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A review of interconnection technologies for improved crystalline silicon solar cell photovoltaic module assembly

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HIGHLIGHTS

- Current interconnection technologies of crystalline Si solar cells are evaluated.
- Technology inducing least stress while supporting PV manufacturing trend is optimal.
- Laser soldering is identified as most efficient PV cell interconnection technology.
- Laser soldering is poised for use to extend MTTF of modules operating in tropics.

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ABSTRACT

The identification, adoption and utilisation of reliable interconnection technology to assembly crystalline silicon solar cells in photovoltaic (PV) module are critical to ensure that the device performs continually up to 20 years of its design life span. With report that 40.7% of this type of PV module fails at interconnection coupled with recent reports of increase in such failure in the tropics, the review of interconnection technologies employed in crystalline silicon solar cells manufacture has become imperative. Such review is capable of providing information that can improve the reliability of the system when adopted which in turn will increase silicon PV module production share more than the current value of 90.956%. This review presents the characteristics of interconnect contacts in conventional cells and other unconventional crystalline silicon cells. It compares series resistance, shadowing losses and the induced thermo-mechanical stress in the interconnection for each interconnection technique employed. The paper also reviews interconnection technologies in these assemblies and presents a comparison of their concept, cell type, joint type, manufacturing techniques and production status. Moreover, the study reviews and discusses the material and technological reliability challenges of silicon solar cells interconnection. The review identifies laser soldering technology as one which has the potential of making interconnection with higher reliability when compared with conventional soldering technology. It was found that this technology supports the current design trend of thinner, wider and cheaper crystalline silicon solar cells significantly whilst producing interconnection that experience relatively lower induced thermo-mechanical stress. The authors recommend that wider acceptance and usage of laser soldering technology could improve the performance and consequently extend the mean-time-to-failure (MTTF) of photovoltaic modules in general and particularly the ones which operates in the tropics. This will enable improvement in the reliability of PV modules for sustainable energy generation.

Contents

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1. Introduction

Photovoltaic (PV) modules constitute significant development in the worldwide green energy sector in the current campaign to increase sustainable energy production. Currently, the module is in huge demand because they are now used to supply electrical power [1,2] to many applications. To meet the demand, the production of solar cells has increased because the modules are assembled by interconnecting solar cells to each other. It is expected that in the year 2020, the world annual production of solar cells will be around 100 GW_p (W_p, is peak power produced under standard test conditions). While this amount of sustainable power production seems substantial, the continued operation of the module up to its design service life has become a concern because the desired power generation is lower than expected.

The silicon solar cells have been identified as the most viable option suitable for large volume production [3]. However, it has been reported that the continual generation of electricity by PV modules, manufactured using this type of cell, in the field for a minimum life span of 20 years has been a concern [1,4–6]. One of the key challenges is untimely failure of solar cells interconnection in the modules [7]. The interconnections provide electrical, mechanical and thermal contact between the solar semiconductor cell and electrodes.

The failure of the interconnection is caused by degradation of solder joints during module's field operations due to temperature cycling. Extreme degradation often culminates in module failure. The existence of this phenomenon and the need to provide solution has been reported in [1,6,8–10]. The analysis of the failure mechanisms of PV modules in the field demonstrates that the modules fail by many different modes. McCluskey [7] and Campeau, et al. [11] have reported that according to a BP study, 40.7% of PV module failures observed were due to cell or interconnect breakage. This finding, in addition to other similar findings, has identified the reliability of PV interconnections as the current challenge in PV modules manufacture.

Consequently, the interconnection technologies of silicon PV modules were selected for review. Silicon PV modules were chosen because the production of silicon-based solar cells was 90% of all solar cells produced globally in 2008 [3]. This production share may have been achieved because Silicon, being the second most abundantly available element on earth [12], has been used as the primary feedstock. For instance, this largest share of production was more than 90.956% of global PV module production in 2013 [13] and this share of production is expected to remain for a long time. This paper explores and characterises silicon solar cell interconnection technologies used in the various crystalline silicon solar cell manufactures.

The objectives of this study are to present an overview of crystalline silicon PV modules while dwelling on the characterisation of the solar cell contact and interconnection technologies. The work advances to seek to review the current reliability challenges of the interconnection of the solar cells with regards to interconnection technique. In addition, the paper reviews research trends in solar cell interconnection and assembly technologies – focusing on the identification of suitable technology to meet long-term reliability demand of PV modules for energy generation.

2. Crystalline silicon solar cells interconnection technologies

The contact and interconnection technology of conventional wafer-based silicon solar cells are discussed in Section 2.1 while challenges of conventional interconnection technology are presented in Section 2.2. A comparison of conventional and unconventional interconnection technologies is discussed in Section 2.3.

2.1. Interconnection technology of conventional crystalline silicon solar cells

The assembly and manufacturing process of conventional solar cells involves converting silicon wafers into solar cells through depositing layers of emitter material and anti-reflection coating (ARC). This process is followed by printing front metal electrode and back contacts on the cell material as well as soldering of highly conductive solder-coated ribbon strip along the length of the cell. An extended part of the ribbon strip is soldered to the back of a neighbouring cell to enable current transfer from the front of one cell to the back of a neighbouring cell in a series connection [5]. The use of low resistant electrode and finer lines for a larger aperture in the manufacture enables the delivery of higher short circuit current (I_{sc}) and fill factor to the ribbon strip [14]. The interconnection of solar cells in crystalline silicon modules by soldering process is a high temperature process which occurs at about 250 °C. The elevated temperature soldering induces thermo-mechanical stress in the solder joints.

Metallization technologies in use for solar cells contact formation include: screen printing, stencil-printing, pad-printing, ink-jet printing, dispensing technology, photolithographic and evaporation process, laser micro-sintering, plating (Nickel) and

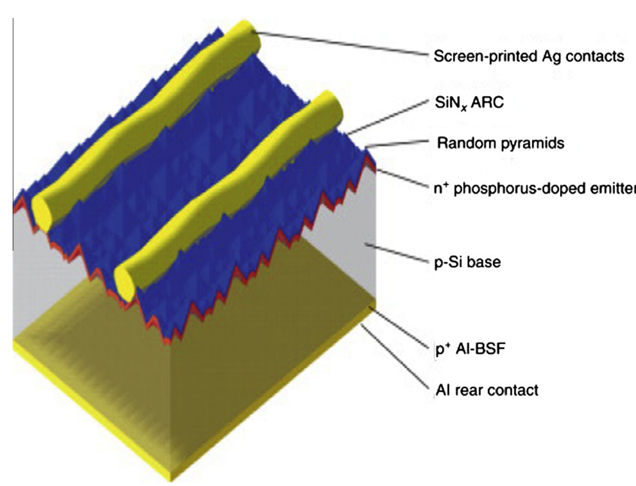

Fig. 1. Typical structure of Al-BSF solar cell [16].