INFLUENCE OF OPTICAL PROPERTIES OF ZNO THIN-FILMS DEPOSITED BY SPRAY PYROLYSIS AND RF MAGNETRON SPUTTERING ON THE OUTPUT PERFORMANCE OF SILICON SOLAR CELL*

BRIJESH TRIPATHI†
School of Solar Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat 382007, India

MALKESH PATEL, ABHIJIT RAY, MANOJ KUMAR
School of Solar Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat 382007, India

ZnO thin-films were deposited by spray pyrolysis and RF magnetron sputtering techniques. The optical reflection of these thin-films is measured using UV-Vis spectrophotometer. The measured optical reflection data is used in PC-1D simulation software to study the output performance of commercial silicon wafer-based solar cell. As far as optical performance is concerned it could be demonstrated that the sprayed ZnO thin-film under laboratory conditions show equivalent performance compared to sputtered ZnO thin-film. The influence of optical properties of 65 nm thick zinc oxide thin-films deposited by vacuum and non-vacuum techniques on quantum efficiency and IV characteristics of commercial silicon-wafer based solar cell is studied and reported here.

1 Introduction
Among II-VI wide band gap semiconductor materials, Zinc oxide (ZnO), as a functional oxide semiconductor material, has been studied in recent years due to its immense applied potential in short wavelength optoelectronic devices and laser diodes [1]. Furthermore, with a wide band gap, high transparency and low resistivity, it can also be used as a window layer and heterojunction partner for heterojunction solar cells [2]. Because of suitable opto-electronic properties and thermal and chemical stability [3], ZnO is used in several devices, such as transparent conductive contacts, photovoltaic cell, varistor, laser diode, UV lasers, thin-film transistors, etc. There are several methods of deposition of ZnO thin-film reported in literature, e.g., molecular beam epitaxy (MBE) [4], chemical vapor deposition [5], metal organic chemical vapor deposition (MOCVD) [6], ion beam deposition [7], atomic layer deposition (ALD) [8], pulsed laser deposition (PLD) [9], RF & DC sputtering [10] and spray pyrolysis [11]. In this article, we present the comparative study of sputtered and sprayed ZnO thin-films for possible application as

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UV absorber layer to reduce thermalization induced heating [12, 13] in crystalline Si solar cells for their likely use under concentrated light (< 100 Sun).

2 Experimental

ZnO thin-films of 65 nm average thickness, as measured by surface profilometer DEKTAK 150 of Veeco, were prepared by spray pyrolysis and RF magnetron sputtering technique on glass substrates. The deposition parameters are summarized in Table 1.

| Spray Pyrolysis | RF magnetron sputtering |
|-----------------|-------------------------|
| Concentration of the zinc acetate solution: 0.1 M | RF Power: 60 Watts |
| Solution flow rate: 1 ml/min | Sputter deposition rate: 2.6 nm/min |
| Air pressure: 3.8 kg/cm² | Base pressure: 0.026 mbar |
| Spray duration: 5 min | Reflected power: 0 Watts |
| Substrate temperature: 400 ± 10°C | Substrate temperature: Room temperature |

The optical reflection of sprayed ZnO thin-film could be calculated by measuring transmission and absorption spectra by UV1 spectrophotometer of Thermo Scientific available at author’s institution. The optical reflection of sputtered ZnO thin-film could be directly measured by LAMBDATM 750 of Perkin Elmer at CEN, IIT Bombay. The optical reflection spectra of these ZnO thin-films are shown in Fig. 1.

3 Simulation

The reflection data of the ZnO thin-films is used in PC-1D, the photovoltaic simulation software [14], to show the performance improvement of commercial silicon solar cell. The modeling parameters for PC-1D simulation are listed in Table 2.
Table 2. PC-1D simulation parameters

| Solar Cell Parameters | Values   | Solar Cell Parameters | Values         |
|-----------------------|---------|-----------------------|----------------|
| Area                  | 156.25 cm² | Emitter doping, N-type| 2.87 x 10²⁰ cm⁻³ |
| Thickness             | 300 μm  | Base doping, P-type   | 1.5 x 10¹⁶ cm⁻³ |
| Front surface texture depth | 3 μm    | Bulk recombination lifetime | 7.2 μs          |
| Emitter contact resistance | 10⁷ Ω | Surface recombination velocity | Sₑ = 10⁶ cm/s; Sₛ = 10⁶ cm/s |
| Base contact resistance | 0.015 Ω | Primary light source Intensity | 0.1 W/cm²      |
| Spectrum              | AM 1.5  |                        |                |

4 Results and Discussion

Using above mentioned parameters PC-1D simulation is done. External quantum efficiency (EQE) of a solar photovoltaic cell is an important parameter to understand the effect of front surface reflection. Lower is the reflection from the front surface higher is the EQE. The commercial crystalline silicon solar cell technology uses silicon nitride thin-film as anti-reflection coating (ARC) to reduce the front surface reflectance [15]. The ZnO thin-films are studied as a potential ARC candidate keeping other advantages of ZnO in to consideration such as its conductivity, thermal and chemical stability. These ZnO thin-films might be used as ARC under concentrated light (<100 Sun). The light trapping properties of ZnO thin-films deposited by both the techniques could be compared with that of silicon nitride thin-films (data from Kumar et al. [15]) via external quantum efficiency plot as shown in Fig. 2. It could be observed that the sprayed ZnO thin-films reduce the absorption of UV radiation in solar photovoltaic cell, which might potentially reduce heating of the cells due to thermalization.

Further, the output electrical parameters of the solar cell were studied. The comparison of current-voltage (I-V) characteristics of these cells shows that the ZnO thin-films deposited by RF magnetron sputtering and spray pyrolysis show comparable performance. The current-voltage characteristic curves of crystalline silicon solar photovoltaic cell with sputtered ZnO thin-film, sprayed ZnO thin-film and silicon nitride thin-film as ARC layer are shown in Fig. 3. Output performance of the above defined solar cell with all three kinds of ARC layers is listed in Table 3. It could be observed that the output parameters such as V₉₀, I₉₀ and FF are comparable due to similar optical performance of sputtered and sprayed ZnO thin-films.
Figure 2. The external quantum efficiency of crystalline silicon solar cell with three different ARCs to reduce front surface reflectance.

Figure 3. The current-voltage (I-V) characteristics of crystalline silicon solar photovoltaic cell using various ARC layers (sputtered ZnO, sprayed ZnO and silicon nitride thin-films).

Table 3. Output performance of crystalline silicon solar cell with three different ARC coatings

| Output performance parameters | ARC for wafer based solar cell |
|------------------------------|-----------------------------|
|                              | Sprayed ZnO | Sputtered ZnO | PECVD SiN |
| Voc (V)                      | 0.6206       | 0.6205        | 0.6202    |
| Isc (A)                      | 5.095        | 5.070         | 4.999     |
| Pm (W)                       | 2.064        | 2.056         | 2.035     |
| Vm (V)                       | 0.466        | 0.465         | 0.462     |
| Im (A)                       | 4.425        | 4.418         | 4.397     |
| FF (%)                       | 65.27        | 65.36         | 65.62     |
| Efficiency (%)               | 13.21        | 13.16         | 13.02     |
5 Conclusion

A comparative study of sputtered and sprayed ZnO thin-films is presented here. It could be concluded that the optical performance of both of these thin-films is comparable. For some specific applications such concentrator photovoltaics the ZnO thin-films might play a better role as UV obstructer, so as to minimize thermalization in the solar photovoltaic cell. This might help in reducing the cell temperature for concentrator photovoltaic application.

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References

1. D. M. Bagnall, Y. F. Chen, Z. Zhu, T. Yao, S. Koyama, M. Y. Shen and T. Goto, Appl. Phys. Lett. 70, 2230 (1997).
2. Z. A. Shukri, L. S. Yip, C. X. Qiu, I. Shih and C. H. Champness, Sol. Energy Mater. Sol. Cells 37, 395 (1995).
3. C. Jin, H. Kim, H. Y. Ryu, H. W. Kim and C. Lee, J. Phys. Chem. C115, 8513 (2011).
4. H. J. Ko, Y. F. Chen, Z. Zhu, T. Yao, I. Kobayashi and H. Uchiki, Appl. Phys. Lett. 76, 1905 (2000).
5. A. P. Roth and D. F. Williams, J. Electrochem. Soc. 128, 2684 (1981).
6. W. I. Park and G. C. Yi, J. Electron. Mater. 30, 32 (2001).
7. J. M. Myung, W. H. Yoon, D. H. Lee, I. Yun, S. H. Bae and S. Y. Lee, Jpn. J. Appl. Phys. 41, 28 (2002).
8. Z. K. Tang, G. K. L. Wong, P. Yu, M. Kawasaki, A. Ohtomo, H. Koinuma and Y. Segawa, Appl. Phys. Lett. 72, 3270 (1998).
9. B. J. Jin, S. Im and S. Y. Lee, Thin Solid Films, 366, 107 (2000).
10. D. C. Look, B. Claflin, Y. I. Alivov, and S.J. Park, Phys. Stat. Sol. (a) 201, 2203 (2004).
11. S. E. Demian, J. Mater. Sci.: Materials in Electronics 5 360 (1994).
12. O. Breitenstein and J. P. Rakotoniaina, J. Appl. Phys. 97, 074905 (2005).
13. B. S. Richards, Sol. Energy Mater. Sol. Cells 90, 2329 (2006).
14. Donald A. Clugston, Paul A. Basore, “PC1D Version 5: 32-Bit Solar Cell Modeling on Personal Computers”, Presented at the 26th IEEE Photovoltaic Specialists Conf., October 1997.
15. B. Kumar, T. Baskara Pandian, E. Sreekiran and S. Narayanan, Proceedings of the 31st IEEE PVSC, Orlando, 1205 (2005).