_{in} = FFI_{sc}V_{oc}/P_{in}, \quad \text{where}$$
$$P_m = I_m V_m \quad \text{and} \quad \text{FF} = I_m V_m / I_{sc} V_{oc}$$

The photovoltaic solar cell parameters were calculated and tabulated (refer Table 1). The histograms of current–voltage characteristics for our (B) annealed (200 °C) and (D) as prepared 0.05 cm^2 SIS type cells measured at bright (input illumination power $P_{in} = 100$ mW/cm^2) were plotted (refer Figs. 1–9). Most of the commercial opto-electronic applications require the films to have low absorption in the visible and high dc conductivity. From the opto-electronic studies, we come to a conclusion that the heavy doping of indium oxide into the zinc oxide matrix increased the approachment of carriers conduction to higher level. The performance of the solar cells is generally determined by many factors, some represents fundamental limitations, while others can be influenced by the technology used. The opto-electronic properties of SIS type solar cells also mainly

Table 1
Solar cell opto-electronic parameters of various SIS structures fabricated by using epi-n-IZO thin films as TCOs

SIS structures	Open circuit voltage V_{oc}, V	Short circuit current I_{sc}, μA/cm^2	Max. rectangle voltage V_m, V	Max. rectangle current I_m, μA/cm^2	Fill factor FF	Efficiency η, %	Power output P_{out}, μW/cm^2	Shunt resistance R_{sh}, MΩ	Series resistance R_s, MΩ
n-IZO/p-InP/RT (B)	0.252	0.792	0.17	0.476	0.4213	0.0004	0.14	0.1	2.4
(D)	0.212	0.116	0.18	0.08	0.465	0.0002	0.080	0.76	8
n-IZO/p-InP/350 °C (B)	0.25	0.756	0.32	0.46	0.489	0.001	0.1	0.07	1.25
(D)	0.044	0.756	0.192	0.4	0.381	0.00006	0.012	0.03	0.13
n-IZO/p-InP/450 °C (B)	0.004	0.4	0.003	2.0	0.434	0.00003	0.01	0.375	8.0
(D)	0.002	0.08	0.001	0.05	0.425	0.0000007	0.00015	0.006	0.05
n-IZO/n-InP/450 °C (B)	0.076	0.76	0.05	0.43	0.359	0.00003	0.022	0.05	0.307
(D)	0.066	0.673	0.039	0.396	0.349	0.000007	0.015	0.04	0.133
n-IZO/n-GaAs/450 °C (B)	0.042	0.78	0.02	0.504	0.3764	0.0001	0.012	0.023	0.2
(D)	0.019	0.8	0.01	0.44	0.29	0.000025	0.005	0.015	0.05
n-IZO/n-Si/450 °C (B)	0.19	0.24	0.12	0.18	0.477	0.0001	0.02	0.104	3.33
(D)	0.172	0.09	0.13	0.04	0.323	0.000025	0.005	0.83	5
n-IZO/p-Si/450 °C	0.332	0.304	0.204	0.184	0.385	0.002	0.0375	0.42	2.85
(D)	0.22	0.172	0.16	0.096	0.407	0.0001	0.02	0.48	3.35

Input illumination power $P_{in} = 100$ mW/cm^2. (B) represents structures annealed at 200 °C; (D) represents as prepared structures.

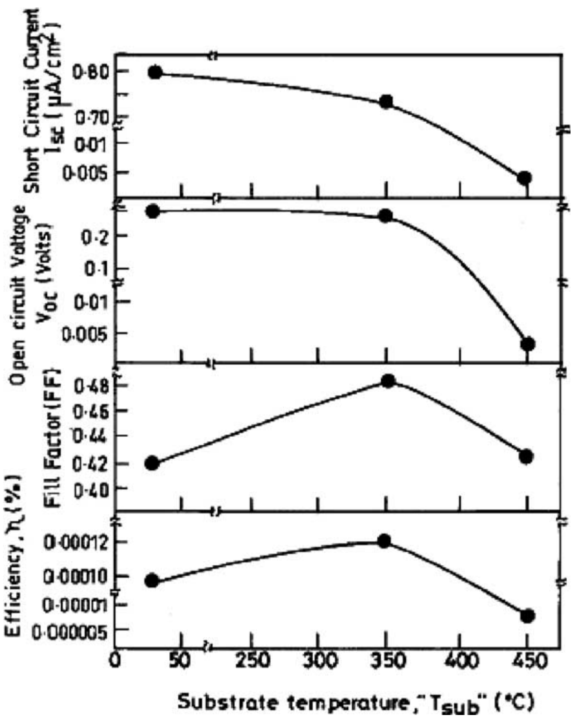

Fig. 1. Epi-n-IZO/⟨1 0 0⟩ p-InP structures: opto-electronic parameters versus substrate temperature, T_{sub} (°C).

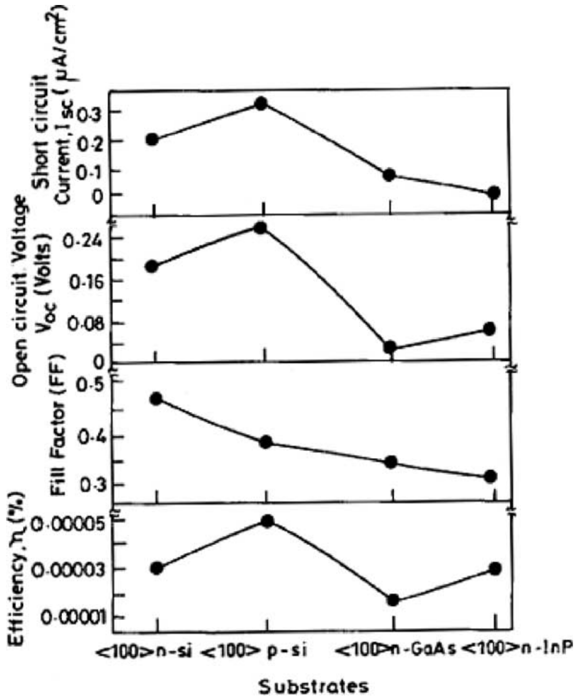

Fig. 2. Epi-n-IZO/⟨1 0 0⟩ Si, GaAs and InP structures prepared at T_{sub}, 450 °C: opto-electronic parameters versus various ⟨1 0 0⟩ substrates.

depend on TCO thin films–single crystal substrate interfacial junction. By absorption of a photon in the semiconductor, an electron–hole pair is created. At the p-side, electrons are act as minority charge carriers and holes are act as majority charge carriers (similarly at the n-side, vice versa). The interfacial insulator layer for-

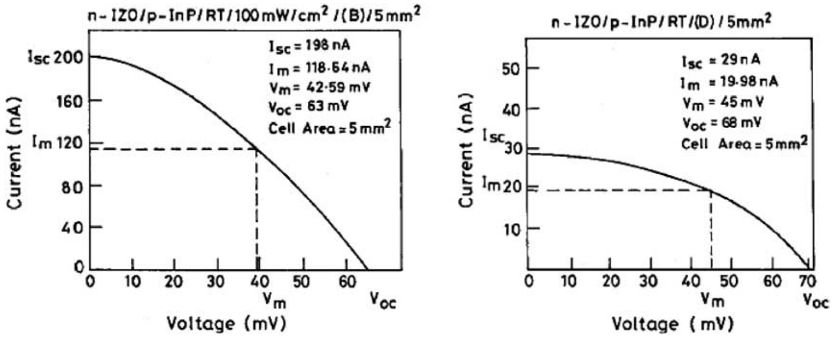

Fig. 3. Opto-electronic (I–V) characteristics of epi-n-IZO/p-InP prepared at RT.

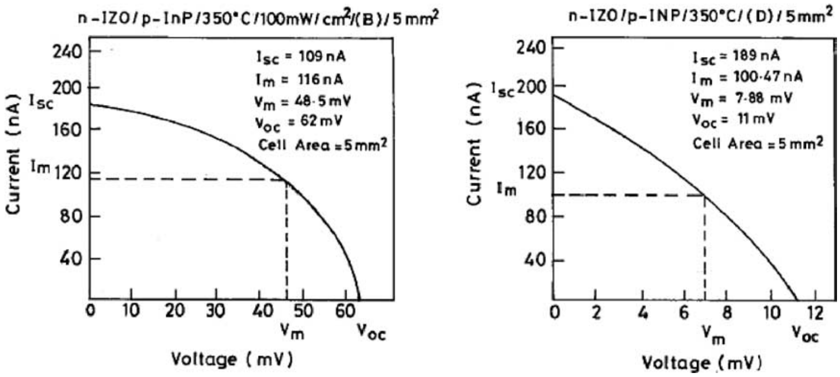

Fig. 4. Opto-electronic (I–V) characteristics of epi-n-IZO/p-InP prepared at 350 °C.

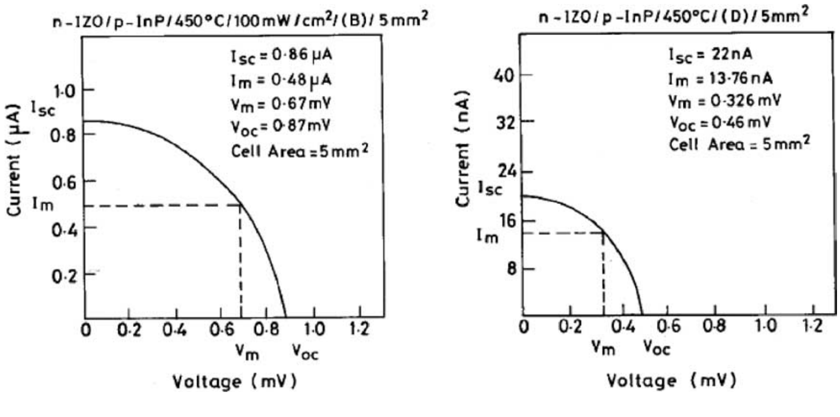

Fig. 5. Opto-electronic (I–V) characteristics of epi-n-IZO/p-InP prepared at 450 °C.

mation at higher T_{sub} leads to depletion of base p-type and n-type semiconductor substrates resulting in an enhanced series resistance (R_s), diminished fill factor (FF) and solar cell conversion efficiency (η). This concept was purely considered as a interface phenomenon. In high substrate temperature deposition process, as has been mentioned earlier, the oxidizing capability of the TCO layer tends to enhance the growth of the interfacial insulator oxide layer. The present technological tools have not reached the stage, to trace out where the exact growth of the interfacial insulator layer has been originated. Also the exact growth kinetics and formation

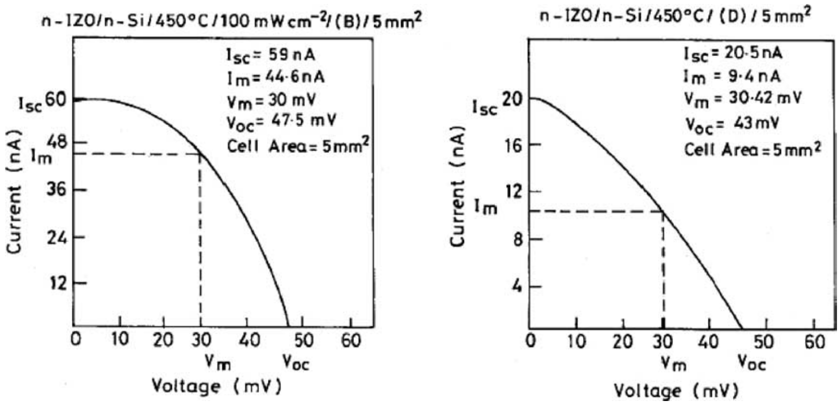

Fig. 6. Opto-electronic (I–V) characteristics of epi-n-IZO/n-Si prepared at 450 °C.

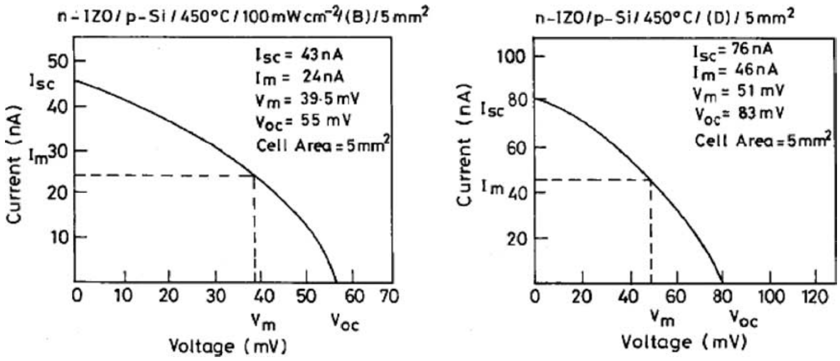

Fig. 7. Opto-electronic (I–V) characteristics of epi-n-IZO/p-Si prepared at 450 °C.

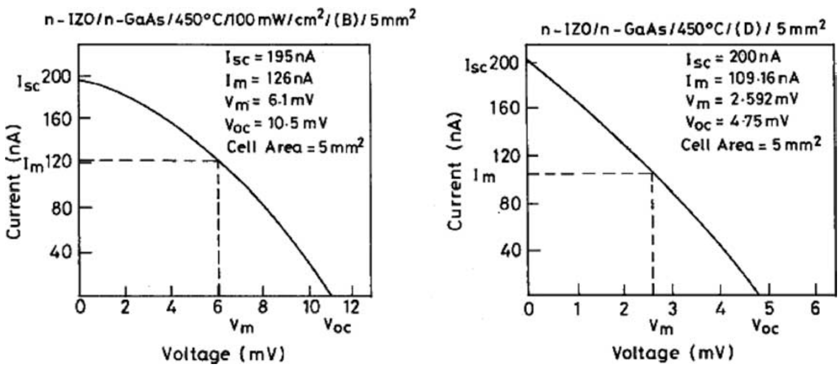

Fig. 8. Opto-electronic (I–V) characteristics of epi-n-IZO/n-GaAs prepared at 450 °C.

mechanism of the interfacial insulator oxide between the TCO and the semiconductor substrate is still not exactly known and has to be one of the subjects of future investigations. It has been established theoretically that an oxide thickness t_o of around 10–15 Å favours good cell efficiencies. However, if the oxide thickness extends over 22 Å, the efficiencies fall dramatically. Also the presence of thick insulation layer in the interface leads to trapping of photoexcited carriers in the potential barrier region and suppressing of photocurrent by recombination of carriers at the insulation layer/⟨1 0 0⟩ substrate interface via interface states. It was recognized that oxidation of the substrate front surface would occur during the high temperature deposition process. Referring to published data on interfacial insulator oxide growth, an estimated 6–7 Å of oxide will be grown by

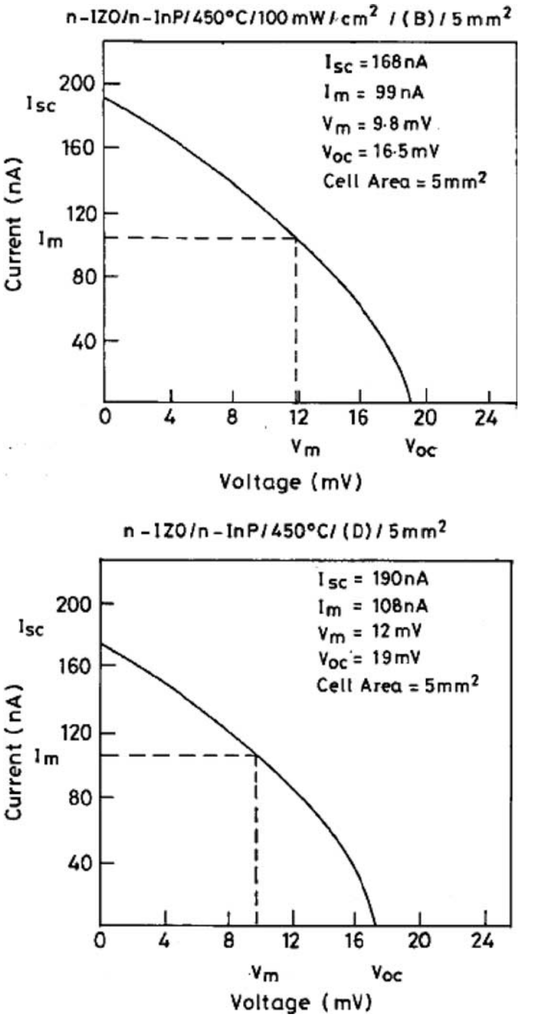

Fig. 9. Opto-electronic (I–V) characteristics of epi-n-IZO/n-InP prepared at 450 °C.

oxidation and strong chemical interaction of TCO with substrate surface during high temperature process. It is expected that during the high substrate temperature deposition in oxygen ambient gas atmosphere, a layer of oxide (SiO_x, As_xO_x and P_xO_x respectively for Si, GaAs and InP substrates) will be grown sandwiched between the IZO epilayer and the substrate. Moreover, IZO is also an oxidizing material and can easily react with substrate enable to form interfacial oxide or other complex oxides. At this stage, we expected that a complex reaction might have occurred between the IZO layer and the semiconductor substrate forming a much thicker oxide layer. It is also thought that the presence of interfacial insulator layer is unavoidable one.

To the best of our knowledge and on the basis of referred literature (Minami, 2000; Lewis and Paine, 2000; Sanchez-Juarez et al., 1998a,b; Gordan, 2000; Ginley and Bright, 2000; Tiburcio-silver et al., 1998; Suzuki et al., 1999; Coutts et al., 2000; Ma et al., 2000; Freeman et al., 2000; Tapan, 1998; Bohmer et al., 1996), which contains more in-sights into the TCO/substrate interface, we state that there may be a complex interfacial insulator region between TCO functional layer and substrate (⟨1 0 0⟩ wafers) materials. Some evidential features from structural, compositional, surface morphological and opto-electronic characterizations may indicate the formation of interfacial insulator layer growth. Thus the TCO thin film layer growth at particular higher substrate temperature (T_{sub}) proceeds through a strong chemical interaction with base semiconductor substrates which leads to a formation of an interfacial insulator layer between the TCOs/base semiconductor substrates i.e., SiO_x, As_xO_x and P_xO_x respectively formed between epi-IZO thin films/⟨1 0 0⟩ Si, GaAs and InP wafers.

Generally the opto-electronic properties of the TCO/substrate contact may also be improved structurally by the extent of the insulator layer growth. Important consideration of a very thin insulation layer between the TCO thin films and the substrates has lead the structure to low reflection loss. The insulator barrier (>22 Å) opposes the flow of majority carriers and favours the flow of minority carriers across the junction. Due to the high conductivity of IZO layer, the extent of the interfacial insulator layer occurs, this should be significantly resulting in an increased series resistance of the epi-n-IZO/⟨1 0 0⟩ wafer contact of the SIS type solar cells. The interfacial layers have higher band gap than the TCO layer. The low carrier concentration of the base semiconductor substrates and large insulator width are the two important factors, which influence the efficiency of the SIS type solar cell. It is thought that the formation of high width (>22 Å) interfacial insulator oxide layer sandwiched between epi-n-IZO and respective ⟨1 0 0⟩ wafer substrate may be the main reason for the low short circuit current density I_{sc} and solar energy conversion efficiency η.

Microformation of elemental Zn and its sub-oxides may also cause an increased light absorption in the epi-n-IZO thin films and thus decreases the current density (I_{sc}) of the solar cells. The lower binding energy peak of Zn in EDAX spectra may indicate the presence of elemental Zn due to the reduction process in TCO thin films. The high insulator layer width (>22 Å), low value of R_{sh} and a high value of R_s have an injurious effect on the performance of fabricated solar cells. Generally, the higher carrier concentration of a heavily doped substrate reduces the insulator layer width within the fruitful limit (<22 Å) resulting in a reduced series resistance, an improved fill factor and open-circuit voltage (V_{oc}). The shunt resistance (R_{sh}) is generally defined as the leakage resistance across the p–n junctions attributed to various leakage paths along the edges of the cells i.e., along dislocations, fine metallic bridges, microcracks and grain boundaries. Also R_s is defined as the internal resistance of the solar cells due to front, base regions and front, back ohmic metal contacts. In PV effect, current flows in the reverse direction and voltage is in the forward direction. The resultant total photocurrent of a solar cell is the sum of currents due to n-region, depletion region and p-region in the SIS structure. We also state that on the basis of origination of current, the total photocurrent in a SIS type structure is the summation of recombination current, tunneling current and injection current. Light trapping or confinement effect of TCOs is a very important property to obtain high collection of incident photons in solar cells.

The effects of substrate temperatures and substrates on indium zinc oxide thin film's opto-electronic properties with ⟨1 0 0⟩ semiconductor substrates were studied. The study on the effect of heavy indium oxide incorporation into the intrinsic zinc oxide thin film's opto-electronic properties with ⟨1 0 0⟩ semiconductor substrates gives added advantages to the indium zinc oxide work.

Moreover optical transparency, anti-reflection (AR), electrical conductivity, carrier mobility and opto-electronic properties of IZO thin films were improved and enhanced for higher substrate temperature depositions. The main reason for the slight rise in efficiency of the cell annealed at 200 °C than as prepared one, also fabricated at high substrate temperature than one fabricated at lower substrate temperature may be due to electron tunneling from the respective substrate's (i.e., ⟨1 0 0⟩ wafers) conduction band to the respective TCO's (i.e., IZO) conduction band. This process was enhanced by traps in the interfacial insulation layer of thickness between 10 and 15 Å. This process is known as trap-assisted tunneling process. Thus the interfacial layer between the oxide semiconductor and base semiconductor substrate has been known to be one of the major features determining SIS solar cell performance. They were also enhanced due to the heavy indium oxide doping. As a result of comparison with previous optical and electrical studies, we observed that due to the heavy incorporation of indium oxide as suitable dopant, the optical, photoluminescence, electrical and opto-electronic properties (with ⟨1 0 0⟩ wafers as substrates) of intrinsic zinc oxide thin films were improved. Among ⟨1 0 0⟩ Si, GaAs and InP substrates, InP showed high degree of crystalline epitaxial lattice matching and better opto-electronic properties with epitaxial IZO thin films. A slight increase in the solar cell conversion efficiency for high T_{sub} thin films on indium phosphide substrates indicates the improvement of cell performance.

We come to a conclusion from the opto-electronic characterization studies that the solar cell characteristics of the fabricated novel SIS type structures using epi-n-IZO thin films as TCOs were confirmed. This indicates the superior performance of SIS junction contacts. The performance of the solar cell characteristics of fabricated SIS structures can be improved by using fundamental technological steps in fabrication, improvements in the electronic contact of the TCOs with substrates i.e., reduction of insulator layer width within the fruitful limit (<22 Å) and electronic grade of semiconductor substrates.

4. Conclusions

We have developed some novel models of iso- and hetero-structures using high quality epi-n-IZO thin films as TCOs and ⟨1 0 0⟩ Si, GaAs and InP semiconductor single crystal wafers as base substrates. The obtained highly transparent, conductive epi-n-IZO thin films for iso- and hetero-SIS type solar cells were considerably greater than that of state-of-the-art of indium tin oxide (ITO) and other commercially valid TCO's by using L-MBE i.e., PLD. The effects of substrate temperatures and substrates on indium zinc oxide thin film growth, opto-electronic properties with ⟨1 0 0⟩ semiconductor substrates were studied. As well as the feasibility of developing some novel models of iso- and hetero-structures using high quality epi-IZO thin films as TCOs and ⟨1 0 0⟩ oriented Si, GaAs and InP semiconductor single crystal wafers as base substrates was also studied simultaneously. Extra-mural study on the effect of heavy indium oxide incorporation into the intrinsic zinc oxide thin film growth and on opto-electronic properties gives added advantages to the indium zinc oxide work. Higher substrate temperature enhanced the transparency and anti-reflection property of IZO thin films. The electrical conductivity and carrier mobility were also increased for the higher substrate temperature deposited IZO thin films. A slight increase in the solar cell conversion efficiency for high T_{sub} thin film and 200 °C annealed indicates the improvement of cell performance. Among ⟨1 0 0⟩ Si, GaAs and InP substrates, indium phosphide gives high quality epitaxial lattice matching to the IZO films.

The optical transparency, electrical conductivity and carrier mobility of intrinsic zinc oxide thin films were enhanced due to the heavy indium oxide doping. The anti-reflection property was also increased. As a result of study, we also observed that due to the heavy incorporation of indium oxide as suitable dopant, the optical, photoluminescence, electrical and opto-electronic properties of intrinsic zinc oxide were improved. The solar cell characteristics of fabricated SIS type structures using epi-n-IZO thin films as TCOs were confirmed by opto-electronic characterization and identified that it was enhanced by higher T_{sub}. Among others, n-IZO/⟨1 0 0⟩ p-InP structures indicates the superior performance of p–n junction contact. The performance of the solar cell characteristics of fabricated SIS structures can be improved by using technological steps in fabrication, improvements in the electronic contact of the TCOs with substrates i.e., reduction of insulator layer width (within the fruitful limit <22 Å) and microelectronic grade of semiconductor substrates.

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