AN ADVANCED TECHNIQUE FOR FORMING TRANSISTORS HAVING RAISED DRAIN AND SOURCE REGIONS WITH DIFFERENT HEIGHT

FIELD OF THE PRESENT INVENTION

The present invention generally relates to the fabrication of integrated circuits, and more particularly, to the formation of locally raised semiconductor regions, such as raised drain and source regions of field effect transistors having extremely shallow pn junctions.

DESCRIPTION OF THE RELATED ART

The fabrication of integrated circuits requires the formation of a large number of circuit elements on a given chip area according to a specified circuit layout. Generally, a plurality of process technologies are currently practiced, wherein for logic circuitry, such as microprocessors, storage chips and the like, CMOS technology is currently the most promising approach due to the superior characteristics in view of operating speed and/or power consumption. During the fabrication of complex integrated circuits using the CMOS technology, millions of complementary transistors, i.e., n-channel transistors and p-channel transistors, are formed on an appropriate substrate. Typically, a MOS transistor, irrespective of whether an n-channel transistor or a p-channel transistor is considered, comprises so-called pn-junctions that are formed at an interface of highly doped drain and source regions with an inversely doped channel region disposed between the drain region and the source region. The conductivity of the channel region is controlled by a gate electrode formed above the channel region and separated therefrom by a thin insulating layer. The conductivity of the channel region depends on the dopant concentration, the mobility of the majority charge carriers, and on - for a given extension of the channel region in the transistor width direction – the distance between the source and drain region, which is also referred to as channel length. Hence, in combination with the capability of rapidly creating a conductive channel below the insulating layer upon application of a specified control voltage to the gate electrode, the conductivity of the channel region substantially determines the characteristics of the MOS transistors. For this reason, the channel length represents a dominant design criterion and a size reduction thereof provides for an increased operating speed of the integrated circuits.

The shrinkage of the transistor dimensions, however, entails a plurality of issues associated therewith, which have to be addressed so as to not unduly offset the advantages obtained by steadily decreasing the channel length of MOS transistors.

One problem in this respect is the requirement of extremely shallow pn junctions. That is, the depth of the source and drain regions with respect to an interface formed by the gate insulating layer and the channel region has to be decreased as the channel length is reduced so as to maintain the required controllability of the conductive channel. The depth of the source and drain regions substantially determines the sheet resistance thereof, which may not be arbitrarily reduced by

correspondingly increasing the dopant concentration in the source and drain regions, since an extremely high dopant concentration may give rise to increased leakage currents. Furthermore, the dopants implanted into these regions at very high concentrations may not be completely activated by conventional rapid thermal anneal cycles without negatively affecting the overall dopant profile within the source and drain regions. That is, for a desired channel length, defined by the pn junctions, an increased dopant concentration requires higher temperatures and/or a prolonged duration of the corresponding anneal cycles, thereby, however, influencing the dopant profile forming the pn junctions by the inevitable thermal diffusion of the dopants, which finally may lead to a non-acceptable variation of the finally achieved channel length.

In an attempt to further reduce the sheet resistance of the drain and source regions, the conductivity thereof is frequently increased by forming a metal silicide of superior conductivity compared to a highly doped silicon. However, since the penetration depth of the metal silicide is restricted by the depth of the pn junctions, the improvement in conductivity in these regions is therefore coupled to the depth of the corresponding pn junctions. Moreover, in many CMOS technologies, a corresponding metal silicide is simultaneously formed on the gate electrode, wherein a shallow junction depth therefore also creates a very shallow metal silicide in the gate electrode, thereby providing only limited improvement in gaining superior gate electrode conductivity.

In one approach, extremely shallow source and drain regions may be formed by raising the source and drain regions above the gate insulation layer/channel region interface and maintaining the drain-source dopant concentration at an acceptable level while providing for the possibility of forming highly conductive metal silicide regions without being restricted by the actual depth of the pn junctions due to the increased size of the raised drain and source regions.

With reference to Figs 1a-1d a typical conventional process flow for forming raised drain and source regions will now be described in more detail.

Fig. 1a schematically shows a cross-sectional view of a field effect transistor 100 at an early manufacturing stage. The transistor 100 comprises the substrate 101, for instance a bulk silicon substrate or an SOI (silicon on insulator) substrate including a buried insulating layer. Above the substrate 101 a substantially crystalline layer 102 is formed with a thickness that is appropriate for forming pn junctions and a channel region therein. For instance, the transistor 100 may represent an SOI transistor with a thickness of the silicon layer 102 in the range of approximately 20-100nm. A gate electrode 103, comprised of polysilicon, is formed above the silicon layer 102 and is separated therefrom by a gate insulation layer 104. The gate insulation layer 104 may be formed in sophisticated devices by a nitrogen containing silicon dioxide layer with a thickness of approximately 0.6-4nm. The residue 105 of an anti-reflective coating covers a top surface 103a of the gate electrode 103, while the sidewalls 103b thereof as well as the remaining surface of the silicon layer 102 are covered by an oxide liner 106.

The transistor 100 as shown in Fig. 1a may be formed in accordance with the following process flow. The substrate 101 may be obtained by a manufacturer of respective substrates in the form of a silicon bulk substrate or in the form of an SOI substrate, wherein the SOI substrate may comprise a crystalline silicon layer that may be formed in accordance with well-established wafer bonding techniques. The silicon layer 102 having the appropriate thickness may then be formed by corresponding process techniques, such as chemical mechanical polishing to thin a given silicon layer of an SOI substrate to a desired thickness and/or by epitaxial growth of silicon on the exposed surface of the SOI substrate or the bulk substrate. The epitaxial growth technique of a semiconductor material is a deposition technique in which the deposited material layer forms a crystalline structure in conformity with the crystalline structure of the underlying material as long as the deposited material is able to form a lattice that is sufficiently similar in structure and lattice spacing to the lattice of the underlying material. After the formation of the silicon layer 102, an insulating layer is formed having a thickness and a composition that are appropriate for forming the gate insulation layer 104. To this end, sophisticated oxidation and/or deposition techniques may be used as are well established in the art. Thereafter, a polysilicon layer of appropriate thickness is deposited by low-pressure chemical vapor deposition. Next, an antireflective coating, for instance comprised of silicon oxynitride, and a resist layer are deposited and are patterned by sophisticated photolithography so as to form an etch mask for a subsequent anisotropic etch process for patterning the gate electrode 103 from the deposited polysilicon layer. Thereafter, the gate insulation layer 104 may be patterned and subsequently the oxide liner 106 may be formed by an appropriately designed oxidation process.

Fig. 1b schematically shows the transistor 100 having formed thereon sidewall spacer elements 107 comprised of a material, such as silicon nitride, that exhibits a moderately high etch selectivity with respect to the underlying oxide liner 106 so that the spacers 107 may be readily removed after a selective epitaxial growth process. The sidewall spacers 107 may be formed by well-established techniques including the deposition, for instance, by plasma-enhanced chemical vapor deposition, of a silicon nitride layer of a specified thickness and a subsequent anisotropic etch process, which reliably stops on and in the liner oxide 106, thereby leaving the spacers 107. A width 107a of the spacer 107 is readily controllable by appropriately adjusting the thickness of the silicon nitride layer. Hence, a lateral extension of epitaxial growth regions adjacent to the gate electrode 103 is substantially determined by the spacer width 107a.

Fig. 1c schematically shows the device 100 with selectively grown silicon regions 108 above the silicon layer 102, wherein a lateral distance of the regions 108 from the gate electrode 103 substantially corresponds to the spacer width 107a (cf. Fig. 1b) plus the minimal thickness of the liner oxide 106. The transistor 100 as shown in Fig. 1c may be obtained by the following processes. Starting from the device as shown in Fig. 1b, the liner oxide 106 is selectively etched so as to expose the silicon layer 102 at portions that are not covered by the spacers 107, the gate electrode 103, and any isolation structures (not shown). Before and/or after the removal of the

liner oxide 106, well-established cleaning procedures may be carried out so as to remove oxide residues and other contaminants that may have accumulated in a surface region of the silicon layer 102. Thereafter, silicon is selectively grown on exposed portions of the silicon layer 102, thereby forming the silicon regions 108 with a specified thickness in conformity with design requirements. Thereafter, the spacer 107 is removed by a selective etch process, for instance, by using hot phosphoric acid, which exhibits an excellent etch selectivity to silicon dioxide and silicon. During this etch process, the residue 105 on top of the gate electrode 103 may also be removed. Thereafter, a conventional process sequence may be performed, as is the case for transistor devices without having the additional selectively grown silicon regions 108. That is, an appropriate number of sidewall spacers may be formed, followed by appropriately designed implantation sequences, so as to establish a required dopant profile in the silicon layer 102.

Fig. 1d schematically shows the transistor 100 after the above mentioned transistor formation process using, for instance, three different sidewall spacers. In Fig. 1d, a first sidewall spacer 109, for instance comprised of silicon dioxide, is located adjacent to the oxide liner 106 and has an appropriate thickness for profiling the dopant concentration in the vicinity of the gate electrode 103 during a subsequent implantation sequence. A second spacer 110 is located next to the first spacer 109 and separated therefrom by an additional liner 106a, followed by an oxide line 111 and a third spacer 112. The width of these spacers 109 and 112 is appropriately selected so as to obtain the desired dopant extension regions 113 and the drain and source regions 114, thereby defining a channel region 115 between the extensions 113 with a specified channel length 116. During the formation of the spacer 109, if comprised of silicon dioxide, the liner 106 is typically etched off the surface portion of the semiconductor layer 102. Therefore, usually the additional liner 106a is deposited prior to the formation of spacer 110. If the first spacer 109 is comprised of silicon nitride the liner 106 is preserved during the anisotropic etch for forming the spacer 109, however, possibly with an inhomogeneous thickness owing to the etch induced damage. Therefore, the liner 106 may be removed and the additional liner 106a may also be deposited in this case. Generally, the formation of the spacers 109, 110 and 112 may be accomplished by well-established spacer technologies, such as described with reference to the spacer 107, wherein the corresponding spacer width may be controlled by the corresponding deposition thicknesses of the respective spacer layers, for instance comprised of silicon nitride, wherein the first spacer 109 and the oxide liner 111 provide for the required etch selectivity in anisotropically patterning the spacers.

As a result, the above-described process flow enables the formation of required shallow pn junctions in the form of the extensions 113, while nevertheless providing for a low contact resistance to the drain and source regions 114 by providing the additional selectively grown silicon regions 108, which may be used to receive a highly conductive metal silicide, wherein the silicidation process does not adversely affect the extensions 113, nor is the silicidation process restricted by the depth of the extensions 113 and the drain and source regions 114.

Although the process flow described above provides for significant improvements in forming raised drain and source regions, there is still room for improvements with regards to process flexibility so as to enhance the device performance. For example, during the formation of the drain and source regions 114 by ion implantation, typically the gate electrode 103 is also heavily doped, thereby increasing the conductivity thereof. In p-channel transistors frequently boron is used as a dopant, which, however, exhibits a high diffusivity during anneal processes. For this reason the maximum implantation energy for doping the source and drain regions 114 may not be selected as high as it would be desirable in view of obtaining a desired penetration depth in the drain and source regions 114, but instead the integrity of the gate insulation layer 104 and possibly of the channel region 115 with respect to diffusing and/or penetrating boron ions has to be taken into consideration when selecting the implantation parameters, thereby possibly compromising the drain and source characteristics.

In view of these problems a need exists for a technique that enables the formation of locally raised semiconductor regions, wherein an enhanced flexibility for instance with respect to the height and/or the dopant concentration of the epitaxial growth regions is obtained.

SUMMARY OF THE INVENTION

Generally, the present invention is directed to a technique that enables the formation of epitaxially grown semiconductor regions with different heights and/or different dopant concentrations, wherein a high degree of compatibility with the conventional process flow is maintained. Different heights of raised semiconductor regions may be obtained by masking one or more specified regions by means of an epitaxial growth mask while selectively exposing one or more other semiconductor regions during a first epitaxial growth process. Thereafter, one or more further semiconductor regions may be exposed and a second epitaxial growth process may be performed so as to further increase the previously formed epitaxial growth regions and newly growing epitaxial growth regions in the newly-exposed semiconductor regions. This sequence may be repeated if a plurality of differently dimensioned epitaxially grown semiconductor regions are required. In this way, two or more raised semiconductor regions may be formed that have different heights so as to more conform to device specific requirements. Moreover, in other illustrative embodiments of the present invention, raised semiconductor regions may be selectively formed by epitaxial growth, and thereafter one or more selected portions of these raised semiconductor regions may be selectively reduced in thickness, by for instance oxidizing the region so as to precisely reduce a height thereof by subsequently removing the oxidized portions.

According to a further illustrative embodiment of the present invention, a method comprises forming a first epitaxial growth mask that exposes a portion of a first semiconductor region while keeping a second semiconductor region covered. Then, a first raised semiconductor region is formed in the exposed portion of the first semiconductor region and a second epitaxial growth mask is formed above the second semiconductor region, wherein the second epitaxial growth

mask exposes a portion of the second semiconductor region. Finally, a second raised semiconductor region is epitaxially grown in the exposed portion of the second semiconductor region.

In a further embodiment the method further comprises introducing one or more dopant species while epitaxially growing at least one of the first and the second raised semiconductor regions.

In a further embodiment a p-type dopant species is introduced into said second raised semiconductor region.

In a further embodiment said drain and source regions are formed in said second semiconductor region by implanting a p-type dopant species.

In a further embodiment the method further comprises forming a metal silicide in said first and second raised semiconductor regions.

In a further embodiment a height of at least one of the first and the second raised semiconductor regions is controlled during the epitaxial growth so as to adjust a distance of said metal silicide to a pn junction formed in said drain and source regions.

In a further embodiment said first and second raised semiconductor regions have differing heights.

According to still a further illustrative embodiment of the present invention, a method comprises epitaxially growing a first and a second raised semiconductor region above a first and a second semiconductor region, respectively, and forming an oxidation mask above the first raised semiconductor region. Next, the second raised semiconductor region is selectively oxidized to form an oxidized portion above the second raised semiconductor region. Finally, the oxidized portion of the second raised semiconductor region is selectively removed.

In a further embodiment forming an oxidation mask includes depositing a mask layer and selectively removing said mask layer from above said second semiconductor region.

In a further embodiment at least one of said first and second semiconductor regions comprises a structural element extending above a surface of said first and second semiconductor regions.

In a further embodiment said structural element comprises a gate electrode structure.

In a further embodiment the method further includes forming a disposable sidewall spacer adjacent to said gate electrode structure prior to epitaxially growing said first and second raised semiconductor regions.

In a further embodiment said step of selectively removing said oxidized portion of said second raised semiconductor region results in said first and second raised semiconductor regions having differing heights.

According to yet another illustrative embodiment of the present invention, a semiconductor device comprises a first gate electrode formed above a first semiconductor region and separated therefrom by a first gate insulation layer. A first raised drain and source region is formed and extends above the first gate insulation layer with a first height. Moreover, a second gate electrode is formed above a second semiconductor region and is separated therefrom by a second gate insulation layer. Additionally, a second raised drain and source region is formed and extends above the second gate insulation layer with a second height that differs from the first height.

In a further embodiment said first and second semiconductor regions are located in a semiconductor layer formed on an insulating layer.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages, objects and embodiments of the present invention are defined in the appended claims and will become more apparent with the following detailed description when taken with reference to the accompanying drawings, in which:

Figs. 1a-1d schematically show cross-sectional views of a conventional transistor device including raised drain and source regions during various manufacturing stages;

Figs. 2a-2e schematically show cross-sectional views of two different semiconductor regions during various manufacturing stages, wherein selectively raised semiconductor regions are formed having different heights above the first and second semiconductor regions in accordance with illustrative embodiments of the present invention; and

Figs. 3a and 3b schematically illustrate a first and a second semiconductor region that receive raised epitaxial growth regions by a common epitaxial growth process, wherein the individual height is adjusted by a selective oxidation process.

DETAILED DESCRIPTION

While the present invention is described with reference to the embodiments as illustrated in the following detailed description as well as in the drawings, it should be understood that the following detailed description as well as the drawings are not intended to limit the present invention to the particular illustrative embodiments disclosed, but rather the described illustrative embodiments merely exemplify the various aspects of the present invention, the scope of which is defined by the appended claims.

The present invention is based on the concept that the characteristics of selectively epitaxially grown semiconductor regions may be adjusted differently for different types of circuit elements or different areas of a semiconductor substrate. One example of circuit elements for which the above concept may be advantageously used are extremely scaled field effect transistor elements, wherein due to the reduced feature sizes even subtle variations of specific design criteria may have a significant impact on the finally obtained transistor performance. For instance, the capacitance of source and drain junctions may require different values at different device locations, which may be taken into account by correspondingly adjusting the height of raised drain and source regions. Moreover, the position of the dopant species for defining the source and drain regions with respect to a semiconductor film, in which raised source and drain regions are formed, may need to be addressed individually for different circuit elements and/or device regions. A further design criterion is the distance of the silicide interface, usually formed to lower the contact resistivity of drain and source regions, with respect to either the position of the pn junction or with respect to the bottom portion of a semiconductor layer. Hence, this distance may be separately adjusted for various regions of a semiconductor substrate so as to individually enhance the device performance. Moreover, as previously noted, a p-channel transistor may require raised source and drain regions of reduced height so as to take into account the increased penetration depth and diffusivity of boron. Consequently, by means of the reduced height, the implantation parameters may be selected so as to avoid undue degradation of a gate insulation layer while nevertheless providing for an optimum dopant profile in the source and drain region having the reduced height.

It should further be noted that in the following illustrative embodiments, a first and a second transistor element is referred to that are formed on respective semiconductor regions which are to receive epitaxially grown semiconductor regions. The present invention, however, should not be restricted to transistor elements, but may be readily applied to any circuit elements requiring the formation of selectively grown epitaxial growth regions of different characteristics; nor is the reference to two different semiconductor regions to be considered as restricting, as the embodiments disclosed herein may be readily applied to a plurality of different semiconductor areas requiring an individually adapted characteristic of the epitaxially grown semiconductor regions.

With reference to Figs. 2a-2d and 3a and 3b, further illustrative embodiments of the present invention will now be described in more detail.

Fig. 2a schematically shows a cross-sectional view of a semiconductor device 200 at an early manufacturing stage. The semiconductor device 200 comprises a substrate 201, which may represent any substrate that is suitable for forming circuit elements thereon. In some embodiments, the substrate 201 may represent a bulk semiconductor substrate, such as a silicon substrate, having formed thereon a semiconductor layer 202, such as a substantially crystalline silicon layer. In other embodiments, the substrate 201 may represent an insulating

substrate, for instance any appropriate substrate having formed thereon an insulating layer, such as a silicon dioxide layer, on which is located the semiconductor layer 202, for example in the form of a crystalline layer. It should be noted that in advanced logic circuits based on CMOS technology, SOI (silicon on insulator) technology is currently considered preferable for forming highly scaled transistor devices. Hence, in particular embodiments, the semiconductor layer 202 represents a crystalline silicon layer with a thickness of approximately 5-50nm that is formed on an insulating layer, often referred to as buried oxide. The semiconductor device 200 further comprises a first device region 240a and a second device region 240b, which are separated from each other and electrically insulated by an isolation structure 220. The isolation structure 220 may be provided in the form of a trench isolation structure that may extend down to the substrate 201 so as to substantially completely electrically insulate the first and second device regions 240a, 240b. It is to be noted that the first and second device regions 240a, 240b are illustrated as neighboring device regions so as to form, for instance, a complementary pair of field effect transistors, whereas in other embodiments the first and second device regions 240a, 240b may represent areas that are significantly spaced apart from each other within a single chip area or are even located in different chip areas within the substrate 201. For instance, different areas of a semiconductor wafer may require the formation of differently dimensioned epitaxial growth regions so as to provide for integrated circuits having other performance characteristics compared to integrated circuits that are formed on other areas.

The first and second device regions 240a, 240b comprise gate electrodes 203a, 203b formed on respective gate insulation layers 204a, 204b. Moreover, respective liners 206a, 206b, for instance comprised of silicon dioxide, are formed on sidewalls of the gate electrodes 203a, 203b and surface portions of the semiconductor layer 202. A top surface of the gate electrodes 203a, 203b are covered by respective cover layers 205a, 205b, which may represent the residue of an anti-reflective coating. Furthermore, a spacer layer 221, for instance comprised of silicon nitride, is formed above the first and second device regions 240a, 240b. In addition, an etch mask 222 is formed over the semiconductor device 200 such that the second device region 240b is substantially completely covered so as to avoid or at least slow down a material removal of the spacer layer 221 in the second device region 240b during a subsequent anisotropic etch process.

A typical process flow for forming the semiconductor device 200 as shown in Fig. 2a may substantially include the same process steps as previously explained with referenced to Fig. 1a, wherein the formation of the isolation structure 220 may be accomplished by well-established photolithography, deposition and etch techniques. Furthermore, corresponding implantation cycles with respective masking steps may be performed so as to establish a desired vertical dopant profile in the semiconductor layer 202 for the first and second device regions 240a, 240b in accordance with the device specifications. In addition to the conventional process flow as described with reference to Fig. 1a, in the present invention the etch mask 222, for instance comprised of a resist material, is formed prior to a first anisotropic etch process so as to form sidewall spacers 207a from the spacer layer 221 in the first device region 240a.

Fig. 2b schematically shows the semiconductor device 200 after the completion of the anisotropic etch process, during which sidewall spacers 207a have been formed adjacent to the gate electrode 203a. Moreover, in Fig. 2b the etch mask 220 is removed and portions of the liner 206a in the first device region 240a are removed so as to expose surface portions 223a of the semiconductor layer 202. The selective removal of the liner 206a may be accomplished by any appropriate etch procedure and, in particular embodiments when the liner 206a is comprised of silicon dioxide, may be achieved by a wet etch process using hydrogen fluoride (HF), whereby under-etch areas 224a may be created. Thereafter, suitable cleaning processes may be performed so as to remove any material residues from the exposed surface portions 223a and/or to remove any contaminants in a surface region of the semiconductor layer 202, wherein the remaining spacer layer 221 reliably maintains an integrity of the second device region 204b. Subsequently, a first epitaxial growth process may be performed, wherein the remaining spacer layer 221 acts as a "global" epitaxial growth mask for the second device region 240b so as to avoid any semiconductor growth on the second device region 240b. Similarly, the sidewall spacers 207a and the cap layer 205a serve as a "local" growth mask and restrict the epitaxial growth to the surface portion 223a and to the underetch regions 224a that may have been formed during the partial removal of the liner 206a.

Fig. 2c schematically shows the semiconductor device 200 with an epitaxially grown semiconductor region 208a that is selectively grown in the first device region 240a. A thickness or height of the epitaxially grown semiconductor region 208a is adjusted during the epitaxial growth process such that the growth process results, in combination with a further epitaxial growth process for forming an epitaxially grown semiconductor region in the second device region 240b, and possibly in combination with additional epitaxial steps when a plurality of differently dimensioned epitaxially grown semiconductor regions is to be formed, in the finally desired height of the semiconductor region 208a. Moreover, in some embodiments, one or more dopant species may be introduced during the epitaxial growth of the semiconductor region 208a, thereby providing for an increased process flexibility in subsequent implantation steps for forming drain and source regions by ion implantation. In one embodiment, the initial height of the epitaxially grown semiconductor region 208a may range from approximately 1-10 nm.

In Fig. 2c a second etch mask 225 is illustrated that substantially covers the first device region 240a so as to substantially avoid any material removal and/or damage in the first device region 240a during a subsequent anisotropic etch process for patterning the remaining spacer layer 221 in the second device region 240b.

Fig. 2d schematically shows the device 200 after completion of the anisotropic etch process, resulting in the formation of sidewall spacers 207b adjacent to the gate electrode 203b. Moreover, the liner 206b is partially removed in the second device region 240b so as to expose the surface portions 223b of the semiconductor layer 202, wherein, depending on the removal process, underetch portions 224b may have been formed, as is also explained with reference to the first

device region 240a. After any cleaning processes for removing material residues and contaminants from the exposed surface portions 223b and of course from the epitaxially grown regions 208a, a further (second) epitaxial growth process is performed, wherein the process parameters are selected so as to obtain a required height of an epitaxially grown region in the second device region 240b if this epitaxial growth process is the last process for the device 200. In other embodiments, when a further epitaxial growth process is to be carried out for a further device region (not shown) that has been covered by a respective epitaxial growth mask during the first epitaxial step and is still covered by the epitaxial growth mask during this second epitaxial growth step, the process parameters are selected so as to obtain an intermediate height, which in combination with the subsequent epitaxial growth, results in the finally desired height for the first and second device regions 240a, 240b and the further device region.

Fig. 2e schematically shows the device 200 after completion of the second epitaxial growth step to form raised semiconductor regions 218b adjacent to the gate electrode 203b and forming additional epitaxial growth regions 218a on top of the previously grown region 208a. Hence, the combination of the epitaxially grown regions 208a, 218a results in a final thickness 219a that is larger than a corresponding final thickness 219b in the second device region 240b. For instance, the second device region 240b may represent a p-channel transistor, wherein the reduced thickness 219b of the raised semiconductor regions 218b compared to the thickness 219a provides for the possibility to deeply implant boron ions into the semiconductor layer 202, while maintaining the superior performance of an n-channel transistor having the increased height 219a and nevertheless avoiding an undue degradation of the gate insulation layer 204b by penetrating and diffusing boron ions. In other aspects, the respective heights 219a, 219b may be selected so as to individually adjust the overall capacitance of drain and source regions of the semiconductor devices, or to correspondingly adjust the distance between metal silicide regions, which are typically formed for enhancing the conductivity of source and drain regions still to be formed, and the bottom of the semiconductor layer 202.

After the second epitaxial growth process, the further manufacturing process may be resumed substantially in a similar way as is described with reference to Figs. 1c and 1d. That is, the spacers 207a, 207b and the cap layers 205a, 205b may be removed, for instance by hot phosphoric acid, and corresponding implantation cycles using corresponding spacers as required may be performed so as to obtain a desired dopant profile as is necessary for corresponding drain and source regions, including respective extension regions. Thereafter, corresponding metal silicide regions may be formed at least in the raised semiconductor regions 218a and 218b in accordance with design requirements.

It should be noted that in the above-illustrated embodiments, the first and second device regions 240a, 240b are separated by the isolation structure 220. In other embodiments, the separation between two different device regions may not necessarily be represented by a trench isolation, but may simply be represented by any physical boundary, or may be simply defined by design

requirements based on specific criteria, such as functionality of a circuit layout and the like. Hence, the separation into the first and second device regions 240a, 240b is substantially obtained by the formation of the first and second etch masks 222, 225, wherein, owing to alignment errors due to the photolithography involved in forming the first and second etch masks 222, 225 may result in an intermediate region that may experience an anisotropic etch atmosphere during patterning of the sidewall spacers 207a and during patterning of the sidewall spacers 207b. In such cases, the liner 206a may advantageously be formed with an appropriate thickness so as to have the capability to withstand two anisotropic etch procedures substantially without exposing any underlying material layers to the anisotropic etch ambient.

In the embodiments described with reference to Figs. 2a-2e, the spacer layer 221 (cf. Fig. 2a) is anisotropically patterned in the first device region 240a while being covered in the second device region 240b, thereby acting as a "local" epitaxial growth mask in the first device region 240a in the form of the spacers 207a. On the other hand, the non-patterned spacer layer 221_serves as a "global" epitaxial growth mask in the second device region 240b (cf. Fig. 2b). In other embodiments, the spacer layer 221 may be patterned simultaneously in the first and second device regions 240a, 240b, similarly to the conventional approach, and after forming corresponding sidewall spacers 207a, 207b in the first and second device regions 240a, 240b, a corresponding etch mask, such as the mask 222, may be formed in one of these regions so that in a subsequent process for removing, for instance, the liner 206a, the corresponding liner 206b is maintained in the second device region 240b. The liner 206b may then serve in the subsequent epitaxial growth process, in combination with the spacer 207b and the cover layer 205b, as a global growth mask, substantially preventing the epitaxial growth of semiconductor material on the second device region 206b. The subsequent manufacturing process may then be continued as is described with reference to Fig. 2d. If the liner 206b is to act as an epitaxial growth mask, it may be advantageous to provide the liner 206a and 206b with an increased thickness compared to the conventional approach so as to substantially maintain the integrity of the liner 206b when corresponding cleaning processes are performed so as to remove any material residues from the exposed surface portions 223a (cf. Fig. 2b) prior to the first epitaxial growth process. Moreover, since the adhesion characteristics of silicon to the liner material of the liner 206b, for instance comprised of silicon dioxide, may differ from the adhesion characteristics of the spacer layer 221, for instance comprised of silicon nitride, a corresponding adaptation of the epitaxial growth parameters may be required. For instance the temperature of the epitaxial growth process may be correspondingly adapted so as to substantially avoid any semiconductor deposition on the exposed liner 206b.

With reference to Figs. 3a and 3b, further illustrative embodiments will now be described, wherein the thickness or height of epitaxially grown semiconductor regions are individually reduced by a selective oxidation process.

In Fig. 3a, a semiconductor device 300 comprises a first device region 340a and a

second device region 340b. The first device region 340a comprises a gate electrode 303a formed above a semiconductor layer 302, which in turn is formed on an appropriate substrate 301. Regarding the substrate 301 and the semiconductor layer 302, the same criteria apply here as are already pointed out with reference to the device 200. Moreover, a gate insulation layer 304a separates the gate electrode 303a from the semiconductor layer 302. A disposable sidewall spacer 307a is formed near sidewalls of the gate electrode 303a and is separated therefrom by a liner 306a. Epitaxially grown semiconductor regions 308a are formed adjacent to the disposable sidewall spacers 307a with a specified thickness or height 319. The epitaxially grown regions 308a may include a liner 309a, for instance in the form of an oxidized portion. The second device region 304b may comprise corresponding circuit components that are indicated by the same reference numerals, except for the letter "b". In particular, although the dimensions of the various components formed on the second device region 340b may differ from those formed on the first device region 340a, the height of the epitaxially grown regions 308b is substantially the same as for the first device region 340a since the regions 308a and 308b are formed by a common epitaxial growth process. The same holds true for the liner 309b. Moreover, the device 300 comprises a mask layer 321, for instance comprised of silicon nitride, wherein a thickness of the mask layer 321 is selected so as to be able to substantially avoid or at least significantly reduce an oxidation of an underlying material when exposed to an oxidizing ambient. For instance, the mask layer 321 may have a thickness of approximately less of 1nm to several nm when comprised of silicon nitride. Additionally, an etch mask 322 is formed over the second device region 340b. The etch mask 322 may be comprised of a resist layer or any other appropriate material having the capability to withstand a specified etch chemistry used for removing the mask layer 321 from the first device region 340a.

A typical process flow for forming the device 300 as shown in Fig. 3a may comprise the same processes as previously described with reference to Figs. 2a to 2e, so as to selectively form the epitaxial growth regions 308a, 308b. Contrary to the conventional process flow, the liner 309a, 309b may be formed by, for instance, oxidizing the device 300. Thereafter, the mask layer 321 may be deposited, for instance by plasma-enhanced chemical vapor deposition, and subsequently the etch mask 322 may be formed by well-established photolithography. Thereafter, the mask layer 321 may be selectively removed from the first device region 340a, for instance by a selective isotropic or anisotropic etch process that stops in or on the liner 309a. Since the mask layer 321 is highly conformally deposited over the first device region 340a, the disposable spacers 307a and the cover layer 305a remain substantially intact if a substantially anisotropic etch recipe is applied for removing the mask layer 321. In case an anisotropic etch process is used, the thickness of the disposable spacer 307a is correspondingly increased by the etch process by the layer thickness of the mask layer 321. Since the thickness of the layer 321 may be selected to be relatively thin, the increase of the width of the disposable spacer 307a does not substantially affect the further processing. After the selective removal of the mask layer 321, the etch mask 322 is also removed and thereafter the device 300 is exposed to an oxidizing ambient, for instance, to an oxygen containing atmosphere at an elevated temperature so as to initiate a highly

controllable selective oxidation process in the epitaxially grown region 308, while an oxidation of the regions 308b is substantially avoided or at least significantly slowed down by the remaining mask layer 321 preserved on the second device region 340b. In other embodiments, an oxidizing solution may be applied to the device 300, possibly after first removing the liner 309a, for instance by means of a wet chemical etch process on the basis of hydrogenated fluoride (HF).

Fig. 3b schematically shows the device 300 after the completion of the highly controllable selective oxidation process, wherein an oxidized portion 310a having a well-controlled thickness 311a has been formed above the epitaxially grown region 308a. Thereafter, the oxidized portion 310a may be removed or the thickness thereof may be reduced, for instance to a value that is similar to that of the liner 309b of the second device region 340b. The removal of the oxidized portion or the thickness reduction thereof may be accomplished by a wet etch process on the basis of, for example, HF. Next, the disposable spacers 307a and the cap layer 305a as well as the remaining mask layer 321 and the disposable spacers 307b and the cap layer 305b may be removed, for instance in a common etch process using hot phosphoric acid. Finally, the liner 309b and possibly the remaining part of the oxidized portion 310a may be removed selectively to the underlying semiconductor material, thereby providing an epitaxially grown region 308a having an effective height 319a and providing a height 319b of the region 308b in the second device region 340b. Since the selective oxidation process for forming the oxidized portion 310a exhibits a superior controllability compared to typical anisotropic or isotropic etch procedures, the finally obtained height 319a is adjustable with high precision so that corresponding device characteristics may be finely tuned.

The further process for completing the semiconductor device 300 may be conducted as previously explained with reference to Fig. 2b.

As a result, the present invention provides for an improved technique to form circuit elements having epitaxially grown semiconductor regions, the heights of which may be individually adjusted in two or more different device regions by selectively providing a global epitaxial growth mask or by selectively reducing a thickness of epitaxially grown regions. In some embodiments both methods may be combined so as to provide superior flexibility in adjusting the height of epitaxially grown regions in a plurality of device regions. Since epitaxially grown raised source and drain regions are currently considered a preferred technique for forming extremely scaled transistor devices, the present invention is particularly advantageous for devices of critical dimensions of approximately 90 nm or less.

Further modifications and variations of the present invention will be apparent to those skilled in the art in view of this description. Accordingly, the description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the present invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments.

Industrial applicability

The present invention relates to microelectronic structures and is therefore industrially applicable

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CLAIMS

1. A method comprising:
forming a first epitaxial growth mask (222) that exposes a portion of a first semiconductor region (240a) while keeping a second semiconductor region (240b) covered;

epitaxially growing a first raised semiconductor region (208a) in said exposed portion of the first semiconductor region (240a);

forming a second epitaxial growth mask (225) that exposes a portion of said second semiconductor region (240b); and

epitaxially growing a second raised semiconductor region (218b) in said exposed portion of the second semiconductor region (240b).

2. The method of claim 1, wherein forming a first epitaxial growth mask comprises depositing a spacer layer over the first and second semiconductor regions; and patterning said spacer layer above said first semiconductor region while covering said spacer layer above said second semiconductor region.

3. The method of claim 2, wherein forming a second epitaxial growth mask comprises forming a cover layer above said first semiconductor region; and patterning said spacer layer above said second semiconductor region.

4. The method of claim 2, wherein said first and second semiconductor regions comprise a gate electrode structure and patterning said first epitaxial growth mask includes anisotropically etching said spacer layer.

5. The method of claim 1, further comprising removing said first and second epitaxial growth masks after forming said first and second raised semiconductor regions.

6. The method of claim 5, wherein at least one of said first and second semiconductor regions comprises a gate electrode structure and the method further comprises forming drain and source regions adjacent to said gate electrode structure after removal of said first and second epitaxial growth masks.

7. The method of claim 5, further comprising forming a gate electrode structure on portions of said first and second semiconductor regions exposed by removing said first and second epitaxial growth masks.

8. A method comprising:
epitaxially growing a first (308a) and a second (308b) raised semiconductor region above a first and a second semiconductor regions (340a, 340b), respectively;

forming an oxidation mask (321) above said first raised semiconductor region (308a);

selectively oxidizing said second raised semiconductor region (308b) to form an oxidized portion (310b) above said second raised semiconductor region (308b); and

selectively removing said oxidized portion (310b) of said second raised semiconductor region (308b).

9. A semiconductor device comprising:
a first gate electrode (203a) formed above a first semiconductor region (240a) and separated therefrom by a first gate insulation layer (204a);

a first raised drain and source region (208a) extending above said first gate insulation layer (204a) with a first height (219a);

a second gate electrode (203b) formed above a second semiconductor region (240b) and separated therefrom by a second gate insulation layer (204b);

a second raised drain and source region (208b) extending above said second gate insulation layer (204b) with a second height (219b) that differs from the first height.

10. The semiconductor device of claim 9, wherein said first height is less than said second height and said first gate electrode and said first raised drain and source regions representing a p- channel transistor.

11. A method, comprising:
epitaxially growing a first and a second raised semiconductor region above a first and a second semiconductor region, respectively, wherein each of said first and second semiconductor regions comprises a gate electrode structure extending above a surface of said first and second semiconductor regions;

forming an oxidation mask above said first raised semiconductor region, wherein forming an oxidation mask includes depositing a mask layer and selectively removing said mask layer from above said second semiconductor region;

selectively oxidizing said second raised semiconductor region to form an oxidized portion above said second raised semiconductor region; and

selectively removing said oxidized portion of said second raised semiconductor region, wherein said step of selectively removing said oxidized portion of said second raised semiconductor region results in said first and second raised semiconductor regions having differing heights.

12. A method, comprising:
epitaxially growing a first and a second raised semiconductor region above a first and a second semiconductor region, respectively, wherein each of said first and second semiconductor regions comprises a gate electrode structure extending above a surface of said first and second semiconductor regions;

forming an oxidation mask above said first raised semiconductor region by depositing a mask layer and selectively removing said mask layer from above said second semiconductor region;

selectively oxidizing said second raised semiconductor region to form an oxidized portion above said second raised semiconductor region; and

selectively removing said oxidized portion of said second raised semiconductor region.

13. A method, comprising:
epitaxially growing a first and a second raised semiconductor region above a first and a second semiconductor region, respectively, wherein each of said first and second semiconductor regions comprises a gate electrode structure extending above a surface of said first and second semiconductor regions;

forming an oxidation mask above said first raised semiconductor region, wherein forming an oxidation mask includes depositing a mask layer and selectively removing said mask layer from above said second semiconductor region;

selectively oxidizing said second raised semiconductor region to form an oxidized portion above said second raised semiconductor region;

selectively removing said oxidized portion of said second raised semiconductor region, wherein said step of selectively removing said oxidized portion of said second raised semiconductor region results in said first and second raised semiconductor regions having differing heights; and

forming a disposable sidewall spacer adjacent to said gate electrode structure prior to epitaxially growing said first and second raised semiconductor regions.

14. A method, comprising:
epitaxially growing a first and a second raised semiconductor region above a first and a second semiconductor region, respectively, wherein at least one of said first and second semiconductor regions comprises a structural element extending above a surface of said first and second semiconductor regions and wherein said structural element comprises a gate electrode structure;

forming an oxidation mask above said first raised semiconductor region, wherein forming an oxidation mask includes depositing a mask layer and selectively removing said mask layer from above said second semiconductor region;

selectively oxidizing said second raised semiconductor region to form an oxidized portion above said second raised semiconductor region; and

selectively removing said oxidized portion of said second raised semiconductor region, wherein said step of selectively removing said oxidized portion of said second raised semiconductor region results in said first and second raised semiconductor regions having differing heights.