

CONNECTING SOLAR CELL TABS TO A SOLAR CELL BUSBAR AND A SOLAR CELL SO PRODUCED

5 TECHNICAL FIELD

The invention concerns use of an adhesive for connecting solar cell tabs to a solar cell busbar and making the adhesive conductive in an alignment step and a solar cell so produced.

BACKGROUND

- 10 Interconnections between surface electrodes, solar cell tabs, of solar cells are often formed by soldering but there is an increasing demand to replace it by alternative methods. This trend is driven by technical and economic as well as by environmental factors.

- Soldering has the following problems. Firstly, soldering requires heavy metals such as lead which are toxic and require expensive measures when the cells are disposed. Secondly, in
15 order to decrease materials costs, there is a trend to decrease the thickness of solar cells. However, thinner layers suffer from cracks arising from soldering. Thirdly, soldering may cause oxidation of connected materials.

- There are two emerging possibilities to overcome the shortcomings of soldering. Ultrasonic welding, where local acoustic vibrations create a solid lead-free weld is one option and
20 another is to use conductive adhesives.

- During the soldering process the solder is applied at high temperatures. When the surface cools the solidified solder induces stress across the surface. This can have detrimental effects to the solar cells as excess stress will promote breakage and warping of the surface. This becomes increasingly problematic when solar cells are produced thinner to reduce material
25 usage and costs. Therefore conductive adhesives are a particularly interesting technology to replace the solders currently used.

In document WO 2008026356 is described an electric connection between an electrode of a solar cell and a wire member by a conductive adhesive film comprising at least 9 % rubber and containing conductive particles having a diameter of 1.33-0.06 % of the film thickness and a volume of conductive particles between 1.7-15.6 vol% and preferable between 2 – 12 or 3 – 8 vol% of the total volume in order to create an adhesive layer with adjoining conductive particles which overcome effects of surface roughness of the electrodes.

Conductive adhesives proposed for solar cell panel production comprises a relatively high fraction of conductive particles such as silver (>1.7 vol-%) in order to secure conductivity of the resulting film. This constitutes a problem because high amounts of conductive particles weakens mechanical properties of the adhesive and increases material cost.

The known conductive adhesives are isotropic mixtures of conductive fillers (e.g. silver or carbon) and polymer matrix. Therefore, in order to form conductive paths of macroscopic dimension, the load of conductive particles must be so high that the particles touch each other forming these paths. The particle packing mirroring this conduction mechanism is understood as the percolation model. The lowest particle fraction where this happens is denoted percolation threshold. For diverse spherical or largely 3-dimensional particles, this threshold is theoretically between 1-17 vol%, but in practice the lower limit is usually not sufficient for securing conductivity.

One exception to the above are modified CNTs whose percolation threshold can be as low as 0.1 vol% due to their highly anisotropic rod like shape that greatly deviates from 3-dimensional particles. A disadvantage of such CNTs is, however, that they are difficult to produce on an industrial scale.

In Schwarz et al. Polymer 43, 3079, 2002 “Alternating electric field induced agglomeration of carbon black filled resins” is observed how carbon black (CB) filled resins below zero-field percolation threshold can form CB networks when a field of 400 V/cm is applied between copper electrodes dipped into the resin.

US 20090038832 describes a method for forming an electrical path having a desired resistance from carbon nanotubes dispersed in a curable polymer matrix. Electrodes are placed in contact with the dispersion and electrical energy in the form of a dielectrophoretic signal at 8 V, 1

MHz is applied over the electrode gap and resistance monitored until a desired electrical resistance is reached. A pure semi-conducting connection can be achieved by burning away metallic nanotubes that may be part of the carbon nanotube mixture, by applying a current after the deposition. The polymer matrix is cured in order to fix the device.

- 5 This account is limited to carbon nanotubes and addresses the problem in microelectronics and circuit boards. The electrode-electrode contacts in a microelectronic circuit board are point like or nearly point like and thus cover only small volumes and only low currents pass in the CNT connections. The carbon nanotubes are difficult to produce on an industrial scale and are expensive and applications involving larger volumes are not realistic today. CNTs are,
10 moreover, difficult to mix with polymers to form high quality dispersions.

DESCRIPTION OF THE INVENTION

- Solar cells generally have surface electrodes, tabs, printed on a substrate of at least one or more single-crystal, polycrystal or amorphous materials. The solar cell busbars shall connect
15 to the tabs for connection between the solar cells. A conductive adhesive layer can be used for the connection.

- Interconnections between solar cell tabs and busbars in solar cell modules cover large areas. The adhesive used for the interconnection must achieve a good mechanical bonding as well as electrical conductivity between the solar cell tabs and busbars. It is an advantage if the
20 adhesive can be made from conventional materials that are available on an industrial scale.

- The invention concerns an interconnection between solar cell tabs and busbars formed by an adhesive comprising a low concentration of conductive particles. The conductive particles can be infusible particles such as carbon particles, metal particles or metal oxide particles. The adhesive is made conductive by applying an electric field over the adhesive when the adhesive
25 is placed between the solar cell tabs and busbars. The adhesive is thereafter stabilised.

The anisotropic adhesive conductive film formed by the application of the electric field and the following stabilisation allows the adhesive to have electric conductive properties at lower concentrations of conductive particles than would otherwise be possible for isotropic conductive adhesives. The lower concentration of conductive particles gives improved

mechanical properties to the adhesive and the alignment of the conductive particles taking place when the electric field is applied secures the electrical conductivity of the adhesive film between the solar cell tabs and busbars.

There are no particular restrictions on the adhesive matrix component. The adhesive is a mixture of a matrix and conductive particles. The mixing can be made by conventional means. A low concentration of conductive particles gives the adhesive good storing properties and thereby makes the adhesive simple to handle in an industrial environment.

The matrix can be an adhesive polymer system of any kind and it can contain one or several components. The adhesive will be stabilised after an alignment step to a second viscosity higher than the first viscosity in order to make the adhesive mechanically stable and to support the aligned conductive particles. In particular, the matrix can be a thermoset polymer system which means that the matrix is originally fluid but can be solidified by cross-links. It can also be a thermoplastic polymer system which means that the polymer is solid or viscous at lower temperatures but can be reversibly melted or plasticised by rising the temperature. It can moreover be a lyotropic polymer system which means that the matrix can be plasticised by solvent and solidified by evaporating this solvent off. It can also be any combination of these systems. For example, the thermoset polymer system can contain solvent for plasticizing it but the stabilization can be based primarily on cross-linking and only secondarily on the solvent evaporation.

The major part of the conductive particles has low aspect ratio, like spherical carbon black or disk-or cone like carbon particles. Aspect ratios range of 1-4, or 1-5, 1-10, 1-20 or 1-100 are typical; i.e. a ratio 1:N where N is greater than or equal to 4 and can be as high as 100 or more. The conductive particles can be a mixture of different carbon particles. Other conductive particles can be used, like silver, gold or metal oxide particles.

Carbon black and carbon nano-discs and cones as well as metal or metal oxide particles are produced on an industrial scale and are thus available for applications involving larger volumes.

The concentration of conductive particles in the matrix can be held low without adverse effects on the conductivity. A concentration around the percolation threshold and up to ten

times lower can give good conductivity after the alignment step. Concentrations in the range of 0.2 to 10 vol%, or 0.2 to 2 vol% or 0.2 to 1.5vol% of conductive particles are useful.

Application of the adhesive can be done by conventional printing or injection techniques, which makes it possible to apply the adhesive to large surfaces in a cost-effective manner. The
5 adhesive has a first viscosity during the application, which shall be low enough that the conductive particles shall be able to move during the subsequent alignment step.

The electric field can be in the order of 0.05 to 10 kV/cm, or 0.05 to 5 kV/cm or 0.1 to 1 kV /cm. This means that for a typical alignment distance in the range of 10 μ m to 1 mm, the voltage applied can be in the range of 0.05 to 1000 V and normally in the range of 5- 100 V.

10 The field is typically an alternating (AC) field, having typically a frequency of 10 Hz to 10 kHz. A direct (DC) electric field can also be used. The voltage levels needed for aligning the conductive particles are low and make the process simple to handle in a production line and do not need the specific arrangements necessary when handling high voltages.

The direction of the electric field is perpendicular to the surfaces of the solar cell tabs and
15 busbars and the electric connections formed by the aligned conductive particles make up a number of conductive paths along the direction of the electric field and thereby connecting the solar cell tabs and busbars.

The electrical field can be applied during lamination with the adhesive of the present invention, both for backside contact solar cells and standard solar cells. Once the solar cells
20 are placed in the glass with encapsulation foil, typically EVA (ethylene vinyl-polymer acetate) and backsheet . The external electrical field is applied in the laminator.

It is also possible to heal aligned conductive particle pathways, if the conductive pathways have become defect or not properly aligned in the first step, the alignment step can be rerun for the case that the stabilisation step of the matrix is not yet performed or if the stabilization
25 step is reversible. This has the advantage that for existing films under preparation of the connections the process need not to be started afresh. The stabilisation step may be, e. g., curing of a thermoset polymer.

LIST OF DRAWINGS

Fig. 1A-B show optical micrographs of assemblies of 0.2 vol-% CNC particles dispersed into the adhesive and aligned by the electric field. Fig. 1C shows the applied geometry of joint electrodes (a) and adhesive with aligned pathways (b).

- 5 Fig. 2 A-F illustrates the connection of solar cell electrodes by conductive adhesive with aligned particles.

Fig. 3 plots the dependence of DC conductivity of 0.2 vol-% CNC particles dispersed into the adhesive against the alignment time. The solid line is guide to the eye.

- 10 Fig. 4 A-E shows the connection of solar cell electrodes by conductive adhesive with aligned particles in a schematic process line

Fig. 5 shows optical micrographs showing the healing of a scratch.

Fig.6 illustrates how this method can be incorporated into a pick and place device.

DETAILED DESCRIPTION OF THE INVENTION

- 15 The invention is described in more detail by the figures and examples. The figures and examples are meant to illustrate the invention, but nevertheless it shall be understood that no limitation of the scope of the disclosure is intended.

Example 1

- 20 This example concerns the preparation of a mixture of conductive particles and polymer matrix that in this example is an thermally cured polymer adhesive; as well as determination of conductivity as a function of particle load; and how the step-like increase in conductivity with increasing particle load can be explained by formation of conductive paths between particles when the contacts are formed with increased particle fraction.

- 25 This example concerns moreover the preparation of the same mixture when the particle load is low, for example 10 times less than the observed percolation threshold, the limit where the

isotropic non-aligned mixture is not conductive; as well as the alignment of this mixture using electric field so that the aligned particles form conductive paths resulting in a conductive material, whose conductivity is directional, for example below the percolation threshold of non-aligned material. The example, moreover, shows change of the viscosity of so obtained material, for instance by curing, so that the alignment and directional conductivity obtained in the alignment step is maintained.

The employed conductive particles were carbon black from Alfa Aesar, carbon cones (CNCs) from n-Tec AS (Norway) and iron oxide ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$) from Sigma-Aldrich.

The employed polymer matrix was a two component low viscosity adhesive formed by combining Araldite® AY 105-1 (Huntsman Advanced Materials GmbH) with low viscosity epoxy resin with Ren® HY 5160 (Vantico AG).

The conductive particles were mixed in the adhesive by stirring for 30 minutes.

Estimated percolation threshold of these materials is at ~ 2 vol-%. The mixtures are conductive above and insulators below this threshold. The conductivity is due to the conductive particles and the polymer is essentially insulator.

To illustrate the benefit of alignment, the materials were the same and similarly prepared as in above but ten times lower particle loads were used.

Fig. 1 illustrates, using optical micrographs, the mixing of assemblies of 0.2 vol-% CNC particles dispersed into the example adhesive before (Fig. 1A) and after an electric field alignment and curing (Fig. 1B).

The scheme shows the applied alignment (out-of-plane) geometry (Fig.1C) that corresponds to that illustrated in Fig. 2. This alignment geometry was used to cover conductive path distances 1 from 10 μm to centimeters, preferentially to millimeters. For an out-of-plane alignment 2 mm $\times$ 15 cm wide layer of material is injected between the solar cell busbar 3 and the solar cell tab 2.

Mixture was aligned using an AC source to obtain aligned pathways (b). In this example the alignment procedure 1 kHz AC-field (0.6-4 kV/cm (rms value)) was employed for 1 minutes for <1 mm electrode spacing.

Fig. 3 shows the conductivity as a function of alignment time illustrating orders of magnitudes conductivity enhancement.

The curing was performed immediately afterwards at 100 °C for 1 minute.

The material remains aligned after curing and conductivity level obtained by alignment is maintained.

Figure 2 A shows a solar cell 4 with tabs 5 collecting the current produced by the photovoltaic effect. Fig 2 B illustrates an isotropic dispersion 8 of conductive particles 6 in an adhesive 7 having a first viscosity. The dispersion 8 is spread onto the solar cell tabs 5 forming a layer of adhesive on each tab as shown in fig 2 C. The external electrodes, the busbars 10 are placed on the adhesive layer, where after alignment of the conductive particles 6 is effected by application of an electric field over the electrodes 5, 10, fig 2 E, indicated by the AC symbol .

Stabilisation of the adhesive dispersions, e.g. by curing, to a second viscosity, higher than the first viscosity, will secure the mechanical strength of the adhesive dispersion and support the aligned conductive particles thus making the adhesive dispersion conductive. The solar cell 4 is now in contact with the busbars 10, because conductive paths have been formed in the adhesive dispersion 8.

The solar cell combines the above-illustrated settings with out-of-plane geometry and short alignment distances plus conveniently low alignment voltages. In a typical example, a 1 mm × 8 cm wide layer of described anisotropic adhesive with 0.2 vol-% carbon load was injected between the silver and copper electrodes of a solar cell. In this case the electrodes were pressed together and the resultant spacing was less than 100 µm. This is followed by electric field alignment and curing, the whole procedure taking typically in the order of ten minutes.

Fig 4 A-E shows a top view of the sequence described in figure 2. The solar cell 4 with tabs 5 are shown in fig 4A, The isotropic dispersion 8 of adhesive 7 and conductive particles 6 are spread on the solar cell tabs (fig 4 B). The busbars 10 are placed on the adhesive (fig 4C) and

alignment of particles by applying a voltage 12 over the electrodes 5,10, fig 4D. Stabilisation of the adhesive e.g. by curing using e.g. UV light or heat, fig 4E.

Example 2

This example shows the robustness of the procedure and shows how electric field heals
5 macroscopic defects in a conductive particle adhesive mixture.

Fig. 5 is optical micrographs showing the healing of the scratch in the case of CNCs. The materials and procedure was similar to that in Example 1, but a macroscopic scratch defect was made by a sharp spike; and the electric field was let on. The optical micrographs showing the healing of the scratch in the adhesive layer, an electric field of 1 kHz, 500 V/cm was let on
10 and the conductive pathways is gradually reforming. After reforming basically all conductive particles are forming conductive pathways in the matrix.

Example 3

This example shows, as illustrated in fig. 6 how a pick and place device is fitted with an electrical field applicator so that the present invention, as explained in example 1, can be used
15 in solar panels with back-side contact cells. The pick and place lifts the solar cell (a) on to the encapsulation foil. Once placed the field is applied from the pick and place head (b). At this stage curing may occur via heating or UV curing if the connecting ribbons are transparent, or curing may occur during the lamination stage at the end of the production line.

Example 4

20 A conductive adhesive according to the present invention is used in thin-film solar panel production where transparent electrodes are used. A thin-film flexible solar cell is built on a plastic substrate using a cadmium telluride p-type layer and a cadmium sulfide n-type layer on a plastic substrate. The semiconductor layers can be amorphous or polycrystalline. A transparent conductive oxide layer overlaid by a busbar network is deposited over the n-type
25 layer. A back contact layer of conductive metal is deposited underneath the p-type layer. The adhesive is applied and becomes conductive as in example 1.

Example 5

For a solar cell one or more wiring members for collecting current and for transmitting current in the solar cell are made of a dispersion of a matrix and conductive particles. The concentration of said conductive particles is below a percolation threshold, so that the dispersion is not conductive. The dispersion has aligned conductive particles in areas where wiring members for collecting current meet wiring members for transmitting current.

Conductive wires are in this way formed directly to connect the solar cell devices, such that the tab or busbar is not needed to make the circuit. The adhesive dispersion of the present invention is used in one or more layered structures, e.g. one layer that is directional conductive replacing the tab, and one layer directional conductive so as to replace the conductive bars. The matrix can be reduced, e.g. by using a solvent, to expose the conductive pathways, so that the next layer can contact to these. The electrical field is applied in the corresponding directions, e.g. using a mask and a remote field, or by using parts of the solar panel under construction as electrodes, so that the conductive particles in the matrix are aligned to form the needed conductive wires.

Claims

1. Use of an adhesive for connecting a solar cell tab to a solar cell busbar, the adhesive comprising a dispersion of a matrix and conductive particles, **characterised by** that
 - a. a major part of the conductive particles of the adhesive have low aspect ratio;
 - 5 b. a layer of the adhesive is applied to the solar cell tab, the adhesive having a first viscosity which allows the conductive particles to rearrange within the layer;
 - c. the solar cell busbar is applied onto the layer;
 - 10 d. an electric field is applied over the layer of adhesive, aligning a number of the conductive particles with the field, thus creating conductive pathways in the adhesive between the solar cell tab and the solar cell busbar;
 - 15 e. changing the viscosity of the adhesive to a second viscosity, said second viscosity being higher than the first viscosity in order to mechanically stabilise the layer and preserve the conductive pathways between the solar cell tab and the solar cell busbar.
2. Use of an adhesive for connecting a solar cell tab and a solar cell busbar, the adhesive comprising a dispersion of a matrix and conductive particles, **characterised by** that
 - a. a major part of the conductive particles in the adhesive have low aspect ratio;
 - 20 b. a layer of the adhesive is injected into a space between the solar cell tab and the solar cell busbar, the adhesive having a first viscosity which allows the conductive particles to rearrange within the layer;
 - c. an electric field is applied over the layer, aligning a number of the conductive particles with the field, thus creating conductive pathways between the solar cell tab and the solar cell busbar;

- d. changing the viscosity of the adhesive to a second viscosity, said second viscosity being higher than the first viscosity in order to mechanically stabilise the layer and preserve the conductive pathways between the solar cell tab and the solar cell busbar.

- 5 3. Use of an adhesive in accordance with claim 1 or 2 **characterised by** that the conductive particles in the adhesive are carbon black, carbon nanodiscs, carbon nanocones or a mixture thereof.
- 10 4. Use of an adhesive in accordance with claim 1 or 2 **characterised by** that the conductive particles in the adhesive comprises metal particles, metal oxide particles, colloidal metal containing particles, or a mixture thereof.
5. Use of an adhesive in accordance with claim 1, 2, 3 or 4 **characterised by** that the aspect ratio of the conductive particles is in the range of 1-100.
6. Use of an adhesive in accordance with claim 5 **characterised by** that the aspect ratio of the conductive particles is in the range of 1-4 or 1-5 or 1-10 or 1-20.
- 15 7. Use of an adhesive in accordance with claim 1, 2, 3, 4, 5 or 6 **characterised by** that a concentration of conductive particles in the adhesive is within the range of 0.2 to 10 vol%, or 0.2 to 2 vol% or 0.2 to 1.5vol%.
- 20 8. Use of an adhesive in accordance with claim 1, 2, 3, 4, 5 or 6 **characterised by** that the electric field applied to align the conductive particles in the adhesive is in the order of 0.05 to 20 kV/cm, or 0.05 to 5 kV/cm or 0.1 to 1 kV.
9. Use of an adhesive in accordance with claim 7 or 8 **characterised by** that the electric field has a frequency of 10 Hz to 1 MHz or 10 Hz to 100 kHz, or 10Hz to 10kHz.
- 25 10. Use of an adhesive in accordance with any of the preceding claims **characterised by** that the conductive pathways in the adhesive are restored by an additional electric field, if the pathways become defect after the alignment step.

11. A solar cell **characterised by** that the solar cell tab and the solar cell busbar are connected by an anisotropic adhesive in accordance with any of claims 1-9.
12. A solar cell in accordance with claim 11 **characterised by** that the solar cell is a back-side contact cell.
- 5 13. A solar cell in accordance with claim 11 **characterised by** that the solar cell is a thin-film solar cell.
- 10 14. A solar cell **characterised by** that one or more wiring members for collecting current and for transmitting current in the solar cell are made of a dispersion of a matrix and conductive particles, the concentration of said conductive particles being near or below a percolation threshold, and the dispersion having aligned conductive particles in areas where wiring members for collecting current meet wiring members for transmitting current.