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Low Cost Large Area Laser Beam Induced Current Measurement System for Characterisation of Photovoltaic Modules

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Abstract— Photovoltaic (PV) modules need to be free from current mismatch between cells for their optimal performance and longevity. Therefore, characterisation tools are essential for evaluation of the performance of individual cells in a PV module. In this study, a low cost, simple and handy large area laser beam induced current (LA-LBIC) measurement system was developed to assess the current levels of module cells. In this system, a laser source mounted onto a motorised scanning stage is used to illuminate a PV module, while measuring the module output current at different positions along the scanning line. The scan is executed across the module, perpendicular to the cells. The LBIC measurement is a non-destructive technique that produces a graphical representation of the photo-current with respect to position in a PV module. The line scan maps revealed the proportion of under-functioning cells to be 85.4% for single crystalline silicon (c-Si), 62.5% for multi-crystalline silicon (mc-Si) and 75% for amorphous silicon module (a-Si). Current variations (current mismatch) between the highest and the lowest performing cells were 99%, 97% and 90% for c-Si, mc-Si and a-Si respectively. Current variations within cells were 31%, 15% and 14% for c-Si, mc-Si and a-Si respectively. In all the different PV module technologies, variations in current between cells were significantly higher than within cells.

Index Terms— Low cost, Large Area-LBIC, photovoltaic modules, characterisation

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1. INTRODUCTION

Solar energy can be harnessed by use of photovoltaic (PV) modules. The PV market has continued to grow steadily over the past decades. Solar cells used to construct PV modules are required to have identical electrical characteristics so that current mismatch in modules is eliminated. When the current generating strength of individual cells in a module differ, it is the weakest cell that determines the overall module current [1]. For optimal performance and longevity of PV modules, homogeneity of the device is a crucial factor to consider. The solar cells in a module may differ in their electrical properties due to the presence of defects arising from the inclusion of impurities during the manufacturing process, cracks during soldering [2], [3], [4], [5], cracks during the cutting of ingots or cracks during transportation or in the field [6]. In thin film modules, the laser scribing process used to isolate and interconnect thin film module cells can cause inhomogeneity in the module [7], [8]. The deposition of the film material over a large area makes it difficult to guarantee uniformity of the film thickness in thin film solar cells, and this leads to performance variation in thin film modules. The effects of the absorber layer thickness on performance of solar cells have been extensively reported [9], [10], [11].

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The ordinary method (current-voltage characterisation) of measuring the optimum power of PV modules is expensive and lacking in a country like Uganda, yet the import of PV modules has increased greatly over the years. The weakness of this method is that it measures the performance of the integral module but not the performance of individual cells, yet the performance of the module is adversely affected if all its cells are not properly matched. A low cost, simple and handy LA-LBIC measurement system has been developed to evaluate the quality of the modules in the Ugandan market, in terms of cell current matching. However, since the module cells are connected in series and current mismatch arising from the cells in the dark is likely, only relative measurements are possible.

2. METHODOLOGY

In this section, the fabrication process for the LA-LBIC measurement system is described. The application of the LA-LBIC measurement system to scan PV modules is also illustrated.

2.1 Fabrication of the LA-LBIC measurement system

The major components of the LA-LBIC measurement system are the scanning stage, on which the scanning light source is mounted and the string tension adjusting system, used to loosen or tighten the string that drives the scanning stage.

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2.1.1 The scanning stage

In the fabrication of the scanning stage, the materials used included 20 cm length of 16 mm x 16 mm metal hollow section, eight rollers, 4 inch bolt and a screw bolt. Four slots were made on each side, near the ends of the hollow section. In each of the slots a roller was fitted in such a way that a small arc enters inside and just touches the 12 mm x 12 mm hollow section running straight through the 16 mm x 16 mm hollow section. Two rollers were fixed on each of the four sides of the rectangular hollow section so that there is no play during the motion of the rollers. Fig. 1 shows how the rollers are fitted on opposite sides of the hollow section and Fig. 2 shows the photograph of the scanning stage.

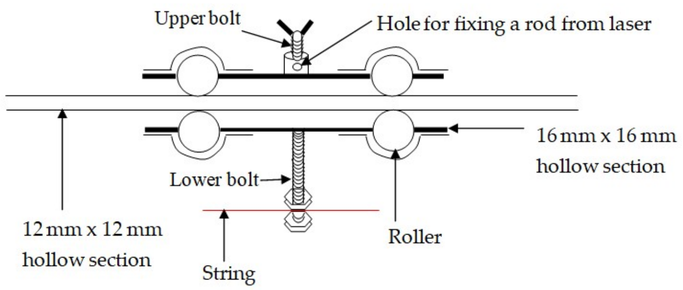

Fig. 1. Schematic of the scanning stage

2.1.2 The string tension adjusting system

This system is made up of a pulley that can be adjusted by using a bolt as shown in Fig. 3. A string passes over the pulley and by loosening or tightening the bolt, the position of the pulley can be changed and consequently changing the tension in the string.

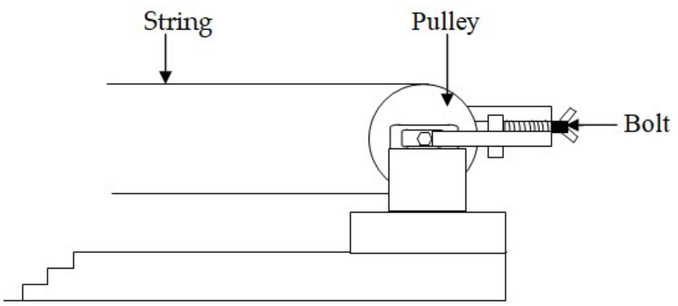

Fig. 2. Schematic diagram of the string tension adjusting system

2.1.2 The LA-LBIC measurement system

Another pulley, driven by a slow moving motor (Type 49TYJ-5/500C, AC 220/240V and 5/6 RPM, 3W) is fixed on a stand and aligned with the pulley on the string tension adjusting system as shown in Fig. 4. The string is fixed on the scanning stage and passed over the two pulleys. As the motor rotates, the rotary motion is transmitted to the string, causing a linear movement of the scanning stage. This makes the laser diode, mounted on the stage, moves at the speed of the motor.

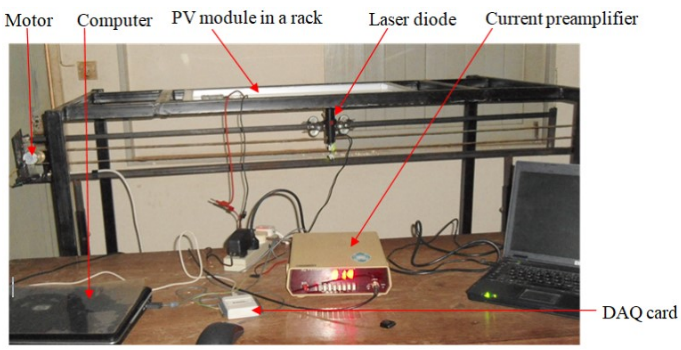

Fig. 3. LA-LBIC measurement system

2.2 Scanning PV modules using the LA-LBIC measurement system

The developed LA-LBIC system and the PV module rack containing the module was set up in a dark room as shown in Fig. 5. The output of the PV module was connected to the Data Acquisition (DAQ) card through the current amplifier. The laser beam of spot diameter 1.5 mm was used to scan the PV module as shown in Fig. 5. During the line scanning process, the laser diode was set in motion by switching on the motor. Line scans were executed across the module, perpendicular to the cells. All the cells in the module were scanned and the line scan map obtained.

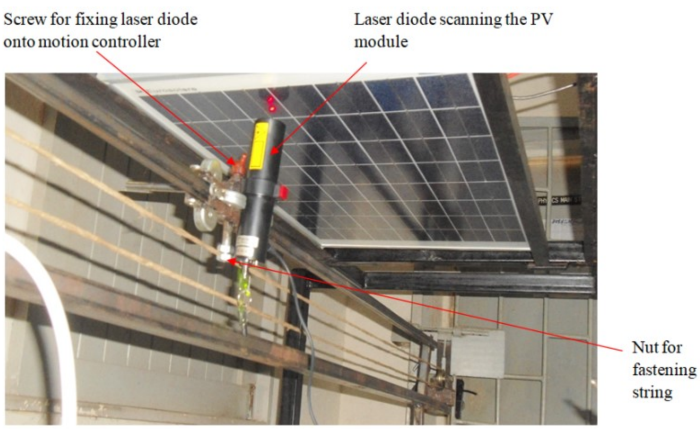

Fig. 4. Line scanning of a PV module

PV modules from three different technologies, namely, monocrystalline silicon (c-Si), multi-crystalline silicon (mc-Si) and amorphous silicon (a-Si) were scanned using the developed LA-LBIC system. The c-Si module consists of 48 cells, the mc-Si module consists of 56 cells and the a-Si module consists of 20 cells. The photograph of the modules is shown in Fig. 6.

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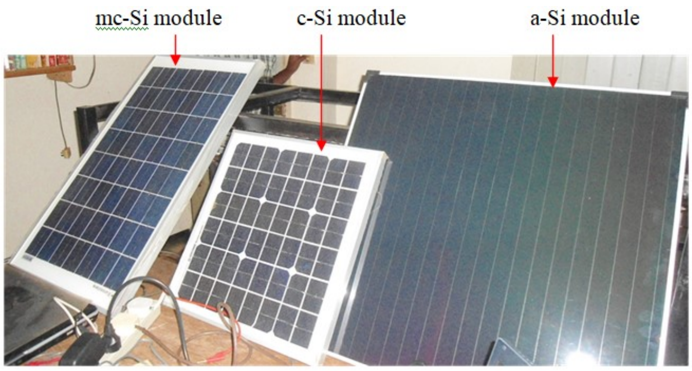

Fig. 5. Photograph of PV modules investigated

3. RESULTS

For easy comparison, all the current values for each cell in each module were expressed in terms of the current generated by the best performing cell. This gives the relative signal strength for each cell in the module. The line scans for c-Si, mc-Si and a-Si module are shown in Fig. 6, 7 and 8 respectively.

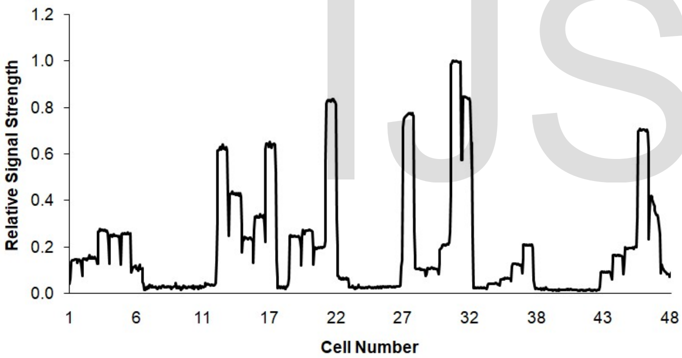

Fig. 6. LA-LBIC line scan signal for c-Si PV module

The value of 50% of the maximum signal strength was arbitrarily taken as a reference point for the determination of the proportion of under functioning cells in the PV modules. The formula below was used to determine the percentage of under functioning cells (U_F)

$$U_F = \frac{N_B}{N_T} \times 100\%$$

where: N_B = Number of cells with signal strength below 50%

N_T = Total number of cells in the module

The percentage of under functioning cells for c-Si PV module,

$$U_F(sc) = \frac{41}{48} \times 100\% = 85.4\%$$

The percentage of under functioning cells for mc-Si PV module,

$$U_F(mc) = \frac{35}{56} \times 100\% = 62.5\%$$

The percentage of under functioning cells for a-Si PV module,

$$U_F(as) = \frac{15}{20} \times 100\% = 75\%$$

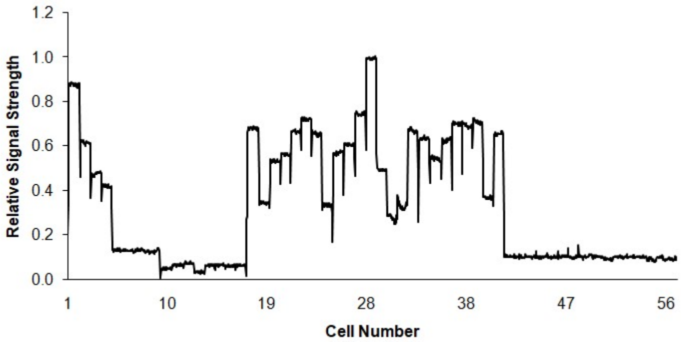

Fig. 7. LA-LBIC line scan signal for mc-Si PV module

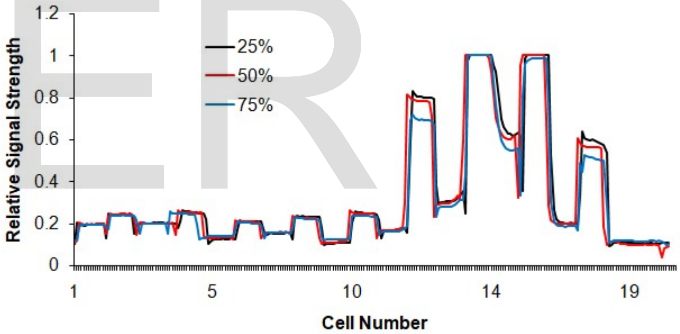

Fig. 8. LA-LBIC line scan signal for a-Si PV module

The c-Si PV module has the highest percentage of under-functioning cells, with a variation in signal strength (current mismatch) of 99% between the worst performing and best performing cell. Current mismatch in mc-Si and a-Si modules are 97% and 90% respectively. Current mismatch between cells in crystalline silicon modules may be attributed to lack of cell sorting during module manufacturing process. However, it is possible that, even when identical cells are used to construct a module, the current levels of the module cells may still vary. This is because, during the stringing of cells in the manufacture of crystalline silicon PV modules, the heat generated during soldering may cause the cells to crack [2], [4], disconnecting the fingers of the affected cells and leading to a reduced photo-response. A weak cell in a module operates in a reverse biased mode, in respect to the rest of the cells in a module and acts as a power dissipater instead of a power generator [12]. In

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addition to lowering the module performance, electrically mismatched cells in a PV module may lead to hot spots [13], hence reducing the lifespan of the module. In the crystalline silicon modules line scans, it is worth noting that the current levels within cells also vary, notably in cell 47 for c-Si module and cell 31 for mc-Si module and the variations are by 31% and 15% respectively. These variations could be due to non-uniform distribution of defects within the cell or from cracks developed during the soldering process. Defects, like grain boundaries in mc-Si, can significantly reduce the material quality by reducing the diffusion length of minority charge carriers [14].

In the a-Si PV module, line scans were performed at 25%, 50% and 75% of the module length, as thin film PV module cells are comparatively longer than the crystalline counterparts. This was done in order to probe homogeneity in current within the same cell. Thin film modules, like a-Si module, are made by deposition of the PV material over a large area and the thickness of the deposited layer is likely to vary. It can be seen in Fig. 8 that variation in current occurs both between and within cells. Variation in current between cells is more pronounced than that within cells. Variation in current between cells may arise from shunts introduced during laser scribing process of cell isolation and interconnection [15]. Variation in current within cells, prominent in cells 12, 15 and 18, is attributed to variation in thickness of the deposited PV material during the manufacturing process. The highest variation in current within cell, of 14%, occurs in cell 12.

5. CONCLUSIONS

A low cost, simple and handy large area laser beam induced current (LA-LBIC) measurement system has been developed, to investigate cell matching in PV modules in the Ugandan market. The system can probe homogeneity in current both between and within cells of a PV module. Three different module technologies namely, c-Si, mc-Si and a-Si were investigated. Higher variations in current occurred between cells than within cells, for all the PV module technologies. Variation in current between cells was highest in c-Si module (99%) and lowest in a-Si module (90%). Variation in current within cells was highest in highest in c-Si module (31%) and lowest in a-Si module (14%). The c-Si module was found to contain the highest percentage of under-functioning cells while the mc-Si module showed the lowest percentage.

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REFERENCES

[1] P. Vorasayan, T.R. Betts, R. Gottschalg, "Limited laser beam induced current measurement: a tool for analysing integrated photovoltaic modules", *Measurement Science and Technology*, 22, pp. 1-7, 2011.(Journal)

[2] J. Wendt, M. Trager, M. Mette, A. Pfennig, B. Jackel, "The link between mechanical stress induced by soldering and micro damages in silicon solar cells", in: *European Photovoltaic Solar Energy Conference, Hamburg, Germany*, pp. 3420-3423, 2009.(Conference proceedings)

[3] M. Abdelhamid, R. Singh, M. Omar, "Review of microcrack detection technique for silicon solar cells", *IEEE Journal of Photovoltaics*, 4 pp. 514-524, 2014. (Journal)

[4] K. Lin, Y. Lee, W. Huang, G. Chen, Y. Kuo, L. Wang, S. Yang, "Detection of soldering induced damages on crystalline silicon solar modules fabricated by hot-air soldering method", *Renewable Energy*, 83, pp. 749-758, 2015. (Journal)

[5] A.M. Gabor, R. Jonoch, A. Anselmo, H. Field, "Solar panel design factors to reduce the impact of cracked cells and tendency for crack propagation", in: *NREL PV Module Reliability Workshop, Denver, U.S.A*, pp. 1-11, 2015.(Workshop proceedings)

[6] J. Barredo, L. Hermanns, A. Fraile, J.C. Jimeno, E. Alarcon, "Study of the edge and surface crack influence in the mechanical strength of silicon wafers", *in: European Photovoltaic Solar Energy Conference, Hamburg, Germany*, pp. 2116-2119, 2009. (Conference proceedings)

[7] A.D. Compaan, I. Matulionis, S. Nakade, "Laser scribing of polycrystalline thin films", *Optics and Lasers in Engineering*, 34, pp. 15-45, 2000.(Journal)

[8] J.J. García-Ballesteros, S. Lauzurica, C. Molpeceres, I. Torres, D. Canteli, J.J. Gandía, "Electrical losses induced by laser scribing during monolithic interconnection of devices based on a-Si:H", *Physics Procedia*, 5, Part A, pp. 293-300, 2010.(Journal)

[9] H.Y. Zhang, W.G. Wang, H. Liu, R. Wang, Y.M. Chen, Z.W. Wang, "Effects of TiO_2 film thickness on photovoltaic properties of dye-sensitized solar cell and its enhanced performance by graphene combination", *Materials Research Bulletin*, 49 (2014) 126-131. (Journal)

[10] L.Li, D.E. Zhao, D.S. Jiang, Z.S. Liu, P. Chen, L.L. Wu, L.C. Le, H. Wang, H. Yang, "The effects of InGaN layer thickness on the performance of InGaN/p-i-n solar cells", *Chinese Physics B*, 22, pp. 1-4, 2013. (Journal)

[11] E.Q.B. Macabebe, C.J. Sheppard, E.E. van Dyk, "Device and performance parameters of Cu(In,Ga)(Se,S)2-based solar cells with varying i-ZnO layer thickness", *Physica B: Condensed Matter*, 404, pp. 4466-4469, 2009.(Journal)

[12] J.L. Crozier, E.E. van Dyk, F.J. Vorster, "Characterization of cell mismatch in a multi-crystalline silicon photovoltaic module", *Physica B: Condensed Matter*, 407, pp. 1578-1581, 2012. (Journal)

[13] W. Herrmann, W. Wiesner, W. Vaassen, "Hot spot investigations on PV modules-new concepts for a test standard and consequences for module design with respect to bypass diodes, *in: Conference Record of the Twenty Sixth IEEE Photovoltaic Specialists Conference* - 1997, 1997, pp. 1129-1132."(Conference proceedings)

[14] D. Kohler, A. Zuschlag, G. Hahn, "On the origin and formation of large defect clusters in multicrystalline silicon solar cells," *Solar Energy Materials and Solar Cells*, 120, pp. 275-281, 2014.(Journal)

[15] A. Wehrmann, S. Puttnins, L. Hartmann, M. Ehrhardt, P. Lorenz, K.

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ISSN 2229-5518

Zimmer, "Analysis of laser scribes at CIGS thin-film solar cells by localized electrical and optical measurements," *Optics & Laser Technology*, 44,pp. 1753-1757, 2012. (Journal)

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