The impact of ribbon properties on measured peel forces

Ulrich Eitner, Li C. Rendler

Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstr.2, 79110 Freiburg, Germany

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 (\( \sigma_y = 62 \text{ MPa} \)) gives lower peel forces than the stiff ribbons (\( \sigma_y = 99 \text{ MPa} \)) while the adhesive fracture energies are higher. The thickness variation from 150 \( \mu \text{m} \) to 200 \( \mu \text{m} \) 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).

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.
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:

$$G_A = G_{ext} - G_S - G_T - G_B$$

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>
<thead>
<tr>
<th>Table I. Mechanical properties and dimensions of the inspected ribbons.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ribbon type</strong></td>
</tr>
<tr>
<td>Hard ribbon, thin (A)</td>
</tr>
<tr>
<td>Hard ribbon, thick (B)</td>
</tr>
<tr>
<td>Soft ribbon, thick (C)</td>
</tr>
</tbody>
</table>

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.
4. Results

4.1. Measured peel forces

The dominant fracture pattern for the peel tests in 90° configuration shows complete silicon cell fracture next to the busbar so that we discard the measured values for the analysis and switch to the 180° setup. There, we find almost no silicon fracture and measure peel forces between 1.5 N and 12 N. The peel curves for ribbon B show the most unstable behaviour among the tested ribbons where sections with local debonding lead to locally staggered force curves. For ribbon A and C we measure continuous peeling behaviour with rather stable force plateaus. For each peel experiment we average the force values and plot the distribution of these values in Figure 2. Ribbon C (soft, 0.2 mm) exhibits the lowest peel forces around 5.5 N while the mean values of ribbons A and B are between 6 and 6.5 N. In conclusion, the investigation of peel forces would lead the finding that the cells with the soft ribbon C exhibit the weakest adhesion in the joints.

4.2. Conversion into adhesive fracture energies

When applying the conversion of peel forces $F$ into adhesive fracture energies $G_A$, the relation between the different ribbons changes. The obtained adhesive fracture energies are shown in Figure 4. Here, the hard ribbons A and B are in the range of 1100 J/m$^2$ to 1200 J/m$^2$ while the mean value of the soft ribbon C gives 1300 J/m$^2$. With respect to adhesive fracture energies, we conclude the soft ribbon to show higher adhesion than the hard ribbons.
5. Conclusion

The investigation indicates that for identical samples the change of peeling angles from 90° to 180° might help to obtain adhesive/cohesive fracture patterns instead of silicon cell fracture. Under identical soldering conditions the low yield ribbon C shows slightly higher adhesion energies than the stiffer ribbons A and B. If only peel forces were taken into consideration, the opposite would be deduced from the test, i.e. slightly lower values of 5.5 N in comparison to 6 – 6.5 N for ribbons A and B. In line with previous investigations [1,2] we find the peel test in its current use in PV to be a weak quality criterion for module integrability of novel cells/metallization schemes. To increase consistency among different test setups, peeling angles and ribbons we propose to make use of the adhesive fracture energy concept [3,4].

Besides the consistency issue of the peel test investigated in this study, the rating of the peel test results for module manufacturing and reliability remains to be discussed. For the module manufacturing process, the bare peel forces may only be used if the peel test setup exactly matches the loading conditions imposed by the specific string handling tool (angle, torsion). Once the soldered cell string is embedded into the module the joints are no longer exposed to the loading case of peeling but rather shear deformation is expected. For further investigation of joint fracture within the module the adhesive fracture energy $G_A$ can be used as an input parameter describing the interfacial strength for LEFM (linear elastic fracture mechanics) modeling while the parameter of peel forces $F$ is useless.

Acknowledgements

The authors like to thank Sinan Yilmaz and Marco Ernst for conducting the experiments and for the preparation of samples.
References