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(54) **MULTI-JUNCTION SOLAR CELL DEVICES**

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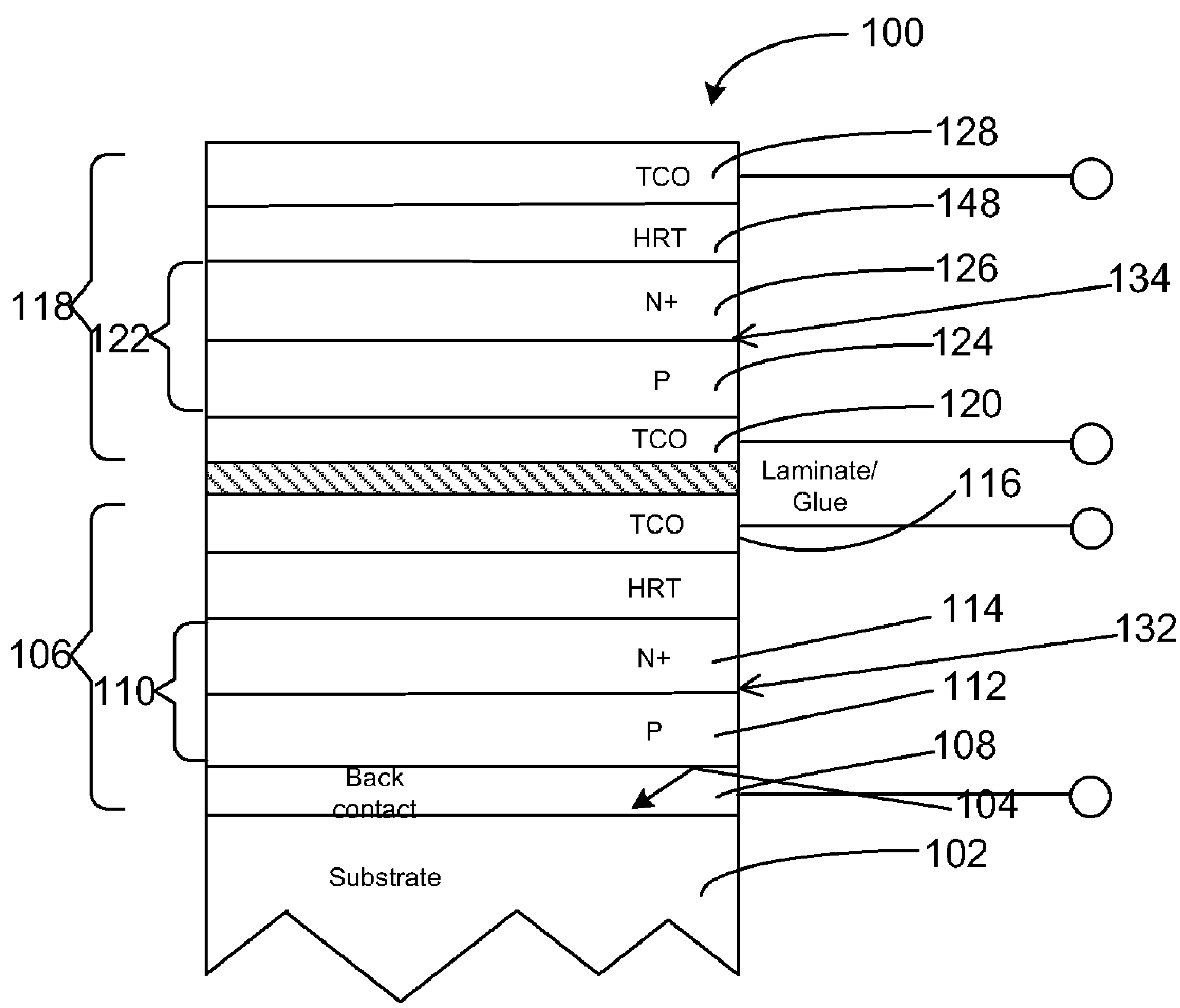
(57) **ABSTRACT**

A photovoltaic cell structure for manufacturing a photovoltaic device. The photovoltaic cell structure includes a substrate including a surface region. A first conductor layer overlies the surface region. The photovoltaic cell structure includes a lower cell structure. The lower cell structure includes a first P type absorber layer using a first semiconductor metal chalcogenide material and/or other semiconductor material overlying the first conductor layer. The first P type absorber material is characterized by a first bandgap ranging from about 0.5 eV to about 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1}. The lower cell structure includes a first N^+ type window layer comprising at least a second metal chalcogenide material and/or other semiconductor material overlying the first P absorber layer. The photovoltaic cell structure includes an upper cell structure. The upper cell structure includes a second P type absorber layer using a third semiconductor metal chalcogenide material. The second P type absorber layer is characterized by a second bandgap ranging from about 1.0 eV to 2.2 eV and a second optical absorption coefficient greater than about 10^4 cm^{-1}. A second N^+ type window layer comprising a fourth metal chalcogenide material overlies the second P absorber layer. A tunneling junction layer is provided between the upper cell structure and the lower cell structure.



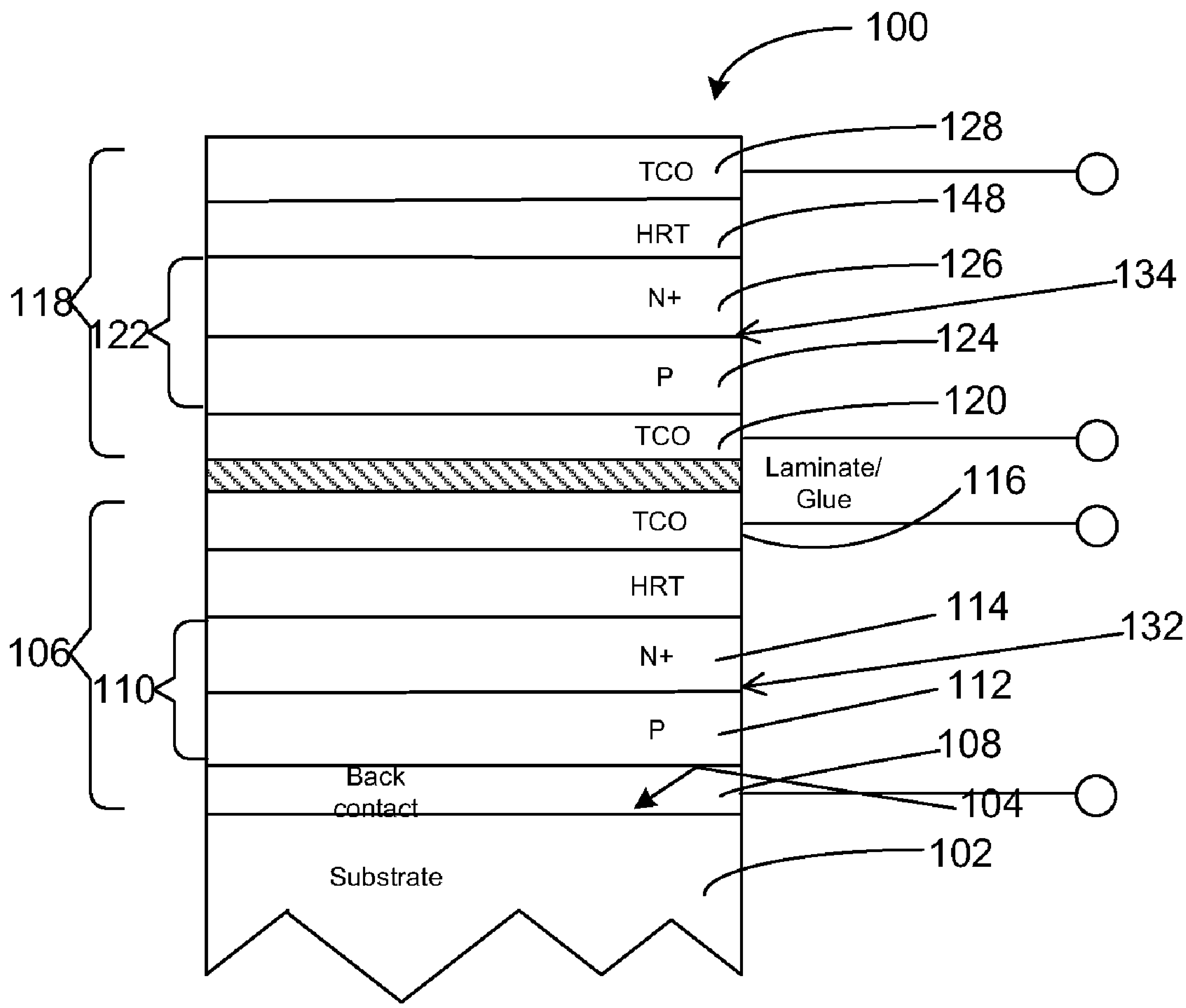


Figure 1

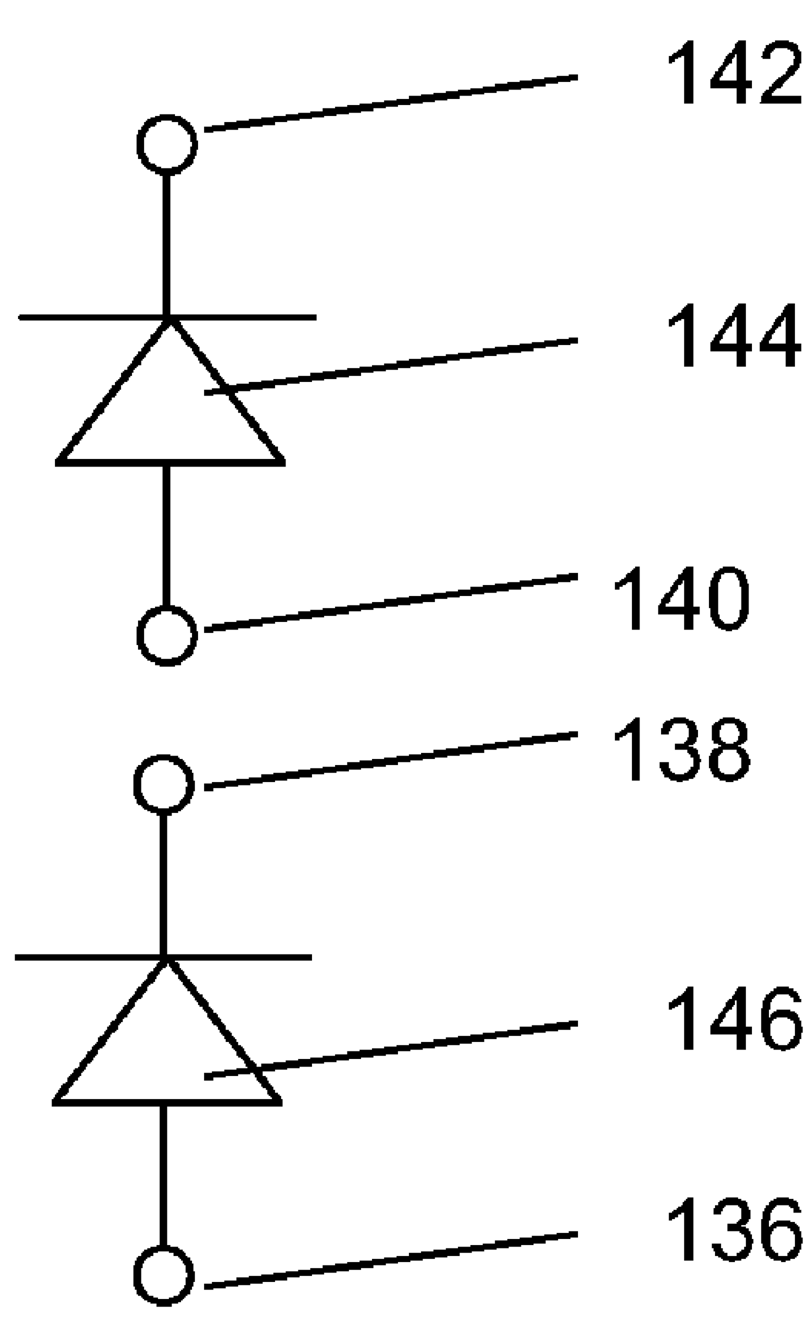


Figure 2

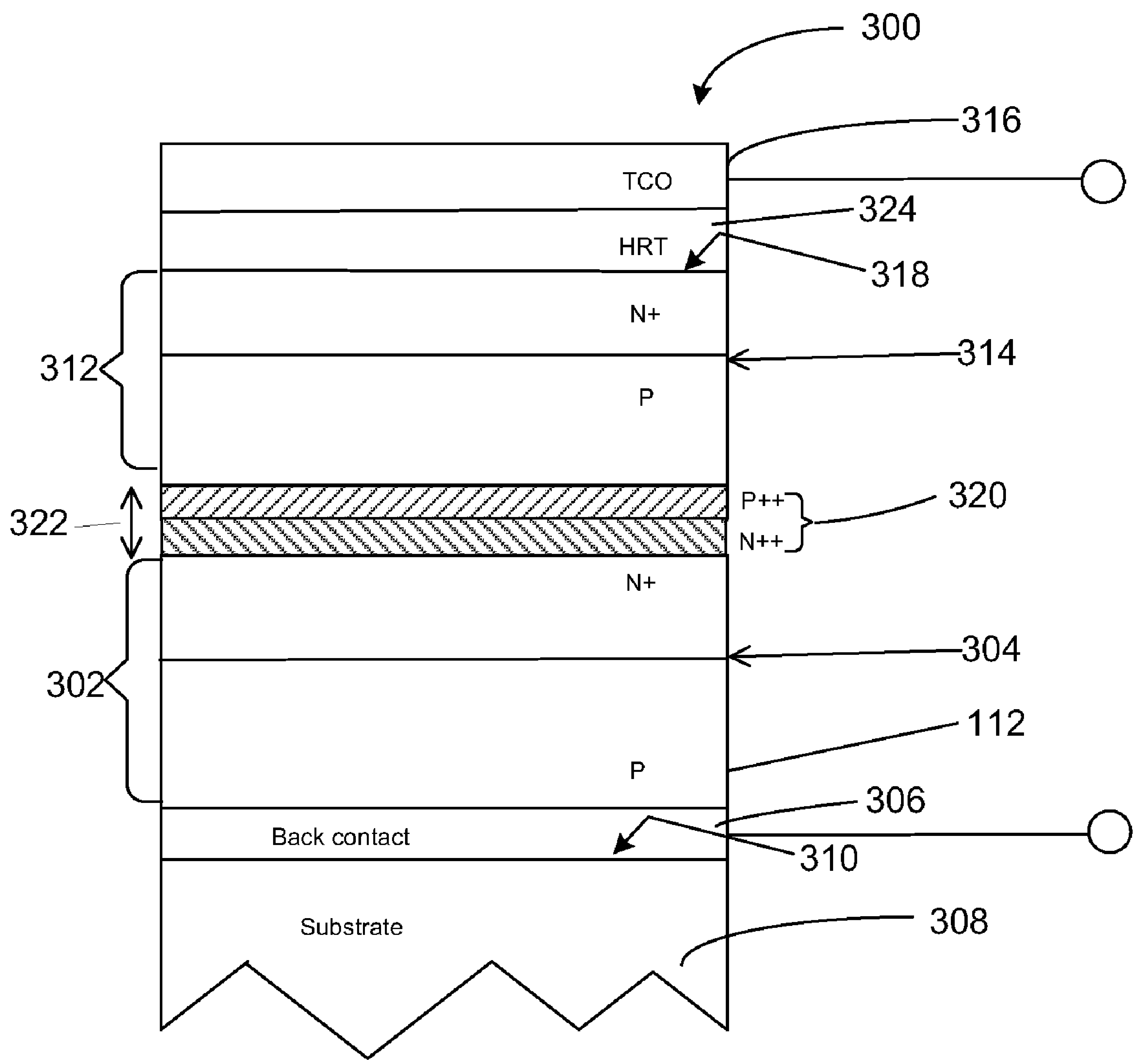


Figure 3

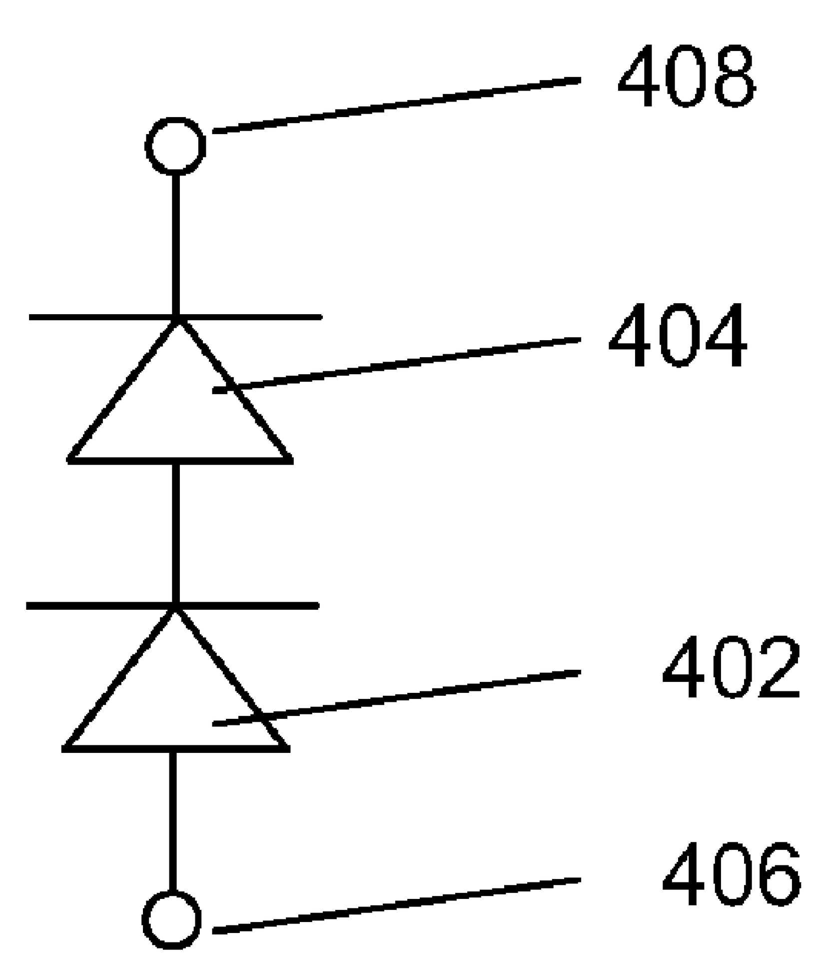


Figure 4

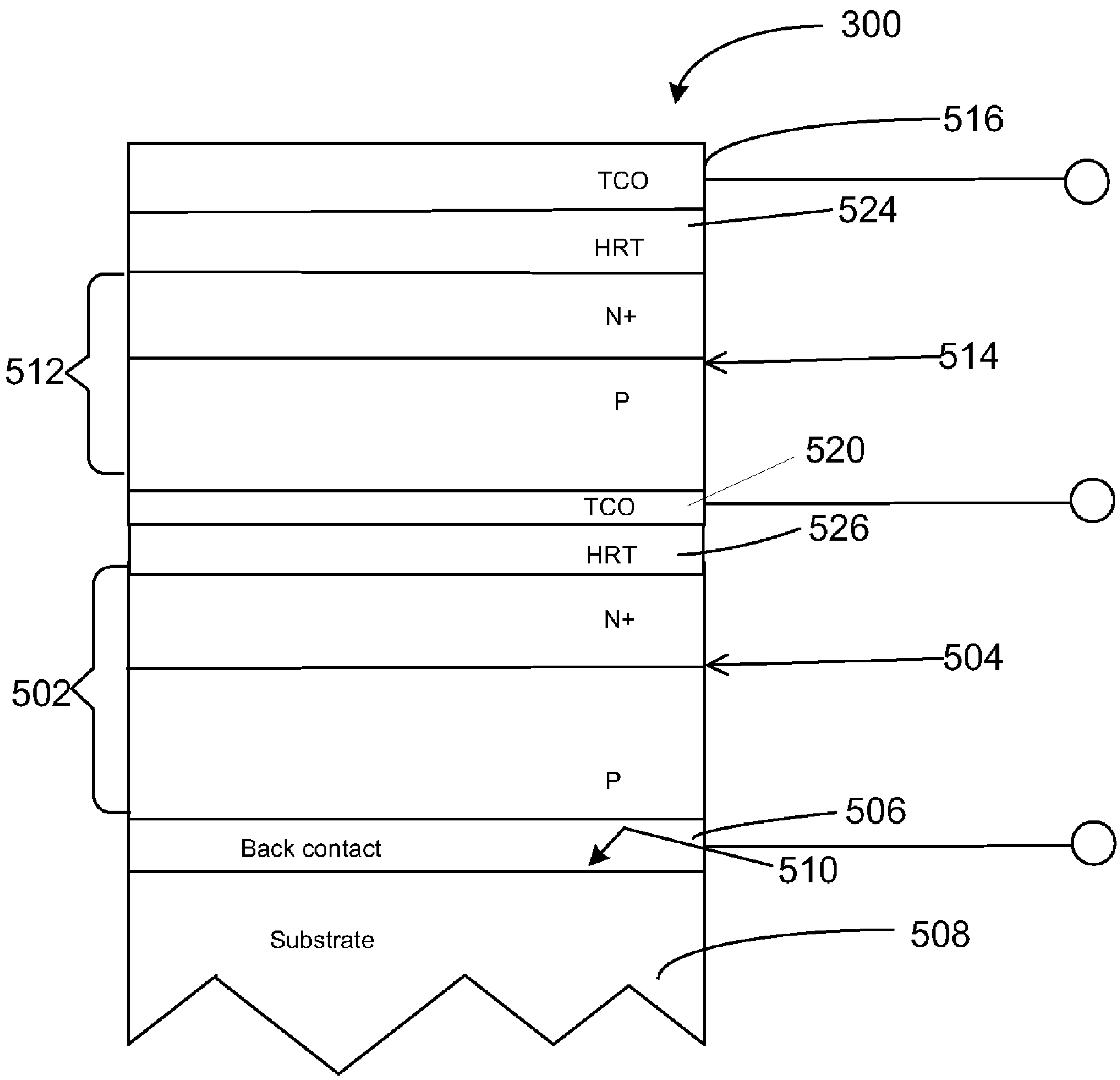


Figure 5

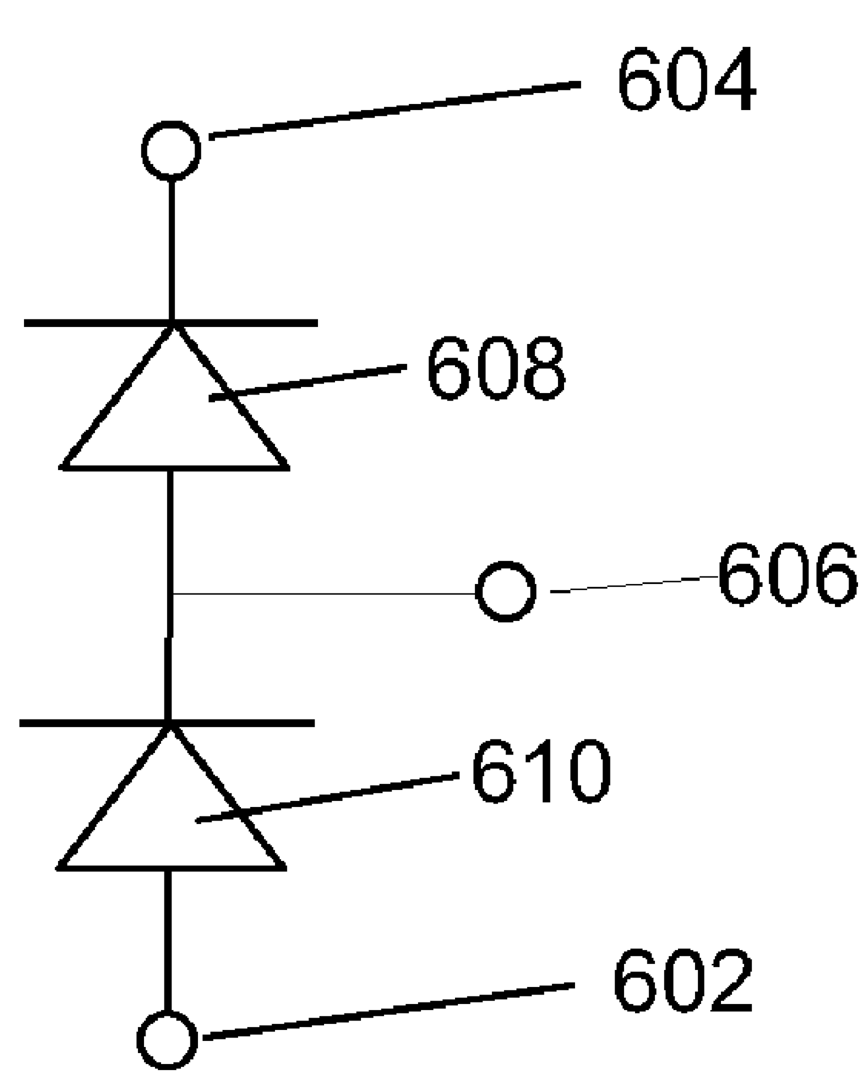


Figure 6

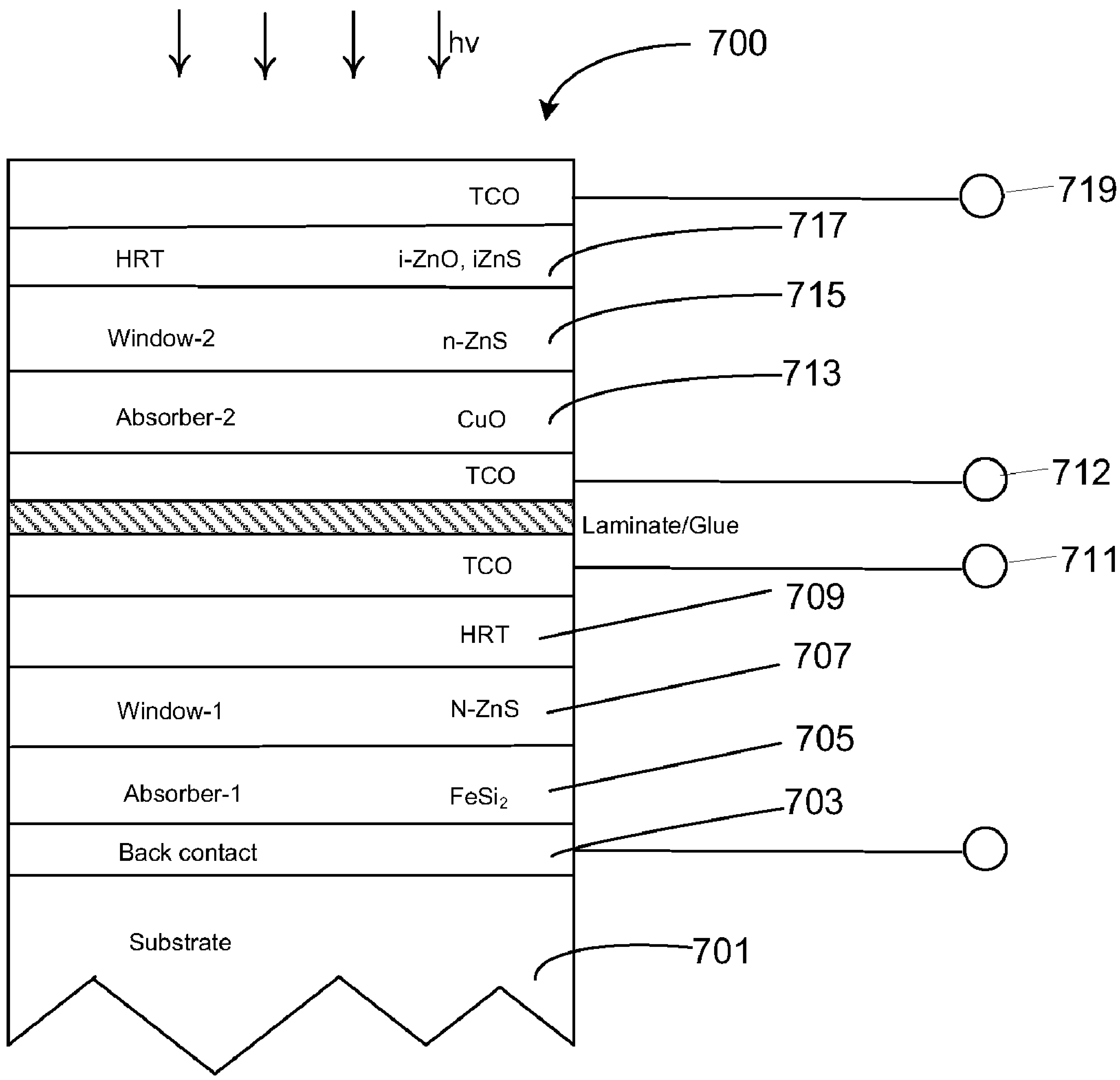

hv
700
TCO
719
HRT
i-ZnO, iZnS
717
Window-2
n-ZnS
715
Absorber-2
CuO
713
TCO
712
Laminate/Glue
TCO
711
HRT
709
Window-1
N-ZnS
707
Absorber-1
FeSi2
705
Back contact
703
Substrate
701

Figure 7

MULTI-JUNCTION SOLAR CELL DEVICES

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 60/988,414, filed Nov. 15, 2007 and U.S. Provisional Patent Application No. 60/988,099, filed Nov. 14, 2007, commonly assigned, incorporated herein by reference for all purposes.

STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

REFERENCE TO A "SEQUENCE LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX SUBMITTED ON A COMPACT DISK

[0003] Not Applicable

BACKGROUND OF THE INVENTION

[0004] The present invention relates generally to photovoltaic cell structure. More particularly, the present invention provides a method and structure of a photovoltaic cell for manufacture of solar module using a thin film process. Merely by way of example, the present method and structure have been implemented using a multijunction configuration, but it would be recognized that the invention may have other configurations.

[0005] From the beginning of time, human beings have been challenged to find way of harnessing energy. Energy comes in the forms such as petrochemical, hydroelectric, nuclear, wind, biomass, solar, and more primitive forms such as wood and coal. Over the past century, modern civilization has relied upon petrochemical energy as an important source. Petrochemical energy includes gas and oil. Gas includes lighter forms such as butane and propane, commonly used to heat homes and serve as fuel for cooking. Gas also includes gasoline, diesel, and jet fuel, commonly used for transportation purposes. Heavier forms of petrochemicals can also be used to heat homes in some places. Unfortunately, petrochemical energy is limited and essentially fixed based upon the amount available on the planet Earth. Additionally, as more human beings begin to drive and use petrochemicals, it is becoming a rather scarce resource, which will eventually run out over time.

[0006] More recently, clean sources of energy have been desired. An example of a clean source of energy is hydroelectric power. Hydroelectric power is derived from electric generators driven by the force of water that has been held back by large dams such as the Hoover Dam in Nevada. The electric power generated is used to power up a large portion of Los Angeles Calif. Other types of clean energy include solar energy. Specific details of solar energy can be found throughout the present background and more particularly below.

[0007] Solar energy generally converts electromagnetic radiation from our sun to other useful forms of energy. These other forms of energy include thermal energy and electrical power. For electrical power applications, solar cells are often used. Although solar energy is clean and has been successful to a point, there are still many limitations before it becomes widely used throughout the world. As an example, one type of solar cell uses crystalline materials, which form from semiconductor material ingots. These crystalline materials include photo-diode devices that convert electromagnetic radiation into electrical current. Crystalline materials are often costly and difficult to make on a wide scale. Additionally, devices made from such crystalline materials have low energy conversion efficiencies. Other types of solar cells use "thin film" technology to form a thin film of photosensitive material to be used to convert electromagnetic radiation into electrical current. Similar limitations exist with the use of thin film technology in making solar cells. That is, efficiencies are often poor. Additionally, film reliability is often poor and cannot be used for extensive periods of time in conventional environmental applications. These and other limitations of these conventional technologies can be found throughout the present specification and more particularly below.

[0008] From the above, it is seen that improved techniques for manufacturing photovoltaic cells and resulting devices are desired.

BRIEF SUMMARY OF THE INVENTION

[0009] According to embodiments of the present invention, techniques including structures for a multijunction solar device are provided. More particularly, embodiments according to the present invention provide a multijunction photovoltaic cell structure and a resulting photovoltaic device using thin film metal chalcogenide semiconductor materials and/or other suitable semiconductor films. But it would be recognized that the present invention has a broader range of applicability.

[0010] In a specific embodiment, a photovoltaic cell structure for manufacturing a photovoltaic device is provided. The photovoltaic cell structure includes a substrate member having a surface region. The photovoltaic cell structure includes a first conductor layer overlying the surface region of the substrate member. The photovoltaic cell structure includes a lower cell structure overlying the first conductor layer. In a specific embodiment, the lower cell structure includes a first P type absorber layer. The first P type absorber layer is characterized by a first bandgap ranging from about 0.5 to about 1.0 eV, but can be others. The first P type absorber layer is characterized by a first optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising 400 nm to 800 nm, but can be others. In a specific embodiment, the first P type absorber layer includes at least a first metal chalcogenide material and/or other suitable semiconductor material. The lower cell structure includes a first N^+ type window layer comprising at least a second metal chalcogenide material and/or other suitable semiconductor material overlying the first P type absorber layer. In a specific embodiment, the photovoltaic cell structure includes an upper cell structure. The upper cell structure includes a second P type absorber layer. The second P type absorber layer comprises at least a third metal chalcogenide material and/or other semiconductor material characterized by a second bandgap ranging from about 1.0 eV to 2.2 eV, but can be others. In an alternative embodiment, the second P absorber layer is characterized by a second bandgap ranging from 1.0 eV to about 2.0 eV, but can be others. In a preferred embodiment, the second P type absorber layer is characterized by a second bandgap ranging from about 1.2 eV to about 1.8 eV and a second optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising 400 nm to 800 nm. In a specific embodiment, the second bandgap is greater than the first bandgap. The upper cell structure includes a second N^+ window layer overlying the second P absorber layer. In a specific embodiment, the photovoltaic cell structure includes a p^{++}/n^{++} layer disposed between the upper cell structure and the lower cell structure. In a specific embodiment, the p^{++}/n^{++} layer provides a tunneling junction for the upper cell structure and the lower cell structure. In a specific embodiment, the photovoltaic cell structure includes an optional buffer layer overlying the second N^+ type window layer. The optional buffer layer is characterized by a resistivity greater than about 10 kohm-cm according to a specific embodiment. A second conductor structure is provided overlying the optional buffer layer. Of course, there can be other variations, modifications, and alternatives.

[0011] In an alternative embodiment, an alternative photovoltaic cell structure for manufacturing of a photovoltaic device is provided. The alternative photovoltaic cell structure includes a substrate including a surface region. The alternative photovoltaic cell structure includes a first conductor structure overlying the surface region of the substrate. The alternative photovoltaic cell structure a lower cell structure overlying the first conductor structure. The lower cell structure includes a first P type absorber layer. The first P type absorber layer includes a first metal chalcogenide material and/or other suitable semiconductor material, characterized by a first bandgap ranging from about 0.5 eV to about 1.0 eV and a first optical absorption coefficient greater than about 10^4 cm^1 in the wavelength range comprising 400 nm to 800 nm in a specific embodiment. The lower cell structure includes a first N^+ type window layer overlying the first P type absorber layer. The first N^+ type window layer can use a second semiconductor metal chalcogenide material and/or a suitable semiconductor material. The first P type absorber layer and the first N^+ type window layer form an interface region characterized by a first pn^+ junction. The alternative photovoltaic cell structure includes a second conductor structure overlying the lower cell structure. In a specific embodiment, an upper cell structure is provided overlying the second conductor structure. The upper cell structure includes a second P type absorber layer. In a specific embodiment, the second P type absorber uses a third metal chalcogenide material characterized by a second bandgap ranging from 1.2 eV to 2.2 eV and a second optical coefficient greater than about 10^4 cm^{-1} for the wavelength range comprising about 400 nm to about 800 nm. In a specific embodiment, the second bandgap is greater than the first bandgap. The upper cell structure includes a second N^+ type window layer overlying the second P type absorber layer. The alternative photovoltaic cell structure includes an optional buffer layer characterized by a resistivity greater than about 10 k-ohm cm overlying the second N^+ type window layer of the upper cell structure. A third conductor layer overlies the buffer layer.

[0012] In a yet alternative embodiment, a photovoltaic cell structure for manufacturing a photovoltaic device is provided. The photovoltaic cell structure includes a substrate having a surface region. The photovoltaic cell structure includes a first photovoltaic cell structure overlying the surface region of the substrate. The first photovoltaic cell structure includes a first conductor layer. The first photovoltaic cell structure includes a first P type absorber layer overlying the first conductor layer. In a specific embodiment, the first P type absorber layer uses a first semiconductor metal chalcogenide material and/or other suitable semiconductor material characterized by a first bandgap ranging from 0.5 eV to 1.0 eV and a first optical absorption coefficient greater than about 10^4 cm^{-1} in the wavelength range comprising about 400 nm to about 800 nm. The first photovoltaic cell structure includes a first N^+ type window layer overlying the first P type absorber layer. In a specific embodiment, the first N^+ type window layer includes at least a second semiconductor metal chalcogenide material and/or other suitable semiconductor material. A second conductor structure overlying the first N^+ type window layer. The photovoltaic cell structure includes a second photovoltaic cell structure. The second photovoltaic cell structure includes a third conductor structure. In a specific embodiment, a second P type absorber layer comprising a third semiconductor metal chalcogenide material characterized by a second bandgap ranging from about 1.0 eV to about 2.2 eV and a second optical absorption greater than 10^4 cm^{-1} in a wavelength range comprising 400 nm to 800 nm. In a specific embodiment, the second bandgap is greater than the first bandgap. A second N^+ type window layer overlies the second P type absorber layer. The second N^+ type window layer is formed using a fourth metal chalcogenide material. The second photovoltaic cell structure includes a fourth electrode structure overlying the second N^+ type window layer. In a specific embodiment, a glue layer or a laminating layer is provided to couple the first photovoltaic cell structure to the second photovoltaic cell.

[0013] In another specific embodiment, a method for manufacturing a photovoltaic device is provided. The method includes providing a first substrate including a first surface region. The method forms a first conductor layer overlying the surface region and a first P type absorber layer overlying the first conductor layer. In a specific embodiment, the first P type absorber layer includes a first metal chalcogenide material and/or other semiconductor material. Preferably, the first P type absorber layer is characterized by a first bandgap ranging from about 0.5 eV to about 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm. The method includes forming a first N^+ type window layer overlying the first P type absorber layer. In a specific embodiment, the first N^+ type window layer includes a second metal chalcogenide material and/or other semiconductor material. A second conductor layer is formed overlying the first N^+ type window layer. In a specific embodiment, the first conductor layer, the first P type absorber layer, the first N^+ type window layer, and the second conductor layer provide for a first photovoltaic cell structure. The method includes providing a second substrate including a second surface region. A third conductor layer is formed overlying the second surface region and a second N^+ type window layer is formed overlying the third conductor layer. The method includes forming a second P type absorber layer overlying the second N^+ type window layer. In a specific embodiment, the second N^+ type window layer includes a third metal chalcogenide material characterized by a second bandgap ranging from 1.0 eV to 2.2 eV, a second optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm. The method forms fourth conductor layer overlying the second P type absorber layer. In a specific embodiment, the third conductor layer, the second P type absorber layer, the second N^+ type window layer and the fourth conductor layer provide for a second photovoltaic cell structure. In a specific embodiment, a glue layer is provided between the first photovoltaic cell structure and the second photovoltaic cell structure. The glue layer is disposed between the second conductor layer and the forth conductor layer in a specific embodiment.

[0014] In a yet another embodiment, a method for manufacturing of a photovoltaic device is provided. The method includes providing a substrate including a surface region. A first conductor structure is formed overlying the surface region. A lower cell is formed overlying the first conductor structure. The lower cell includes a first P type absorber layer. In a specific embodiment, the first P type absorber layer includes a first metal chalcogenide material and/or other semiconductor material. The first P type absorber layer is characterized by a first bandgap ranging from about 0.5 eV to 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm. The lower cell includes a first N^+ type window layer comprising a second metal chalcogenide material and/or other semiconductor material overlying the first P type absorber layer. The method forms a second conductor structure overlying the lower cell structure. The method includes forming an upper cell structure overlying the second conductor structure. The upper cell structure includes a second P type absorber layer. The P type absorber layer includes a third metal chalcogenide material overlying the second conductor layer. In a specific embodiment, a bandgap ranging from 1.0 eV to 2.2 eV, and a second optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm characterize the second P type absorber layer. The upper cell structure includes a second N^+ type window layer overlying the second P type absorber layer. In a specific embodiment, the method forms a buffer layer overlying the second N^+ type window layer of the upper cell structure. The buffer layer is characterized by a resistivity greater than about 10 k-ohm cm in a specific embodiment. A third conductor layer is formed overlying the buffer layer.

[0015] In a still yet another embodiment, a method for manufacturing a photovoltaic device is provided. The method includes providing a substrate including a surface region. A first conductor layer is formed overlying the surface region and a lower cell structure is formed overlying the first conductor layer. The lower cell structure includes a first P type absorber including at least a first metal chalcogenide material and/or other suitable semiconductor material overlying the first conductor layer. The first P type absorber material is characterized by a first bandgap ranging from 0.5 eV to 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1}, and a first thickness ranging from 0.5 um to 2 um. The lower cell structure includes a first N^+ type window layer comprising at least a second metal chalcogenide material and/or other suitable semiconductor material overlying the first P type absorber layer. In a specific embodiment, the method forms a tunneling junction layer overlying the first N^+ type window layer of the lower cell. The tunneling junction layer includes at least a p^{++} type semiconductor material and an n^{++} type semiconductor material in a specific embodiment. The method includes forming an upper cell structure. The upper cell structure includes a second P type absorber material overlying the tunneling junction layer. In a specific embodiment, the second P type absorber material includes at least a third metal chalcogenide material. In a specific embodiment, the second P type absorber material is characterized by a second bandgap ranging from 1.0 eV to 2.2 eV, a second optical absorption coefficient greater than about 10^4 cm^{-1}, and a second thickness ranging from 0.5 um to 2 um. A second N^+ type window layer comprising at least a fourth metal chalcogenide material is formed overlying the second absorber layer. The method includes forming a buffer layer overlying the second N^+ type window layer of the upper cell structure. The buffer layer is characterized by a resistivity greater than about 10 kohm-cm in a specific embodiment. A second conductor layer is formed overlying the buffer layer.

[0016] Depending on the embodiment, one or more of these features may be included. The present invention provides a multijunction solar cell structure using metal chalcogenides and other semiconductor materials. The present structure can be provided using easy to use processes using convention equipment without further modifications. Depending upon the embodiment, each of the metal chalcogenide semiconductor material may provided as nanostructured or in bulk. In a specific embodiment, the present solar cell structure provides a higher conversion efficiency in converting sunlight into electric energy. Depending on the embodiment, the conversion efficiency may be 15 percent to 20 percent or greater for the resulting multijunction solar cell. Additionally, the present multifunction solar cell structure can be provided using large scale manufacturing processes, which reduce cost in manufacturing of the photovoltaic devices. Depending on the embodiments, one or more of these benefits may be achieved. These benefits will be described more fully throughout the present specification, and particularly below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a simplified diagram illustrating a photovoltaic cell structure according to an embodiment of the present invention.

[0018] FIG. **2** is a simplified circuit diagram illustrating the photovoltaic cell structure in FIG. **1**.

[0019] FIG. **3** is a simplified diagram illustrating an alternative photovoltaic cell structure according to an embodiment of the present invention.

[0020] FIG. **4** is a simplified circuit diagram illustrating the photovoltaic cell structure in FIG. **2**.

[0021] FIG. **5** is a simplified diagram illustrating an alternative photovoltaic cell structure according to an embodiment of the present invention.

[0022] FIG. **6** is a simplified circuit diagram illustrating the photovoltaic cell structure in FIG. **5**.

[0023] FIG. **7** is a simplified diagram illustrating an example of a photovoltaic cell structure according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0024] According to embodiments of the present invention, techniques directed to photovoltaic cell structure are provided. More particularly, embodiments according to the present invention provide a multijunction photovoltaic cell structure and a resulting photovoltaic cell having a high conversion efficiency. But it would be recognize that embodiments according to the present invention have a much broader range of applicability.

[0025] FIG. **1** is a simplified diagram illustrating a photovoltaic cell structure **100** for manufacturing a multifunction solar module according to an embodiment of the present invention. As shown, the photovoltaic cell structure includes a substrate member **102** having a surface region **104**. The substrate member can be made of an insulator material, a conductor material, or a semiconductor material, depending on the application. In a specific embodiment, the conductor material can be nickel, molybdenum, aluminum, or a metal alloy such as stainless steel and the likes. In a specific embodiment, the semiconductor material may include silicon, germanium, silicon germanium, compound semiconductor material such as III-V materials, II-VI materials, and others. In a specific embodiment, the insulator material can be a transparent material such as glass, quartz, fused silica, and the like. Alternatively, the insulator material can be a polymer material, a ceramic material, or a layer material or a composite material depending on the application. The polymer material may include acrylic material, polycarbonate material, and others, depending on the embodiment. Of course, there can be other variations modifications, and alternatives.

[0026] As shown in FIG. **1**, the photovoltaic cell structure includes a first photovoltaic cell structure **106**. In a specific embodiment, the first photovoltaic cell structure includes a first electrode structure **108**. In a specific embodiment, the first electrode structure uses a first conductor material characterized by a resistivity less than about 10 ohm-cm. The first electrode structure can be made of a suitable material or a combination of materials. The first electrode structure can be made from a transparent conductive electrode or materials that are light reflecting or light blocking depending on the embodiment. Examples of the transparent conductive electrode can include indium tin oxide (ITO), aluminum doped zinc oxide, fluorine doped tin oxide and others. In a specific embodiment, the transparent conductive electrode may be provide using techniques such as sputtering, chemical vapor deposition, electrochemical deposition, and others. In a specific embodiment, the first electrode structure may be made from a metal material. The metal material can include gold, silver, nickel, platinum, aluminum, tungsten, molybdenum, a combination of these, or an alloy, among others. In a specific embodiment, the metal material may be deposited using techniques such as sputtering, electroplating, electrochemical deposition and others. Alternatively, the first electrode structure may be made of a carbon based material such as carbon or graphite. Yet alternatively, the first electrode structure may be made of a conductive polymer material, depending on the application. Of course there can be other variations, modifications, and alternatives, modifications, and alternatives.

[0027] Referring again to FIG. **1**, the first photovoltaic cell structure includes a lower cell **110** overlying the first electrode structure. In a specific embodiment, the lower cell includes a first absorber layer **112** characterized by a P type impurity characteristics. That is, the first absorber layer absorbs electromagnetic radiation forming positively charged carriers within the first absorber layer. In a specific embodiment, the first absorber layer comprises a first metal chalcogenide semiconductor material and/or other suitable semiconductor material. The first absorber layer is characterized by a bandgap. In a specific embodiment, the first absorber layer has a first bandgap of ranging from about 0.7 eV to about 1.2 eV. In an alternative embodiment, the first absorber layer can have a first bandgap of about 0.5 eV to about 1.2 eV. In a preferred embodiment, the first absorber layer can have a bandgap of about 0.5 eV to about 1.0 eV. The first metal chalcogenide semiconductor material can include a suitable metal oxide. Alternatively, the first metal chalcogenide semiconductor material can include a suitable metal sulfide. Yet alternatively first metal chalcogenide semiconductor material can include a metal telluride or metal selenide depending on the application. In certain embodiments, the first absorber layer can be provided using a metal silicide material such as iron disilicide material, which has a P type impurity characteristics, and others. In a specific embodiment, the first absorber layer can be deposited using techniques such as sputtering, spin coating, doctor blading, powder coating, electrochemical deposition, inkjeting, among others, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0028] In a specific embodiment, the first absorber layer has an optical absorption coefficient greater than about 10^4 cm^{-1} for electromagnetic radiation in a wavelength range of about 400 nm to about 800 nm. In an alternative embodiment, the first absorber layer can have an optical absorption coefficient greater than about 10^4 cm^{-1} for electromagnetic radiation in a wavelength range of about 450 nm to about 700 nm. Of course there can be other variations, modifications, and alternatives.

[0029] Referring to FIG. **1**, the lower cell includes a first window layer **114** overlying the first absorber layer. In a specific embodiment, the first window layer has a N^+ impurity type characteristics. In a preferred embodiment, the first window layer is characterized by a bandgap greater than about 2.5 eV, for example ranging from 2.5 eV to about 5.5 eV. In a specific embodiment, the first window layer comprises a second metal chalcogenide semiconductor material and/or other suitable semiconductor material. Alternatively, the second metal chalcogenide semiconductor material can comprise a semiconductor metal sulfide, a semiconductor metal oxide, a semiconductor metal telluride or a semiconductor metal selenide material. In certain embodiment, the first window layer may use an n-type zinc sulfide material for a iron disilicide material as the first absorber layer. In a specific embodiment, the first window layer can be deposited using techniques such as sputtering, spin coating, doctor blading, powder coating, electrochemical deposition, inkjeting, among others, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0030] Again referring to FIG. **1**, the first photovoltaic cell structure includes a second electrode structure **116** overlying the lower cell in a specific embodiment. The second electrode structure is in electrical contact with the window layer in a specific embodiment. In a specific embodiment, the second electrode structure uses a conductor material characterized by a resistivity less than about 10 ohm-cm. In a specific embodiment, the second electrode structure can be made of a suitable material or a combination of materials. The second electrode structure is preferably made from a transparent conductive electrode material. Materials that are light reflecting or light blocking may also be used depending on the embodiment. Examples of the optically transparent material can include indium tin oxide (ITO), aluminum doped zinc oxide, fluorine doped tin oxide and others. In an alternative embodiment, the second electrode structure may be made from a metal material. The metal material can include gold, silver, nickel, platinum, aluminum, tungsten, molybdenum, a combination of these, or an alloy, among others. In a specific embodiment, the metal material may be deposited using techniques such as sputtering, electroplating, electrochemical deposition and others. Yet alternatively, the second electrode structure may be made of a carbon based material such as carbon or graphite. In certain embodiments, the second electrode structure may be made of a conductive polymer material, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0031] As shown in FIG. **1**, photovoltaic cell structure **100** includes a second photovoltaic cell structure **118**. In a specific embodiment, the second photovoltaic cell structure includes a third electrode structure **120**. In a specific embodiment, the third electrode structure uses a conductor material characterized by a resistivity less than about 10 ohm-cm. In a specific embodiment, the third electrode structure can be made of a suitable material or a combination of materials. The third electrode structure is preferably made from a transparent conductive electrode. Materials that are light reflecting or light blocking may also be used depending on the embodiment. Examples of the optically transparent material can include indium tin oxide (ITO), aluminum doped zinc oxide, fluorine doped tin oxide and others. In an alternative embodiment, the second electrode structure may be made from a metal material. The metal material can include gold, silver, nickel, platinum, aluminum, tungsten, molybdenum, a combination of these, or an alloy, among others. In a specific embodiment, the metal material may be deposited using techniques such as sputtering, electroplating, electrochemical deposition, and others. Yet alternatively, the second electrode structure may be made of a carbon based material such as carbon or graphite. In certain embodiments, the second electrode structure may be made of a conductive polymer material, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0032] The upper photovoltaic cell includes an upper cell **122** overlying the third electrode structure. The upper cell includes a second absorber layer **124** overlying the third electrode structure. In a specific embodiment, the second absorber layer is characterized by a P type impurity characteristics. That is, the second absorber layer absorbs electromagnetic radiation forming positively charged carriers within the second absorber layer. In a specific embodiment, the second absorber layer comprises a third metal chalcogenide semiconductor material. The third metal chalcogenide semiconductor material is characterized by a second bandgap. In a specific embodiment, the second bandgap is greater than the first bandgap. In a specific embodiment, the second bandgap can range from about 1.0 eV to about 2.2 eV. In an alternative embodiment, the second bandgap can range from about 1.0 eV to about 2.5 eV. In a preferred embodiment, the third bandgap can range from about 1.2 eV to about 1.8 eV. The third metal chalcogenide semiconductor material can include a suitable semiconductor metal oxide. Alternatively, the third metal chalcogenide semiconductor material can include a suitable metal sulfide. Yet alternatively third metal chalcogenide semiconductor material can include a suitable semiconductor metal telluride or metal selenide depending on the application. In a specific embodiment, the second absorber layer is provided using a copper oxide material, which has a p type impurity characteristics. Of course there can be other variations, modifications, and alternatives.

[0033] Referring again to FIG. **1**, the upper cell includes a second window layer **126**. In a specific embodiment, the second window layer has a N^+ impurity type characteristics. In a specific embodiment, the second window layer is characterized by a bandgap greater than about 2.5 eV, for example, ranging from about 2.5 eV to 5.0 eV. In a specific embodiment, the second window layer comprises a fourth metal chalcogenide semiconductor material. The fourth metal chalcogenide semiconductor material can include a suitable semiconductor metal sulfide, a suitable semiconductor metal oxide, a suitable semiconductor metal telluride or a suitable semiconductor metal selenide material. In a specific embodiment, the second window layer may be provided using a sinc sulfide material, which has an N type impurity characteristics. In a specific embodiment, the second window layer may be deposited using techniques such as sputtering, doctor blading, inkjeting, electrochemical deposition, and others.

[0034] In a specific embodiment, the second photovoltaic cell structure includes a fourth electrode structure **128** overlying the upper cell. In a specific embodiment, the fourth electrode structure uses a conductor material characterized by a resistivity less than about 10 ohm-cm. In a specific embodiment, the fourth electrode structure can be made of a suitable material or a combination of materials. The fourth electrode structure is preferably a transparent conductive electrode. Materials that are light reflecting or light blocking may also be used depending on the embodiment. Examples of the transparent conductive electrode can include indium tin oxide (ITO), aluminum doped zinc oxide, fluorine doped tin oxide and others. In an alternative embodiment, the fourth electrode structure may be made from a metal material. The metal material can include gold, silver, nickel, platinum, aluminum, tungsten, molybdenum, a combination of these, or an alloy, among others. In a specific embodiment, the metal material may be deposited using techniques such as sputtering, electroplating, electrochemical deposition and others. Yet alternatively, the fourth electrode structure may be made of a carbon based material such as carbon or graphite. In certain embodiments, the fourth electrode structure may be made of a conductive polymer material, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0035] In a specific embodiment, the first photovoltaic cell structure and the second photovoltaic cell structure are coupled together using a glue layer **130** to form a multijunction photovoltaic cell structure as shown in FIG. **1**. As shown, photovoltaic cell structure **100** includes a first junction region **132** caused by the first absorber layer and the first window layer. Photovoltaic cell structure **100** includes also a second junction region **134** caused by the second absorber layer and the second window layer. The glue layer is a suitable material that has desirable optical and mechanical characteristics. Such material can be ethyl vinyl acetate or polyvinyl butyral and the like, but can also be others. As shown in FIG. **2** a simplified circuit representation **130** of the multijunction cell structure is depicted. As shown, the multijunction photovoltaic cell structure has four terminals **136**, **138**, **140**, and **142** provided by the first electrode structure, the second electrode structure, the third electrode structure, and the fourth electrode structure. The multijunction photovoltaic cell has two photodiodes **144** and **146** as provided by the upper cell and the lower cells. Of course one skilled in the art would recognize other variations, modifications, and alternative.

[0036] In a specific embodiment, the photovoltaic cell structure can have an optional buffer layer **148** disposed between the second conductor structure and the second absorber layer of the upper cell as shown in FIG. **1**. The optional buffer layer is characterized by a resistivity greater than about 10 kohm-cm and is preferably optically transparent in a specific embodiment. Of course there can be other variations, modifications, and alternatives.

[0037] FIG. **3** is a simplified diagram illustrating another photovoltaic cell structure **300** for manufacture of a multijunction solar cell module according to an alternative embodiment of the present invention. Photovoltaic cell structure **300** is configured to have two junctions and two electrode. As shown, photovoltaic cell structure **300** includes a lower cell **302** which includes a first pn^+ junction **304**. The lower cell can have a same material composition as the lower cell as described above in connection with the photovoltaic cell structure in FIG. **1**. The lower cell is in electrical contact with a first electrode structure **306** which overlies a surface region **310** of a substrate member **308** also as described above for FIG. **1**.

[0038] Photovoltaic cell **300** includes an upper cell **312** which includes a second pn^+ junction **314**. The upper cell also has a same material composition as the upper cell as described above in connection with the photovoltaic cell structure in FIG. **1**. A second electrode structure **316** overlies and in electrical contact with a surface region **318** of the upper cell.

[0039] In a specific embodiment, a tunneling junction layer **320** is provided between the upper cell and the lower cell as shown in FIG. **3**. The tunneling junction layer comprises a p++/n++ layer and is characterized by a thickness **322**. In a specific embodiment, the tunneling junction layer can be adjusted, either by way of thickness, or by way of dopant characteristics, to provide an optimized current flow between the upper cell and the lower cell. Of course there can be other variations, modifications, and alternatives.

[0040] Optionally, photovoltaic cell structure **300** can include a buffer layer **324**, which is optional, disposed between the second conductor structure and the upper cell. The buffer layer prevents diffusion of, for example, electrode materials into the photovoltaic cell in subsequent high temperature processing steps. Buffer layer **324** may be made from a high resistance transparent material having a resistivity greater than 10 kOhm-cm in a specific embodiment. Example of such high resistance transparent material can include intrinsic semiconductor such as intrinsic zinc oxide, intrinsic zinc sulfide and the like. Of course there can be other variations, modifications, and alternatives.

[0041] FIG. **4** is a simplified circuit diagram for photovoltaic cell structure **300** according to an embodiment of the present invention. As shown, the photovoltaic cell structure includes a first photodiode **402**, a second photodiode **404**, a first electrode terminal **406**, and a second electrode terminal **408**. Photovoltaic cell structure **300** can be characterized by two junctions, provided by each of the photodiodes and two electrode terminals. The first photodiode and the second photodiode are connected in series by means of the tunneling junction. Of course there can be other variations, modifications, and alternatives.

[0042] FIG. **5** is a simplified diagram illustrating a photovoltaic cell structure **500** for manufacturing of a multijunction solar module according to another alternative embodiment of the present invention. Photovoltaic cell structure **500** is configured to have two junctions and three electrode terminals. As shown, photovoltaic cell structure **500** includes a lower cell **502** which includes a first pn^+ junction **504**. The lower cell can have a same material composition as the lower cell as described above in connection with the photovoltaic cell structure in FIG. **1**. The lower cell is in electrical contact with a first electrode structure **506** which overlies a surface region **510** of a substrate member **508** also as described above for FIG. **1**.

[0043] Photovoltaic cell structure **500** includes an upper cell **512** which includes a second pn^+ junction **514**. The upper cell can have a same material composition as the upper cell as described above in connection with the photovoltaic cell structure in FIG. **1**. A second electrode structure **516** overlies and in electrical contact with the upper cell.

[0044] In a specific embodiment, a third conductor structure **520** is provided between the upper cell and the lower cell as shown in FIG. **5**. The third conductor structure connects the upper cell and the lower cell in series in a specific embodiment. In a specific embodiment, the third conductor structure is characterized by a resistivity less than about 10 ohm-cm. The third electrode structure can be made of a suitable material or a combination of materials. The third electrode structure is preferably made from a transparent conductive electrode or materials. Examples of the transparent conductive material can include indium tin oxide (ITO), aluminum doped zinc oxide, fluorine doped tin oxide and others. In an alternative embodiment, the third electrode structure may be made from a metal material. The metal material can include gold, silver, nickel, platinum, aluminum, tungsten, molybdenum, a combination of these, or an alloy, among others. In a specific embodiment, the metal material may be deposited using techniques such as sputtering, electroplating, electrochemical deposition and others. Yet alternatively, the third electrode structure may be made of a carbon based material such as carbon or graphite. In certain embodiments, the third electrode structure may be made of a conductive polymer material, depending on the application. Of course there can be other variations, modifications, and alternatives.

[0045] In certain embodiments, the photovoltaic cell structure **500** can include an optional first buffer layer **524** disposed between the second conductor structure and the upper cell as shown in FIG. **5**. Photovoltaic cell structure **500** can also include an optional second buffer layer **526** provided between the third electrode structure and the lower cell. These buffer layers prevent diffusion of, for example, electrode materials into the respective photovoltaic cells in subsequent high temperature processing steps. In a specific embodiment, the buffer layers are characterized by a resistivity greater than about 10 kohm-cm and can be provided using a suitable metal oxide. Of course there can be other variations, modifications, and alternatives.

[0046] FIG. **6** is a simplified circuit representation **600** of the photovoltaic cell structure in FIG. **5**. As shown in FIG. **6**, the photovoltaic cell structure has 3 terminals **602**, **604**, and **606** provided by the first electrode structure, the second electrode structure, and the third electrode structure The photovoltaic cell has two photodiodes **608** and **610** as provided by the upper cell and the lower cell. Of course one skilled in the art would recognize other variations, modifications, and alternative.

[0047] FIG. **7** is a simplified cross-sectional view of an example of a hetero-junction cell **700** according to an embodiment of the present invention. As shown, the cell has a substrate **701** including a surface region. In a specific embodiment, the substrate can be a glass material, although other materials can be used. In a specific embodiment, the cell has a first conductor layer **703**, which is a back contact, overlying the surface region. As an example, the back contact is a metal material. To define the lower cell structure, a first P type absorber (e.g., P-) comprising an iron disilicide material **705** is included. Further details of forming iron disilicide material have been described in U.S. patent application Ser. Nos. 12/209,801 (Attorney Docket No. 026335-001410US) filed Sep. 12, 2008, which claims priority to US Provisional Application No. 60/976,239, filed Sep. 28, 2007 and 12/210,173 (Attorney Docket No. 026335-001510US) filed Sep. 12, 2008, which claims priority to U.S. Provisional Application 60/976,317, filed Sep. 28, 2007), and hereby incorporate by reference for all purpose. In a specific embodiment, a first N^+ type window layer is included. In a specific embodiment, the first N^+ type window layer is provided by a N—ZnS material. In a specific embodiment, a high resistance transparent layer **709**, which is optional, overlies the first N^+ type window layer. As an example, the high resistance layer can be intrinsic ZnS, intrinsic ZnO or other suitable materials.

[0048] Overlying the lower cell is a transparent conductive oxide **711**, which can be ZnO (doped with aluminum), SnO_3 (doped with fluorine), or other suitable materials. Disposed between the lower and upper cells is a lamination layer and can be a glue layer, which is optically transparent. The lamination layer may be provided using an EVA material or a PVB material in a specific embodiment. To form an upper cell structure, a third transparent conductive oxide **712** is provided according to a specific embodiment. A second P type absorber layer **713** comprising a copper oxide material or other suitable material is formed overlying transparent conductive oxide **712**. A second N^+ type window layer **715** comprising an n-ZnS material is overlying the second P type absorber layer. In a specific embodiment, a second high resistance transparent layer **717** is overlying the second N^+ type window layer. As an example, the second high resistance transparent layer **717** can be intrinsic ZnS, intrinsic ZnO, or other suitable materials. A transparent conductive oxide **719** is formed overlying high resistance transparent layer **717** according to a specific embodiment. Of course, depending upon the embodiment, the materials and/layers specified can be applied to other cell configurations such as three electrode, two electrode, and others.

[0049] It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art. For example, embodiments according to the present invention have been described using a two cell configuration. It is understood that the present invention can be extended to include N cells ($N \geqq 2$). Various modifications and changes are to be included within the spirit and purview of this application and scope of the appended claims.

1. A photovoltaic cell structure for manufacturing a photovoltaic device, the photovoltaic cell structure comprises:

a substrate including a surface region;

a first conductor layer overlying the surface region;

a lower cell structure, the lower cell structure comprising a first P type absorber comprising at least a first metal chalcogenide material and/or other suitable semiconductor material overlying the first conductor layer, the first P type absorber material being characterized by a first bandgap ranging from 0.5 eV to 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1}, and a first thickness ranging from 0.5 um to 2 um;

a first N^+ type window layer comprising at least a second metal chalcogenide material and/or other suitable semiconductor material overlying the first P type absorber layer;

a tunneling junction layer overlying the first N^+ type window layer of the lower cell, the tunneling junction layer comprising at least a p^{++} type semiconductor material and an n^{++} type semiconductor material;

an upper cell structure, the upper cell structure comprising:

a second P type absorber material comprising at least a third metal chalcogenide material overlying the tunneling junction layer, the second P type absorber material being characterized by a second bandgap ranging from 1.0 eV to 2.2 eV and a second optical absorption coefficient greater than about 10^4 cm^{-1}, a second thickness ranging from 0.5 um to 2 um;

a second N^+ type window layer comprising at least a fourth metal chalcogenide material overlying the second absorber layer;

a buffer layer overlying the second N^+ type window layer of the upper cell structure; the buffer layer being characterized by a resistivity greater than about 10 kohm-cm; and

a second conductor layer overlying the buffer layer.

2. The structure of claim **1** wherein the substrate is a semiconductor, for example, silicon, germanium, compound semiconductor material such as a III-V gallium arsenide, germanium, silicon germanium, and others.

3-5. (canceled)

6. The structure of claim **1** wherein the first metal chalcogenide material is selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or semiconductor metal telluride.

7. The structure of claim **1** wherein the second metal chalcogenide material is selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or a semiconductor metal telluride, or a semiconductor metal silicide.

8. The structure of claim **1** wherein the third metal chalcogenide material is selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or semiconductor telluride.

9. The structure of claim **1** wherein the fourth metal chalcogenide material is selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or a semiconductor metal telluride.

10. The structure of claim **1** wherein the first P type absorber layer comprises an iron disilicide material.

11. The structure of claim **1** wherein the first N^+ type window layer comprises a zinc sulfide material.

12. The structure of claim **1** wherein the second P type absorber layer comprises a copper oxide material.

13. The structure of claim **1** wherein the second N^+ window layer comprises a zinc sulfide material.

14. The structure of claim **1** wherein the first bandgap is less than the second bandgap.

15. (canceled)

16. The structure of claim **1** wherein the first conductor layer comprises a transparent conducting oxide material selected from ZnO:Al, SnO:F, ITO, and others.

17. (canceled)

18. The structure of claim **1** wherein the second conductor layer comprises a transparent conducting oxide material selected from ZnO:Al, SnO:F, ITO, and others.

19. (canceled)

20. The structure of claim **1** wherein the tunneling junction layer provides a series connection between the upper cell structure and the lower cell structure.

21. A photovoltaic cell structure for manufacturing of a photovoltaic device, the structure comprises:

a substrate including a surface region;

a first conductor structure overlying the surface region;

a lower cell structure overlying the first conductor structure, the lower cell comprising:

a first P type absorber layer comprising a first metal chalcogenide material and/or other semiconductor

material, the first P type absorber layer being characterized by a first bandgap ranging from about 0.5 eV to 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm;
a first N^+ type window layer comprising a second metal chalcogenide material and/or other semiconductor material overlying the first P type absorber layer;
a first buffer layer overlying the first N^+ type window layer;
a second conductor structure overlying the lower cell structure;
an upper cell structure overlying the second conductor structure, the upper cell structure comprising:
a second P type absorber layer comprising a third metal chalcogenide material overlying the second conductor layer, a bandgap ranging from 1.0 eV to 2.2 eV, a second optical absorption coefficient greater than about 10^4 cm in a wavelength range comprising about 400 nm to about 800 nm characterize the second P type absorber layer;
a second N^+ type window layer overlying the second P type absorber layer;
a second buffer layer overlying the second N^+ type window layer of the upper cell structure; the buffer layer being characterized by a resistivity greater than about 10 k-ohm cm; and
a third conductor layer overlying the buffer layer.

22. The structure of claim **21** wherein the substrate is a semiconductor, for example, silicon, germanium, compound semiconductor material such as a III-V gallium arsenide, germanium, silicon germanium, and others.

23-42. (canceled)

43. A photovoltaic cell structure for manufacturing a photovoltaic device, the structure comprises:
a substrate including a surface region;
a first photovoltaic cell structure overlying the surface region; the first photovoltaic cell structure comprising:
a first conductor layer;
a first P type absorber layer overlying the first conductor layer, the first P type absorber layer comprising a first metal chalcogenide material and/or other semiconductor material, the first P type absorber layer being characterized by a first bandgap ranging from about 0.5 eV to about 1.0 eV, a first optical absorption coefficient greater than about 10^4 cm^{-1} in a wavelength range comprising about 400 nm to about 800 nm.
a first N^+ type window layer comprising a second metal chalcogenide material and or other semiconductor material overlying the first P type absorber layer;
a second conductor layer overlying the first N^+ type window layer;
a second photovoltaic cell structure; the second photovoltaic cell structure comprising:
a third conductor layer;
a second P type absorber layer comprising a third metal chalcogenide material, the second P type absorber layer being characterized by a second bandgap ranging from 1.0 eV to 2.2 eV, a second optical absorption coefficient greater than about 10^4 cm in a wavelength range comprising about 400 nm to about 800 nm;
a second N^+ type window layer overlying the second P type absorber layer;
a fourth conductor layer overlying the second N^+ type window layer; and
a glue layer coupling the first photovoltaic cell structure to the second photovoltaic cell structure.

44. The structure of claim **43** wherein the substrate is a semiconductor, for example, silicon, germanium, compound semiconductor material such as a III-V gallium arsenide, germanium, silicon germanium, and others.

45-48. (canceled)

49. The structure of claim **43** wherein the second metal chalcogenide material is selected from is selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or semiconductor metal telluride.

50-54. (canceled)

55. The structure of claim **43** wherein the second N^+ window layer comprises a metal chalcogenide material selected from a semiconductor metal oxide, a semiconductor metal sulfide, a semiconductor metal selenide, or semiconductor metal telluride.

56-126. (canceled)

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