

EPITAXIALLY DEPOSITED SOURCE/DRAINBackground

This invention relates generally to metal oxide semiconductor field effect transistors.

5 Metal oxide semiconductor field effect transistors include a gate that is self-aligned with a source/drain. The source/drain may include a deeper or heavily doped region and a shallower and lightly doped region, sometimes called a tip or source/drain extension.

10 Gate underlap is the amount by which the source/drain material diffuses under the gate after ion implantation and subsequent heat processing. After implantation, the material that is implanted is exposed to heat which causes the material to move downwardly into the substrate and, to a lesser extent, laterally under the gate. Thus, in a system
15 using an ion implanted source/drain extension, the amount of underdiffusion is determined as a function of junction depth.

It is desirable to have relatively shallow junction depth for the source/drain extension to support smaller
20 transistor dimensions. Usually, in source/drain extension implantation techniques, the minimum tip junction depths are determined by the necessary gate underlap.

The shallower the source/drain extension, generally the shorter the gate lengths that may be utilized without
25 increasing off-state leakage currents. Extension doping under the gate edge is needed to ensure a low resistance path between the inversion layer under the gate and the highly doped source/drain extension region. The low resistance is needed for a high drive currents, which are
30 critical for high circuit switching speeds.

Thus, there is a need for better ways to make source/drain junctions of field effect transistors.

Brief Description of the Drawings

Figure 1 is a greatly enlarged, cross-sectional view at one stage of manufacture;

Figure 2 is an enlarged, cross-sectional view at a subsequent stage of manufacture in accordance with one embodiment of the present invention;

Figure 3 is an enlarged, cross-sectional view at still a subsequent stage of manufacture in accordance with one embodiment of the present invention;

Figure 4 is an enlarged, cross-sectional view at a subsequent stage of manufacture in accordance with one embodiment of the present invention; and

Figure 5 is an enlarged, cross-sectional view at still a subsequent stage of manufacture in accordance with one embodiment of the present invention.

Detailed Description

Referring to Figure 1, a heavily doped semiconductor substrate 12 may be covered by a sacrificial, undoped, or lightly doped epitaxial silicon layer 18. The layer 18 may be less than 500 Angstroms thick in one embodiment. A gate electrode structure including a gate 16 formed over a gate dielectric 14 may be defined on the epitaxial silicon layer 18.

The selective deposition of the sacrificial epitaxial silicon layer 18 may be carried out, for example, using dichlorosilane-based chemistry in a single wafer chemical vapor deposition reactor, such as an Epsilon 3000 epitaxial reactor, available from ASM International NV, Bilthoven, Netherlands. The film may be deposited with gas flows of 150-200sccm of dichlorosilane, 100-150sccm of HCl, 20slm of H₂ at 825°C in a processed pressure of 20Torr. Under these processing conditions, a deposition rate of 10-15 nanometers per minute may be achieved for silicon on exposed substrate

while achieving selectivity to spacer and oxide regions. Other deposition techniques may also be used.

The arrangement shown in Figure 1 is sometimes called a delta doped transistor. Because there is relatively high
5 doping below the epitaxial layer 18, a large delta or change in concentration occurs at the interface between the substrate 12 and the epitaxial silicon layer 18.

The structure shown in Figure 1 may be covered by a spacer material and then anisotropically etched to form the
10 sidewall spacers 28 shown in Figure 2. Some limited etching of the epitaxial silicon 18 may occur at the same time depending on the selectivity of the spacer etch.

After spacer formation, a selective wet etch may remove the exposed portions of the epitaxial silicon layer 18 and
15 may continue etching under the gate 16 to achieve the undercut structure shown in Figure 3. The extent of gate 16 undercut can be controlled by adjusting the etch time.

The epitaxial silicon layer 18 may be selectively etched with a variety of hydroxide-based solutions, for
20 example. However, for high selectivity of the undoped or lightly doped layer 18 to the heavily doped substrate 12, relatively mild processing conditions may be employed.

In one embodiment, an aqueous ammonium hydroxide solution in the concentration range of 2 to 10 percent by
25 volume at 20°C may be used together with sonication. The sonication may be provided by a transducer that dissipates ultra or megasonic energy with a power of .5 to 5 watts per cm² in one embodiment of the present invention. Since the delta doped transistor has a heavily doped region below the
30 undoped region, it may serve as an etch stop layer for the wet etch.

After the wet etch undercut, a doped selective epitaxial silicon layer 50 may be grown. A shallow, highly

doped source/drain extension 50a laterally extends the desired distance under the gate 16 edge and the sidewall spacer 28, as shown in Figure 4. A thicker source/drain region 50b is aligned with the edge of the spacer 28 and extends away from the spacer 28. The spacer 28 enables the length of the extension 50a to be tailored and allows the thickness of the layer 50 to expand without shorting to the gate 16. The thicker region 50b reduces resistance of the region 50 and brings the lower resistance region close to the edge of the gate 16.

In forming the P-type MOS (PMOS) transistor, the source/drain extension 50a and raised source/drain 50b may be formed by selectively depositing epitaxial boron doped silicon or silicon germanium with a germanium concentration of up to 30 percent, as one example. Under the processing conditions of 100sccm of dichlorosilane, 20slm H₂, 750-800°C, 20Torr, 150-200sccm HCl, diborane flow of 150-200sccm and GeH₄ flow of 150-200sccm, a highly doped silicon germanium film with a deposition rate of 20 nanometers per minute, a boron concentration of 1E20 cm⁻³, and a germanium concentration of 20 percent may be achieved in one embodiment. A low resistivity of 0.7-0.9 mOhm-cm results from the high boron concentration of the film.

Low resistivity provide the benefit of high conductivity in the extension and source/drain regions in some embodiments. This lowered resistivity may reduce the external resistance. The larger unit cell of the silicon germanium present in source/drain regions 50b may exert compressive strain on the channel, which in turn may result in enhanced mobility and transistor performance in some embodiments.

In the N-type transistor (NMOS), the source/drain 50b and source/drain extension 50a may be formed using *in situ*

phosphorus doped silicon deposited in one embodiment. The silicon may be deposited selectively under processing conditions of 100sccm of dichlorosilane, 25-50sccm HCl, 200-300sccm of 1 percent PH₃ with a H₂ gas carrier flow of 20slm at 750°C and 20Torr. A phosphorous concentration of 2E20 cm⁻³ with a resistivity of 0.4-0.6 mOhm-cm may be achieved in the deposited film in one embodiment.

Thereafter, a second thin spacer 34 may be formed using conventional techniques as shown in Figure 5. A deep source/drain 32 may be formed by ion implantation using the spacers 28 and 34 and the gate 16 as a mask. The annealing of the deep source/drain 32 may be done in a way that reduces or minimizes the dopant diffusion including the dopant in the layer 50.

The characteristics of the shallow source/drain extensions 50a and the degree by which they underlap the gate 16 may be independent of the characteristics of the deep source/drain junction 32. The extent of extension underlap of the gate 16 of the source/drain extension 50a may be controlled as desired.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is:

1. A method comprising:
forming a metal oxide semiconductor field effect transistor having an epitaxially deposited source/drain that extends under the edges of a gate electrode.

5 2. The method of claim 1 including forming a source/drain extension that extends under the edges of a gate electrode.

3. The method of claim 1 including forming a sacrificial epitaxially deposited material over a substrate
10 and forming a gate electrode over said epitaxially deposited layer.

4. The method of claim 3 wherein forming a sacrificial epitaxially deposited material includes epitaxially depositing a silicon material.

15 5. The method of claim 3 including selectively etching said epitaxially deposited material.

6. The method of claim 5 including using sonication to selectively etch said material.

7. The method of claim 3 including forming a sidewall spacer on said gate electrode and etching under said
20 sidewall spacer.

8. The method of claim 5 including selectively etching said epitaxially deposited material so as to undercut said gate electrode.

9. The method of claim 8 including depositing an epitaxial material on said substrate and extending under said gate electrode.

10. The method of claim 9 including forming a doped
5 epitaxial material.

11. The method of claim 8 including forming said epitaxial material to be thinner near the gate electrode and thicker spaced from said gate electrode.

12. The method of claim 1 including forming a delta
10 doped transistor.

13. A field effect transistor comprising:
a substrate;
a doped epitaxial semiconductor material formed
over said substrate; and
15 a gate electrode formed over said doped epitaxial semiconductor material, said doped epitaxial semiconductor material extending under said gate electrode.

14. The transistor of claim 13 including a source/drain having a source/drain extension, said
20 source/drain extension being formed of said doped epitaxial semiconductor material and extends under the edges of the gate electrode.

15. The transistor of claim 14 wherein said material has a first thickness near said gate electrode and a second
25 thickness spaced from said gate electrode, said second thickness being greater than said first thickness.

16. The transistor of claim 15 including a sidewall spacer, said material extending under said sidewall spacer.

17. The transistor of claim 16 wherein said second thickness is aligned with said sidewall spacer.

5 18. The transistor of claim 13 wherein said transistor is a delta doped transistor.

19. The transistor of claim 13 including an ion implanted source/drain under said doped epitaxial semiconductor material.

10 20. A method comprising:
forming a epitaxial semiconductor layer over a semiconductor substrate wherein the epitaxial semiconductor layer has a lower doping concentration than the substrate;
forming a gate structure including a gate
15 electrode and a sidewall spacer over said epitaxial semiconductor layer; and
selectively etching the exposed portion of said epitaxial semiconductor layer as well as a portion of said epitaxial semiconductor layer under said gate electrode.

20 21. The method of claim 20 including epitaxially depositing a doped semiconductor material over said substrate to fill the region under said gate electrode and under said sidewall spacer.

25 22. The method of claim 21 wherein said epitaxial semiconductor layer has a first thickness under said gate electrode and a second thickness spaced from said gate electrode.

23. The method of claim 22 including forming said second thickness in alignment with said spacer.

24. The method of claim 20 including forming a deep source/drain region by ion implantation.

5 25. The method of claim 20 including forming said epitaxial semiconductor layer extending under said gate electrode and having a greater thickness outbound of said gate electrode and a lesser thickness under said gate electrode.