PLASMA GRID IMPLANT SYSTEM FOR USE IN SOLAR CELL FABRICATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to co-pending U.S. Provisional Application Serial Number 61/219,379, filed June 23, 2009, entitled "PLASMA GRID IMPLANT SYSTEM FOR USE IN SOLAR CELL FABRICATIONS," which is hereby incorporated by reference in its entirety as if set forth herein.

FIELD OF THE INVENTION

The present invention relates generally to the field of solar cells and other large substrate implant applications. More particularly, the present invention relates to solar cell devices and methods of their formation.

BACKGROUND OF THE INVENTION

Although traditional beamline implantation of wafers can provide high power density, it has several disadvantages. For example, it only provides a single beamlet. Additionally, it uses a lot of power in a small beam spot, and the wafer gets quite hot. As a result, productivity is low.

SUMMARY OF THE INVENTION

~~In one aspect of the present invention, a plasma grid implantation system is provided.~~ The system comprises: a plasma source configured to provide plasma; a first grid plate comprising a plurality of apertures configured to allow ions from the plasma in a plasma region to pass therethrough, wherein the first grid plate is configured to be positively biased, either continuously in DC mode or in pulsed mode, by a power supply; a second grid plate comprising a plurality of apertures configured to allow the ions to pass therethrough subsequent to the ions passing through the first grid plate, wherein the second grid plate is configured to be negatively biased, either continuously in DC mode or in pulsed mode, by a power supply; and a substrate holder configured to support a substrate in a position where the substrate is implanted with the ions subsequent to the ions passing through the second grid plate.

In some embodiments, the position of at least one of the first grid plate, the second grid plate, and the substrate holder is configured to be adjusted between a homogeneous ~~implantation position and a selective implantation position, the homogeneous implantation~~

In one aspect of the present invention, there is provided a plasma grid implantation system for fabricating solar cells from a substrate, comprising: a plasma source configured to provide plasma in a plasma region; a first grid plate comprising a plurality of apertures configured to allow ions from the plasma region to pass through the first grid plate, wherein the first grid plate is positively biased by a power supply; a second grid plate comprising a plurality of apertures configured to allow the ions to pass through the second grid plate subsequent to the ions passing through the first grid plate, wherein the second grid plate is negatively biased by a power supply; a third grid plate disposed between the second grid plate and the substrate holder, the third grid plate comprising a plurality of apertures configured to allow the ions to pass through the third grid plate subsequent to the ions passing through the second grid plate, wherein the third grid plate is coupled to ground potential; a substrate holder configured to support the substrate in a position where the substrate is implanted with the ions subsequent to the ions passing through the third grid plate to thereby dope the substrate and fabricate a solar cell; a chamber defined by chamber walls, wherein the plasma region, the first grid plate, the second grid plate, and the third grid plate are housed within the chamber; and, a conveyor belt transporting the substrates from an atmospheric side to vacuum side inside the chamber; wherein: the position of at least one of the first grid plate, the second grid plate, and the substrate holder is configured to be adjusted between a homogeneous implantation position and a selective implantation position; the homogeneous implantation position is configured for a single laterally-homogeneous ion implantation across the substrate on the substrate holder, wherein the single laterally-homogeneous ion implantation is formed from a combination of beamlets that have passed through different apertures of the third grid plate and combined by space charge expansion into a uniform beam; the selective implantation position is configured for a plurality of laterally spaced-apart ion implantations of the substrate on the substrate holder, wherein the plurality of laterally spaced-apart ion implantations is formed from individual ion beamlets that have passed through the different apertures of the third grid plate; and, wherein the first grid plate, the second grid plate and the third grid plate form a grid plate assembly, wherein the grid plate assembly is configured to focus the beamlets into known shapes onto the substrate to thereby form the selective implantation.

~~position is configured to enable a single laterally-homogeneous ion implantation across the~~ substrate on the substrate holder, wherein the single laterally-homogeneous ion implantation is formed from a combination of ions that have passed through different apertures of the second grid plate, and the selective implantation position is configured to enable a plurality of laterally spaced-apart ion implantations of the substrate on the substrate holder, wherein the plurality of laterally spaced-apart ion implantations is formed from ions that have passed through the different apertures of the second grid plate.

In some embodiments, the system further comprises a third grid plate disposed between the second grid plate and the substrate holder, and the third grid plate comprises a plurality of apertures configured to allow the ions to pass therethrough subsequent to the ions passing through the second grid plate. In some embodiments, the third grid plate is grounded. In some embodiments, the position of at least one of the third grid plate and the substrate holder is configured to be adjusted between a homogeneous implantation position and a selective implantation position, the homogeneous implantation position configured to enable a single laterally-homogeneous ion implantation across the substrate on the substrate holder, wherein the single laterally-homogeneous ion implantation is formed from a combination of ions that have passed through different apertures of the second grid plate, and the selective implantation position configured to enable a plurality of laterally spaced-apart ion implantations of the substrate on the substrate holder, wherein the plurality of laterally spaced-apart ion implantations is formed from ions that have passed through the different ~~apertures of the second grid plate.~~

In some embodiments, the apertures of at least one of the first grid plate and the second grid plate are substantially circular holes. In some embodiments, the apertures of at least one of the first grid plate and the second grid plate are elongated slots. In some embodiments, each one of the apertures of at least one of the first grid plate and the second grid plate comprises a top end and a bottom end, wherein the bottom end is closer to the substrate holder than the top end, and wherein the diameter of each aperture gradually increases from the top end to the bottom end.

In some embodiments, the first grid plate and the second grid plate comprise a material chosen from the group consisting of: silicon, graphite, silicon carbide, and tungsten. In some embodiments, ~~the system further comprises a chamber defined by chamber walls, wherein the plasma region, the first grid plate, and the second grid plate are housed within the chamber, and wherein~~ the chamber walls are configured to repel ions in the plasma region

using a magnetic field. In some embodiments, one or more magnets are coupled to the chamber walls.

In another embodimentaspect of the present invention, a method of ion implantation is provided. The method comprises: providing a plasma within a plasma region of a chamber; positively biasing a first grid plate, wherein the first grid plate comprises a plurality of apertures and is disposed in a first position; negatively biasing a second grid plate, wherein the second grid plate comprises a plurality of apertures and is disposed in a first position; flowing ions from the plasma in the plasma region through the apertures in the positively-biased first grid plate; flowing at least a portion of the ions that flowed through the apertures in the positively-biased first grid plate through the apertures in the negatively-biased second grid plate; and implanting a substrate with at least a portion of the ions that flowed through the apertures in the negatively-biased second grid plate, wherein the substrate is disposed in a first position.

In some embodiments, a shadow mask comprising a plurality of openings formed therethrough is disposed a predetermined distance away from the substrate, and the method further comprises flowing at least a portion of the ions that flowed through the apertures in the negatively-biased second grid plate through the openings in the shadow mask before implanting the substrate.

In some embodiments, a photoresist mask comprising a plurality of openings formed therethrough is placed in contact with the substrate, and the method further comprises flowing at least a portion of the ions that flowed through the apertures in the negatively-biased second grid plate through the openings in the photoresist mask before implanting the substrate.

In some embodiments, the method further comprises: adjusting the position of at least one of the first grid plate, second grid plate, and the substrate holder to a second position; providing a plasma within the plasma region subsequent to the adjustment to the second position; flowing ions from the plasma in the plasma region through the apertures in the positively-biased first grid plate subsequent to adjustment to the second position; flowing at least a portion of the ions that flowed through the apertures in the positively-biased first grid plate through the apertures in the negatively-biased second grid plate subsequent to adjustment to the second position; and implanting a substrate with at least a portion of the ions that flowed through the apertures in the negatively-biased second grid plate subsequent to adjustment to the second position, wherein the implantation performed when the at least one of the first grid plate, second grid plate, and the substrate holder was in the first position forms a single laterally-homogeneous ion implantation across the substrate, wherein the

embodiments, each one of the apertures of at least one of the first grid plate and the second grid plate comprises a top end and a bottom end, wherein the bottom end is closer to the substrate holder than the top end, and wherein the diameter of each aperture gradually increases from the top end to the bottom end.

In some embodiments, the first grid plate and the second grid plate comprise a material chosen from the group consisting of: silicon, graphite, silicon carbide, and tungsten. In some embodiments, the plasma region, the first grid plate, and the second grid plate are housed within a chamber that is defined by chamber walls, and wherein the chamber walls are configured to repel ions in the plasma region using an electric field.

In some embodiments, the method further comprises the step of applying a pulsed voltage to the plasma. In some embodiments, the method further comprises the step of applying a pulsed voltage to the substrate. In some embodiments, the pulsed voltage is directed towards a plurality of different locations on the substrate.

In some embodiments, the method further comprises: passing the substrate through a first plurality of differentially-pumped stages prior to the substrate being implanted with the ions, wherein each stage in the first plurality of differentially-pumped stages comprises a lower pressure than the previous stage in the first plurality of differentially-pumped stages; passing the substrate from the first plurality of differentially-pumped stages directly to an implantation stage; passing the substrate from the implantation stage directly to a second plurality of differentially-pumped stages subsequent to the substrate being implanted with the ions, and passing the substrate through the second plurality of differentially-pumped stages, wherein each stage in the second plurality of differentially-pumped stages comprises a higher pressure than the previous stage in the second plurality of differentially-pumped stages, wherein the implantation stage comprises a lower pressure than any of the stages in the first plurality and second plurality of differentially-pumped stages.

In yet another embodiment~~aspect~~ of the present invention, a plasma grid implantation system is provided. The system comprises: a plasma source configured to provide plasma; a grid assembly comprising a plurality of grid plates, wherein each grid plate comprises a plurality of apertures configured to allow ions from the plasma to pass therethrough; and a substrate holder configured to support a substrate in a position where the substrate is implanted with the ions subsequent to the ions passing through the plurality of apertures of the grid plates, wherein at least one of the substrate holder and the grid plates is configured to be adjusted between a homogeneous implantation position and a selective implantation position, wherein the homogeneous implantation position is configured to enable a single laterally-

homogeneous ion implantation across the substrate on the substrate holder, the single laterally-homogeneous ion implantation being formed from a combination of ions that have passed through different apertures of the second grid plate, and wherein the selective implantation position is configured to enable a plurality of laterally spaced-apart ion implantations of the substrate on the substrate holder, the plurality of laterally spaced-apart ion implantations is formed from ions that have passed through the different apertures of the second grid plate.

In some embodiments, the plurality of grid plates comprises: a first grid plate comprising a plurality of apertures configured to allow ions from the plasma in a plasma region to pass therethrough; and a second grid plate comprising a plurality of apertures configured to allow the ions to pass therethrough subsequent to the ions passing through the first grid plate. In some embodiments, the first grid plate is configured to be positively-biased by a power supply. In some embodiments, the second grid plate is configured to be negatively-biased by a power supply. In some embodiments, the plurality of grid plates further comprises a third grid plate comprising a plurality of apertures configured to allow the ions to pass therethrough subsequent to the ions passing through the second grid plate. In some embodiments, the third grid plate is configured to be grounded. In some embodiments, the first grid plate, the second grid plate, and the substrate holder are all configured to have their positions adjusted.

In yet another embodiment~~aspect~~ of the present invention, a method of ion implantation is provided. The method comprises: providing a plasma within a plasma region of a chamber; providing a grid assembly comprising a plurality of grid plates, wherein each grid plate comprises a plurality of apertures; flowing a first set of ions from the plasma in the plasma region through the apertures in each of the grid plates in the grid assembly while each of the grid plates is in a first position; homogeneously implanting a substrate with at least a portion of the first set of ions that flowed through the apertures in the grid plates while the substrate is supported in a first position by a substrate holder, thereby forming a single laterally-homogeneous ion implantation across the substrate from a combination of the first set of ions that have passed through different apertures of the same grid plate; adjusting the position of the substrate or at least one of the grid plates to a second position; flowing a second set of ions from the plasma in the plasma region through the apertures in each of the grid plates in

the grid assembly subsequent to the adjustment to the second position; selectively implanting the substrate with at least a portion of the second set of ions that flowed through the apertures in the grid plates subsequent to the adjustment to the second position, thereby forming a plurality of laterally spaced-apart ion implantations on the substrate from a portion of the second set of ions that have passed through different apertures of the same grid plate.

In some embodiments, the adjusting step comprises adjusting the position of the substrate. In some embodiments, adjusting the position of the substrate comprises moving the substrate closer to the grid assembly.

In some embodiments, the adjusting step comprises adjusting the position of one of the grid plates. In some embodiments, adjusting the position of one of the grid plates comprises moving one of the grid plates closer to the substrate.

In some embodiments, the plurality of grid plates comprises a first grid plate and a second grid plate, the first grid plate being positively-biased, and the second grid plate being negatively biased. In some embodiments, the plurality of grid plates further comprises a third grid plate that is grounded.

In yet another embodimentaspect of the present invention, a method of ion implantation is provided. The method comprises: providing a first single type of dopant material to a plasma generator; the plasma generator breaking up the first single type of dopant material into a first plurality of dopant species; and implanting a substrate with the first plurality of dopant species.

In some embodiments, the substrate is implanted with the first plurality of dopant species in a single implantation step. In some embodiments, each one of the dopant species is implanted into the substrate at a different depth. In some embodiments, the first single type of dopant material is phosphine. In some embodiments, the first plurality of dopant species comprises P^-, P^{++}, P^{+++}, P_2^+, P_3^-, and P_5^-. In some embodiments, the first single type of dopant material is boron or arsenic.

In some embodiments, a combination of different types of dopant material is used to implant different pluralities of dopant species. In some embodiments, the different types of dopant material can be provided in precursor form as gasses, liquids, solids, or any combination thereof.