Nanoscale Light-harvesting Scheme on Flexible CIGS Solar Cells Using Antireflective ZnO Nanorod Arrays

Y. H. Hsiao, L. K. Yeh, H. P. Wang, and J. H. He*

Institute of Photonics and Optoelectronics, and Department of Electrical Engineering, National Taiwan University, Taipei 106, Taiwan, ROC
*jhhe@ntu.edu.tw

In the last decade, thin-film solar cell technology has been a new research trend in photovoltaic industry due to its cost-effective manufacture process and the potential as a flexible photovoltaic module.[1-3] Among the various candidates for thin film absorber materials, Cu(In,Ga)Se_2 (CIGS) shows superior performance for its high optical absorption coefficient.[3] For example, Chirilă et al. have demonstrated a 18.7% efficiency for CIGS solar cell fabricated on flexible polymer films.[4]

In order to suppress the surface reflection and further enhance the cell performance, an antireflection (AR) coating is often applied on the solar cell. Nanostructured AR coatings show superior properties in many aspects compared to the conventional quarter-wavelength counterparts, including broadband working range, omnidirectionality, and polarization insensitivity.[5,6]

In this study, ZnO nanorod arrays (NRAs) were synthesized by a hydrothermal method on flexible CIGS solar cells as an AR coating. The aqueous solution method, owing to its low-temperature synthesis process and ability of large-area uniformity, is compatible with the existing manufacture process of the thin-film technology. Our results suggest that the ZnO nanorod arrays is not only an effective AR coating but also adaptable for flexible thin-film photovoltaic devices.

The reflection of the flexible CIGS solar cell with ZnO nanorod arrays is suppressed in a wide wavelength range (400nm~1100nm), as seen in Fig. 1. As a result of the antireflection property of the ZnO NRAs, a higher J_{sc} is obtained for the ZnO NRAs-coated CIGS solar cell, and the cell efficiency is boosted. The current density-voltage curves of the solar cells are shown in Fig. 2, and the photovoltaic characteristics are summarized in table 1. A bending test is carried out in order to examine the endurance of flexible CIGS solar cells with the nanorod array by bending 100~500 times with bending radius of ~5mm. The outcome is shown in Fig. 3, which indicates that the cell performance is maintained after the bending test. These results suggest that the as-fabricated ZnO nanorod array is a suitable AR coating for flexible photovoltaic applications.

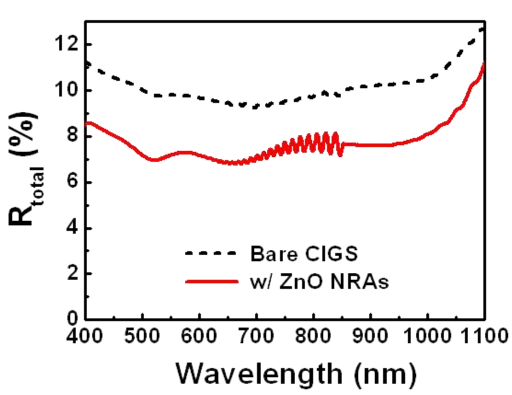

Figure 1 Total reflectance spectra. The measurement is carried out on a standard UV-visible spectrometer.

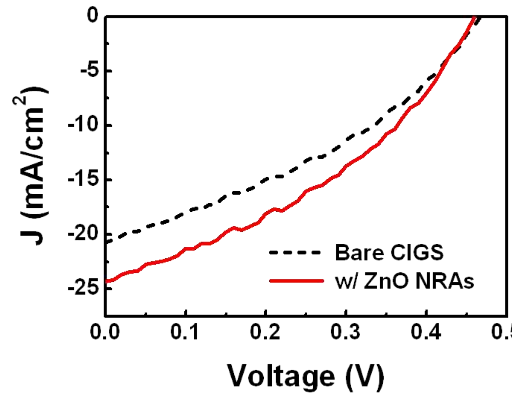

Figure 2 J-V characteristics measured on the bare and ZnO NRAs-coated CIGS solar cells.

Table 1 Photovoltaic characteristics of the CIGS cell with different surface condition

	J_{sc} (mA cm^{-2})	V_{oc} (V)	Fill Factor	η (%)
Bare CIGS	20.72	0.47	0.36	3.49
w/ ZnO NRAs	24.31	0.46	0.38	4.22

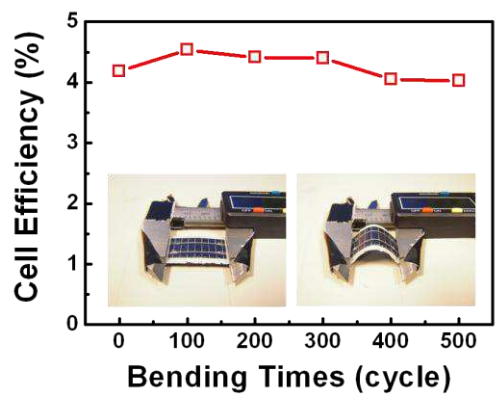

Figure 3 The efficiency of the as-fabricated ZnO NRAs-coated CIGS solar cell as a function of bending times. Insets show the release and bending states.

REFERENCES

[1] K. L. Chopra, P. D. Paulson, and V. Dutta, "Thin-Film Solar Cells: An Overview", Prog. Photovolt: Res. Appl., vol. 12, pp. 69–92, 2004.
[2] F. Kessler, D. Rudmann, "Technological Aspects of Flexible CIGS Solar Cells and Modules", Solar Energy, vol. 77, pp. 685-695, 2004
[3] M. Kaelin, D. Rudmann, A. N. Tiwari, "Low Cost Processing of CIGS Thin Film Solar Cells", Solar Energy, vol. 77, pp. 749-756, 2004
[4] A. Chirilă, S. Buecheler, F. Pianezzi, P. Bloesch, C. Gretener, A. R. Uhl, C. Fella, L. Kranz, J. Perrenoud, S. Seyrling, R. Verma, S. Nishiwaki, Y. E. Romanyuk, G. Bilger, A. N. Tiwari, "Highly Efficient Cu(In,Ga)Se_2 Solar Cells Grown on Flexible Polymer Films", Nature Materials, vol. 10, pp. 857–861, 2011
[5] L. K. Yeh, K. Y. Lai, G. J. Lin, P. H. Fu, H.-C. Chang, C. A. Lin, and J. H. He, "Giant Efficiency Enhancement of GaAs Solar Cells with Graded Antireflection Layers Based on Syringelike ZnO Nanorod Arrays", Adv. Energy Mater., vol. 1, pp. 506-510, 2011
[6] G. J. Lin, K. Y. Lai, C. A. Lin, Y.-L. Lai, and J. H. He, "Efficiency Enhancement of InGaN-Based Multiple Quantum Well Solar Cells Employing Antireflective ZnO Nanorod Arrays", IEEE Elec. Dev. Lett., vol. 32, NO. 8, pp. 1104-1106, 2011