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Advanced Spin Coater to Increase the Performance of Solar Cells

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ABSTRACT

This research paper designates to design and development of spin coating device. Coating process is carried out on solar cell with modified device. Film thickness and uniformity is depends on spinning speed, time and rate of evaporation. To overcome the drawbacks from existing coating device, to propose the low cost, high response modified spin coater device, which can process both thin film coating as well as annealing process at quick response? The experiment process as ZNO is dipped to coat on the solar cells by using the developed cost modified spin coater device. In this experimentation, ARM Processor LPC 11U24 and L293 AC motor driver for controlling signals for uniform various controlling speeds is increased from 150 rpm up to 2000 rpm, when increase the motor speed, it is possible to spreading of the solution side of the drum, so we covered spin plate with steel drum and top layer also covered with transparent acrylic glass .And vacuum pump is used to remove the gas or humidity in the drum. This spinning is ability to make defect free and uniform thin film on the solar and provide better efficiency of the economic factor. When increasing the rate of evaporation instantly in the spin coater which results in smooth and uniform thin film. Surface of the layer and availability of solution is determined by the energy dispersive X-ray spectroscopy (EDS) and Scanning electron microscopy (SEM) respectively. Field Emission Scanning Electron Microscope (FESEM) image is used to analysis the ZNO thin film coating in modified spin coater device. The proposed modified spin cating device achieved the efficiency as 5.2% respectively.

Keywords: zinc oxide, AC motor, heating unit, Vacuum pump, spinning disk and solar cell.

1 INTRODUCTION

Solar electricity is a constantly expanding energy source nowadays and solar cells have found diversity of applications ranging from consumer devices and small scale distributed power systems to centralized megawatt size power plants. Solar energy reached high attention with people because of its applications and advantages. The research for solar panel is rapidly increasing for getting maximum efficiency.

Table 1: Nomenclature

Nomenclature		
S.NO	**Chemical formula**	**Name**
1	C	carbon
2	CO	Carbon oxide
3	N	Nitrogen
4	O	oxygen
5	S	sulphur
6	Si	silicon
7	ZnO	Zinc oxide
8	Zn	Zinc

The conversion process of panel is affected by many factors, in that reflectance is the important factor. In the past, inorganic materials such as silicon [1] have produced typical solar cells. However, very costly materials and energy-intensive processes of processing are required. Silicon crystals are expensive to employ in solar cells. Silicon crystals are manually combined. The purification of silicon is laborious, however, and much silicon is wasted. Moreover, as the performance of silicon cells diminishes when the temperature increases, a cooling system is needed for the long-term concentrated functioning of silicone cells. Research into innovative manufacturing procedures is put into considerable effort. Several experiments have proven that ZnO is highly resistant to high-energy radiation and therefore appropriate for space uses. In all acids and alkalis it can be easily etched. This allows it to be employed in small size devices like transparent electrodes, display window materials and solar cells. It also has an indigenous substratum [2].

In a variety of technical applications it is employed, such as porcelain enamels, heat resistant glass, volcanic active agent, rubber and plastic additives, UV protection and fungus static pigments, protective spacecraft coverings, a cigarette filter component, optical waveguide healing ointments, etc. By depositing channel layer onto a flexible substrate through low temperature procedures, transparent TFTs and the achievement of additional functions in photo detection utilizing the ZnO channel ZnO has played a major role for manufacturing transparent Thin Film Transistor (TFT). This eliminates the protective covering for the prevention of light exposure as ZnO-based transistors are insensitive to visible light. The deposited ZnO maintains usually a crystalline phase, even at room temperature. The deposition method is done. ZnO has almost UV emission, transparency, conductivity, and resistance to electronic degradation at high temperatures, which is essential properties. Moreover, because of the highest melting point (2248k) and huge coherent energy (1.89ev), ZnO is the hardest of the II-VI semiconductors as well a major piezo-electric semi-conductor (d=12.2 = 10-12 CN) with an excellent piezoelectric coefficient KL =0,27 and great adhesion on different media. Numerous coating technologies for depositing thin films are now available.

Dip coating methods, Sol gel methods and spin coating methods are the many methods of coating. All methods, however, have their own distinct limits and include compromises with regard to process specifications, substrate limits, desired film characteristics and costs. So it is difficult for any individual application to choose the optimum strategy. Spin-coating is an approach used on flat substrates to prepare uniform, thin coatings. The well-reinforced glass suspension, which is rotated at a high speed to disperse the liquid by a centrifugal force, contains one drop of prepared solution. A spin coater is a programmable equipment used for spinning coating. The substratum is constantly revolved, so that the fluid is extended and there is a thin layer of the desired thickness. The solvent used is usually volatile and simultaneously evaporates. The high spinning angular velocity, the thinner the film. The film's thickness relies also on the solution's concentration. Spin coating is commonly employed in micro-manufacturing, in which thin films can be made about 100 nm in thickness.

Common spin-coating defects, as striations, include radially-focused thickness lines in the as-coated film and chuck mark patterns can be generated by thermal "communication" among the solution at the top of the wafer and the metal vacuum chuck of the wafer. The surrounding environment can influence the quality of the coating while creating coatings in the ambient environment. The humidity of the surrounding air is a critical variable.To overcome this effect and also to increase the absorption of sunlight thin coating is applied on the top layer of panel. The material used for thin coating increases the absorption. This thin coating process can be done by many methods [3]. Compared to all, spin coating method is very easy to use and low in cost [4]. Commonly, the process of spin coating unit is applying solution on the surface by spinning method. But in this paper, several modification is given to the spin coater device to give better performance in thin film coating. Here, commercial solar panel (100 cm^2) is taken for the research, which is already coated with silicon nitrideanti-reflex coating (ARC) [5]. In this double layer antireflective coating [6]

ZnO is applied on the solar cell with the newly developed spin coater device to show the performance of device and efficiency of panel.

2 LITERATURE SURVEY

In this section we discussed the existing coating scheme with benefits and drawback, which helps us to find the existing problem and to solute that problem.In firstly, Emslie and Myerhofer et.al., [7] have suited and explained the four stage of spin coater device at a constant rate and fluid viscous forces control fluid thinning actions and a substrate spinningstage at a constant rate and solvent evaporation controls the coating thinning manners. Thirunavukkarasu. C [8] et al., have toimprove the performance of the spin coating device, and also experiments by varying its parameter like spinning speed, Viscosity of solution and rate of evaporation on annealing process. Manikandan . N et al., [9] have designed the spin coating machine, which consist of stepper motor,Dc brushless motor, syringe system, and Arm processor. The spinning speed is the main factor to obtain uniform thickness. Hence, the ARM processor used to drive the motor for controlling and monitoring the speed precisely.Sadegh-cheri M [10] have used the two sensors for to measure and control the spin speed of the spin coat as infrared (IR) andLEDs. The spin coater was tested for coating polydimethylsiloxane (PDMS) polymer in the range of 1000–9000 r pmspin speed. The total cost of the spin coater is less than $30 and power consumption of 5 W, respectively. Gurucharan V [11] et al., have further developed with touch screen interference, where we can give input for the parameter like spinning speed and time which is also displayed in LCD with help of microcontroller. So many researchers are done with parameter of speed but the rate of evaporation is considered as main factor to get the desired thickness of thin film. Here the device is modified and inbuilt with some parts to perform the annealing process.

3 MATERIALS AND METHODS

In this following section, we introduce the proposed methodology of modified spin coater device. And also we discussed and offered the different materials for preparing the modified spin coater device, which is mentioned in below table 2 as follows.

Table 2: Material for proposed modified spin coater

S.NO	Materials
1	AC motor
2	ARM Processor LPC 11U24
3	Energy dispersive X-ray spectroscopy (EDS)
4	Field Emission Scanning Electron Microscope (FESEM)
5	L293 motor driver
6	Heat blower gun

7	Solar cell (100 cm2)
8	State Relay(SSR)
9	Scanning electron microscopy (SEM)
10	spin coater machine
11	Vacuum pump
12	zinc oxide (4µl)

3.1 zinc oxide

As a suitable substrate material due to its isomorphic structure, zinc oxide has garnered considerable interest. ZnO single crystal substrates have several advantages for wireless power amplifier applications based both on nitride and oxide. Low substratum defect density and isomorphic grid in relation to GaN lead to films that enhance the performance of device manufacturers figure 1. It is represented by the ZnO structure root model. The substrate's semi-isolating feature avoids parasite streams in field effect transistors and allows direct electrical characterisation of epitaxial films in the form of thin films in particular. Since ZnO bulk is expensive and unavailable in large wafers currently, two-dimensional growth is always chosen for interface energy from ZnO to saphir or other oxide substrates, resulting in good quality film at a lower (less than 700°C) temperature. Due to the theoretical predictions of room temperature ferromagnetsZnO is a potential material for spintronics uses. Curie temperature > 300K for Mn-doped ZnO type p and n-type doping for Fe, Co or Ni alloyed is an example. For example. With alloying processes, band gap power ranges from 3.3eV to 4.5 eV. Therefore, the doubling hetero-structured LEDs and quantum well lasers can be employed as an active layer.

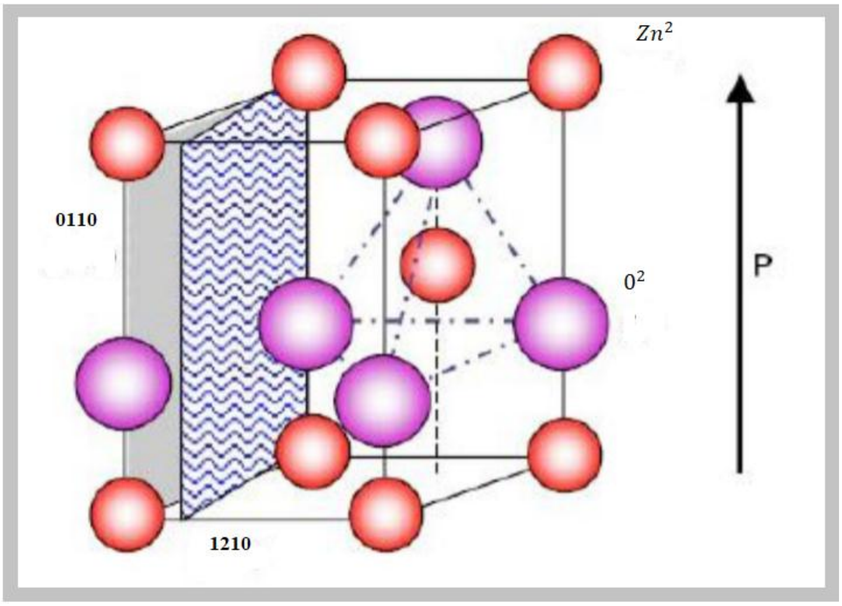

Figure 1: The ZnOwurtzite structure

3.2 Preparation of solution

For anti-reflex coating (ARC), several materials are used to increase the optical properties of solar panel. ZnOis large band gap semiconductor and also have low resistivity, high optical properties [12]. Preparation of zinc oxide is done by sol-gel process. This approach converts a collection of chemistry processes in an irreversible way into an infinite molecular weight three dimensional (gel) network filling the same volume as the solution molecular reactor precursors (sol).

Zinc acetate dehydrate is a starting material. Absolute ethanol and distilled water are solvent and stabilizer. 1g of zinc acetate dehydrate was dissolved in 10ml of ethanol, then it stirred with magnetic stirrer device on a hot plate at 60 ℃ for 60 minutes, which result in cloudy solution. After 30 minutes, the solution settled and clear. To keep the solution stable for 2 months, 10ml of distilled water was added drop by drop gradually. Further the solution stirred at 100℃ for 3 hours. Then the spin coating process started with ZnO solution. The Figure 2. Shows the preparation of ZnO solution in magnetic stirrer,

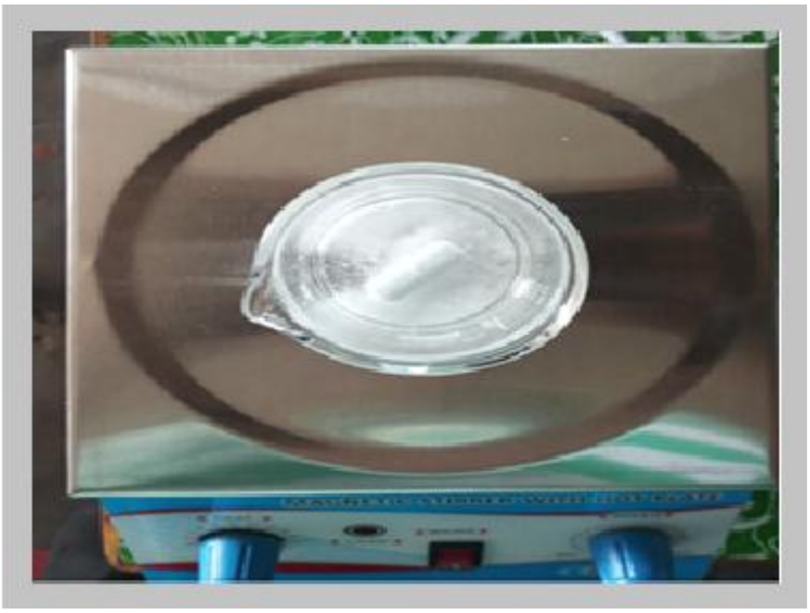

Figure 2: Magnetic Stirrer

3.3 Fabrication of spin coater

The new model spin coater unit is shown in figure. 3. It is developed with programmable human machine interface (HMI), AC motor, Regulated power supply, vacuum pump, heating unit, thermocouple, SCR, SSR etc., The Regulated power supply is given to the AC motor with rating of 220v which rotates up to 8000 rpm. The speed of the motor is controlled by Solid State Relay(SSR).The motor shaft is coupled with spin plate. The spin plate is made up of acrylic glass of 6mm thickness where the substrate placed with help of vacuum suction cup. Vacuum suction cup is used to hold the substrate when substrate rotates in high speed.To avoid spreading of the solution, spin plate was covered with steel drum and top layer also covered with transparent acrylic glass

To give better performance from existing method the vacuum pump, heat blowing gun and thermocouple are kept inside through a hole from top of the unit. The vacuum pump is used to remove gas or air molecule from the drum. The heat blowing gun is for annealing process which is used to provide necessary temperature. Thermo couple is to measure the temperature. To avoid short circuit SCR is used. Here, the programmable human machine interference is acts as user interference to display data of temperature, spinning speed through touch screen and also easy to controlling the operation of device. The micro pipette is placed centre of the unit to inject solution.

Figure 3: Construction of Modified spin coater

3.4 Spin coater working

The commercial solar cell of area 100 cm^2 is kept in the suction cup.These types of solar cells are covered with wax to avoid damage. To remove the wax from the top of the solar cell, it is kept in thinner for 20 mins. Then the layer is easily removed and dried with cotton cloth.Initially spin coater device is made to rotate at 150 rpm. After ZnOsolution about 4µlis inject through micro pipette for coating.The motor speed is increased to 2000 rpm. This process continued to three times. To get thin film coating on the solar cell, it should be dried.The heat blower gun provides heat at 350K [13] inside the drum to dry the ZnO coating on the substrate for 20 minutes. The high temperature affects the crystalline structure of thin film and band gap. The thermocouple helps to maintain constant temperature. All the parameter value given are display in LCD. After annealing process, the humidity presents inside the drum is sucked out by the vacuum pump. The pressure value is 60kpa. The gas or humidity presents in the drum will affect the thin film layer on the solar cell, which leads to create holes on the top layer.

4 SPIN COATING MATHEMATICAL MODELLING

An essential aspects in spin coating is spin speed. The speed of the substrate (rpm) influences the amount of radial force imparted to the liquid resin, as well as the velocity and turbulence of the air instantly above it. The final film thickness is often defined by the high-speed spin step [14]. At this stage, relatively slight fluctuations of 50 rpm can result in a 10% difference in thickness. The film thickness is mostly determined by the force used to shear the fluid resin towards the substrate's edge and the drying rate, which affects the viscosity of the resin. As the resin dries, its viscosity increases to the point where the radial force of the spin process can no longer transport the resin over the surface. At this stage, increasing the spin duration will not result in a significant drop in film thickness.

The balance of viscous and centrifugal forces per unit volume for Newtonian fluid is calculated using cylindrical polar co-ordinates (r, θ, z) with the origin at the center of rotation, z vertical to the plane, and the axes r and of revolving with the plane with angular velocity..

$$-\eta \frac{\partial^2 v}{\partial z^2} = \rho\omega^2 r \quad (1)$$

where ρ is identify as the fluid density, is the absolute viscosity, and $v$is identify as the fluid velocity in the radial direction of r. Integrating twice with reverence to z and applying a suitable boundary condition to ensure that shear is zero at the fluid's free surface; that is $\partial v \ \partial z = 0 \ at \ z = h$.

$$v = \frac{1}{\eta}\left(-\frac{1}{2}\rho\omega^2 r z^2 + \rho\omega^2 r h z^2\right) \quad (2)$$

The q is radial flow, per unit length of the perimeter is given by,

$$q = \int_0^h v(z)dz = \frac{\rho\omega^2 r h^2}{3\eta} \quad (3)$$

The equation of continuity is used to construct a differential equation for h, and the height reduction must balance with the radial flux.

$$\frac{\partial h}{\partial t} = \frac{1}{r}\frac{\partial(rq)}{\partial r} = -K\left(\frac{1}{r}\right)\frac{\partial}{\partial r}(r^2 h^3) \quad (4)$$

Where $K = \rho\omega^2/3\eta$

Before we look for a general solution to Equation (4), examine the particular solution that is just dependent on time t..

$$\frac{\partial h}{\partial t} = -2Kh^3 + 3Krh^2\frac{\partial h}{\partial r} \quad (5)$$

Since the film is uniform at the start, hence ∂h ∂r = 0 which gives

$$\frac{\partial h}{\partial t} = -2Kh^3 \text{or} \frac{\partial h}{h^3} = -2K\partial t \quad (6)$$

Eq. (6) is the coating thinning rate. we have

$$h = \frac{h_0}{\sqrt{1+4Kh_0^2 t}} = \frac{h_0}{\sqrt{1+\frac{4Kh_0^2 \rho \omega^2 t}{3\eta}}} \quad (7)$$

where, h_0 is the thickness of the film at time zero.

Solvent evaporation becomes a key contributor to final film thickness over time. To calculate the impact on final coating thickness. As long as the rotation rate is remained constant, evaporation is a constant throughout spinning. As a result, he simply multiplied the thinning rate by a constant evaporation factorequation (6).

5 RESULTS AND DISCUSSIONS

In this section we followed the experimental results of the proposed spin coated device. In this experimental study, we used the a typical solar cell is coated with single layer Anti-Reflective Coating with silicon nitride gives open circuit voltage about 0.52v. Then it is coated with ZnO solution with normal spin coater. The proposed method results are obtained by using EDS and FESEM to analysis the presence of ZnO on the substrate and crystalline growth respectively

5.1 Performance analysis

In this section, analysis the performance of solar cell efficiency by calculating the different calculation. The performance of the solar cell efficiency is compared with existing spin coting device and proposed modified spin coating device.

Voc (v)

The Voc (v) is expressed as an open-circuit voltage, also defined as maximum voltage available from a solar cell, and this occurs at zero current.

$$Voc(V) = \frac{nKT}{q} In\left(\frac{I_L}{I_o} + 1\right) \quad (8)$$

Isc(mA)

TheIsc(mA) is expressed as a short-circuit current (ISC), the unit is measures as milli amphere.The current through the solar cell when the voltage across the solar cell is zero.

$$I_{SC=qG(L_n+L_P)} \quad (9)$$

FF

The FF is expressed as a fill factor, which determines the maximum power from a solar cell. The ratio of the maximum power from the solar cell to the product of Voc and Isc.

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{OC}} \quad (10)$$

Efficiency (η)

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as

$$\eta = \frac{V_{OC} I_{OC} FF}{P_M} \quad (11)$$

Comparative analysis

In this section we experiment the two spin coating device is used to calculate the performance efficiency of solar cell. The two devices such as existing spin coating and proposed modified spin coating device. Both device experiment are evaluated as follows,

Existing spin coating device

In this coating device is coated in spin coater with separate annealing process, in below figure 4 shows that the FESEM image of coating with separate annealing process of existing scheme. when we start the spinning process at the speed of 15rpm while we drop the 4 µl of Zno solution on the cell. After the motor speed is rise to 2000 rpm at the spinning time as 45 secs. Then the Substrate kept in oven for 10 mins at 300 deg Celsius temperature. At the period of moving the substrate from spin coater to oven, when the coated ZnO material is affected by atmosphere impurities or particles, and also it is dried partially in atmospheric temperature and then only it is kept in oven, so different temperature will affect the surface of the layer and thickness increased. This cause the coating coated surface may goes to rough condition. The surface is not uniform and rough condition. The performance of cell with low photon absorption and less conductivity. In figure 5 shows that the EDS for ZnO in solar cell.

Base(2)

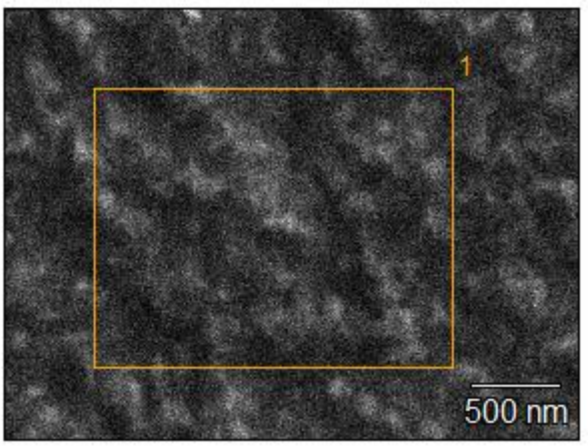

Figure 4: FESEM image of ZnO thin film coating with separate annealing process

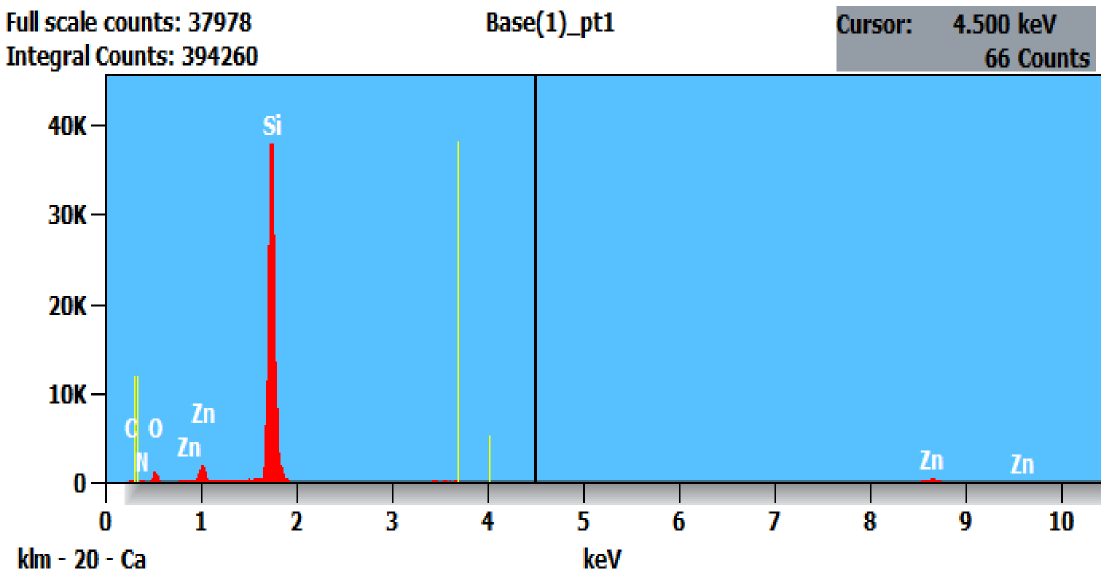

Figure 5: Existing EDS for ZnO in solar cell

The existing coated solar cell performance parameter is evaluated in the below table 3 and described as follows as,

Table 3: Performance analysis of existing spin coated cell.

Voc (v)	Isc (mA)	FF	Efficiency %
0.4	20.3	0.55	4.4

6 MODIFIED SPIN COATING DEVICE

Generally thickness of thin film is depends on speed of the spinning device, viscosity of solution, spinning time, annealing temperature and rate of evaporation. Research have been always done with the parameters speed, time and solutions viscosity. In this rate of evaporation is also another important factor for thin film coating. If the speed of motor and viscosity of solution is in good condition but rate of evaporation decreased which gives rough surface and increase in film thickness

Hence to increase the rate of evaporation, the annealing process is also combined with spin coater with heating unit. This drier can make the solar antireflective thin film without intervening of time. The humidity presents in the drum is also removed by the vacuum pump. The surface morphology of ZnO thin film coating on silicon cell is investigated by EDS. The fig 6. Shows the FESEM image of ZnO thin film coating in modified spin coater device.

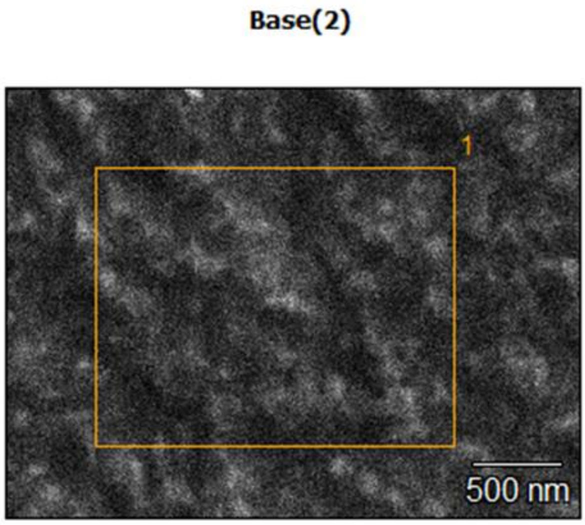

Figure 6: FESEM image of ZnO thin film coating in modified spin coater device

In this modified coating experiment conducted the spinning process is start at the speed of 15rpm while we drop the 4 µl of Zno solution on the cell. After the motor speed is increases to 2000 rpm at the spinning time as 45 secs. Then the Substrate kept in oven for 10 mins at 300 deg Celsius temperature. Highlight process of this modified spin coating process is substrate kept in the spin coater itself and with help heater unit 125k applied inside the device and the temperature is measured and displayed in LCD with help of thermocouple. And the humidity present inside the device also removed by vacuum pump at low rate pressure. Due to this modified process, surface of the layer is smooth and uniform. So the thickness is less and provide high conductivity.Figure 7. Gives the EDS analysis of crystalline growth when increasing the rate of evaporation and surface is very smooth.

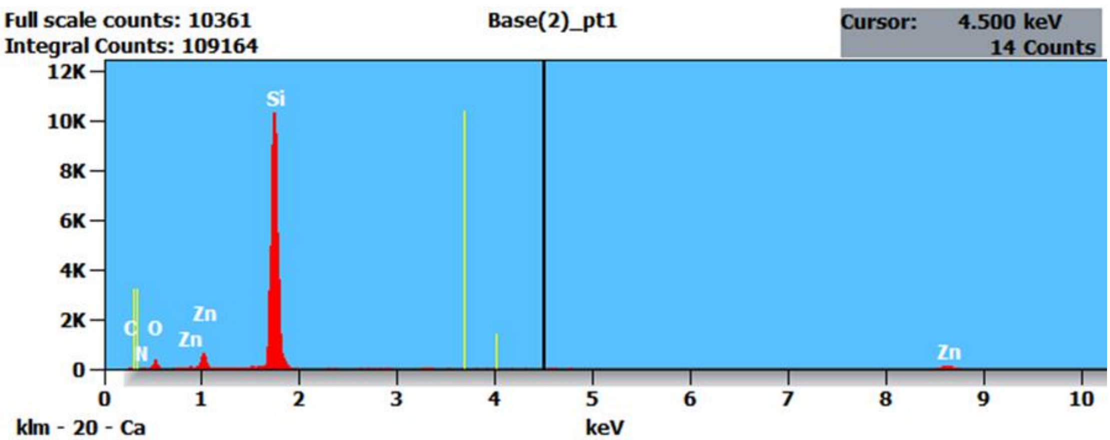

Figure 7: Modified EDS for ZnO in solar cell

Table 4: Performance analysis of modified spin coated cell.

Voc (v)	Isc (mA)	FF	Efficiency
0.47	18.7	0.62	5.2

In Table 3 shows that the performance analysis of modified spin coating device.The ZnO is coated on the silicon cell with modified spin coater. In this annealing process is combined with spin coater device to increase the rate of evaporation of thin film coating. The voltage of this cell is increased 0.8v than existing cell.

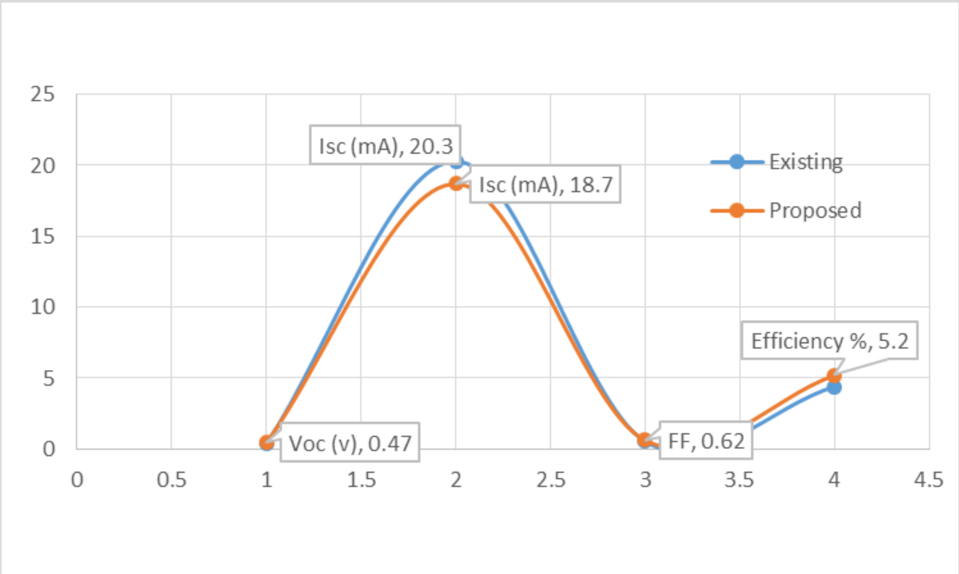

Figure 8: Comparison of existing with proposed method

In the above 8 figure mentioned the comparison of proposed method with existing techniques. In this comparison, proposed modified spin coated cell reached the efficiency of 5.2%. But the normal spin coating cell reached the efficiency of 4.4%. in proposed model achieved greater efficiency of 0.8v when compared with existing device efficiency.

7 CONCLUSION

In this study, ZnO solution is deposited on the substrate, then the annealing process is given to the substrate which is coated. The humidity and gases present inside the device is removed by vacuum pump. Hence this process increases the rate of evaporation of the thin film. ARM Processor LPC 11U24 and L293 is used to control the spinning speed. EDS and FESEM analysis shows the presence of ZnO on the substrate and crystalline growth respectively. By this results analysis, the rate of evaporation of the solvent is also main parameter in thin film coating which decreases the thickness of the film. The transparency of the coating also increased in annealing process and the layer of the thin film is very smooth and uniform.SEM analysis of results shows, when the crystalline growth at that time rate of evaporation is increasing and formed the very smooth surface. This fabrication of modified spin coater is low in cost, compact and easy to use. The efficiency comparison of existing with modified spin coated cell efficiency is greater than 0.8v In this experimental study conclude to recommend that the proposed model is applied to real time application of spin coating for solar cells.

Declaration

I / We declare that "it is not been submitted anywhere before as well as not been published in other journals". It does not comprise that is outrageous, indecent, deception, stealing, defamatory, or else opposing to rules. I/we pursued the Journal's accepted "Publication ethics and malpractice" declaration provided in website of journal in concern part and responsible for the rightness (or copying) and article genuineness.

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Conflicts of Interest

- Not Applicable

Availability of data and Materials

- Data and coding will be shared whenever it is required for the review.

Authors Contributions

- Both the authors are equally contributed their skills and effort to produce this article.

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