

Semifinished Product of a Multi-Junction Solar Cell and Method for Producing a Multi-Junction Solar Cell

The invention concerns a semifinished product of a multi-junction solar cell according to the preamble of claim 1, and a method for producing a solar cell according to the preamble of claim 9.

US 4,744,194 discloses a method for removing III-V based solar cell layers from a supporting substrate by means of selective chemical etching processes. In addition, methods for separating semiconductor layers from their substrates based on chemical etching processes are known from US 4,883,561 and US 2010/0116784 A1. The separation of semiconductor layers by means of the ion implantation method is known from US 5,374,564. Furthermore, optical methods for separation of semiconductor materials, in particular separation of LED layers based on group III nitrides from substrates with large band gaps, are known from DE 196 49 594 A1 and US 6,071,795. Additionally, another solar cell structure is known from US 7,785,989 B2.

Against this background, the object of the invention is to specify a device that advances the state of the art.

The object is attained by a semifinished product of a multi-junction solar cell with the features of claim 1, and by a method for producing a solar cell according to the preamble of claim 9. Advantageous embodiments of the invention are the subject matter of dependent claims.

Provided according to the first object of the invention is a semifinished product of a multi-junction solar cell comprising a semiconductor body that is designed as a first partial solar cell and has a first band gap, comprising a semiconductor body that is designed as a second partial solar cell and has a second band gap, wherein the first

semiconductor body and the second semiconductor body form a material-to-material connection with a tunnel diode, and the first band gap is different from the second band gap, and comprising a first substrate material implemented as a substrate layer, wherein a sacrificial layer is formed between the first substrate material and the first partial solar cell, and the first substrate material is removed from the first semiconductor body with the destruction of the sacrificial layer. It should be noted that the two partial solar cells are arranged in a stack and that a partial solar cell refers to a semiconductor body that generates electrical energy by direct conversion from the energy of incident photons of a certain region of the solar spectrum. The sensitivity regions of the partial solar cells are chosen such that all partial solar cells together utilize the solar spectrum in a maximally ideal fashion. Conversion efficiencies of up to 40% can be achieved today using the concept of stacked multi-junction solar cells. Moreover, it should be noted that preferably only the sacrificial layer is destroyed during separation from the substrate.

Provided according to the second object of the invention is a method for producing a multi-junction solar cell comprising a first substrate material implemented as a substrate layer, wherein a semiconductor body is produced that is designed as a first partial solar cell and has a first band gap, and a semiconductor body is produced that is designed as a second partial solar cell and has a second band gap, wherein a material-to-material connection with a tunnel diode is formed between the first semiconductor body and the second semiconductor body, and the first band gap is different from the second band gap, wherein a sacrificial layer is formed between the first substrate material and the first partial solar cell, and in a subsequent process step the first substrate material is removed from the first semiconductor body with the destruction of the sacrificial layer.

One advantage of the sacrificial layer on the substrate is that the stacked multi-junction solar cell can be removed from the substrate in a simple and cost-effective manner. The multi-junction solar cell can be separated from the substrate by means of the separation process without damaging either the substrate or the multi-junction solar cell. It is advantageous to remove any residues of the sacrificial layer on the substrate or first

partial solar cell by means of a cleaning process after the separation. Moreover, it is advantageous that additional partial solar cells can be applied to the multi-junction solar cell after removal from the substrate layer, and by this means high-efficiency multi-junction solar cells consisting of a stack of 3, 4, or more partial solar cells can be produced. The term "high-efficiency solar cells" is understood to mean solar cells that have a conversion coefficient above 25%.

It is preferred for the stacked multi-junction solar cell to be implemented as a III-V solar cell, which is to say as a solar cell consisting of compound semiconductors from the 3rd and 5th major groups of the periodic table. Furthermore, the substrate can be reused for producing multi-junction solar cells. Because the substrates are very cost-intensive, production costs can be sharply reduced through reuse of the substrates. Another advantage of the novel separation technique is that the removal can now be performed very quickly and reliably. Investigations have shown that the novel method and the novel structure can be used to particular advantage on multi-junction solar cells for space flight applications, which have a typical size of 8 cm x 4 cm or larger. In addition, it is also advantageous to use the novel removal process for producing multi-junction solar cells whose size is less than 8 cm x 4 cm, preferably in a range from 1 mm² to 400 mm². Multi-junction solar cells of this type with a small size can be used by preference in terrestrial concentrator systems.

In especially advantageous fashion, the sacrificial layer can be implemented such that the sacrificial layer can be locally heated with the absorption of electromagnetic energy. The substrate can be separated easily from the solar cell stack by means of the thermal decomposition of the sacrificial layer that thus occurs. By this means, throughput and yield in production are increased, and production costs are reduced.

For thermally induced decomposition of the sacrificial layer resulting from the absorption of electromagnetic radiation, it is preferred for the sacrificial layer to have a band gap with an energy of less than 1.5 eV, most preferably less than 1.2 eV. As a result, the sacrificial layer is not transparent to visible light, and has an absorption band in the

infrared spectral region. It is ideal but not mandatory for the sacrificial layer to have the smallest band gap energy of all layers of the stacked multi-junction solar cell. If the other layers of the stacked multi-junction solar cell, which is to say in particular the stack composed of the first semiconductor body and second semiconductor body, are designed to be transparent to the incident electromagnetic radiation, which preferably is in the infrared wavelength region, it is ensured by this means that the electromagnetic energy incident through the stack composed of the first semiconductor body and second semiconductor body is only absorbed in the sacrificial layer. It is advantageous to match the band gap energy of the sacrificial layer and the energy of the incident electromagnetic radiation to one another. Investigations have shown that it is advantageous to match the absorption band of the sacrificial layer to the wavelength of an infrared laser device with a pulsed laser having an energy of approximately 1.16 eV, for example a Nd-YAG laser having a wavelength of 1064 nm. To this end, the band gap energy of the sacrificial layer is set to a value of ≤ 1.15 eV.

Investigations have shown that different materials are suitable for the sacrificial layer depending on the type of substrate. Starting from a GaAs substrate, an InP substrate, or a Ge substrate, it is especially advantageous to form the sacrificial layer from InAs, GaAs, InSb, GaSb, InP, or their ternary and quaternary mixed semiconductors. On account of the low band gap of Ge, an epitaxially grown Ge sacrificial layer, in particular, is especially suited to a multi-junction solar cell on a GaAs substrate or an InP substrate. It is advantageous to form the sacrificial layer in a thickness between 10 nm and 200 nm.

In one further development, the sacrificial layer has a lattice constant that is different from the lattice constant of the first partial solar cell. Investigations have shown that it is advantageous for the sacrificial layer to be deposited on the substrate with a lattice mismatch.

In an alternative embodiment, the sacrificial layer is lattice-matched to the first partial solar cell. In this case, when the sacrificial layer is produced the lattice constant is chosen to be essentially equal to that of the first partial solar cell.

Investigations have shown that it is especially advantageous according to one further development for a buffer layer to be formed between the sacrificial layer and the first partial solar cell, and for the buffer layer to have a material-to-material connection to the first partial solar cell. Especially during removal, the buffer layer acts as an additional protective layer and prevents damage to the first semiconductor body. Investigations have shown that it is advantageous to choose the buffer layer to be lattice-matched, which is to say to choose the lattice constant of the buffer layer to be comparable to the lattice constant of the first partial solar cell. In particular, it is advantageous to choose the thickness of the buffer layer to be between 100 nm and 2 μm ; most preferably, the thickness of the buffer layer is chosen to be 500 nm.

According to another further development, the buffer layer is implemented as a Bragg reflector. This has the effect that light that is not absorbed in the first semiconductor body is reflected back into the first semiconductor body. In this way, the efficiency of the multi-junction solar cell can be increased.

According to one embodiment, a support layer that has a material-to-material connection to the second partial solar cell is arranged on the second partial solar cell. Investigations have shown that the support layer mechanically stabilizes the solar cell after removal of the substrate, in particular when at least one additional partial solar cell is applied on the first partial solar cell after removal in order to form a multi-junction solar cell consisting of 3, 4, or more partial solar cells.

The invention is explained in detail below with reference to the drawings. Like parts are labeled with identical designations here. The embodiments shown are highly schematic, which is to say that the distances and lateral and vertical extents are not to scale, and

unless otherwise specified also do not have any derivable geometric relationship to one another. In the drawings,

Figures 1a – 1d show a cross-section of different embodiments and production steps of a semifinished product of a multi-junction solar cell.

The illustration in Figure 1a shows a schematic cross-section of a semifinished product with a stacked arrangement of a multi-junction solar cell 10, having a substrate layer 20, a sacrificial layer 30, a first semiconductor body 40, and a second semiconductor body 50 with a material-to-material connection to the first semiconductor body 40. A tunnel diode is formed between the first semiconductor body 40 and the second semiconductor body 50. The sacrificial layer is preferably attached to the first semiconductor body 40 lying thereon. The multi-junction solar cell is preferably designed as a III-V solar cell, in particular using InGaAs and InGaP. Furthermore, the first semiconductor body 40 is designed as a first partial solar cell and the second semiconductor body 50 is designed as a second partial solar cell, wherein the first partial solar cell has a first band gap and the second partial solar cell has a second band gap different from the first band gap. Moreover, the sacrificial layer has a third band gap, wherein the third band gap is chosen to be smaller than the first and second band gaps. In addition, the substrate layer consists of a substrate material with a fourth band gap, wherein the fourth band gap is preferably less than 1.6 eV and preferably larger than the third band gap.

A second embodiment of a semifinished product is shown in the illustration in Figure 1b. Only the differences from the embodiment shown in the illustration in Figure 1a are explained below. A support layer 100 is formed on the second semiconductor body 50. The support layer can also be implemented to particular advantage as a plastic film and serves to mechanically stabilize the stack composed of the first and second semiconductor bodies 40 and 50 after removal.

The illustration in Figure 1c shows a process step that further develops the semifinished product from Figure 1b. Only the differences from the embodiments shown in one of the

preceding figures are explained below. The sacrificial layer is heated and decomposed by means of infrared radiation, preferably by means of an infrared laser. Here, the wavelength of the radiation is matched to the absorption capacity of the sacrificial layer 30. Investigations have shown that irradiation with light takes place through the front side of the multi-junction solar cell, which is to say through the stack composed of the first and second semiconductor bodies 40 and 50, or alternatively through the substrate layer 20. In the case of exposure through the front side, it is advantageous in one embodiment, as shown in Figure 1c, to apply the support layer 100 even before irradiation if the support layer 100 is transparent to the wavelength of the infrared laser. According to an alternative embodiment, it is advantageous to apply the support layer only after irradiation with infrared light. In this case, exposure of the semifinished product takes place according to the embodiment shown in Figure 1a, through the front side and/or rear side. The support layer applied after irradiation can then be used, in particular, to lift the multi-junction solar cell off of the substrate 20.

According to a further development, it is especially advantageous to expose the sacrificial layer 30 simultaneously through the front side, which is to say through the semiconductor bodies 40 and 50 with or without the support layer 100, and through the substrate layer 20. The sacrificial layer 30 is intensely heated by the irradiation with light. In this process, the multi-junction solar cell is separated from the substrate 20 with the destruction of the sacrificial layer 30.

The illustration in Figure 1d shows a process step that further develops the semifinished product from Figure 1c. Only the differences from the embodiments shown in one of the preceding figures are explained below. After the complete removal of the sacrificial layer 30, the multi-junction solar cell is turned over and a third semiconductor body 110 is formed on the first semiconductor body 40. It should be noted that the third semiconductor body 110 is also implemented as a III-V compound.

Claims

1. Semifinished product of a multi-junction solar cell (10) comprising
 - a semiconductor body (40) that is designed as a first partial solar cell and has a first band gap,
 - a semiconductor body (50) that is designed as a second partial solar cell and has a second band gap, wherein the first semiconductor body (40) and the second semiconductor body (50) form a material-to-material connection with a tunnel diode, and
 - the first band gap is different from the second band gap,
 - a first substrate material implemented as a substrate layer (20), and
 - a sacrificial layer (30) is formed between the first substrate material and the first partial solar cell,

characterized in that

the substrate layer (20) is implemented as a GaAs or InP or Ge substrate, and

the sacrificial layer (30) has a third band gap, wherein the third band gap is smaller than the first band gap and smaller than the second band gap, and

wherein

the third band gap is less than 1.2 eV, and

the stack composed of the first semiconductor body (40) and the second semiconductor body (50) is designed to be transparent for incident electromagnetic radiation in the infrared wavelength region, and

the sacrificial layer (30) has an absorption band in the infrared spectral region so that

the electromagnetic energy incident through the stack is absorbed only in the sacrificial layer, in order to

remove the first substrate material from the first semiconductor body with the destruction of the sacrificial layer.

2. Semifinished product according to claim 1, characterized in that the sacrificial layer (30) has a lattice constant that is different from the lattice constant of the first partial solar cell.
3. Semifinished product according to claim 1, characterized in that the sacrificial layer (30) is lattice-matched to the first partial solar cell.
4. Semifinished product according to one of the preceding claims, characterized in that the substrate layer (20) has a band gap with an energy of less than 1.5 eV.
5. Semifinished product according to one of the preceding claims, characterized in that the second partial solar cell has a support layer with a material-to-material connection to the second partial solar cell.
6. Semifinished product according to claim 1, characterized in that a buffer layer is formed between the sacrificial layer (30) and the first partial solar cell, and the buffer layer has a material-to-material connection to the first partial solar cell.
7. Semifinished product according to claim 6, characterized in that the buffer layer is implemented as a Bragg reflector.
8. Semifinished product according to one of the preceding claims, characterized in that a support layer (100) that has a material-to-material connection to the second partial solar cell is arranged on the second partial solar cell.
9. Method for producing a multi-junction solar cell (10) comprising
 - a first substrate material implemented as a substrate layer (20), wherein
 - a semiconductor body (40) that is designed as a first partial solar cell and has a first band gap is produced,
 - a semiconductor body (50) that is designed as a second partial solar cell and has a second band gap is produced, wherein a material-to-material connection

with a tunnel diode is formed between the first semiconductor body (40) and the second semiconductor body (50), and
the first band gap is different from the second band gap, and
a sacrificial layer (30) is formed between the first substrate material and the first partial solar cell,

characterized in that

the substrate layer (20) is formed from a GaAs or InP or Ge substrate, and
the sacrificial layer (30) is implemented with a third band gap of less than 1.2 eV, wherein the third band gap is smaller than the first band gap and smaller than the second band gap, and the stack composed of the first semiconductor body (40) and the second semiconductor body (50) is designed to be transparent for incident electromagnetic radiation in the infrared wavelength region, and
in a subsequent process step, the first substrate material is removed from the first semiconductor body (40) with the destruction of the sacrificial layer (30) by the means that the electromagnetic radiation incident through the stack composed of the first semiconductor body (40) and the second semiconductor body (50) is absorbed in the sacrificial layer (30).

10. Method according to claim 9, characterized in that a buffer layer that has a material-to-material connection to the first partial solar cell is produced between the sacrificial layer (30) and the first partial solar cell.
11. Method according to claim 10, characterized in that the buffer layer is implemented as a Bragg reflector.
12. Method according to claim 10 or claim 11, characterized in that a support layer (100) that has a material-to-material connection to the second partial solar cell is arranged on the second partial solar cell.
13. Method according to one of claims 9 through 12, characterized in that the sacrificial layer (30) is heated and decomposed by means of absorption of an

electromagnetic wave, and the first partial solar cell and the second partial solar cell are removed from the sacrificial layer (30) together.

14. Method according to one of claims 9 through 13, characterized in that an additional single-junction solar cell or an additional multi-junction solar cell is formed on the first partial solar cell or the second partial solar cell, and the additional single-junction solar cell or the additional multi-junction solar cell has a band gap different from the first partial solar cell and the second partial solar cell.