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Fiordalice et al.

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(54) **SEMICONDUCTOR DEVICE HAVING A TITANIUM-ALUMINUM COMPOUND**

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(21) Appl. No.: **08/254,854**

(22) Filed: **Jun. 6, 1994**

Related U.S. Application Data

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(51) **Int. Cl.**[7] **H01L 23/48**
(52) **U.S. Cl.** **257/751**; 257/758; 257/764; 257/771
(58) **Field of Search** 257/764, 765, 257/768, 771, 751, 758, 763

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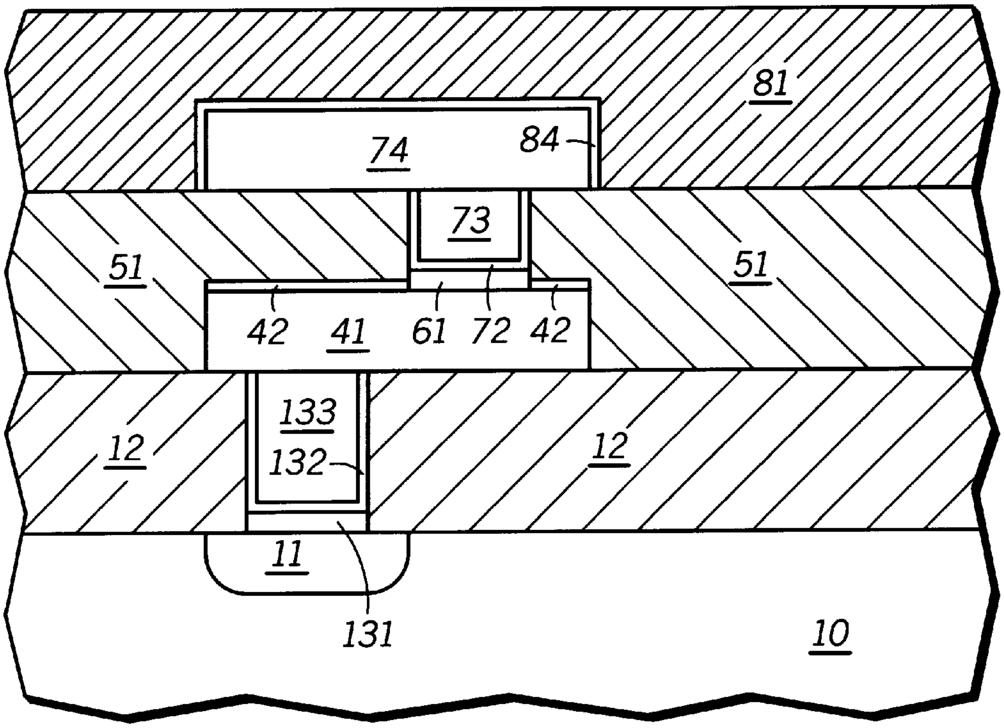
(57) **ABSTRACT**

The present invention includes a process for forming an intermetallic layer and a device formed by the process. The process includes a reaction step where a metal-containing layer reacts with a metal-containing gas, wherein the metals of the layer and gas are different. In one embodiment of the present invention, titanium aluminide may be formed on the sides of an interconnect. The process may be performed in a variety of equipment, such as a furnace, a rapid thermal processor, a plasma etcher, and a sputter deposition machine. The reaction to form the intermetallic layer is typically performed while the substrate is at a temperature no more than 700 degrees Celsius.

6 Claims, 3 Drawing Sheets



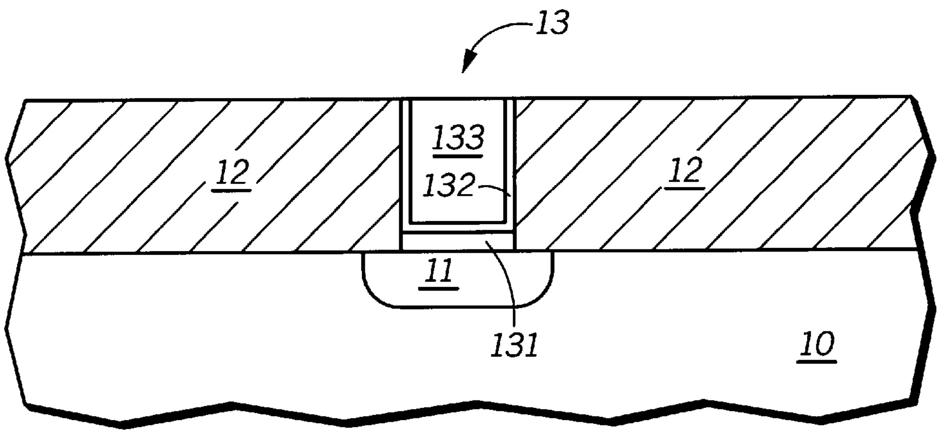


FIG.1

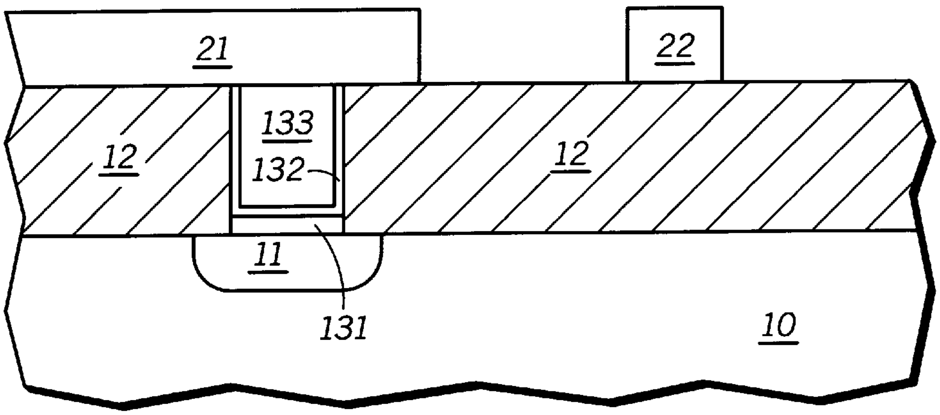


FIG.2

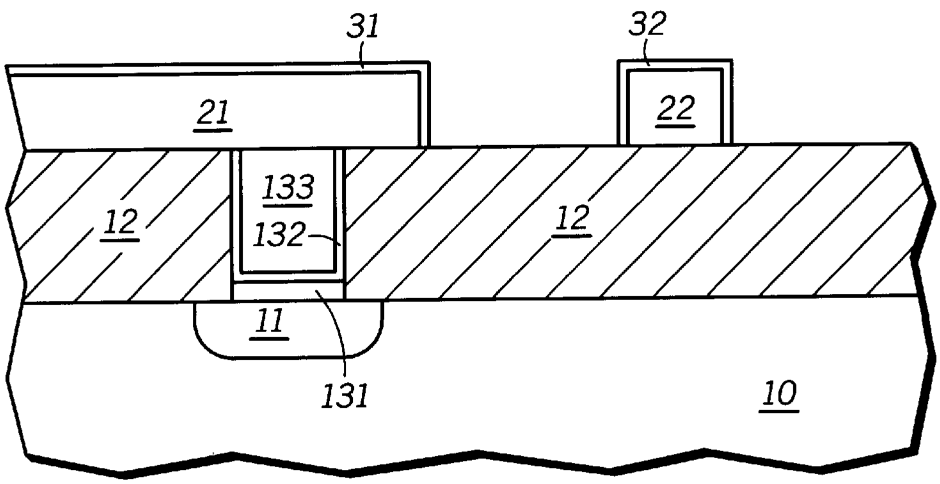


FIG.3

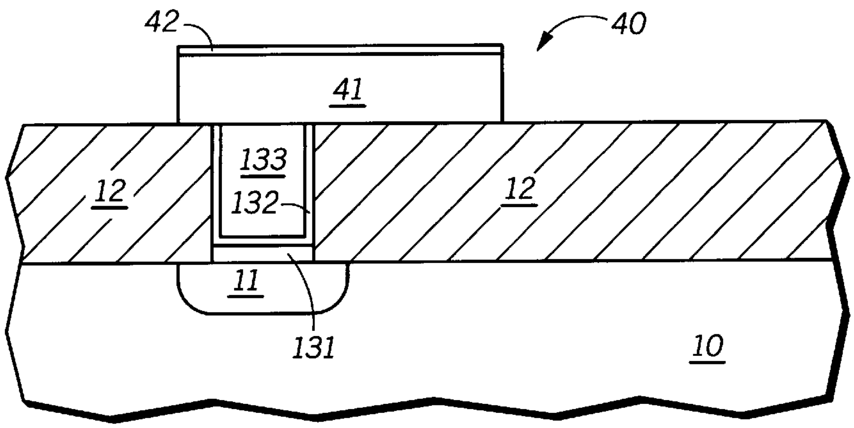


FIG. 4

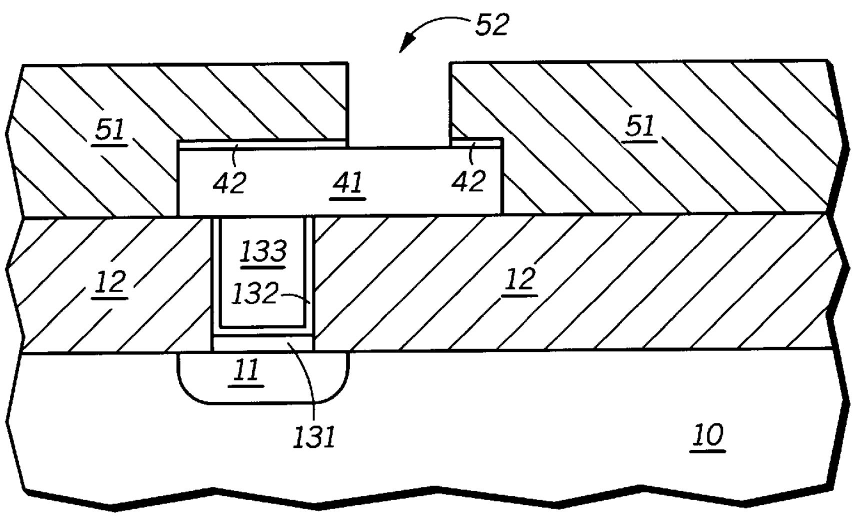


FIG. 5

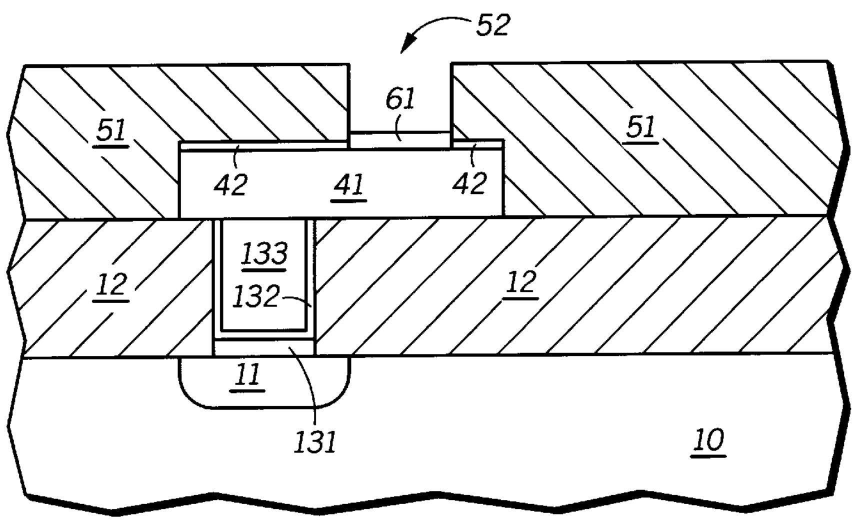


FIG. 6

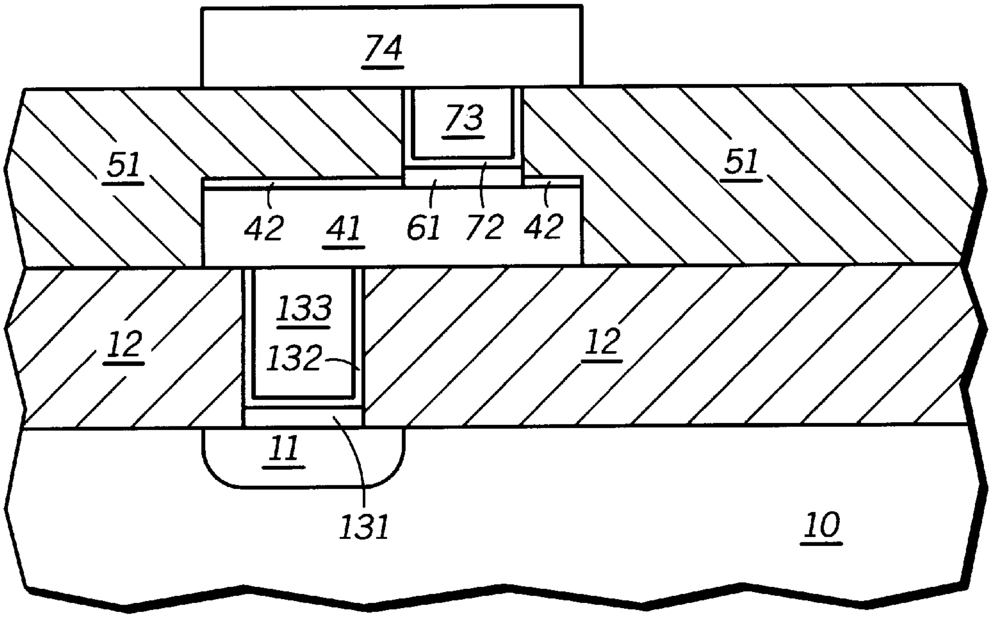

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FIG. 7

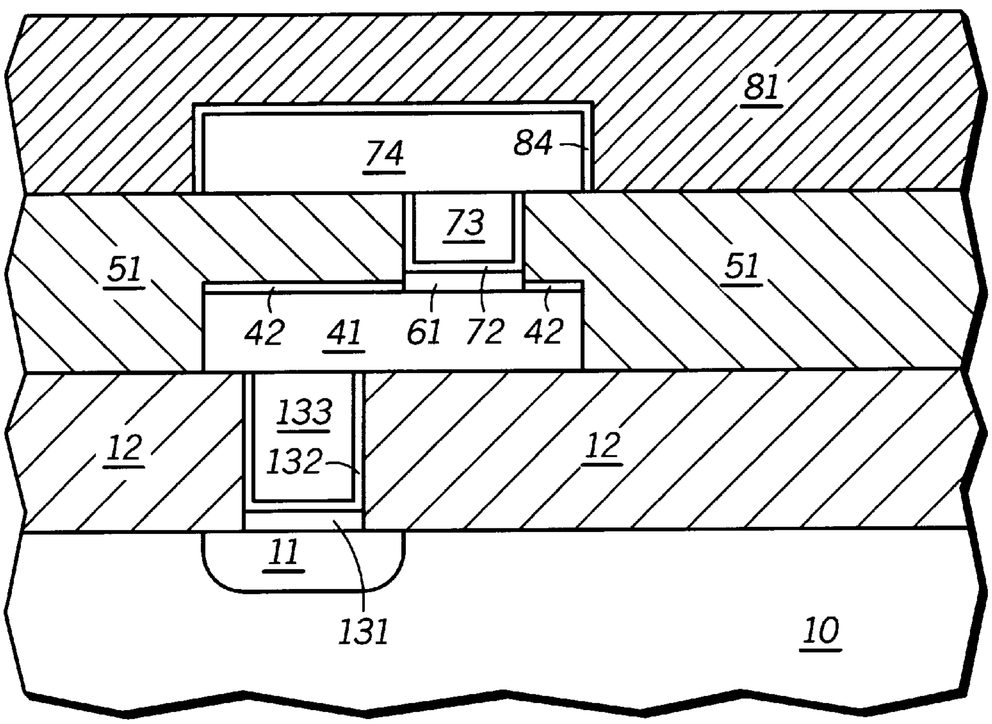
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FIG. 8

SEMICONDUCTOR DEVICE HAVING A TITANIUM-ALUMINUM COMPOUND

This is a continuation divisional of application Ser. No. 08/024,042, filed Mar. 1, 1993 now U.S. Pat. No. 5,358,901 filed on Oct. 25, 1994.

FIELD OF THE INVENTION

The present invention relates to the field of semiconductor devices, and in particular, to processes for forming an intermetallic by reacting a metal with a gas and devices formed by the process.

BACKGROUND OF THE INVENTION

An intermetallic material is a material that comprises a plurality of metallic elements. Intermetallic materials, in which one of the metallic elements is a refractory metal, are used in the aviation and aerospace industries. Refractory-metal intermetallics are sometimes used in aircraft parts because of their light weight and durability compared to other metals. In the aviation and aerospace industry, refractory-metal intermetallics are usually formed at temperatures of at least 800 degrees Celsius. Such a high temperature of formation is unacceptable for the semiconductor industry. The intermetallics are usually part of a contact, interconnect, or via and are formed relatively late in a semiconductor process flow (after a silicide layer or doped regions, such as emitter or source/drain regions, have been formed). Heating a substrate to a temperature higher than about 700 degrees Celsius is generally undesired.

Within the semiconductor industry, intermetallic materials are being investigated to examine their ability to reduce electromigration and oxidation of metals within contacts or interconnects. An example of an intermetallic used in the semiconductor industry is titanium aluminide ($TiAl_3$). Titanium aluminide may be formed by sputtering or evaporating a layer of aluminum, sputtering or evaporating a layer of titanium, and reacting the layers to form titanium aluminide. This method of forming titanium aluminide is actually a type of solid-solid reaction because one solid reacts with another solid.

Although the solid-solid reaction that forms titanium aluminide is typically performed at a temperature less than 700 degrees Celsius, the process suffers from several detriments. As used in this specification, intermetallic step coverage is defined as the thickness of the intermetallic layer at its thinnest point along the side of a patterned metal layer divided by the thickness of the intermetallic layer formed on the top of the patterned metal layer. The intermetallic step coverage is expressed as a percentage. Using the solid-solid reaction that forms titanium aluminide, the intermetallic step coverage is typically no more than 10 percent and may even reach 0 percent in which case, the titanium aluminide is not formed along all of the sides of the aluminum layer. Electromigration, oxidation, and hillock formation may not be sufficiently reduced in a lateral direction because of the lower intermetallic step coverage. The unreacted titanium may: 1) form undesired electrical connections because of etch complications, 2) have undesired reactions before forming or with subsequently formed layers that contact the unreacted titanium, or 3) complicated a subsequent patterning step during the formation of interconnects.

SUMMARY OF THE INVENTION

The present invention includes a process for forming an intermetallic layer by reacting a metal layer over a substrate

with a metal-containing gas, wherein the metals in the layer and the gas are different. The present invention also includes a device formed using the process. In one embodiment, a titanium aluminide layer is formed by reacting an aluminum-containing layer with titanium tetrachloride, which is a gas during the reaction. The gas allows the titanium aluminide layer to be formed on exposed sidewalls of a patterned aluminum-containing layer. Different embodiments of the invention may use a furnace, a rapid thermal processor, a plasma etcher, or a sputter deposition machine for a reactor. An embodiment of the present invention forms an intermetallic layer formed while the substrate is at a temperature no higher than 700 degrees Celsius during the reaction.

Other features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements, and in which:

FIGS. **1–3** each include cross-sectional views of a portion of a substrate at various process steps in forming a titanium aluminide layer in accordance with one embodiment of the present invention.

FIGS. **4–8** each include cross-sectional views of a portion of a substrate at various process steps in forming a titanium aluminide layer in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The present invention includes a process for forming an intermetallic layer by reacting a metal layer over a substrate with a metal-containing gas, wherein the metals in the layer and the gas are different. The present invention also includes a device formed using the process. Embodiments of the invention describe the use of the invention in a furnace, a rapid thermal processor, a plasma etcher, or a sputter deposition machine. The intermetallic layer is typically formed while the substrate is at a temperature no higher than 700 degrees Celsius. Two examples are described immediately below. Benefits, fabricating options, and general reactions are described later in the specification.

EXAMPLE 1

FIG. **1** includes a cross-sectional view of a semiconductor substrate prior to forming an interconnect. A doped region **11** lies within a silicon substrate **10**. A patterned insulating layer **12** lies over the substrate and includes a contact plug **13** to the doped region **11**. The contact plug **13** includes a titanium silicide layer **131**, a titanium nitride layer **132**, and a tungsten layer **133**. A metal layer is deposited on the insulating layer **12** and the contact plug **13** by a sputter deposition process. The metal layer is about 98 weight percent aluminum with about 1 weight percent silicon and about 1 weight percent copper. The metal layer is patterned to form interconnects **21** and **22** as shown in FIG. **2**.

The substrate including the interconnects **21** and **22** are placed into a rapid thermal processor (RTP). The RTP is pumped down to evacuate the reaction chamber of the RTP. After being pumped down, the temperature of the reaction chamber is adjusted to about 375 degrees Celsius. The

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