

Experimental and Simulation Study of ZnO based TCO electrodeposited on n silicon substrate to improve the Performance of heterojunction solar cells

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Abstract—Transparent conductive oxide TCO (ZnO) films were prepared by electro-deposition anodization on n type (100) silicon wafer in the aim to achieve a high efficiency in photovoltaic energy conversion. The ZnO layer were analyzed to improve the heterojunction (HIT) solar cell performance as the FF, J_{cc}, VCO, η, and the optical properties as QE, X ray diffraction. Measurements show that the preferred orientation of ZnO films grown on Si substrate has (002). The simulations of a-Si/c-Si heterojunction solar cell were carried out to reveal the cell parameters. Our results show that the solar cell heterojunction is hypersensitive to the ZnO layer. The beneficial effect of implementing ZnO front contact for increasing electrical energy conversion properties of HIT solar cell was compared to the cell without the ZnO layer.

Keywords— (HIT solar cell, efficiency, ZnO-based TCO layer)

I. INTRODUCTION (HEADING 1)

Transparent conductive oxide (TCO) films have high transmittance in the visible region of the electromagnetic spectrum combine with reasonable high conductivity. TCO films have therefore been used extensively as components in optoelectronic devices with applications in heterostructure with intrinsic thin layer (HIT) solar cells, light emitting diodes(LEDs), flat and touch panel displays [1,2], Zinc oxide (ZnO) has been actively investigated as an alternative to standard Indium Tin Oxide (ITO) material used in these above mentioned applications, because ZnO is cheaper, non toxic and readily available, Hetero junction with intrinsic thin layer (HIT) cells, first developed by Sanyo Ltd, are silicon cell than combine the high efficiency of crystalline silicon (a-Si:H): This structure both the emitter and the back surface field (BSF) layers the high quality performance of HIT solar cells has been demonstrated with efficiencies over 22% in laboratory cells and over 20% in mass production cells based on textured n type Czochralsky (CZ) crystalline silicon (c-Si) [3,4]. Numerical simulation is now important for the

understanding, design, and optimization of high-efficiency solar cells. The modeling of crystalline silicon wafers is well understood, while the amorphous layer and the interface between the a-Si:H layer and the c-Si are more difficult to model. The simulation of an a-Si:H/c-Si solar cell is a demanding task due to the advanced physics models and the large number of material parameters involved. AFORS-HET (Automat for Simulation of Heterostructures) software has been used for simulating heterojunction solar cells [5]. AFORS-HET provides a convenient way to evaluate the role of the various parameters present in the fabrication process of HIT solar cells, such as thickness, doping concentration, minority carrier lifetime, defect recombination, band gap, and resistivity. Recently, researchers have performed simulation studies and optimized important basic parameters, such as thickness and doping concentration, and they believed that the a-Si:H layer should be extremely thin and heavily doped to achieve a high-efficiency solar cell.[7,8]. However, as there is little information on how and why these parameters influence the carrier transport properties, and even less information on the influence of the work functions of the transparent conducting oxide (TCO) and back surface field (BSF) layer on the performance of the solar cell, further investigation is still essential.

This paper is devised into parts, first stating with a presentation of the results of investigations of the structural properties of TCO (ZnO) films prepared by electrodeposition technique. The second part presents the simulation used to evaluate the performance of the ZnO/a.Si(n)/a.Si:H(i)/c.Si(p)/Al-BSF(p+)/Al heterojunction solar cell. Finally, discussion about the results about the experimental and simulation study, mainly concerns the conversion efficiency η, quantum efficiency QE and the other performances of solar cells as the factor form (FF), short circuit density(J_{sc}), the open circuit voltage (V_{oc}) with and without the ZnO layer prepared by electrodeposition method.

II. EXPERIMENTAL PART: ELABORATION AN STRUCTURAL PROPERTIES OF ZnO FILM

A. Deposition of *zno* layer:

The ZnO layers were deposited on silicon substrates using electrochemical anodization. The electrolytic solutions were prepared using aqueous solution of 5mM ZnCl₂ with a PH about 6. To ensure a good conductivity of the solution allowing optimal conditions for the deposition of ZnO, the samples were introduced at 65°C during time between 10 and 15min 0.1 M KCl, “Fig.1”

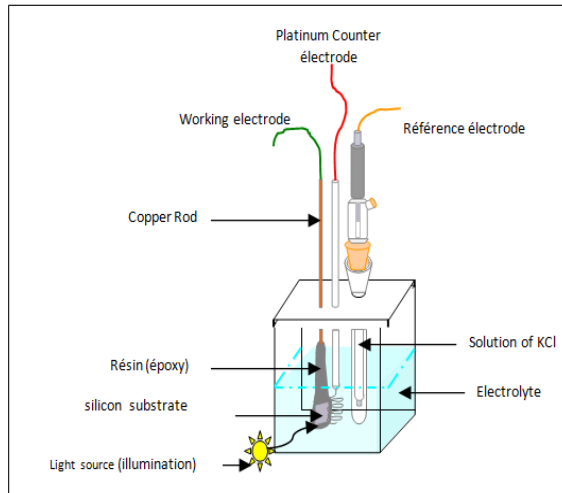


Fig.1. Descriptive schematic of anodization cell

B. Structural properties:

The DRX of ZnO films prepared on silicon substrate is displayed in “Fig.2”. The most intensive peak diffraction observed at 63°, can be indexed to n-Si (1 0 0) diffraction. The strong peak intensity of the nano-composites ZnO is located at 34.22°. Also, others peaks displayed for the ZnO peaks having intensity weaker than the first, located at 31.21, 38.17° and 45,32° corresponding to the (100),(101) and (102) planes of ZnO, respectively. The XRD analysis indicates that the films of ZnO presents a preferential orientation along the n-Si (1 0 0) substrate. It is similar with a strong (0 0 2) peak which located at 34.12° and a number of weaker peaks with (1 0 0), (1 0 2), (1 0 1), which indicates that the particles on Si wafer are of perfect c-axis orientation. The scanning electron microscopy (SEM) images of the ZnO growth by electrodeposition are shown in “Fig. 3”. We assume the size of ZnO between 4 – 13 nm.

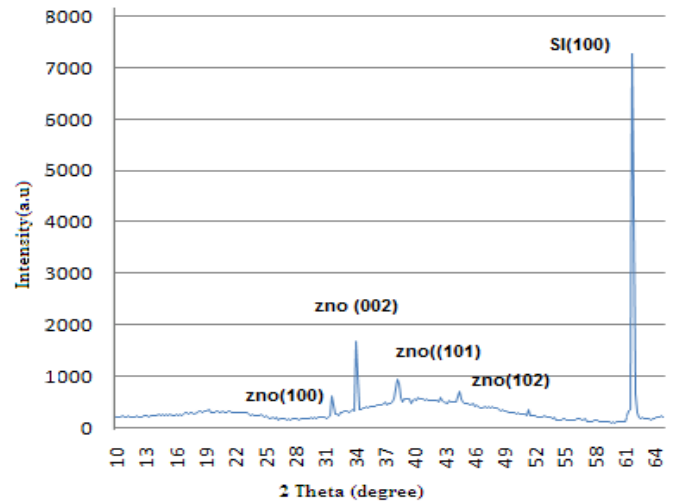


Fig.2. X-ray diffraction patterns of ZnO films prepared on Si substrates at a potential $E = -1.3V/SCE$ for 10min

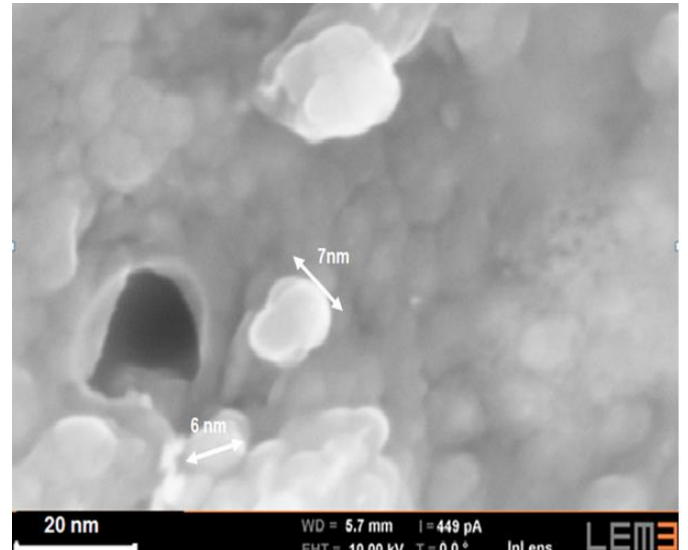


Fig.3. SEM image of the ZnO thin film electrodeposited on silicon substrate

III. SIMULATION PART: THE STRUCTURE OF THE SOLAR CELL AND SIMULATION DETAILS:

AFORS-HET, based on solving the one-dimensional Poisson and the continuity equations using Shockley–Read–Hall recombination statistics, is widely used for studying heterojunction solar cells. The structure of the simulated HIT solar cells is ZnO/ a-Si:H/n a-Si:H/i -c-Si/p /Al BSF /Al, and a schematic is shown in “Fig. 4”. In the present simulation, AM1.5 radiation was used as the illumination source with a power density of 100 mW/cm² , For the p-c-Si substrate, oxygen defects with a density of $1 \times 10^{11} \text{ cm}^{-3} \text{ eV}^{-1}$ located at 0.56 eV above E_v ($E_v + 0.56$) are assumed. The defect states is a single distribution of electrons (holes) is 1×10^{-14} (1×10^{-14}) ,Other important thing is the Interface defect density (Dit) between the i-a-Si:H/c-Si the density of defects ($\text{cm}^{-2} \text{ eV}^{-1}$) is $1 \times 10^9 - 1 \times 10^{13}$ (continuous distribution)[11]. The main

simulated parameters of the different layers are listed in “Tab.I” The surface recombination velocities of electrons and holes were both set as $1 \times 10^7 \text{cm/s}$. During the simulation processes, the transparent conductive oxide .In the ZnO layer prepared in the present study by electrodeposition method and thus. We have taken in consideration parameters found during the structural and optical characterization, as presented above. the thickness of the ZnO layer obtained was 80nm and the light reflection of front contact was set to be at standard values for such devices ie 0.1 and 1 respectively the AFORS-HIT software environment .which is one dimensional solar cell device simulator was employed to simulated this cell “, the important parameters to be discussed are open circuit, voltage (V_{oc}),short circuit density (J_{sc}) and the efficiency (η), V_{oc} is the voltage when no current pass through the cell , whereas J_{sc} is the current when no voltage is applied. The integration of The ZnO layer in the cell heterojunction changed clearly the performance of the cell.

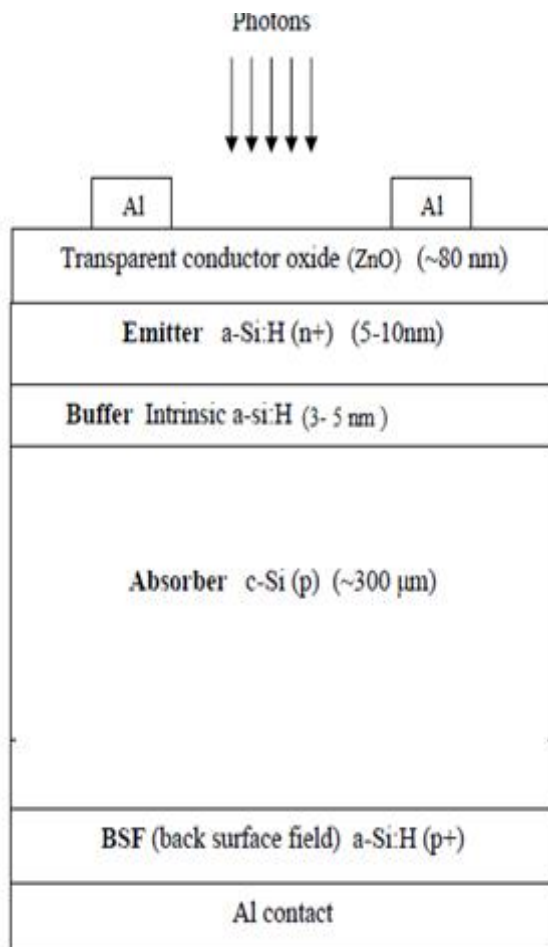


Fig.4. A schematic diagram of a ZnO/a-Si:H/n a-Si:H/i -c-Si/p/Al BSF /Al solar cell

TABLE I. THE MAIN PARAMETERS FOR THE SIMULATION

	a-Si H(n)	a-Si H(i)	c-Si H(p)	Al-BSF (P ⁺)
Layer thickness (nm)	10	5	3×10^5	5×10^3
Dielectric constant dk	11.9	11.9	11.9	11.9
Band gap $E_g(\text{eV})$	1.74	1.72	1.12	1.12
Electron affinity $\chi(\text{eV})$	3.9	3.9	4.05	4.05
Effective conduction band density(cm^{-3})	1×10^{20}	1×10^{20}	2.8×10^{19}	2.8×10^{19}
Effective valence band density(cm^{-3})	1×10^{20}	1×10^{20}	1.04×10^{19}	1.04×10^{19}
Electron mobility($\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$)	5	5	1040	202.4
Hole mobility($\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$)	1	5	412	77.15
Doping concentration of donators (cm^{-3})	1×10^{20}	0	1.5×10^{19}	1×10^{20}
Doping concentration of acceptors (cm^{-3})	0	0	0	0
Thermal velocity of electron ($\text{cm}^3 \text{s}^{-3}$)	1×10^7	1×10^7	1×10^7	1×10^7
Thermal velocity of holes ($\text{cm}^3 \text{s}^{-3}$)	1×10^7	1×10^7	1×10^7	1×10^7
Auger recombination coefficient for electron($\text{cm}^6 \text{s}^{-1}$)	0	0	2.2×10^{-31}	2.2×10^{-31}
Auger recombination coefficient for hole ($\text{cm}^6 \text{s}^{-1}$)	0	0	9.9×10^{-32}	9.9×10^{-32}

IV. RESULTS AND DISCUSSION

The performance of the solar cell is influenced by many parameters the addition of each layer we are observed the characterization $j(v)$ change after each integration i.e. the HIT solar cell with or without insertion of Zno layer to i-a-Si:H buffer layer or p+-a-Si:H BSF layer was investigated, and their $J - V$ characteristics are shown in “Fig. 5”. The variations of V_{oc} , J_{sc} , FF of the solar cell as a function of many factors of each layer. On the one hand, it is well known that a high quality i-a-Si:H buffer layer acts as the passivation of the a-Si:H/c-Si interface layer in the actual fabrication process of a HIT solar cell. On the other hand, the middle band diagram of (Fig. 6 a.b) shows that the i-a-Si:H buffer layer can hinder the photon-generated carrier recombination from the n-a-Si:H emitter layer to the p-c-Si base layer, which can improve the short-circuit current of the solar cell by inserting an i-a-Si:H buffer layer. However, when a p+-a-Si:H BSF layer is added, the J_{sc} and V_{oc} are signify, the significant conduction and

valence band offsets (ΔE_C and ΔE_V) between the p-c-Si base and p⁺-a-Si:H BSF layer can be clearly observed in (Fig 6.c.d)

Such a conduction band offset can provide a mirroring for minority carriers (electrons) from the back contact compare to those with no p⁺-a-Si:H BSF layer , but in our work we studied just the influence of the ZnO layer “Fig 6.d” , the HiT cell with and without ZnO layer , we know that the ZnO transparent conductor oxide has a large gap (3.4eV) this parameter increase the probability of absorption of the photons and decrease the number of photons reflected, the p-c-Si layer will absorb more incident light and JSC will increase, these parameters will change with the insertion of the ZnO layer, the J(V) characterization is shown in “Fig.5” with and without ZnO layer, the current circuit increase 32.48 to 38.78 mA/cm² ,and the other parameters were also changed, the voltage changed from 650.1 to 690.4 mV, an efficiency of 20.07% is obtained. It is evident that the integration of ZnO was helped increasing the absorption of the light, the ZnO film grown on silicon substrate was applied as transparent front contact for the ZnO/ n-a-Si:H/i-a-Si:H/p-c-Si/p⁺-a-Si:H/Al BSF /Al solar cell device and its properties and efficiency were compared with those of a reference cell , the parameters obtained by the software environment are summarized in “Table.II”.

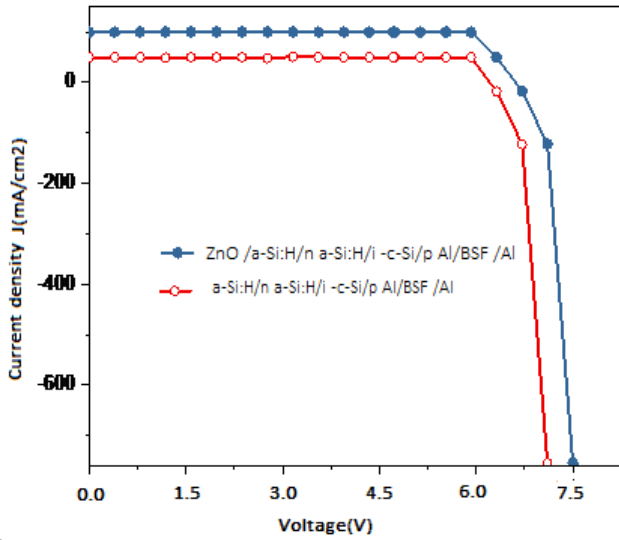


Fig .5. J(V) characteristic of ZnO /a-Si:H/n a-Si:H/i -c-Si/p Al/BSF /Al solar cells with and without ZnO

TABLE II. PERFORMANCE OF THE SOLAR CELL WITH AND WITHOUT ZNO LAYER

	$J_{sc}(\text{mA}/\text{cm}^2)$	$V_{oc}(\text{mV})$	FF	η (%)
Hit solar cell with ZnO layer	38.78	690.4	71.29	20.07
Hit solar cell without ZnO layer	32.48	650.1	65.13	16.38

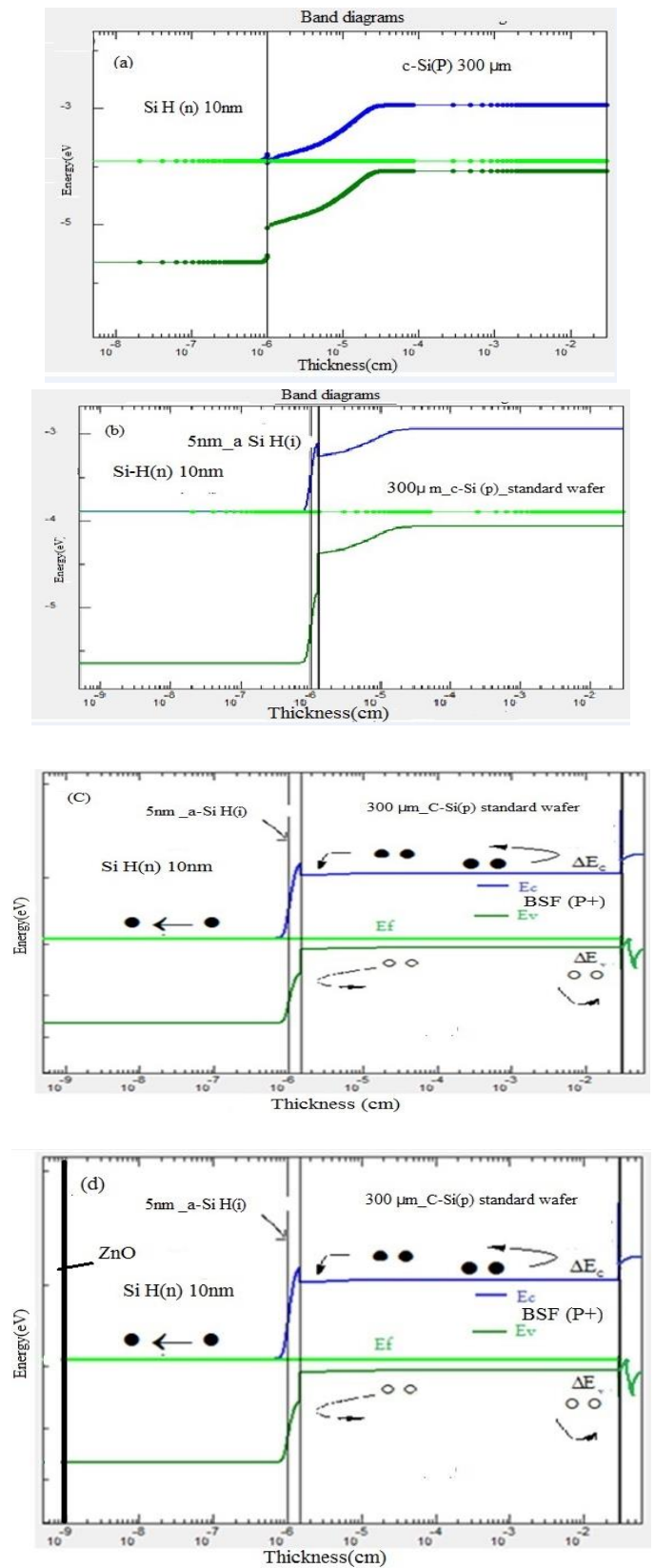


Fig.6. The corresponding band diagrams of solar cell after insertion of each layer a) a-Si:H/i -c-Si/p b) a-Si:H/n a-Si:H/i -c-Si/p c) a-Si:H/n -a-Si:H/i -c-Si/p Al/BSF /Al d) ZnO /a-Si:H/n a-Si:H/i -c-Si/p Al/BSF /Al

In ref [12] Zhao et al, have fabricated HIT silicon solar cells with conversion efficiency above to 19% whereas the thin solar cells fabricated by Dao et al [13] have a conversion efficiency of 17.86% this comparison with results of literature points out the good quality of the ZnO front films obtained in the present study, The Quantum Efficiency (QE) measurement explores the performance of a solar cell at different wavelengths across the solar spectrum. The external quantum efficiency (QE) is defined as the ratio of the collected carriers to the incident photons per unit area per unit time.

The solar cell with the ZnO front contact presents a higher response in near UV-Visible- near IR(350nm-1200nm) than the cell without ZnO layer, Thus, as it is well known that the performance of heterojunction cell depends on TCO front contact, in "Fig.7" the QE measurements confirm this possible improvement of the functioning of HIT solar cell by an integrating of ZnO layer in the structure.

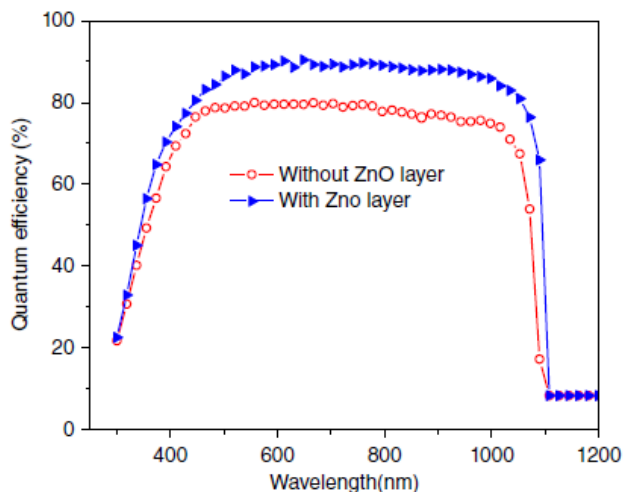


Fig. 7. Quantum efficiency of /a-Si:H/n a-Si:H/i -c-Si/p /Al/BSF /Al Al solar cells with and without ZnO

CONCLUSION:

ZnO films were deposited on silicon substrate by electrodeposition method in the aim to get optimised thin film for heterostructure with intrinsic layer or HIT, structural characterization of ZnO film, using XRD and SEM technique points out an arrangement of the nanoparticles uniform mostly highly oriented with c-axis being perpendicular to the substrate. The ZnO films electrodeposited were inserted in ZnO/ a-Si:H/n a-Si:H/i -c-Si/p /Al BSF /Al solar cell and its performance were thoroughly investigated using AFORS-HET software. During the simulation, we have taken in consideration parameters found during the experimental part of the ZnO, the efficiency increased 16.38% without ZnO films to 20.07% with the integration of the ZnO, and the others main parameters as the JSC, Voc and the FF were also significantly changed. In summary, these results indicate that

it is possible to obtain a solar cell with good performance by insertion of TCO (ZnO).

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