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(54) **METHOD FOR FORMING A GEXSI1-X BUFFER LAYER OF SOLAR-ENERGY BATTERY ON A SILICON WAFER**

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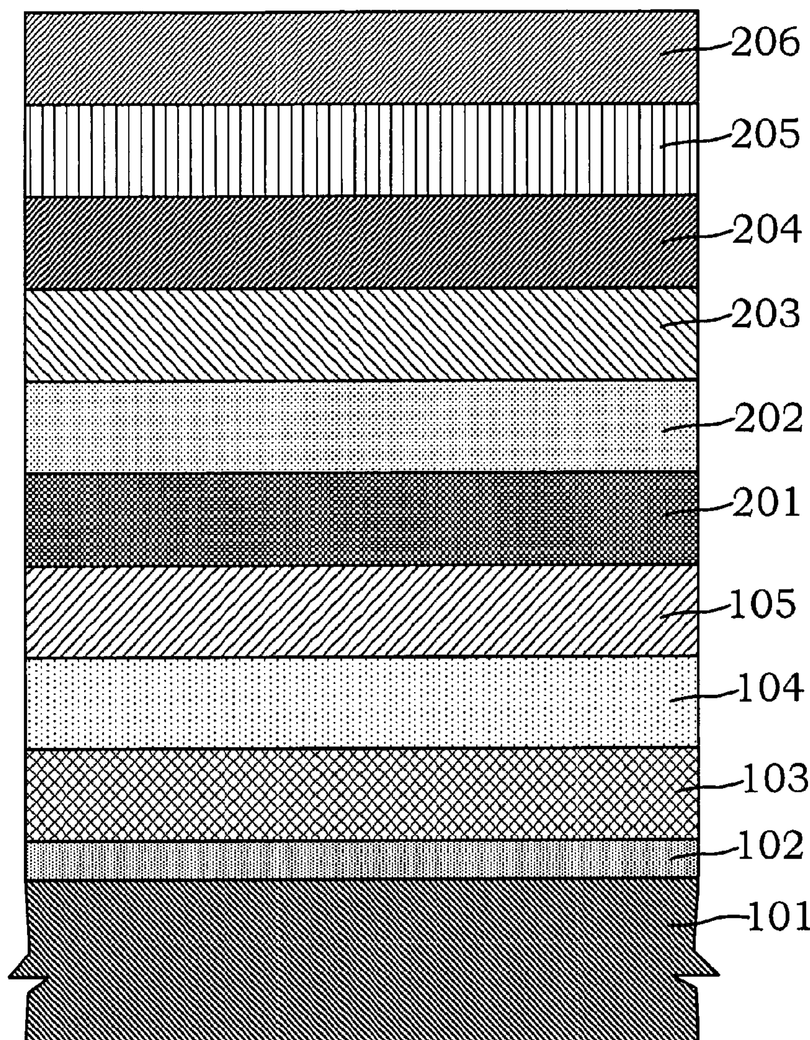
(57) **ABSTRACT**

The method is disclosed that Si^+ is implanted on Si substrate to enhance strain relaxation at the interface between the metamorphic Ge_xSi_{1-x} buffer layers and Si substrate, in order to facilitate the growth of a high quality Ge on Si substrate. And several Ge_xSi_{1-x} buffer layers ($Si/Ge_{0.8}Si_{0.2}/Ge_{0.9}Si_{0.1}/Ge$) are grown on top of Si substrate by UHVCVD. Then grow pure Ge layer of low dislocation density on Ge_xSi_{1-x} buffer layer. Finally, grow up high efficiency III-V solar cell on Ge_xSi_{1-x} buffer layer.



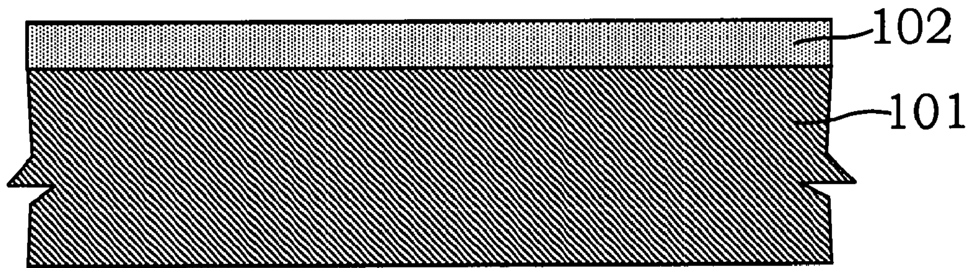


Figure 1A

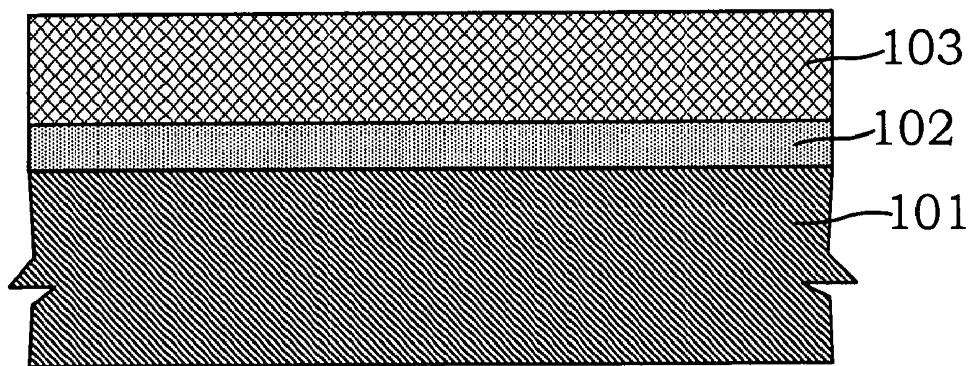


Figure 1B

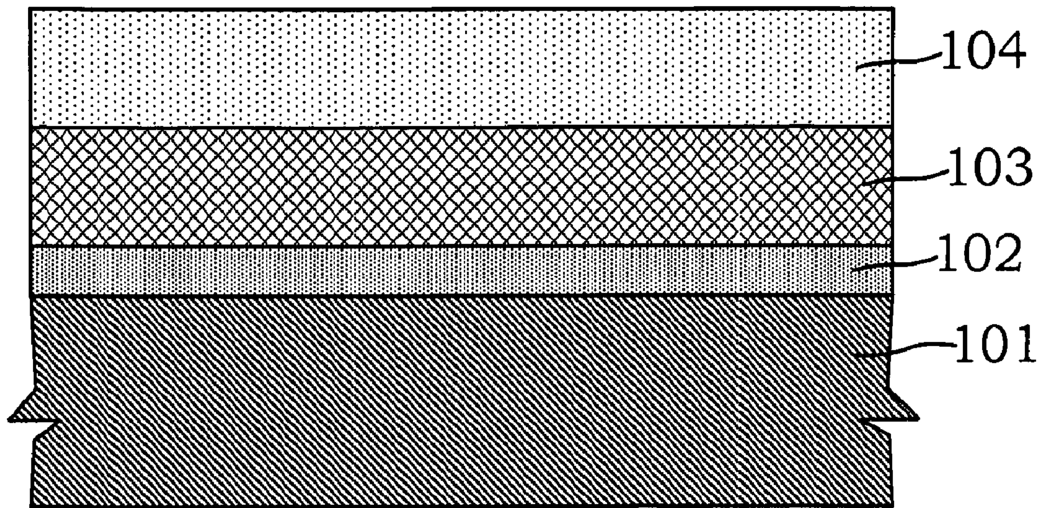


Figure 1C

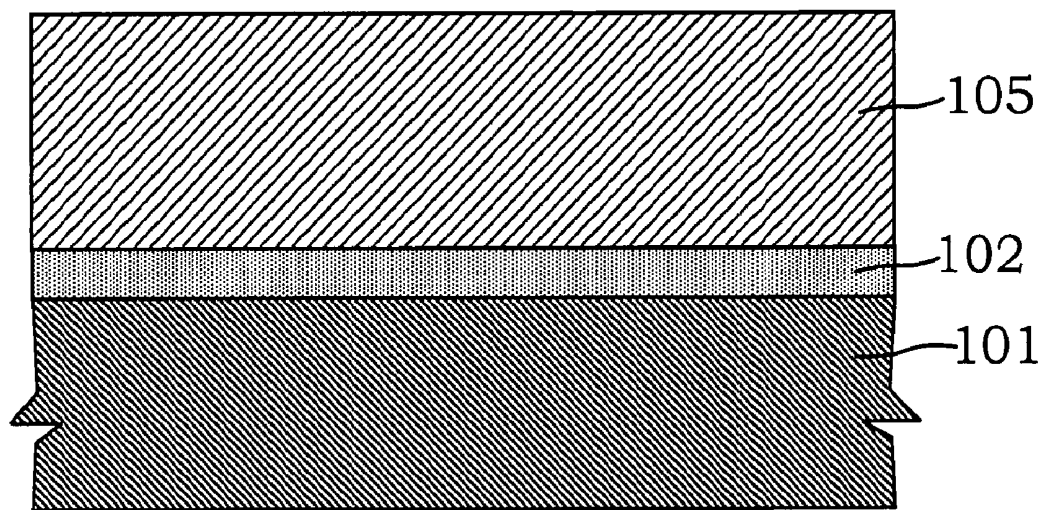


Figure 1D

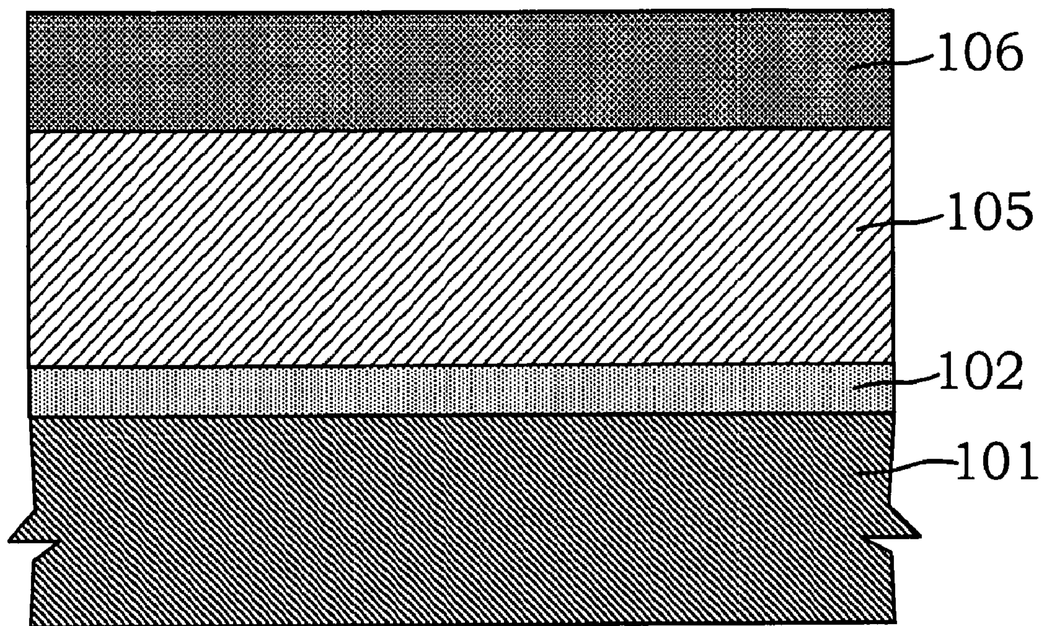


Figure 1E

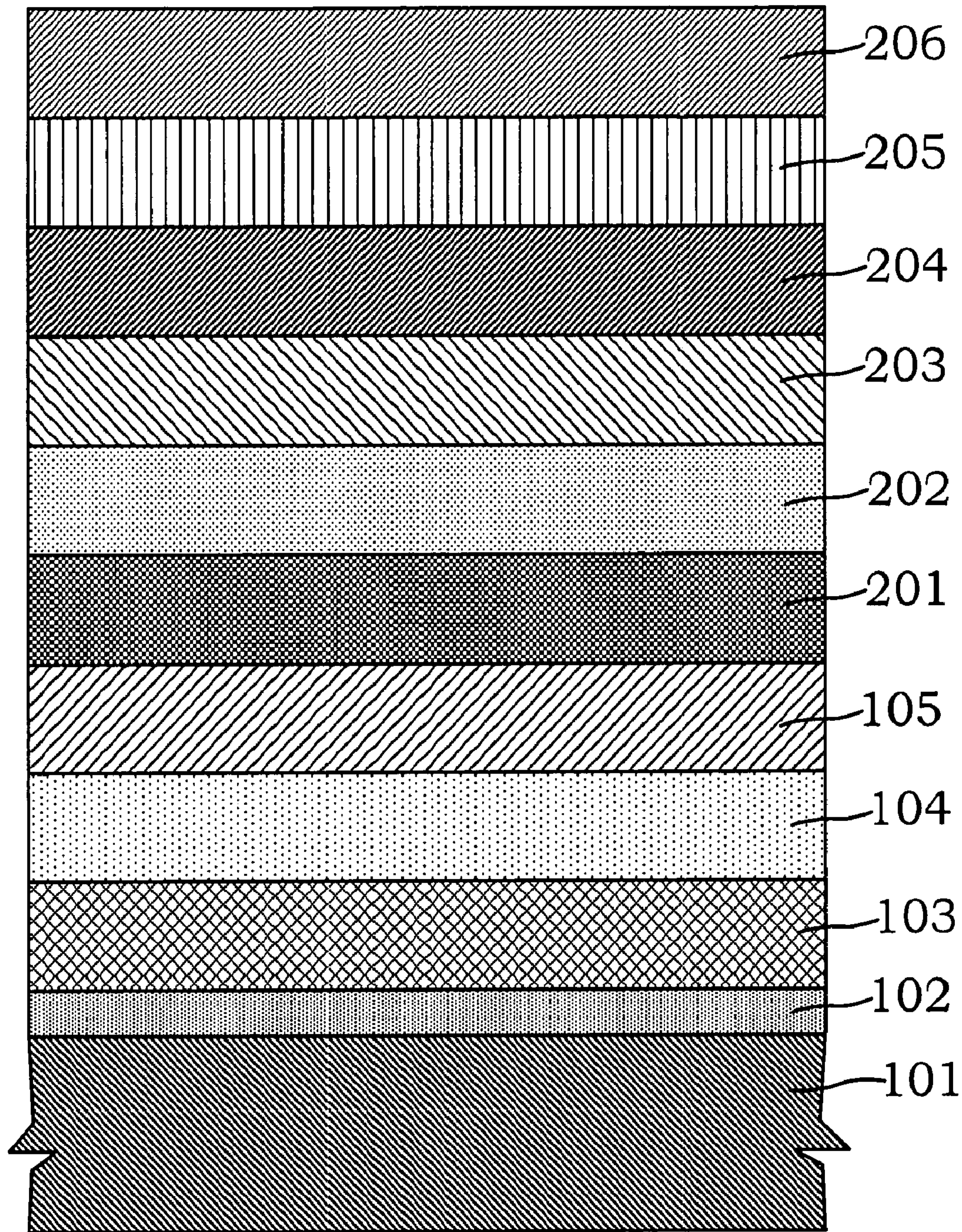


Figure 2

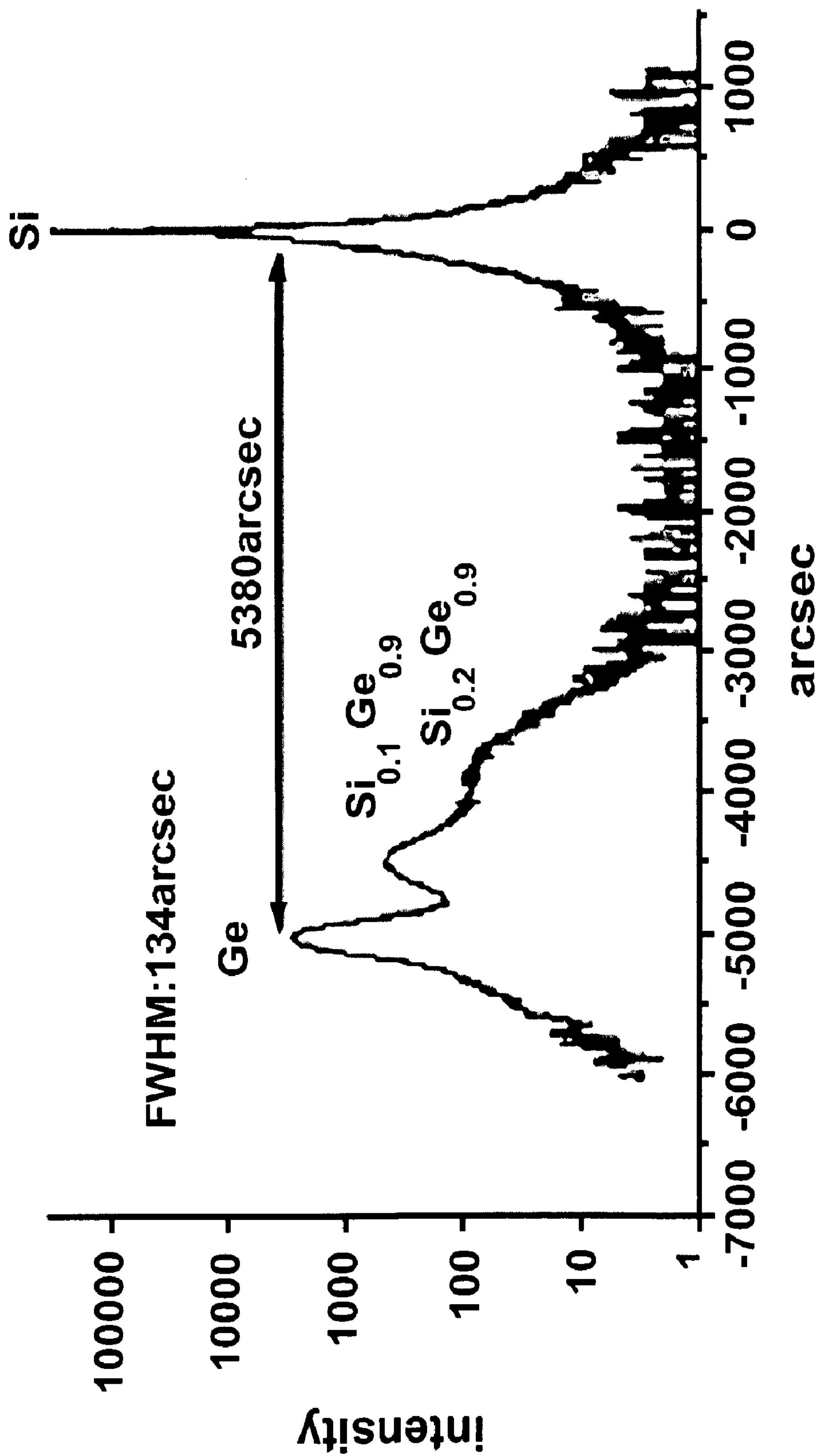


Figure 3

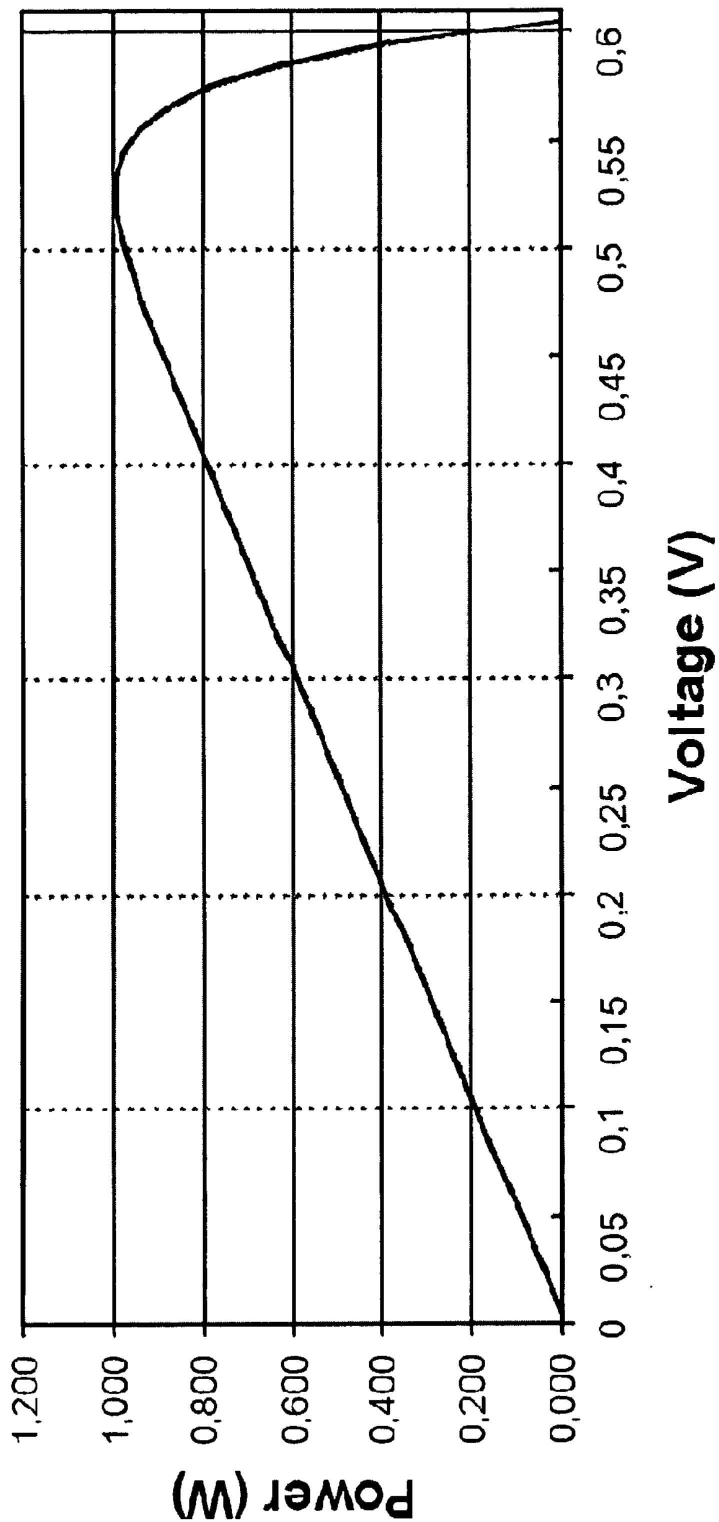


Figure 4A

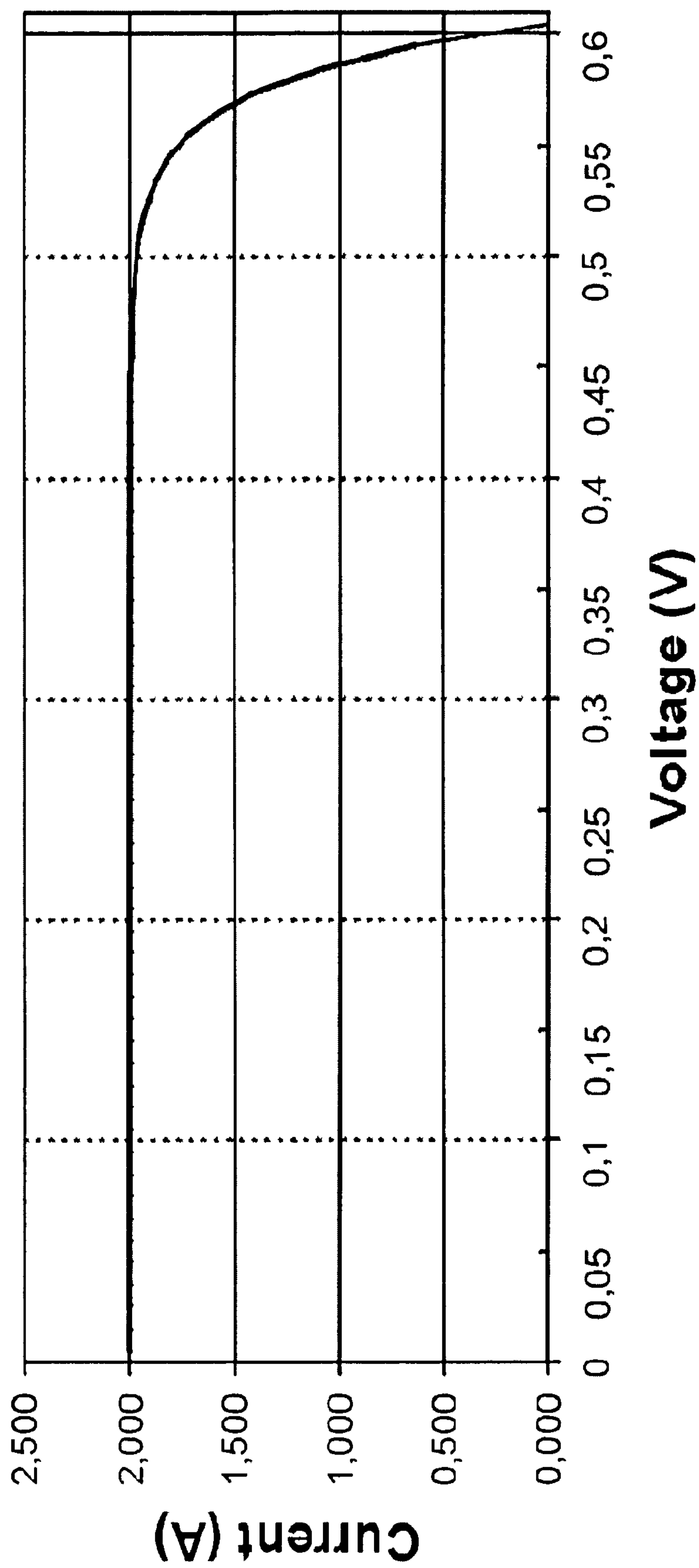


Figure 4B

METHOD FOR FORMING A GEXSI1-X BUFFER LAYER OF SOLAR-ENERGY BATTERY ON A SILICON WAFER

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The invention relates to a method for forming a Ge_xSi_{1-x} buffer layer, particularly to a method for forming a Ge_xSi_{1-x} buffer layer of solar-energy battery on a silicon wafer.

[0003] 2. Description of the Prior Art

[0004] The germanium-based (Ge) as a base substrate of InGaP/InGaAs/GaAs/Ge solar cell has become the main structure of III-V triple-junction solar cell, since the emergence of high-efficiency III-V triple-junction solar cell facing the world. In other words, these solar cells are composed of the gallium arsenide (GaAs) material system. At present, a lot of materials can be matched with the GaAs lattice, such as InGaAsP, InGaAlP, and AlGaAs etc. The growth technology of these materials is very mature, which is used by the industry widely. Due to these materials own the larger energy gap, they are able to be used on the junction with energy gap greater than GaAs. When the energy gap is smaller than GaAs, except germanium, it is very difficult to find other mature materials which can match with the GaAs lattice.

[0005] In the conventional GaAs solar cell fabrication process, the Metal Organic Chemical Vapor Deposition (MOCVD) is usually employed to deposit the Ge layer, InGaP layer, InGaAs layer, and the buffer layers sequentially on the germanium substrate by series packing, finally the electrodes and anti-reflect layers are coated on both ends of above-mentioned layers to form the finished product of solar cell. The absorption spectrum distribution and power generation efficiency of solar cell will be influenced by the composed elements of every conjunction layer, the lattice matching of every epitaxial layer, and the quality of crystal-type, in order to fabricate the high-efficiency solar cell that is best the lattice matching and the best energy gap distribution, also, the composed elements of every conjunction layer, the lattice matching of every epitaxial layer, and the quality of crystal-type will often become the key-point of bottleneck and fabrication yield for the technological development of solar cell.

[0006] Thus in the conventional technological area of solar energy, the germanium substrate is collected. The III-V semiconductors are grown on the germanium substrate. The total weight is relatively heavy, and the price of germanium substrate is quite higher as well. The maximum size of germanium substrate is only 4 inches, and it is unable to produce larger product. Thus the cost of Ge-based solar cell cannot be reduced for the industrial requirement.

[0007] In addition, the conventional method usually use $Si_{1-x}Ge_x$ (x=0~1) to grow the germanium on the silicon wafer. This method has the shortcomings, such as thicker SiGe buffer layer (up to about 10 μm), higher manufacturing cost and difficult fabrication process integration. And the surface of Ge will be rougher due to the generation of cross hatch pattern.

[0008] Thus in order to respond the demand for the related technology of solar cell, it is necessary to develop relevant technologies of solar cell, to save the cost of manpower and time, and to form the high-efficiency solar cell.

SUMMARY OF THE INVENTION

[0009] The invention does not use the germanium substrate of conventional solar cell technology but the GaAs is deposited on the silicon substrate to form the solar cell instead. The ion implantation method is used to reduce the stress between the silicon wafer and the SiGe epitaxial layer. Then the SiGe buffer layer is grown on the silicon substrate. Furthermore, the Ge thin layer is grown on the SiGe buffer layer, and the solar cell structure is grown on the Ge layer.

[0010] The invention can lighten the weight of the solar cell. The invention can be grown on larger silicon wafer (above six inches), which can reduce the cost greatly.

[0011] The invention uses the Si^+ implanted Si substrate to enhance the strain relaxation at the interface between the Si substrate and the SiGe epitaxial layer.

[0012] The invention grows the SiGe buffer layer on the Si substrate, and uses the generated stress field between the interface to block the formation and penetration of dislocations, in order to reduce the dislocation density of the SiGe epitaxial layer.

[0013] The invention uses the Si substrate as the substrate of III-V solar cell, which can raise the mechanical property of the solar energy chip effectively, in order to reduce the manufacturing cost and lighten the weight of the solar cell.

[0014] The invention can raise the light concentration folds of the solar cell, adjust the interface of different materials, and raise the conversion efficiency.

[0015] The invention can make the flexible solar cell, the main characteristics are the followings:

[0016] It can be used as energy gap material directly, it can absorb sunlight effectively. The conversion efficiency of multiple-junction solar cell is up to 39%. It can still maintain good operation feature at the environment of high temperature. It is suitable to be used under the light concentration condition.

[0017] The advantage and spirit of the invention can be understood further by the following detail description of invention and attached Figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as well becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0019] FIG. **1**A to FIG. **1**E show a preferred embodiment of the invention.

[0020] FIG. **2** shows a preferred embodiment of the invention.

[0021] FIG. **3** shows the X-ray diffraction diagram of the invention.

[0022] FIG. **4**A shows the power performance for the solar cell of the invention.

[0023] FIG. **4**B shows the electric charge performance for the solar cell of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0024] The invention uses the silicon substrate instead of the conventional Ge substrate, and uses P-type SiGe as the buffer layer. The P-type substrate is used as the positive

electrode, and the contact material of P-type electrode is combined at both ends to form the solar cell.

[0025] As shown in FIG. **1**A, a method for forming a GeSi buffer layer of solar-energy battery on a silicon wafer is illustrated. Provide a silicon substrate **101** firstly. The silicon substrate **101** is a P-type substrate, which can be used as the positive electrode. The Si^+ implantation method is used to form a Si^+ implantation layer **102** on the silicon substrate **101**. The purpose is to upset the lattice of the silicon substrate **101**, to facilitate the growth of relaxed SiGe layers in the next step.

[0026] As shown in FIG. **1**B, the Ultra High Vacuum Chemical Vapor Deposition (UHVCVD) is used to grow the first relaxed SiGe layer **103** (also called as the SiGe buffer layer **103**) on the Si^+ implantation layer **102**. It is the doping p plus (p^+) layer, and its growth condition is 450° C. and 30 mTorr.

[0027] As shown in FIG. **1**C, the Ultra High Vacuum Chemical Vapor Deposition (UHVCVD) is used to grow the second relaxed SiGe layer **104** (also called as the SiGe buffer layer **104**) on the first relaxed SiGe layer **103**. It is the doping p plus (p^+) layer, and its growth condition is 450□ and 30 mTorr.

[0028] As shown in FIG. **1**D, the first relaxed SiGe layer **103** and the second relaxed SiGe layer **104** can be combined to as a layer, which is called the relaxed SiGe layer **105** or the SiGe buffer layer **105**. It is the doping p plus (p^+) layer.

[0029] As shown in FIG. **1**E, the Ultra High Vacuum Chemical Vapor Deposition (UHVCVD) is used to grow a Ge layer **106** on the relaxed SiGe layer **105** or the SiGe buffer layer **105**. It is the doping p plus (p^+) layer. The mutual action between the SiGe buffer layer and the dislocation can block the formation of dislocation. The invention can reduce the thickness of the SiGe epitaxial layer. Normally, the thickness of the SiGe epitaxial layer ($Si/Ge_{0.8}Si_{0.2}/Ge_{0.9}Si_{0.1}/Ge$) can be reduced from 10 μm to 0.45 μm.

[0030] As shown in FIG. **2**, the Metal Organic Chemical Vapor Deposition (MOCVD) is used to grow the InGaAs layer **201**, the InGaP layer **202**, the n^- GaAs layer **203**, the p^+ GaAs layer **204**, and the textured InGaAlP layer **205**. The solar cell chip can obtain high-efficiency and full-spectrum absorption effect through using texture, quantum well, and multiple-junction epitaxial structure. The Plasma Enhanced Convention Vapor Deposition (PECVD) is used to implant Si^+ ion, to increase N-type doping concentration of photovoltaic elements and reduce the interface resistance. The H^+ ion is implanted to deactivate the ionization bond. Finally, the Inductively-Coupled Plasma (ICP) is used to deposit a SiN covering layer **206**.

[0031] The invention is mainly to form the III-V solar cell on the silicon substrate. Before the growth of the SiGe epitaxial layer, the Si^+ implantation is used to enhance the stress relaxation at the interface between the silicon substrate and the SiGe epitaxial layer. Then, the relaxed SiGe buffer layer is grown on the silicon substrate. The stress between the interface is used to block the formation and penetration of dislocations, in order to reduce the dislocation density on the metamorphic SiGe buffer layer. The dislocation density on the SiGe epitaxial layer can be reduced to $3\times10^6/cm^2$, and the root mean square (RMS) value on Ge surface can reach to 0.38 nm without generating cross hatch pattern. The contact material of P-type electrode is combined at both ends to form the solar cell, to reduce the fabrication cost of III-V high-efficiency solar cell.

[0032] FIG. **3** shows the X-ray diffraction diagram of the invention, which shows the existence of SiGe.

[0033] FIG. **4**A shows the power performance for the solar cell of the invention, where the power is the ordinate axis and the voltage is the abscissa axis.

[0034] FIG. **4**B shows the electric charge is stored by the solar cell of the invention, where the current is the ordinate axis and the voltage is the abscissa axis.

[0035] It is understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be construed as encompassing all the features of patentable novelty that reside in the present invention, including all features that would be treated as equivalents thereof by those skilled in the art to which this invention pertains.

What is claimed is:

1. A method for forming a GeSi layer of solar-energy battery on a silicon wafer, comprising:

forming a Si^+ ion implantation layer on a silicon substrate;

forming a relaxed SiGe layer on the Si^+ implantation layer; and

forming a Ge layer on the relaxed SiGe layer, in order to form the Ge layer on the silicon wafer of solar cell.

2. The method according to claim **1**, wherein the silicon substrate is a P-type substrate.

3. The method according to claim **2**, wherein the P-type substrate is provided as a positive electrode.

4. The method according to claim **1**, wherein the method used to form the Si^+ ion implantation layer comprises Si^+ ion implantation method.

5. The method according to claim **1**, wherein the method used to form the relaxed SiGe layer comprises Ultra High Vacuum Chemical Vapor Deposition.

6. The method according to claim **1**, wherein the relaxed SiGe layer is a SiGe buffer layer.

7. The method according to claim **1**, wherein the relaxed SiGe layer is a doping p plus (p^+) layer.

8. The method according to claim **1**, wherein the method used to form the Ge layer comprises Ultra High Vacuum Chemical Vapor Deposition.

9. A method for forming a GeSi layer of solar-energy battery on a silicon wafer, comprising:

providing a silicon substrate;

forming a Si^+ ion implantation layer on the silicon substrate;

forming a relaxed SiGe layer on the Si^+ ion implantation layer; and

forming a Ge layer on the relaxed SiGe layer, in order to form the Ge layer on the silicon wafer of solar cell.

10. The method according to claim **9**, wherein the silicon substrate is a P-type substrate.

11. The method according to claim **10**, wherein the P-type substrate is used as a positive electrode.

12. The method according to claim **9**, wherein the method used to form the Si^+ ion implantation layer comprises Si^+ ion implantation method.

13. The method according to claim **9**, wherein the method used to form the relaxed SiGe layer comprises Ultra High Vacuum Chemical Vapor Deposition.

14. The method according to claim **9**, wherein the relaxed SiGe layer is a SiGe buffer layer.

15. The method according to claim **9**, wherein the relaxed SiGe layer is a doping p plus (p^+) layer.

16. The method according to claim **9**, wherein the method used to form the Ge layer comprises Ultra High Vacuum Chemical Vapor Deposition.

17. A method for forming a solar-energy battery on a silicon wafer, comprising:

providing a silicon substrate;

forming a Si^+ ion implantation layer on the Si substrate;

forming a relaxed SiGe layer on the Si^+ implantation layer;

forming a Ge layer on the relaxed SiGe layer;

forming an InGaAs layer on the Ge layer;

forming an InGaP layer on the InGaAs layer;

forming a n^- GaAs layer on the InGaP layer;

forming a p^+ GaAs layer on the n^- GaAs layer;

forming an InGaAlP layer on the p^+ GaAs layer; and

depositing a SiN covering layer on the InGaAlP layer, in order to form the solar cell.

18. The method according to claim **17**, wherein the silicon substrate is a P-type substrate.

19. The method according to claim **18**, wherein the P-type substrate is provided as a positive electrode.

20. The method according to claim **17**, wherein the method used to form the Si^+ implantation layer comprises Si^+ ion implantation method.

21. The method according to claim **17**, wherein the method used to form the relaxed SiGe layer comprises Ultra High Vacuum Chemical Vapor Deposition.

22. The method according to claim **17**, wherein the relaxed SiGe layer is a SiGe buffer layer.

23. The method according to claim **17**, wherein the relaxed SiGe layer is a doping p plus (p^+) layer.

24. The method according to claim **17**, wherein the method used to form the Ge layer comprises Ultra High Vacuum Chemical Vapor Deposition.

25. The method according to claim **17**, wherein the method used to form the InGaAs layer comprises Metal Organic Chemical Vapor Deposition.

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