

SEMICONDUCTOR DEVICE WITH TRANSISTOR LOCAL INTERCONNECTS

FIELD OF THE INVENTION

[0001] The present invention generally relates to semiconductor devices, and more particularly relates to local interconnects between transistors in semiconductor devices.

BACKGROUND OF THE INVENTION

[0002] As the size of semiconductor devices continues to decrease, the ability to create standard cell library logic devices, such as scan-D flip-flops and multiplexers, becomes more difficult. This is particularly the case at the 20 nm node, where lithographic limitation results in a lack of scaling of standard cell library devices. Cross-coupling of transistors is critical to the scaling of key stand cell library devices. Without cross-coupling, logic scaling will take up more area of the semiconductor device. Furthermore, traditional cross-coupling utilizing a standard metal layer will also occupy large amounts of area. Either of these conditions is obviously undesirable, leading to a larger semiconductor device or less functionality in the semiconductor device.

[0003] Accordingly, it is desirable to provide cross-coupling of transistors without reliance on a standard metal layer to produce standard cell library devices while conserving semiconductor device area. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description of the invention and the appended claims, taken in conjunction with the accompanying drawings and this background of the invention.

BRIEF SUMMARY OF THE INVENTION

[0004] A semiconductor device is provided for implementing at least one logic element. In one aspect of the invention, the semiconductor device includes a semiconductor substrate with a first transistor and a second transistor formed on the semiconductor substrate. Each of the transistors includes a source, a drain, and a gate. A CA layer is electrically connected to at least one of the source or the drain of the first transistor. A CB layer is electrically connected to at least one of the gates of the transistors and the CA layer.

[0005] In another aspect of the invention, the semiconductor device includes a semiconductor substrate with a first transistor, a second transistor, and a third transistor

formed on the substrate. The transistors are disposed sequentially from the first transistor through the third transistor. Each of the transistors includes a source, a drain, and a gate. A first CB layer is electrically connected to the gate of the first transistor. A second CB layer is electrically connected to the gate of the third transistor. A CA layer electrically connects the first CB layer and the second CB layer and is electrically insulated from the gate of the second transistor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention will hereinafter be described in conjunction with the following drawing FIG.s, wherein like numerals denote like elements, and

[0007] FIG. 1 is a cross-sectional side view of a portion of a semiconductor device;

[0008] FIG. 2 is a top view of one embodiment of the semiconductor device showing gates of transistors, various local interconnect layers, and trench silicide layers;

[0009] FIG. 3 is a top view of another embodiment of the semiconductor device showing a metal layer disposed above the gates of the transistors and the various local interconnect layers;

[0010] FIG. 4 is a top view of a portion of a first embodiment of the semiconductor device;

[0011] FIG. 5 is a top view of a portion of a second embodiment of the semiconductor device;

[0012] FIG. 6 is a top view of a portion of a fourth embodiment of the semiconductor device;

[0013] FIG. 7 is a cross-sectional side view the fourth embodiment of the semiconductor according to the line 7-7 shown in shown in FIG. 6;

[0014] FIG. 8 is a top view of a portion of a fifth embodiment of the semiconductor device;

[0015] FIG. 9 is a top view of a portion of a sixth embodiment of the semiconductor device; and

[0016] FIG. 10 is a side view of a portion of a seventh embodiment of the semiconductor device according to the line 10-10 shown in FIG. 2.

DETAILED DESCRIPTION

[0017] The following detailed description of the invention is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention.

Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description of the invention.

[0018] Referring to the figures, wherein like numerals indicate like parts throughout the several views, a semiconductor device **20** is shown and described herein. The semiconductor device **20** may be part of an integrated circuit (not separately numbered) as is well recognized by those skilled in the art.

[0019] Referring to FIG. 1, the semiconductor device **20** includes a semiconductor substrate **22**. The semiconductor device **20** includes a plurality of transistors **24**. Specifically, in the illustrated embodiments, the transistors **24** are field-effect transistors (FETs) and more specifically, metal-oxide-semiconductor field-effect transistors (MOSFETs). Each of the transistors **24** includes a source **26**, a drain **28**, and a gate **30**.

[0020] The sources **26** and drains **28** are formed in and/or on the substrate **22** using techniques that are well known to those skilled in the art. In the illustrated embodiments, the sources **26** and drains **28** are formed as raised sources **26** and drains **28**, i.e., at least a portion of the sources **26** and drains **28** are formed above the substrate **22**. In the configuration shown in FIG. 1, the raised source **26** and drain **28** each extend about 15 nm above the substrate **22**. However, other dimensions may be alternatively realized. The raised sources **26** and drains **28** may be formed using embedded silicon germanium (eSiGe) techniques as is appreciated by those skilled in the art. Of course, other techniques may be implemented to form the raised sources **26** and drains **28**. Furthermore, in other embodiments (not shown), the sources **26** and drains **28** may not be raised above the substrate **22**.

[0021] The gates **30** are typically formed above the substrate **22** using techniques well known to those skilled in the art. In the illustrated embodiments, the gates **30** are formed primarily of polycrystalline silicon, commonly referred to as polysilicon or simply PolySi, disposed above the substrate **22**. However, the gates **30** may also be formed from other materials, e.g., a high- κ metal. In the configuration shown in FIG. 1, the gate **30** extends about 35 nm above the substrate **22**. However, other dimensions for the gates **30** may be alternatively realized.

[0022] As can be seen with reference to FIG. 2, the gates **30** are formed as linear strips **31** generally parallel to one another. Gaps **32** may be formed in the strips **31** such that more than one transistor **30** may be disposed longitudinally along each strip **31**. Such gaps **32** may be formed using cut mask techniques as readily appreciated by those skilled in the art.

[0023] Referring to FIGS. 1 and 3, the semiconductor device 20 includes at least one metal layer 33 disposed above the sources 26, drains 28, and gates 30 of the transistors 24 as is appreciated by those skilled in the art. The metal layers 33 facilitate electrical communication between the various logic elements of the device 20 and other logic elements of the device 20 as well as other systems apart from the device 20. The metal layers 33 are routinely labeled and referred to as M1, M2, etc., as is also appreciated by those skilled in the art. In the configuration shown in FIG. 1, one metal layer 33 is disposed about 165 nm above the substrate 22. However, other distances and dimensions for the metal layer 33 may be alternatively realized.

[0024] The semiconductor device 20 further includes at least one local interconnect layer 34, 36 to selectively connect the sources 26, drains 28, and gates 30 of the transistors 24 to other sources 26, drains 28, and gates 30 of other transistors 24. The at least one local interconnect layer 34, 36 may also be selectively connected to the at least one metal layer 33. The at least one local interconnect layer 34, 36 is disposed between the at least one metal layer 33 and the substrate 22. Said another way, the metal layer 33 is disposed above the at least one local interconnect layer 34, 36 with respect to the substrate 22. The at least one local interconnect layer 34, 36 of the illustrated embodiments is formed primarily of tungsten. In other embodiments, the at least one local interconnect layer 34, 36 is formed primarily of copper. However, the local interconnect layers 34, 36 may be formed of or include other elements or compounds.

[0025] Various embodiments of the semiconductor device 20 showing different shapes, arrangements, and electrical connections of the at least one local interconnect layer 34, 36 are shown in the various figures and described below. A first local interconnect layer 34 is referred to herein as a CA layer 34 and a second local interconnect layer 36 is referred to herein as a CB layer 36. Of course, multiple CA layers 34 and multiple CB layers 36 may be implemented in the semiconductor device 20 and other local interconnect layers (not shown) may also be implemented. Typically, the CA layer(s) 34 electrically connect to sources 26 or drains 28 while the CB layer(s) 36 electrically connect to gates 30. However, such typical configuration should certainly not be viewed as limiting. In fact, in some of the embodiments described below, CA layer(s) 34 and/or CB layer(s) 36 may not be connected to sources 26, drains 28, or gates 30.

[0026] The use of the CA and CB layers 34, 36 in the illustrated embodiments may be utilized to produce a variety of standard cells, such as, for example, scan-D flip-flops. In the

prior art, a metal layer is typically utilized in to provide the connection for scan-D flip-flops. By utilizing the CA and CB layers **34, 36**, which are disposed closer to the substrate than the typical metal layer, the resulting scan-D flip-flops have a reduced area when compared to prior art devices.

[0027] The semiconductor device **20** may further include one or more trench silicide layers **37**. The trench silicide layer **37** may be utilized to electrically connect the source **26** and/or drain **28** of the transistor **24** to one of the CA or CB layers **34, 36**, and typically the CA layer, as shown in FIG. 1. As such, the trench silicide layer **37** is sandwiched between one of the CA or CB layers **34, 36** and the at least one of the source **26** or the drain **28** of the transistor **24**. The trench silicide layer **37** is formed by cutting a trench (not separately numbered) in a dielectric (not shown) to the depth of the substrate **22** and filling the trench with a silicide material. For example, the silicide material may be a metal, such as nickel, cobalt, or tungsten.

[0028] The trench silicide layer **37** of the configuration shown in FIG. 1 has a height of about 50 nm. The CA layer **34** of FIG. 1 is supported by the trench silicide layer **34** and has a height of about 40 nm. The CB layer **36** of FIG. 1 has a height of about 70 nm. The CA layer **34** and CB layer **36** of FIG. 1 are generally level with one another with respect to the substrate **22**. Furthermore, as can be seen in FIG. 1, the CA and CB layers **34, 36** of the illustrated embodiments do not extend more than 105 nm above the substrate **22**. Of course, the heights and dimensions of the trench silicide layer **37**, the CA layer **34**, and the CB layer **36** may be different in alternative embodiments depending on any number of factors.

[0029] The semiconductor device **20** may include a plurality of vias **38** to selectively provide electrical connections between the CA or CB layers **34, 36** and the at least one metal layer **33**. As such, one of the vias **38** may be disposed between the at least one metal layer **33**, and one of the CA or CB layers **34, 36**. The vias **38** are formed primarily of a metal, such as copper. However, other metals or electrically conductive materials may also be suitable. The vias **38** of the configuration shown in FIG. 1 have a height of about 60 nm.

[0030] In a first embodiment, as shown in FIG. 4, the semiconductor device **20** includes at least a first transistor **24a** and a second transistor **24b**. The semiconductor device **20** includes a CA layer **34** and a CB layer **36**. The CA layer **34** is electrically connected to at least one of the source **26a** or the drain **28a** of the first transistor **24a**. A CB layer **36** is electrically connected to at least one of the gates **30** of the transistors **24a, 24b**. Depending on the particular application, the CB layer **36** may be electrically connected to both of the gates **30** of

the transistors **24a**, **24b**. The first and CB layers **34**, **36** are also electrically connected to one another.

[0031] In the first embodiment, the CA layer **34** extends between a first end **40** and a second end **42**. The CB layer **36** is disposed generally at a center **44** of the CA layer **34** between the ends **40**, **42**. More specifically, an end **46** of the CB layer **36** is disposed generally at the center **44** of the CA layer **34**. As such, when viewed from above, the first and CB layers **34**, **36** form a long 'T' shape.

[0032] A second embodiment of the semiconductor device **20**, is substantially similar to the first embodiment, but further includes a trench silicide layer **37** disposed between the CA layer **34** at least one of the source **26** or the drain **28** of the first transistor **24a**. Such an arrangement can be seen with reference again to FIG. 1.

[0033] In a third embodiment, as shown in FIG. 5, the semiconductor device **20** includes at least the first transistor **24a** and the second transistor **24b**. The semiconductor device **20** includes a first CA layer **34a** and a CB layer **36**. The first CA layer **34a** is electrically connected to at least one of the source **26a** or the drain **28a** of the first transistor **24a**. The CB layer **36** is electrically connected to at least one of the gates **30a**, **30b** of the transistors **24a**, **24b**. Depending on the particular application, the CB layer **36** may be electrically connected to both of the gates **30a**, **30b** of the transistors **24a**, **24b**. The first and CB layers **34**, **36** are also electrically connected to one another.

[0034] In the third embodiment, like the first embodiment, the CA layer **34** extends between the first end **40** and the second end **42**. However, in the third embodiment, the CB layer **36** is disposed adjacent one of the ends **40**, **42**. As such, when viewed from above, the first and CB layers **34**, **36** form a long 'L' shape. The long 'L' shape of the third embodiment allows the CB layer **36** to be disposed apart from a second CA layer **48** to prevent electrical conductivity between the CB layer **36** and the second CA layer **48**.

[0035] Referring to FIGS. 6 and 7, a fourth embodiment of the semiconductor device **20** includes a first transistor **24a**, a second transistor **24b**, and a third transistor **24c** formed on the substrate **22**. The transistors **24** are disposed sequentially from the first transistor **24a** through the third transistor **24c**. The device **20** may further include a fourth transistor **24d** wherein the transistors **24** are disposed sequentially from the first transistor **24a** through the fourth transistor **24d**.

[0036] A first CB layer **36a** is electrically connected to the gate **30a** of the first transistor **24a** and a second CB layer **36b** is electrically connected to the gate **30c** of the third transistor

24c. A CA layer **34** electrically connects the first CB layer **36a** and the second CB layer **36b** to one another. As such, the gate **30** of the first transistor **24a** and the gate **30c** of the third transistor **24c** are electrically connected to one another through the CB layers **36a**, **36b** and the CA layer **34**.

[0037] The CA layer **34** is electrically insulated from the gate **30b** of the second transistor **24b**. As such, the CA layer **34** forms a “bridge” or a “jumper” over the gate **30b** of the second transistor **24b**. One or more insulating layers **44** may be sandwiched between the CA layer **34** and the gate **30** of the second transistor **24b**. The one or more insulating layers **44** may also be sandwiched between the CA layer **36** and the substrate **22**.

[0038] Depending on the particular logic element needs, the second CB layer **36b** may also be electrically connected to the gate **30** of the fourth transistor **24d**. Furthermore, the CA layer **34** may also be electrically connected to at least one of the source **26** or the drain **28** of one of the transistors **24a**, **24b**, **24c**. As is shown in FIGS. 6 and 7, the CA layer **34** and the CB layers **34a**, **34b** are disposed above the gates **30** of the transistors **24a**, **24b**, **24c**, **24d** with respect to the substrate **22**.

[0039] In a fifth embodiment, the semiconductor device **20** includes a semiconductor substrate **22** with a first transistor **24a** and a second transistor **24b** disposed on the substrate **22**, as illustrated in FIG. 8. A first CB layer **36a** is electrically connected to the gate **30a** of the first transistor **24a** and a second CB layer **36b** is electrically connected to the gate **30a** of the second transistor **24b**. A CA layer **34** extends longitudinally between a first end **40** and a second end **42**. The first CB layer **36a** is electrically connected to the CA layer **34** adjacent the first end **40** of the CA layer **34**. The second CB layer **36b** is electrically connected to the CA layer **34** adjacent the second end **42** of the CA layer **34**.

[0040] The gate **30a** of the first transistor **24a** extends longitudinally as part of a first linear strip **31a** and the gate **30b** of the second transistor **24b** extends longitudinally as part of a second linear strip **31b**. The first and second strips **31a**, **31b** are generally parallel to one another and spaced apart from one another. The CA layer **34** is generally perpendicular to the first and second CB layers **36a**, **36b**. As such, the CA layer **34** extends generally parallel to the strips **31a**, **31b** and is disposed between the strips **31a**, **31b**. Accordingly, the CA layer **34** and the CB layers **36a**, **36b** collectively form a zig-zag or generally S-shape when viewed from above.

[0041] The semiconductor device **20** of the fifth embodiment may further include a third transistor **24c** and a fourth transistor **24d**. The gate **30c** of the third transistor **24c** extends

longitudinally as part of the first strip **31a** and the gate **30d** of the fourth transistor **24d** extends longitudinally as part of the second strip **31b**. A gap **32** separates the gate **30a** of the first transistor **24a** from the gate **30c** of the third transistor **24c** and the gate **30b** of the second transistor **24b** from the gate **30d** of the fourth transistor **24d**. As such, the gates **30** of the first and second transistors **24a**, **24b** are cater-corner from one another and that the CA layer **34** extends across the gap **32**.

[0042] In a sixth embodiment, as shown in FIG. 9, the semiconductor device **20** includes a semiconductor substrate **22** with a first transistor **24a** and a second transistor **24b** disposed on the substrate **22**. The gates **30a**, **30b** of the transistors **24a**, **24b** extend longitudinally and generally parallel to one another. The first gate **30a** is formed as part of a first linear strip **31a** and the second gate **30b** is formed as part of second linear strip **31b**. A single CB layer **36** is electrically connected to both of the gates **30** of the first and second transistors **24a**, **24b**. The gates **30a**, **30b** of the transistors **24a**, **24b** may not be directly adjacent one another. As such, the CB layer **36** forms a zig-zag shape to electrically connect both transistors **24a**, **24b**.

[0043] Specifically, as shown in FIG. 9, the device **20** includes a third transistor **24c** and a fourth transistor **24d**. The gate **30c** of the third transistor **24c** extends longitudinally as part of the first strip **31a** and the gate **30d** of the fourth transistor **24d** extends longitudinally as part of the second strip **31b**. A first gap **32a** separates the gate **30a** of the first transistor **24a** from the gate **30c** of the third transistor **24c**. A second gap **32b** separates the gate **30b** of the second transistor **24b** from the gate **30d** of the fourth transistor **24d**. The gaps **32a**, **32b** of the sixth embodiment are not aligned with one another.

[0044] Referring to FIGS. 2 and 10, the semiconductor device **20** of a seventh embodiment includes a first transistor **24a** and a second transistor **24b**. A trench silicide layer **37** electrically connects the source **26a** or the drain **28a** of the first transistor **24a** to the source **26b** or the drain **28b** of the second transistor **24b**. Specifically, FIG. 10 shows the first transistor **24a** being an n-type FET and the second transistor **24b** being a p-type FET and that the raised drains **28a**, **28b** of the transistors **24a**, **24b** are electrically connected to one another via the trench silicide layer **37**.

[0045] The gate **30a** of the first transistor **24a** and the gate **30b** of the second transistor **24b** are formed from a common linear strip **31**. As such, the gates **30a**, **30b** extend linearly with respect to one another. The trench silicide layer **37** is disposed on one side of the gates **30a**, **30b**. That is, the trench silicide layer **37** does not cross over the gates **30a**, **30b** or the common linear strip **31** while still electrically connecting the drains **28a**, **28b** of the transistors **24a**,

24b. Said another way, the trench silicide layer **37** need not cross a “poly boundary” formed by the linear strip **31**. This arrangement may be utilized to produce scan scan-D flip-flops. The resulting scan-D flip-flops have a reduced area when compared to prior art devices. Of course, the arrangement may be utilized in producing logic devices other than the scan-D flip-flops, as will be realized by those skilled in the art.

[0046] The semiconductor device **20** of the seventh embodiment may also include a single-sided contact (not shown) electrically connected to each gate **30a**, **30b** of the transistors **24a**, **24b**. By utilizing a single-sided contact, i.e., a contact that does not extend over the entire width of the gates **30a**, **30b**, the risk of dielectric breakdown between the trench silicide layer **37** and the gates **30a**, **30b** is reduced.

[0047] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention, it being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims and their legal equivalents.

Claims

1. A semiconductor device comprising:
a semiconductor substrate;
a first transistor and a second transistor formed on said semiconductor substrate;
each of said transistors comprising a source, a drain, and a gate;
a CA layer electrically connected to at least one of said source or said drain of said first transistor; and
a CB layer electrically connected to both of said gates of said transistors and said CA layer.
2. A semiconductor device as set forth in claim 1 wherein said CA layer extends between a first end and a second end and wherein said CB layer is disposed at a center between said ends of said CA layer.
3. A semiconductor device as set forth in claim 1 wherein said CA layer extends between a first end and a second end and wherein said CB layer is disposed adjacent one of said ends of said CA layer.
4. A semiconductor device as set forth in claim 1 further comprising a trench silicide layer sandwiched between said CA layer and said at least one of said source or said drain of said first transistor to electrically connect said CA layer and said at least one of said source or said drain of said first transistor.
5. A semiconductor device as set forth in claim 1 wherein said CA layer and CB layer each comprise tungsten.
6. A semiconductor device as set forth in claim 1 wherein said CA layer and CB layer each comprise copper.

7. A semiconductor device as set forth in claim 1 further comprising a metal layer disposed above said CA layer and said CB layer with respect to said substrate.
8. A semiconductor device as set forth in claim 8 further comprising at least one via electrically connecting at least one of said CA layer and said CB layer to said metal layer.
9. A semiconductor device comprising:
 - a semiconductor substrate;
 - a first transistor, a second transistor, and a third transistor formed on said substrate and disposed sequentially from said first transistor through said third transistor;
 - each of said transistors comprising a source, a drain, and a gate;
 - a first CB layer electrically connected to said gate of said first transistor;
 - a second CB layer electrically connecting said gate of said third transistor; and
 - a CA layer electrically connecting said first CB layer and said second CB layer and electrically insulated from said gate of said second transistor.
10. A semiconductor device as set forth in claim 10 wherein said CA layer is electrically connected to one of said source or said drain of one of said transistors.
11. A semiconductor device as set forth in claim 10 further comprising a fourth transistor comprising a source, a drain, and a gate formed on said substrate wherein said transistors are disposed sequentially from said first transistor through said fourth transistor.
12. A semiconductor device as set forth in claim 12 wherein said second CB layer is electrically connected to said gate of said fourth transistor.
13. A semiconductor device as set forth in claim 10 wherein said CA layer and said CB layers are disposed above said gates of said transistors with respect to said substrate.
14. A semiconductor device as set forth in claim 14 further comprising a metal layer disposed above at least one of said CA layers and said CB layer with respect to said substrate.

15. A semiconductor device as set forth in claim 15 further comprising at least one via electrically connecting said metal layer to at least one of said at least one CA layer and said CB layer.

16. A semiconductor device as set forth in claim 10 wherein said CA layer and said CB layers comprise tungsten.