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ScienceDirect

Energy Procedia 92 (2016) 500 – 504

Energy Procedia

6th International Conference on Silicon Photovoltaics, SiliconPV 2016

The impact of ribbon properties on measured peel forces

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Abstract

The peel test of soldered/glued ribbons on solar cell metallizations is the critical test in the PV industry and research community to qualify the integrability of cells into modules. It has been shown that the peeling angle of the test setup strongly influences the measured peel forces [1,2], leading to higher forces for decreasing peeling angles < 90° and weakest forces for 135°. Here, we apply the theory of Kinloch and Kawashita [3,4] to determine the adhesive fracture energies G_A from 180° peel tests of three different ribbons which differ in compliance (softness) and thickness. The experiments show that the soft ribbon (σ_y = 62 MPa) gives lower peel forces than the stiff ribbons (σ_y = 99 MPa) while the adhesive fracture energies are higher. The thickness variation from 150 µm to 200 µm of the hard ribbon has no significant effect on the adhesive energy. Furthermore, our investigation confirms that switching from 90° peeling angles to 180° helps to reduce silicon fracture patterns at high forces. In conclusion, the adhesion does not only depend on the surface properties of cell metallization schemes and soldering conditions, but also on the choice of ribbon used for the peel test. We therefore recommend to use the adhesive fracture energy G_A instead of the normalized peel forces to improve the consistency and comparability between different peel testing setups and ribbon materials as the peel test is essential for accepting (or rejecting) novel metallization concepts (plating, metallization pastes) and interconnection technologies (low melting solder alloys, conductive adhesives).

Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.

Keywords: Peel Test; Interconnection; Ribbon; Adhesion; PV Module

1. Introduction

In the PV community, the peel test is used to qualify the adhesion of interconnection ribbons on solar cell metallizations. The measured peel forces and the fracture patterns serve as a quality criterion to accept or reject a cell type for module integration, to validate a novel metallization paste formulation or a conductive glue and to adjust manufacturing process such as paste printing/firing or soldering in a tabber-stringer. In the German solar cell standard DIN EN 50461 a peel test is specified on the basis of the standard DIN EN 61189-2 for electronic components and materials. There, a perpendicular force of > 1 N/mm at a loading speed of 50 mm/min is specified.

Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.
doi:10.1016/j.egypro.2016.07.133

However, as the tests is applied in various ways in photovoltaics with respect to cell preparation, peeling angle, loading speed, observed fracture pattern and required force limit, a consistent comparison of test results does not exist at present.

In addition to previous publications, we show that the concept of adhesive fracture energies might overcome this lack of consistency of the peel test in PV. We therefore analyze the forces and deduced adhesive fracture energies of three different ribbons soldered onto identical cell structures in order to experimentally determine the effect of ribbon stiffness and thickness.

2. Basic concept of adhesive fracture energies

The concept of Kinloch and Kawashita [3,4] divides the energy G_{ext} delivered by the moving force sensor into contributions for deforming the peeling arm (already peeled section of the ribbon) - both plastically (G_S) and elastically (G_T) - and plastic bending energy at the peel front G_B. The remaining part is the adhesive fracture energy G_A which quantifies the energy needed to break the interfacial bonds of the joint:

$$G_A = G_{ext} - G_S - G_T - G_B \qquad (1)$$

In order to determine G_S, G_T and G_B from measured peel forces F, the mechanical properties (i.e. the stress-strain-relation) of the ribbon need to be known. For further details on the mechanical model and the calculation of the different energy terms we refer to [3,4].

3. Experimental

We characterize the initial mechanical properties of the ribbons by performing tensile tests prior to the peel experiments. For each of the three ribbons, 6 specimens are tested. We use a Zwick 0.5kN tensile testing machine with an optical strain sensor for measuring the deformation. The stress-strain curves are shown in Fig.1. The mechanical parameters listed in Table 1 are deduced from the stress-strain curves and do not correspond to quantities obtained by testing according to standards (elastic modulus E, yield strength $R_{p0.2}$) but should be regarded as fit parameters to separate the ribbon behavior into an elastic and a plastic section.

Table I. Mechanical properties and dimensions of the inspected ribbons.

Ribbon type	width b (mm)	thickness h (mm)	Young's modulus E (GPa)	Yield stress σ_y (MPa)
Hard ribbon, thin (A)	1.5	0.15	85	60
Hard ribbon, thick (B)	1.5	0.2	62	62
Soft ribbon, thick (C)	1.5	0.2	22	40

We solder the ribbons of type A, B and C onto the front side of monocrystalline industrial silicon solar cells with 3 continuous busbars using a CONSOL soft touch soldering station from MeyerBurger. We use identical soldering parameters for all three groups. The peel tests (30 tests for ribbon A, 29 tests for ribbon B and 30 tests for ribbon C) are performed 24 hours after soldering on a Zwick tester with a fixture for 90° and 180° peeling angles. We translate the measured peel forces into adhesive fracture energies by using the calculation procedure described in [4]. The relation between peel forces and adhesive fracture energies for a 180° configuration is shown in Fig. 3.