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Strain effect on the performance of amorphous silicon and perovskite solar cells

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ABSTRACT

Clean, plentiful, and easy-to-harvest solar energy is the ultimate renewable energy. It is becoming more important as the world begins to take notice of the burgeoning carbon emission problems that come with burning fossil fuels. Thin-film solar cells have been increasingly used for energy harvesting. This paper studies the effect of mechanical deformation on the performances of amorphous silicon (a-Si) and perovskite solar cells. Compression and tension tests were conducted on a-Si solar cells bonded to Fiber-Reinforced Polymer (FRP) plates. Tension tests were also carried out on perovskite solar cells deposited on glass substrate. A projector was used to illuminate the cells during the mechanical tests to simulate 100% sun. J-V characteristic curves were measured at different strain levels until failure of the samples. The experimental results suggest the presence of strain thresholds for a-Si solar cells under both compression and tension loading conditions, below which the a-Si solar cells work properly while the performance degrades rapidly once the strain goes beyond the strain thresholds. Perovskite solar cells are more ductile with a maximum tensile strain of 3%, and they show negligible degradation of performance before the fracture of glass substrate.

1. Introduction

The solar power industry has gained global interest in the last few decades. Being one of the renewable sources of energy, solar energy is becoming a primary source of energy considering limited resources for fossil fuel. As a result, solar cells have been increasingly used in different applications, including space stations, solar cars, military camps, buildings, and solar farms.

Nowadays, silicon-based solar cells are the most widely used solar cells that are commercially available. However, their relatively high cost is an obstacle for the solar industry to become a dominant source of energy. Current research is focused on reducing the cost by using relatively cheap materials such as organic and inorganic-organic (hybrid) solar cells, e.g., perovskite solar cells. Recently, perovskite solar cells have achieved an efficiency of about 22%, compared to around 14% for a-Si solar cells (NREL, 2017).

Ongoing research at Iowa State University is focused on integrating the solar cells with civil structures, which can reduce the installation cost due to the elimination of the mounting structures and provide an aesthetic view. In order for the solar cells to work properly when attached to supporting structures, the effect of mechanical loading (or strain effect) on the solar efficiency needs to be evaluated, as the supporting structures are frequently subjected to different strain states externally or internally.

The research on the strain dependency of solar cells' performance could date back when large-area electronics (LAE) were introduced. LAE can be solar cells, displays, X-ray sensors that are flexible and nonbreakable. Early research studied the performance of LAE when subjected to bending strains. The objective was to develop LAE that were flexible enough to be mounted on roofs, tents, and wrapped around the fingertip [Gleskova and Wagner (1999), Suo et al. (1999), Theiss and Wagner (1996), Utsunomiya and Yoshida (1989)]. It was concluded that amorphous silicon (a-Si) solar cells could achieve high flexibility and performed well under bending. Other solar cells were also developed to provide flexibility, such as Cadmium telluride (CdTe) and Copper indium gallium diselenide (CIGS). These solar cells are known as "thin-film solar cells" [Aberle (2009), Chopra et al. (2004)].

It was not until mid-2000's that a-Si solar cells could be manufactured for commercial use. Since then, several studies were focused on integrating solar cells as a part of the structural system. Among others, Keller et al. (2010) investigated the thermal and mechanical behavior of small-scale sandwich specimen with two types of silicon-

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Table 1
Material properties.

	Type	Tensile strength (MPa)	Tensile modulus (GPa)	Compressive strength (MPa)	Density (gm/cm^3)
Resin	404 Isophthalic resin	503.3	36.5	82.73	1.1
E-glass fiber	Chopped Strand Mat	2000	72.4	–	2.56

Table 2
Mechanical properties of solar module.

Solar module type	Thickness (mm)	Length (mm)	Width (mm)	Aperture size (mm)	Weight (g)
SP3-12	0.19	63.5	12.7	50.8 × 12.7	0.34

Table 3
Electrical properties of solar module.

Solar module type	Wattage (W)	Voltage (V)	Open-circuit voltage (V)	Current (mA)	Short-circuit current (mA)
SP3-12	0.0255	3.0	4.5	8.5	10.7

based solar cells, which were polycrystalline silicon cells and thin-film silicon solar cells deposited on low cost plastic foil substrates. They found that exposure to artificial sunlight increased the temperature of the solar cells to almost the glass transition temperature of the resin used for encapsulation. The results showed that polycrystalline solar cells encountered higher temperature than thin-film silicon solar cells. Bending tests were performed to simulate walking loads. They found that polycrystalline silicon experienced an early brittle failure. Pascual et al. (2014) encapsulated a-Si solar cells into Glass Fiber Reinforced Polymer (GFRP) using hand lay-up and vacuum method. Light transmittance and solar radiation were measured, and they observed that 83% of solar irradiance in the band of 300–800 nm reached the solar cell surface. Sugar et al. (2007) conducted tension tests on a-Si solar cells, measured their performances, and plotted the relationships between the Maximum Power Point (MPP) and Fill Factor (FF) against tensile strain. Additional cyclic loading tests were performed on the same type of solar cells. It was found that the MPP and FF decreased with the increase of the applied load (Sugar 2007). Maung et al., 2010 glued microcrystalline p-i-n thin-film solar cells to Carbon FRP (CFRP) and tested them under cyclic loading. A slight efficiency degradation of solar cells was recorded after 0.3% strain and a significant degradation was observed at the strain level of 1% when subjected to a cyclic loading for up to 100 cycles. Kim and Cheong (2014) performed a parametric study on the adhesive material that was used to bond monocrystalline silicon solar cells to composite plates, including ethylene vinyl acetate (EVA), resin, and elastic adhesion. They found that the elastic adhesion was suitable for maintaining the electrical performance of the solar module regardless of the loading. Fan et al. (2015) investigated the mechanical and electrical performances of organic photovoltaic (OPV) with two different substrates: Ethylene tetrafluoroethylene (ETFE) and Polyethylene terephthalate (PET). OPV is a multilayer photovoltaic composite which is known for fabrication easiness, low cost and flexibility to be integrated into structures. They found that adding Ag layer to the poly-3-hexyl thiophene (PEDOT) could maintain higher conductance than Ag layer. However, rapid drop

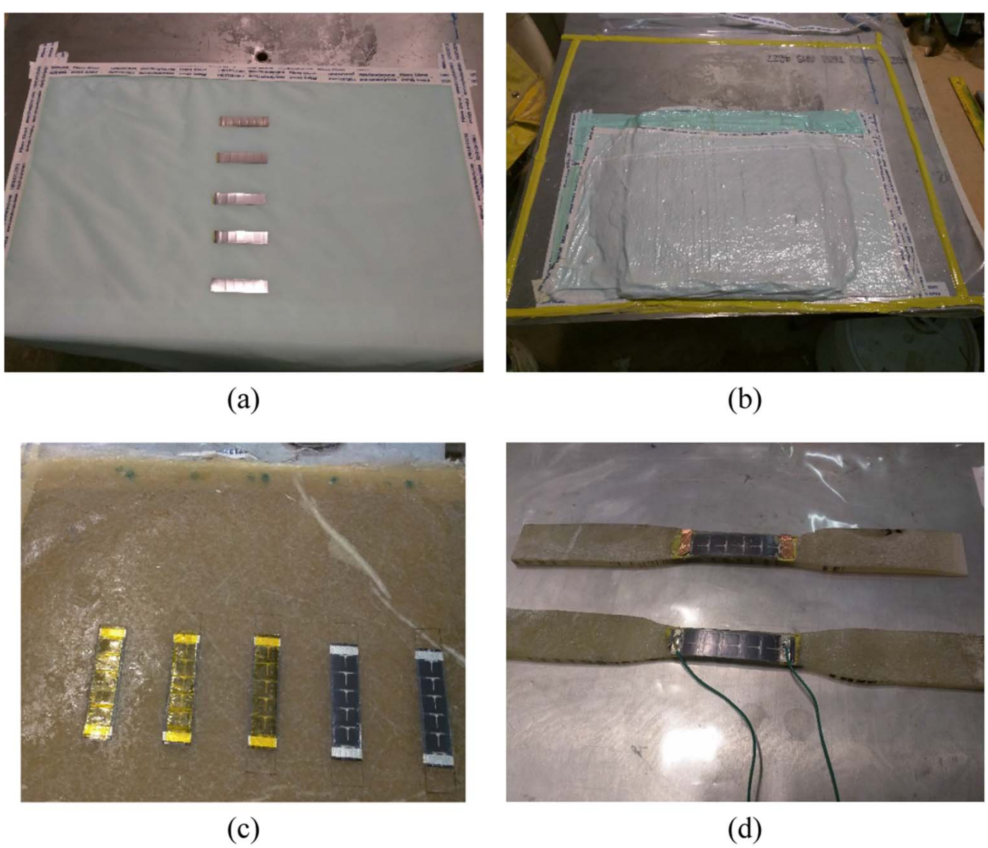

Fig. 1. Sample preparation process (a) solar modules attached to peel ply, (b) sealed bag during curing process, (c) solar module attached to FRP plate, (d) soldering wires to tension samples.