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An alloy and method for increasing the thermal stability of nickel silicide

THIS INVENTION relates to an alloy and method for improving the thermal stability of nickel silicide.

Self-aligned silicidation (salicidation) is widely used in integrated circuits to reduce polycrystalline silicon interconnect resistance and source/drain contact resistance. Currently, $TiSi_2$ is used for salicidation, but the formation of its low resistivity phase is dependent on linewidth leading to an increase in sheet resistance for gate lines narrower than 0.5 μm. To alleviate this problem, $CoSi_2$ is likely to replace $TiSi_2$ for the next generation of integrated circuit designs. However, junction leakage, a relatively large consumption of Si and the difficulty in producing uniform layers seem to be the limiting factors for the application of this silicide to ultra-shallow junctions. Recently, it has been demonstrated that nickel monosilicide (NiSi) is a potential candidate for deep sub-micron complementary metal-oxide semiconductor (CMOS) devices, because its sheet resistance remains unchanged even for linewidths down to 0.1 μm. In addition, the consumption of Si is also relatively low during the formation of NiSi. However, the transformation of NiSi into the high resistively disilicide ($NiSi_2$) at an elevated temperature can be a concern for the back end process. Recently, it has been shown that for narrow linewidths and small contacts with a width ranging from 0.1 to 0.6 μm, the formation of the high resistivity $NiSi_2$ phase can occur at temperatures as low as 400°C although on blanket films the $NiSi_2$ phase is formed at 700-750°C. Since the devices are subjected to a temperature higher than 400°C during process integration, appropriate process or material modification is required to

increase the thermal stability for successful integration of nickel silicide in deep sub-micron devices.

It has been demonstrated that the addition of a small amount of platinum to a nickel film prior to silicide formation can result in an increase in its thermal stability without adversely affecting the attractive features of the NiSi film as a contact material. With an increase in thermal stability, nickel silicide is potentially the next most viable contact material for deep submicron ULSI circuits.

It is an object of the present invention to seek to increase the thermal stability of nickel silicide. Accordingly, the present invention provides a method of improving the thermal stability of nickel monosilicide comprising the addition of a palladium content to nickel to provide a nickel palladium alloy prior to silicidation.

Another aspect of the present invention provides a method of fabricating a silicon device comprising the steps of depositing a nickel film comprising a palladium content on a silicon region and annealing the palladium containing nickel film and the silicon region to form a nickel monosilicide layer.

Preferably, the palladium content is 3 at.% or greater.

Conveniently, the palladium content is 10 at.% or less.

Advantageously, the nickel palladium alloy includes a content of other material.

Preferably, the other material content comprises a content of one or a mixture of platinum, titanium, cobalt or chromium.

A further aspect of the present invention provides a nickel palladium alloy including a palladium content of 10 at.% or less.

Another aspect of the present invention provides a silicon device having a nickel monosilicide film, the nickel monosilicide film having been formed on the semiconductor device by silicidation of a nickel film having a palladium content.

The thermal stability of NiSi can be improved significantly by the addition of Pd. 5 at.% of Pd increases the nucleation temperature of NiSi to $NiSi_2$ above 800°C and 10 at.% of Pd to above 850°C. The NiSi film should be stable above 800°C to be compatible with the present silicon devices fabrication technology.

In order that the present invention may be more readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

FIGURE 1a shows the X-ray diffraction spectra of pure nickel film after annealing at 700°C, 750°C and 800°C;

FIGURE 1b shows the X-ray diffraction spectra of a nickel film having 5 at.% palladium after annealing at 800°C, 850°C and 900°C;

FIGURE 1c shows the X-ray diffraction spectra of a nickel film having 10 at.% palladium after annealing at 800°C, 850°C and 900°C;

FIGURE 2 is a graph showing the relationship between the temperature of nucleation of $NiSi_2$ as a function of palladium content in a nickel film;

FIGURE 3 is a graph showing the relationship between resistivity and annealing temperatures for nickel, nickel (5 at.% Pd), and Ni (10 at.% Pd); and

FIGURE 4 is a graph showing the relationship between film resistivity and increasing palladium content.

To be compatible with silicon device fabrication technology and the silicon devices produced thereby, it is necessary for nickel silicon films to be stable at temperatures above 800°C. The addition of small amounts of palladium can increase the thermal stability of nickel monosilicide. In particular, the addition of 5 at.% Pd increases the nucleation temperature of NiSi to $NiSi_2$ to above 800°C. Further, the addition of 10 at.% Pd increases the nucleation temperature of NiSi to $NiSi_2$ to above 850°C. These represent significant improvements to the thermal stability of nickel monosilicide.

It has been shown that the thermal stability of nickel monosilicide films is improved by increasing the palladium content in the nickel film. For the microelectronics industry, the actual requirement is that the silicide film is stable at temperatures in the region of 800°C in order for the film to be useful in the fabrication process. It has been found that at palladium contents below 3 at.% the silicide film is not as stable as required for use in the microelectronic industry. Accordingly, the palladium content should preferably be 3 at.% or above. As the palladium content increases in the Ni film, the resistivity of the resultant film also increases. This is preferable to avoid films with high resistivity - that is to say, a resistivity greater than 25 $\mu\Omega$.cm. To satisfy this

requirement, it is preferable that the palladium addition to the nickel film should be 10 at.% or below. Thus, the preferred range for palladium addition to nickel film is from 3 to 10 at.%.

The resultant palladium contracting nickel film need not be pure and may include a content of other materials such as, preferably, platinum, titanium, cobalt or chromium, either as individual contents or as a mixture. Other materials including other alloying elements can be added.

Examples

Pure Ni and Ni(Pd) films with a thickness ranging from 30 to 50 nm were deposited onto (100) wafers by conventional deposition techniques such as sputtering, electron-beam evaporation, or filament evaporation. If the sputtering method is used, then the nickel-platinum alloy film can be deposited by sputtering nickel-platinum alloy target or by co-sputtering a pure nickel target and a pure platinum target. Alternatively, the layers can be deposited sequentially, with either the nickel or the platinum layer being deposited first. The composition of the Ni(Pd) films measured by Rutherford back scattering was equal to 5 at.% and 10 at.%. Annealing of one-minute duration was performed by rapid thermal processing (RTP) in a N_2 atmosphere at temperatures ranging from 600 to 950°C. X-ray diffraction (XRD), scanning electron microscopy and Rutherford back scattering techniques were used to study the formation, microstructure and orientation of the silicide. The sheet resistance of the films was measured by the conventional four point probe technique and used to deduce the resistivity of the film from the film thickness measured by Rutherford back scattering.

Figures 1a, 1b and 1c show the X-ray diffraction spectra of the pure Ni, Ni(5 at.% Pd) and Ni(10 at.% Pd) films after annealing.

For pure Ni films, see Figure 1a, annealed at temperatures between 500 and 700°C, peaks corresponding to polycrystalline NiSi only are present. Above 700°C, relatively strong $NiSi_2$ peaks, with the orientation (100)$NiSi_2$/(100)Si, were observed together with very low intensity peaks of $NiSi_2$.

For Ni(5 at.% Pd) films, the peaks corresponding to polycrystalline NiSi are present at temperatures below 900°C, see Figure 1b. For samples annealed at 850°C, the peaks corresponding to $NiSi_2$ are observed in addition to the NiSi peak.

For Ni(10 at.% Pd) films, a similar behaviour is observed but the temperatures are shifted higher: NiSi is stable at a temperature below 900°C and $NiSi_2$ is formed only at 900°C. Therefore, the addition of Pd leads to an increase in the nucleation of $NiSi_2$. Figure 2 shows that this increase depends almost linearly on the Pd content of the Ni film. In addition, NiSi is found to be stable in Pd containing films at higher temperatures and is stable even when $NiSi_2$ is formed.

Figure 3 illustrates how the resistivity of the Ni films varies as a function of the annealing temperature. For the Ni, Ni(5 at.% Pd), and Ni(10 at.% Pd) films an increase in resistivity occurs for samples annealed at 750°, 800°, 900°C. This increase is due to the formation of $NiSi_2$ in the case of pure Ni films and to film agglomeration in the case of Ni(Pd) films. However, the temperature at which the increase in resistivity occurs is shifted to higher values when the content of Pd is increased.

Figure 4 shows that the film resistivity increases with increasing Pd content. This is attributed to the charge carrier scattering usually observed in the presence of soluble impurities. The linear increase in the resistivity indicates that Pd is at least partly dissolved in NiSi as a soluble element.

Thus, these experimental results show that the thermal stability of NiSi films (regarding both the film agglomeration and the nucleation temperature of $NiSi_2$) is increased by increasing Pd content. For specific application in the microelectronics industry, it is necessary that the silicide film is stable at temperatures in the region of 800°C in order for the Ni film to be usefully integrated in the fabrication process as discussed earlier. Thus, the palladium content should preferably be from 3 at.% to 10 at.%.

In the present specification "comprise" means "includes or consists of" and "comprising" means "including or consisting of".

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS:

1. A method of improving the thermal stability of nickel monosilicide comprising adding a palladium content to nickel to provide a nickel palladium alloy prior to silicidation.

2. A method of fabricating a silicon device comprising the steps of depositing a nickel film comprising a palladium content on a silicon region and annealing the palladium containing nickel film and the silicon region to form a nickel monosilicide layer.

3. A method according to Claim 2, wherein the nickel and palladium are deposited by sputtering a nickel/palladium alloy target.

4. A method according to Claim 2, wherein the nickel and palladium are deposited by co-sputtering a pure nickel target and a pure palladium target.

5. A method according to Claim 2, wherein the nickel and palladium are deposited by the sequential deposition of nickel and palladium.

6. A method according to any preceding claim, wherein the palladium content is 3 at.% or greater.

7. A method according to any preceding claim, wherein the palladium content is 10 at.% or less.

8. A method according to any preceding claim, wherein the nickel palladium alloy includes a content of other material.

9. A method according to Claim 8, wherein the other material content comprises a content of one or a mixture of platinum, titanium, cobalt or chromium.

10. A nickel palladium alloy including a palladium content of 10 at.% or less.

11. A nickel palladium alloy according to Claim 10 including a palladium content of 3 at.% or greater.

12. A nickel palladium alloy according to Claim 10 or 11, wherein the nickel palladium alloy includes a content of other material.

13. A nickel palladium alloy according to Claim 12, wherein the other material content comprises a content of one or a mixture of platinum, titanium, cobalt or chromium.

14. A silicon device having a nickel monosilicide film, the nickel monosilicide film having been formed on the semiconductor device by silicidation of a nickel film having a palladium content.

15. Any novel feature or combination of features disclosed herein.