devices. Attempts were made to keep such impurities away from electronic device structures by providing gettering sites which are sinks for metallic impurities. Recent developments require shifting such gettering sites closer to the electronic device structures in order to reduce the diffusion length which impurities have to cover in order to reach the gettering sites.

US 2006/0175613 A1 discloses a method comprising growing a gettering layer over a semiconductor substrate and forming an epitaxial layer over the gettering layer.

The object of the present invention is to provide a solution to the above mentioned problems which is less complex and more effective than known solutions.

Summary of the invention

The inventors have found that the presence of nitrogen in the silicon epitaxial layer at a concentration of 1 x 10^{16} atoms/cm^3 or more and 1 x 10^{20} atoms/cm^3 or less reduces the nucleation and propagation of dislocations. Moreover, nitrogen incorporated into the silicon epitaxial layer in accordance with the present invention is readily accessible for oxygen-nitrogen interaction, which allows the formation of an oxygen-enriched region having an oxygen peak-concentration in a certain depth from the surface of the epitaxial layer. The oxygen-enriched region exhibits gettering activity for metallic impurities.

According to a first aspect, the claimed invention is directed to an epitaxial wafer, comprising a silicon substrate wafer having a first side and a second side, and an elemental silicon epitaxial layer deposited on the first side of the silicon substrate wafer, and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, the elemental silicon epitaxial

layer being doped with nitrogen at a concentration of more than 1 x 10^{16} atoms/cm^3 and 1 x 10^{20} atoms/cm^3 or less, or at least one of the one or more additional epitaxial layers being doped with nitrogen at a concentration of more than 1 x 10^{16} atoms/cm^3 and 1 x 10^{20} atoms/cm^3 or less, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers being doped with nitrogen at a concentration of more than 1 x 10^{16} atoms/cm^3 and 1 x 10^{20} atoms/cm^3 or less.

The at least one of the one or more additional epitaxial layers which is doped with nitrogen is preferably a further silicon epitaxial layer. Each of the additional epitaxial layers can be further silicon epitaxial layers.

According to an embodiment, the invention is directed to an epitaxial wafer according to the first aspect, wherein the silicon epitaxial layer is doped with nitrogen and an additional epitaxial layer deposited on top of the silicon epitaxial layer is not doped with nitrogen.

According to a further embodiment, the invention is directed to an epitaxial wafer according to the first aspect, wherein the silicon epitaxial layer is not doped with nitrogen and an additional epitaxial layer deposited on top of the silicon epitaxial layer is doped with nitrogen.

According to a further embodiment, the invention is directed to an epitaxial wafer according to the first aspect, wherein the silicon epitaxial layer is deposited on the silicon substrate wafer to completely or partially cover the silicon substrate wafer. The presence of the silicon epitaxial layer on the substrate wafer can be restricted to regions where electronic device structures are built.

According to a further embodiment, the invention is directed to an epitaxial wafer according to the first aspect or to a further embodiment, wherein the silicon epitaxial layer is additionally doped with at least one electrically active dopant belonging to group III or group V of the periodic table of elements. Preferred dopants are boron, phosphorous, arsenic and antimony.

According to further embodiment, the invention is directed to an epitaxial wafer according to the first aspect or to a further embodiment, wherein the silicon epitaxial layer doped with nitrogen, or the at least one of the one or more additional epitaxial layers which is doped with nitrogen, or the silicon epitaxial layer doped with nitrogen and the at least one of the one or more additional epitaxial layers which is doped with nitrogen comprises an oxygen-enriched region which exhibits gettering activity for metallic impurities. The concentration of oxygen in the oxygen-enriched region has an in-depth profile comprising a peak. The peak-concentration of oxygen is located in a depth direction of the silicon epitaxial layer doped with and/or the at least one of the one or more additional epitaxial layers which is doped with nitrogen.

The peak-concentration of oxygen in the oxygen-enriched region is preferably 1×10^{17} atoms/cm^3 or more and 1×10^{19} atoms/cm^3 or less (new ASTM).

The distance of the peak-concentration of oxygen in the oxygen-enriched region from the interface between the silicon substrate wafer and the silicon epitaxial layer is preferably 50 nm or more and 2 μm or less. The location of the peak-concentration of the oxygen-enriched region in depth direction from the surface of the silicon epitaxial layer is preferably deeper than the depth of a region intended to be used as electronically active region.

The distance of the peak-concentration of oxygen in the oxygen-enriched region from an interface between the at least one of the one or more additional epitaxial layers which is doped with nitrogen and a lower layer adjacent thereto is preferably 50 nm or more and 2 μm or less.

The inventors found that the diffusion coefficient of nitrogen in the silicon epitaxial layer is significantly lower than the diffusion coefficient published in literature (P.Pichler, Intrinsic Point Defects, Impurities, and Their Diffusion in Silicon, Springer (2004), p.383). The reduction of the diffusion coefficient by a factor of about 5000 suggests that nitrogen is bound in the lattice of the silicon epitaxial layer in a different manner compared to the system examined in published literature.

According to a further aspect, the invention is directed to a method for producing an epitaxial wafer according to the first aspect or to a further embodiment, the method comprising providing a silicon substrate wafer having a first side and a second side; and depositing at a deposition temperature, an elemental silicon epitaxial layer on the first side of the silicon substrate wafer and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, wherein the elemental silicon epitaxial layer, or at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers is deposited by chemical vapor deposition in the presence of a deposition gas atmosphere containing one or more silicon precursor compounds and one or more nitrogen precursor compounds, wherein the deposition temperature is 940°C or less and equal to or higher than a temperature which is sufficient to cause the decomposition of the one or more silicon precursor compounds and the one or more nitrogen precursor compounds in the

deposition gas atmosphere; and doping the elemental silicon epitaxial layer, or the at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and the at least one of the one or more additional epitaxial layers with nitrogen at a concentration of more than 1 x 10^{16} atoms/cm^3 and 1 x 10^{20} atoms/cm^3 or less during the deposition thereof.

A suitable silicon substrate wafer can be obtained, e.g. by cutting a wafer from a silicon single crystal produced by the CZ method or the FZ method, and by subjecting the edge and the sides of the cut wafer to crystal damage removal and shaping operations, e.g. lapping and/or grinding, etching and polishing.

The silicon substrate wafer has a first side (front side) and a second side (back side). It is preferred that at least the first side of the silicon substrate wafer has a polished surface. A silicon epitaxial layer is deposited on the first side of the silicon substrate wafer by chemical vapor deposition (CVD). During deposition, gases containing one or more silicon precursor compounds and one or more nitrogen precursor compounds flow over the silicon substrate wafer which is heated to a deposition temperature. The precursor compounds are thermally decomposed providing silicon and nitrogen for the growth of the silicon epitaxial layer.

For example, silicon compounds such as silane (SiH_4), disilane (Si_2H_6), dichlorosilane (SiH_2Cl_2) or trichlorosilane ($SiHCl_3$) can be used as silicon precursor compounds.

For example, nitrogen compounds such as ammonia (NH_3) or other organic compounds containing nitrogen can be used as silicon precursor compounds.

Claims

1. An epitaxial wafer, comprising a silicon substrate wafer having a first side and a second side, and an elemental silicon epitaxial layer deposited on the first side of the silicon substrate wafer, and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, the elemental silicon epitaxial layer being doped with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less, or at least one of the one or more additional epitaxial layers being doped with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers being doped with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less.

2. The epitaxial wafer of claim 1, wherein the elemental silicon epitaxial layer is doped with nitrogen and an additional epitaxial layer deposited on top of the silicon elemental epitaxial layer is not doped with nitrogen.

3. The epitaxial wafer of claim 1, wherein the elemental silicon epitaxial layer is not doped with nitrogen and an additional epitaxial layer deposited on top of the elemental silicon epitaxial layer is doped with nitrogen.

4. The epitaxial wafer of claim 1, wherein the elemental silicon epitaxial layer completely covers the silicon substrate wafer.

5. The epitaxial wafer of claim 4, wherein the elemental silicon epitaxial layer partially covers the silicon substrate wafer.

6. The epitaxial wafer of claim 1, wherein the elemental silicon epitaxial layer is additionally doped with at least one electrically active dopant belonging to group III or group V of the periodic table of elements.

7. The epitaxial wafer of claim 1, wherein the elemental silicon epitaxial layer doped with nitrogen, or the at least one of the one or more additional epitaxial layers which is doped with nitrogen, or the elemental silicon epitaxial layer doped with nitrogen and the at least one of the one or more additional epitaxial layers which is doped with nitrogen comprises an oxygen-enriched region exhibiting gettering activities and having a peak concentration of oxygen.

8. The epitaxial wafer of claim 1, wherein the epitaxial wafer has an oxygen enriched layer having an oxygen concentration peak where the concentration of oxygen is from 1 x 10^{17} atoms/cm^3 to 1 x 10^{19} atoms/cm^3.

9. The epitaxial wafer of claim 8, wherein the peak oxygen concentration lies from 50 nm to 2 μm below an interface between the silicon substrate wafer and the elemental silicon epitaxial layer.

10. The epitaxial wafer of claim 8, wherein the peak oxygen concentration lies from 50 nm to 2 μm below an interface between at least one of the one or more additional epitaxial layers which is doped with nitrogen and a lower layer adjacent thereto.

11. A method for producing an epitaxial wafer of claim 1, comprising:

a) providing a silicon substrate wafer having a first side and a second side;

b) depositing at a deposition temperature, an elemental silicon epitaxial layer on the first side of the silicon substrate wafer and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, wherein the elemental silicon epitaxial layer, or at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers is deposited by chemical vapor deposition in the presence of a deposition gas atmosphere containing one or more silicon precursor compounds and one or more nitrogen precursor compounds, wherein the deposition temperature is 940 °C or less and equal to or higher than a temperature which is sufficient to cause the decomposition of the one or more silicon precursor compounds and the one or more nitrogen precursor compounds in the deposition gas atmosphere; and

c) doping the elemental silicon epitaxial layer, or the at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and the at least one of the one or more additional epitaxial layers with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less during the deposition thereof.

12. The method of claim 11, wherein the elemental silicon epitaxial layer is deposited in the presence of the one or more nitrogen precursor compounds, and at least one of the one or more additional epitaxial layers is deposited in the absence of the one or more nitrogen precursor compounds.

13. The method of claim 11, wherein the elemental silicon epitaxial layer is deposited in the absence of the one or more nitrogen precursor compounds and at least one of the one or more additional epitaxial layers is deposited in the presence of the one or more nitrogen precursor compounds.

14. The method of claim 11, further comprising subjecting the epitaxial wafer to a post-epi anneal.

15. A method for producing an epitaxial wafer of claim 8, comprising:

a) providing a silicon substrate wafer having a first side and a second side;

b) depositing at a deposition temperature, an elemental silicon epitaxial layer on the first side of the silicon substrate wafer and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, wherein the elemental silicon epitaxial layer, or at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers is deposited by chemical vapor deposition in the presence of a deposition gas atmosphere containing one or more silicon precursor compounds and one or more nitrogen precursor compounds, wherein the deposition temperature is 940 °C or less and equal to or higher than a temperature which is sufficient to cause the decomposition of the one or more silicon precursor compounds and the one or more nitrogen precursor compounds in the deposition gas atmosphere; and

c) doping the elemental silicon epitaxial layer, or the at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and the at least one of the one or more additional epitaxial layers with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less during the deposition thereof.

16. A method for producing an epitaxial wafer of claim 9, comprising:

a) providing a silicon substrate wafer having a first side and a second side;

b) depositing at a deposition temperature, an elemental silicon epitaxial layer on the first side of the silicon substrate

wafer and optionally one or more additional epitaxial layers on top of the elemental silicon epitaxial layer, wherein the elemental silicon epitaxial layer, or at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and at least one of the one or more additional epitaxial layers is deposited by chemical vapor deposition in the presence of a deposition gas atmosphere containing one or more silicon precursor compounds and one or more nitrogen precursor compounds, wherein the deposition temperature is 940 °C or less and equal to or higher than a temperature which is sufficient to cause the decomposition of the one or more silicon precursor compounds and the one or more nitrogen precursor compounds in the deposition gas atmosphere; and

c) doping the elemental silicon epitaxial layer, or the at least one of the one or more additional epitaxial layers, or the elemental silicon epitaxial layer and the at least one of the one or more additional epitaxial layers with nitrogen at a concentration of more than 1×10^{16} atoms/cm^3 and 1×10^{20} atoms/cm^3 or less during the deposition thereof.

17. The method of claim 11, wherein the epitaxial wafer has an oxygen enriched layer having an oxygen concentration peak where the concentration of oxygen is from 1×10^{17} atoms/cm^3 to 1×10^{19} atoms/cm^3.

18. The method of claim 17, wherein the peak oxygen concentration lies from 50 nm to 2 μm below an interface between the silicon substrate wafer and the elemental silicon epitaxial layer.

19. The method of claim 17, wherein the peak oxygen concentration lies from 50 nm to 2 μm below an interface between at least one of the one or more additional epitaxial layers which is doped with nitrogen and a lower layer adjacent thereto.

20. The epitaxial wafer of claim 1, having at least one epitaxial layer doped with nitrogen in an amount of from 2.5 x 10^7 atoms/cm^3 to less than 1 x 10^{20} atoms/cm^3.