of improvement of substantially the damage-free laser-ablation process according to the invention.

Advantages and applications of the invention.

Application of the static thermodynamic model that describes the fluence threshold for pulsed laser ablation of SiO2 on Si with a buffer layer of a-Si of varying thickness, allows production of c-Si material based electronic components that are highly efficient, since ablation is obtained with almost no significant damage to the c-Si. Having also solved the heat equation for the SiO2 – a-Si –Si stack, the temperature distribution within the a-Si film and the Si substrate may be predicted and used for controlling important parameters related to performing the method of the invention, and to control properties of the c-Si wafer or chip product that was subjected to the ablation process. A material according to the invention having an interface thermal resistance between a-Si and Si is important by allowing a lower laser fluence ablation threshold, and by effecting a protection of the c-Si lattice that is located under the SiO2 layer in the area where the SiO2 is ablated by the energy of the laser beam pulse. The results obtained in the various embodiments of the invention are in good agreement with the experimental data provided by the present inventors, illustrating the advantage of including in the model the expected contribution from the native oxide layer to the thermal resistance of the interface.

In a first aspect of the invention it is provided a method for ablating a part of an electrically insulating layer covering a surface of a silicon crystal wafer or chip, comprising providing said silicon crystal wafer or chip comprising on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogenized or semiconductor level doped grade amorphous silicon, and on the layer of amorphous silicon, a layer of the electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon, and irradiating the surface of the silicon crystal wafer or chip by a pulsed laser beam of an optical energy fluence and a pulse duration adapted to melt and evaporize the layer of amorphous silicon in an area corresponding to a footprint or a cross sectionof the laser beam, so as to ablate a corresponding area of the electrically insulating layer.

In a second apsect of the invention it is provided the method according to the first aspect , wherein the laser beam wavelength is about or close to 532 nanometers, the optical energy fluence is between 0.3 and 0.5 Joules per square centimeter, preferably about 0.32 Joules per square centimeter, and the pulse duration is about 142 nanoseconds.

A third aspect of the invention provides a method according to the first or second aspect, wherein providing said silicon crystal wafer or chip comprises providing said silicon crystal wafer or chip having on top of the clean surface of the crystal wafer or chip, and located between the clean surface of the crystal wafer or chip and the amorphous silicon layer, a narrow silicon oxide layer having a thickness corresponding substantially to an oxide layer thickness obtained naturally by exposing a clean surface of the substantially pure or semiconductor level doped silicon crystal wafer or chip to a normal atmosphere mixture of gases at a normal atmospheric pressure and a normal room temperature.

In a fourth aspect of the invention a method for controlling an apparatus for method for ablating a part of an electrically insulating layer covering a surface of a silicon crystal wafer or chip comprising on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogenized semiconductor level doped grade amorphous silicon, and on the layer of amorphous silicon, a layer of the electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon, the method comprising controlling a pulsed laser beam source of said apparatus using the thermodynamic model that predicts the laser fluence ablation threshold of SiO2 on a-Si layers of varying thickness, as disclosed in the description under the chapter heading "Theoretical considerations".

A fifth aspect of the invention provides a computer program on a carrier comprising computer instruction executable in a programmable apparatus to to carry out the steps of the method of any one of the first, second or third aspect, or to carry out the steps of the method of the fourth aspect.

A sixth aspect of the invention provides a photovoltaic cell, comprising the substantially pure or semiconductor level doped silicon crystal wafer or chip produced by the method of any one of the first, second, third or fourth aspect.

A seventh aspect of the invention provides a photovoltaic cell, comprising the crystal wafer or chip produced in an programmable apparatus operated by the computer program according to the fifth aspect.

Patent Claims

~~1. A method for processing a substantially pure or semiconductor-level doped silicon crystal wafer or chip for adapting the wafer or chip for laser beam ablation of an electrically insulating surface layer carried on the wafer or chip, comprising producing on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogenized or semiconductor-level doped-grade amorphous silicon, and producing on the layer of amorphous silicon, an electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon.~~

~~2. The method of claim 1, wherein producing the layer of amorphous silicon includes processing the layer of amorphous silicon to exhibit a predetermined optical absorbance at said optical optical wavelength of said laser beam.~~

~~3. The method of claim 2, wherein processing the layer of amorphous silicon includes hydrogenizing the amorphous silicon to a hydrogen content in a range from 5% to 15% atomic.~~

~~4. The method of claim 2 or 3, wherein the predetermined optical absorbance exhibits at least one absorbance peak at an optical wavelength of about or close to 532 nanometers.~~

~~5. The method of any one of the preceding claims, wherein the wavelength of the laser beam is about or close to 532 nanometers.~~

~~6. The method of any one of the preceding claims, wherein the thickness of the layer of amorphous silicon is preferably in a range from about 5 nanometers to about 300 nanometers, more preferably in a range from about 50 nanometers to about 200 nanometeres, and still more preferably about 100 nanometers.~~

~~7. The method of any one of the preceding claims, comprising producing on top of the clean surface of the crystal wafer or chip, a narrow silicon oxide layer having a thickness corresponding substantially to an oxide layer thickness obtained naturally by exposing a clean surface of the substantially pure or semiconductor-level doped silicon crystal wafer or chip to a normal atmosphere mixture of gases at a normal atmospheric pressure and a normal room temperature, such that~~

narrow silicon oxide layer becomes located between the clean surface of the crystal wafer or chip and the amorphous silicon layer.

8. The method of any one of the preceding claims, wherein the thickness of the narrow layer of silicon oxide is about 1 to 5 nanometers

9. A substantially pure or semiconductor level doped silicon crystal wafer or chip adapted for laser ablation of an electrically insulating surface layer carried on the wafer or chip, comprising
on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogeniszed or semiconductor level doped grade amorphous silicon, and
on the layer of amorphous silicon, a layer of the electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon.

10. The silicon crystal wafer or chip of claim 9, wherein the layer of amorphous silicon includes processing the layer of amorphous silicon exhibits a predetermined optical absorbance.

11. The silicon crystal wafer or chip of claim 10, wherein the layer of amorphous silicon includes amorphous silicon hydrogenized to a hydrogen content in a range from 5% to 15% atomic.

12. The silicon crystal wafer or chip of claim 10 or 11, wherein the predetermined optical absorbance exhibits at least one absorbance peak at an optical wavelength of about or close to 532 nanometers.

13. The silicon crystal wafer or chip of any one of the claims 9 - 12, wherein the wavelength of the laser beam is about or close to 532 nanometers.

14. The silicon crystal wafer or chip of any one of the claims 9 - 13, wherein the thickness of the layer of amorphous silicon is preferably in a range from about 5 nanometers to about 300 nanometers, more preferably in a range from about 50 nanometers to about 200 nanometeres, and still more preferably about 100 nanometers.

15. The silicon crystal wafer or chip of any one of the claims 9 - 14, comprising

~~on top of the clean surface of the crystal wafer or chip, and located between the clean surface of the crystal wafer or chip and the amorphous silicon layer, a narrow silicon oxide layer having a thickness corresponding substantially to an oxide layer thickness obtained naturally by exposing a clean surface of the substantially pure or semiconductor level doped silicon crystal wafer or chip to a normal atmosphere mixture of gases at a normal atmospheric pressure and a normal room temperature.~~

~~16. The silicon crystal wafer or chip of claim 15, wherein the thickness of the narrow layer of silicon oxide is about 1 to 5 nanometers.~~

~~17.~~1. A method for ablating a part of an electrically insulating layer covering a layer of amorphous silicon, the layer of amorphous silicon contacting a top surface of a silicon crystal wafer or chip, said method comprising:

providing said silicon crystal wafer or chip comprising the electrically insulating layer covering the layer of amorphous silicon, and wherein the layer of amorphous silicon is in direct physical contact with contacting the top surface of the silicon crystal wafer or chip, and the electrically insulating layer is in direct physical contact with top surface of the layer of amorphous silicon,

wherein the amorphous silicon layer is one of the group consisting of i) a pure amorphous silicon, ii) a hydrogenized amorphous silicon, and iii) a semiconductor level doped grade amorphous silicon,

wherein the electrically insulating layer is transparent to an optical wavelength of a pulsed laser beam that is absorbable in the layer of amorphous silicon, and wherein a portion of the electrically insulating layer is in vertical registration covering a corresponding portion of the layer of amorphous silicon also in the vertical registration and a location on the top surface of the silicon crystal wafer or chip; and

using the pulsed laser beam of the optical wavelength absorbable in the layer of amorphous silicon, irradiating, through the portion of the electrically insulating layer and the corresponding portion of the layer of amorphous silicon, the location on the top surface of the silicon crystal wafer or chip with the pulsed laser beam having an optical energy fluence and a pulse duration set to melt and evaporate the corresponding portion of the layer of amorphous silicon in an area corresponding to a cross section of the pulsed laser beam and to ablate a vertically-registered corresponding area of the portion of the electrically insulating layer in an amount corresponding to the cross section of the pulsed laser beam.

~~A method for ablating a part of an electrically insulating layer covering a surface of a silicon crystal wafer or chip, comprising~~
~~providing said silicon crystal wafer or chip comprising on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogenized or semiconductor level doped grade amorphous silicon, and on the layer of amorphous silicon, a layer of the electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon, and~~
~~irradiating the surface of the silicon crystal wafer or chip by a pulsed laser beam of an optical energy fluence and a pulse duration adapted to melt and evaporize the layer of amorphous silicon in an area corresponding to a footprint or a cross sectionof the laser beam, so as to ablate a corresponding area of the electrically insulating layer.~~

~~18.~~2. The method of claim ~~17~~, wherein the laser beam wavelength is ~~about or close to~~ 532 nanometers, the optical energy fluence is between 0.3 and 0.5 Joules per square centimeter, ~~preferably about 0.32 Joules per square centimeter,~~ and the pulse duration is ~~about~~ 142 nanoseconds.

~~19. The method of claim 17 or 18, wherein providing said silicon crystal wafer or chip comprises providing said silicon crystal wafer or chip having on top of the clean surface of the crystal wafer or chip, and located between the clean surface of the crystal wafer or chip and the amorphous silicon layer, a narrow silicon oxide layer having a thickness corresponding substantially to an oxide layer thickness obtained naturally by exposing a clean surface of the substantially pure or semiconductor level doped silicon crystal wafer or chip to a normal atmosphere mixture of gases at a normal atmospheric pressure and a normal room temperature.~~

~~20. A method for controlling an apparatus for method for ablating a part of an electrically insulating layer covering a surface of a silicon crystal wafer or chip comprising~~
~~on top of a substantially clean surface of the silicon crystal wafer or chip, a layer of amorphous silicon, the amorphous silicon being a substantially pure or hydrogenized semiconductor level doped grade amorphous silicon, and on the layer of amorphous silicon, a layer of the electrically insulating surface layer being substantially transparent to an optical wavelength of a laser beam that is extensively absorbed in the layer of amorphous silicon, the method comprising controlling a pulsed laser beam source of~~

~~said apparatus using the thermodynamic model that predicts the laser fluence ablation threshold of SiO2 on a-Si layers of varying thickness, as disclosed in the description under the chapter heading "Theoretical considerations".~~

~~21.~~3. A carrier comprised of a non- transitory computer readable medium containing a computer program comprising computer instruction executable in a programmable apparatus to carry out the steps of the method of claim 1.
~~A computer program on a carrier comprising computer instruction executable in a programmable apparatus to carry out the steps of the method of any one of claims 1 – 8, or to carry out the steps of the method of any one of claims 17 – 19, or to carry out the steps of the method of claim 20.~~

4. A carrier comprised of a non- transitory computer readable medium containing a computer program comprising computer instruction executable in a programmable apparatus to carry out the steps of the method of claim 2.

~~22.~~5. The method of claim 1, wherein the method produces a photovoltaic cell with the silicon crystal wafer or chip having the ablated corresponding area of the portion of the electrically insulating layer, and

wherein the amorphous silicon layer is one of the group consisting of i) a pure amorphous silicon, and ii) a semiconductor level doped grade amorphous silicon.
~~A photovoltaic cell, comprising the substantially pure or semiconductor level doped silicon crystal wafer or chip produced by the method of any one of claims 1 – 8, or by the method of any one of claims 17 – 20.~~

6. The method of claim 2, wherein the method produces a photovoltaic cell with the silicon crystal wafer or chip having the ablated corresponding area of the portion of the electrically insulating layer,

wherein the amorphous silicon layer is one of the group consisting of i) a pure amorphous silicon, and ii) a semiconductor level doped grade amorphous silicon.

~~23. A photovoltaic cell, comprising the crystal wafer or chip according to of any one of claims 9 – 16.~~

~~24.~~7. The carrier comprised of the non-transitory computer readable medium of claim 3 or 4, wherein the method produces a photovoltaic cell with the silicon crystal wafer or

chip having the ablated corresponding area of the portion of the electrically insulating layer.

~~A photovoltaic cell, comprising the crystal wafer or chip produced in an programmable apparatus operated by the computer program of claim 21.~~

8. The method of claim 1 or 2, wherein the method produces a photovoltaic cell with the silicon crystal wafer or chip having the ablated corresponding area of the portion of the electrically insulating layer, and
wherein the amorphous silicon layer is one of the group consisting of i) a pure amorphous silicon, and ii) a semiconductor level doped grade amorphous silicon.

9. The carrier comprised of the non-transitory computer readable medium of claim 3 or 4, wherein the method produces a photovoltaic cell with the silicon crystal wafer or chip having the ablated corresponding area of the portion of the electrically insulating layer.

10. The method of claim 1, wherein the laser beam wavelength is 532 nanometers, and the optical energy fluence is between 0.3 and 0.5 Joules per square centimeter.

11. The method of claim 1, wherein the laser beam wavelength is 532 nanometers, the optical energy fluence is 0.32 Joules per square centimeter, and the pulse duration is 142 nanoseconds.

12. A method for ablating a part of an electrically insulating layer covering a layer of amorphous silicon, the layer of amorphous silicon contacting a top surface of a silicon crystal wafer or chip, said method comprising:

providing said silicon crystal wafer or chip comprising the electrically insulating layer covering the layer of amorphous silicon, wherein the layer of amorphous silicon is in direct physical contact with the top surface of the silicon crystal wafer or chip,

wherein the amorphous silicon layer is one of the group consisting of i) a pure amorphous silicon, ii) a hydrogenized amorphous silicon, and iii) a semiconductor level doped grade amorphous silicon, wherein the electrically insulating layer is transparent to an optical wavelength of a pulsed laser beam that is absorbable in the layer of amorphous silicon, and

wherein a portion of the electrically insulating layer is in vertical registration covering a corresponding portion of the layer of amorphous silicon also in the vertical registration and a location on the top surface of the silicon crystal wafer or chip; and

using the pulsed laser beam of the optical wavelength absorbable in the layer of amorphous silicon, irradiating, through the portion of the electrically insulating layer and the corresponding portion of the layer of amorphous silicon, the location on the top surface of the silicon crystal wafer or chip with the pulsed laser beam having an optical energy fluence and a pulse duration set to melt and evaporate the corresponding portion of the layer of amorphous silicon in an area corresponding to a cross section of the pulsed laser beam and to ablate a vertically-registered corresponding area of the portion of the electrically insulating layer in an amount corresponding to the cross section of the pulsed laser beam.