

Internal distribution code:

- (A) [] Publication in OJ
(B) [] To Chairmen and Members
(C) [X] To Chairmen
(D) [] No distribution

D E C I S I O N
of 18 October 2001

Case Number: T 0737/97 - 3.4.3

Application Number: 88113499.3

Publication Number: 0304073

IPC: H01L 21/263

Language of the proceedings: EN

Title of invention:

Method for manufacturing semiconductor device with Schottky electrodes

Applicant:

KABUSHIKI KAISHA TOSHIBA

Opponent:

-

Headword:

Sputter etching/TOSHIBA

Relevant legal provisions:

EPC Art. 56, 84

Keyword:

"Inventive step (no)"

"Functionally independent features relating to different technical problems"

Decisions cited:

-

Catchword:

-



Case Number: T 0737/97 - 3.4.3

D E C I S I O N
of the Technical Board of Appeal 3.4.3
of 18 October 2001

Appellant: KABUSHIKI KAISHA TOSHIBA
72, Horikawa-cho
Saiwai-ku
Kawasaki-shi
Kanagawa-ken 210-8572 (JP)

Representative: Ritter und Edler von Fischern, Bernhard,
Dipl.-Ing.
Hoffmann Eitle
Patent- und Rechtsanwälte
Postfach 81 04 20
D-81904 München (DE)

Decision under appeal: Decision of the Examining Division of the
European Patent Office posted 7 February 1997
refusing European patent application
No. 88 113 499.3 pursuant to Article 97(1) EPC.

Composition of the Board:

Chairman: R. K. Shukla
Members: G. L. Eliasson
M. J. Vogel

Summary of Facts and Submissions

I. European patent application No. 88 113 499.3 was refused in a decision of the examining division dated 7 February 1997. The ground for the refusal was that the subject matter of claim 1 filed with the letter dated 8 October 1996 did not involve an inventive step having regard to the prior art documents

D1: Journal of Vacuum Science and Technology A, vol. 4, No. 6, November/December 1986, pages 3091 to 3094;

D4: JP-60-173872 with corresponding Patent Abstracts of Japan and complete translation in English;

D6: B. Chapman, *Glow Discharge Processes* (John Wiley and Sons, New York, 1980), pages 197 to 199 and 255; and

D7: US-A-4 585 517.

II. The reasoning of the examining division in the decision under appeal can be summarized as follows:

(A) The method of claim 1 for forming a semiconductor device differs from that known from document D1 in that

(a) a film of $WSi-N_x$ is formed instead of WN_x ;

(b) chemical cleaning is performed prior to sputter cleaning, whereas document D1 does not mention any cleaning step before the sputter etching; and

- (c) prior to sputter etching, a shutter for shielding the target for the reactive sputtering is closed, whereas document D1 does not mention any shutter.
- (B) Since the features (a) to (c) are not functionally interdependent, they can be considered separately.
- (C) Feature (a) is known from document D4 using the same Ar/N₂ ambient in the sputtering chamber as in document D1. Therefore, the skilled person seeking an alternative to the formation of a WN_x film using a W target, as described in document D1, would regard the reactive sputtering process known from document D4 to be a clearly suitable alternative, in particular since the methods of documents D1 and D4 are very similar.
- (D) As to feature (b), it is well-known in the art to remove native oxide using a liquid etchant, in particular since sputter etching is a slow process. The combination of chemical cleaning and sputter etching is also known from document D7.
- (E) Regarding feature (c), a shutter is conventionally provided in sputter equipments, and as is known from document D6, which is an excerpt from a text-book, a shutter is used to protect a target during the cleaning of a substrate by sputter etching.

III. The appellant (applicant) lodged an appeal on 7 April 1997, paying the appeal fee the same day. A statement of the grounds of appeal was filed on 17 June 1997 together with an amended claim 1.

IV. In response to a communication from the Board accompanying a summons to oral proceedings, the appellant submitted further claims with the letters dated 18 and 25 September 2001.

V. At the oral proceedings held on 18 October 2001, the appellant requested that the decision under appeal be set aside and a patent be granted on the basis of any one of the following requests:

Main request:

Claims: claim 1 as filed with the statement of the grounds of appeal on 17 June 1997;
and
claims 2 to 7 as filed with the letter dated 8 October 1996 with claim 7 as amended according to the appellant's request dated 17 June 1997

Description: pages 1, 2, 2a, 3 to 6 as filed with the letter dated 23 July 1993;
page 7 as originally filed

Drawings: Sheets 1 and 2 as originally filed

Auxiliary request I

Claims: claim 1 as filed with the letter dated 25 September 2001

Auxiliary request II

Claims: claims 1 to 25 as filed with the letter dated 18 September 2001 with claim 22 being deleted.

VI. Claim 1 according to the appellant's main request reads as follows:

"1. A method of manufacturing a semiconductor device, comprising the steps of:

ion-implanting silicon ions (Si^+) into a main plane of a GaAs substrate (11);

annealing said GaAs substrate (11) to form an n-type impurity region (12) on the main plane of said GaAs substrate (11);

chemically cleaning said GaAs substrate (11) to remove an oxide film unintentionally formed on the main plane of said GaAs substrate (11);

setting said GaAs substrate (11) in a sputtering processing chamber (1) so that said main plane is placed at a predetermined location;

effecting sputter etching on said GaAs substrate (11) in an atmosphere of an inert gas (Ar) so that a surface of the main plane of said GaAs substrate (11) is partially removed; and

effecting reactive sputtering on the main plane of said GaAs substrate (11) in a given atmosphere to deposit on the main plane of said GaAs substrate (11) a tungsten silicide film (13) in which a composition ratio of tungsten and silicon is 1:0.6;

wherein the sputter processing chamber (1) being held substantially in the vacuum condition while performing the process for the step of sputter

etching the surface of said GaAs substrate (11) to the step of sputter depositing said tungsten silicide film (13); and

wherein prior to effecting said step of sputter etching on said GaAs substrate (11) a shutter (4) for shielding an electrode (3) acting as target in the reactive sputtering step being closed."

VII. Claim 1 according to the appellant's first auxiliary request reads as follows:

"1. A method of manufacturing a semiconductor device having a Schottky electrode, said method comprising the steps of:

ion-implanting silicon ions (Si^+) into a main surface of a GaAs substrate (11);

annealing said GaAs substrate (11) to form an n-type impurity region (12) on the main surface of said GaAs substrate (11);

chemically cleaning said GaAs substrate (11) to remove an oxide film unintentionally formed on the main surface of said GaAs substrate (11);

setting said GaAs substrate (11) in a sputtering processing chamber (1) which includes a target electrode (3) and a shutter (4), so that said main surface is placed at a predetermined location;

subjecting the main surface of said GaAs substrate to a sputter etching process performed in an atmosphere of an inert gas (Ar) so that the main surface of said GaAs substrate (11) is

partially removed, while said shutter (4) is kept closed for shielding said electrode (3) during said sputter etching process;

thereafter, and after opening of said shutter (3) for using enabling said electrode (3) acting as a target, depositing on the main surface of said GaAs substrate (11) a tungsten silicide film (13), in which WSi film a composition ratio of tungsten and silicon is 1:0.6, by reactive sputtering on said main surface so as to form said Schottky electrode, without removing said GaAs substrate from said sputtering processing chamber (1) so as to be held substantially in the vacuum condition within said sputtering processing chamber, said reactive sputtering being performed in an inert gas atmosphere including N₂ to form a nitride film of said tungsten silicide film on the main surface of said GaAs substrate, wherein a partial pressure of N₂ in said inert gas atmosphere is selected to be substantially 10%, thereby producing a WSi-Nx/GaAs wafer; and

annealing said WSi-Nx/GaAs wafer at 800° C for a predetermined period of time so as to restore damage caused thereto in the depositing step."

VIII. Claim 1 according to the appellant's second auxiliary request reads as follows:

"1. A method of manufacturing a semiconductor device having a Schottky electrode, said method comprising the steps of:

subjecting a surface of a GaAs substrate to a

sputter etching process in a sputtering processing chamber of a sputtering device, said sputtering process being performed in an atmosphere of an inert gas;

depositing a refractory metal by reactive sputtering on the surface of said GaAs substrate to form said Schottky electrode in said processing chamber, without removing said GaAs substrate from said sputtering processing chamber (1) so as to be held substantially in the vacuum condition within said processing chamber, said reactive sputtering being performed in an inert gas atmosphere including N₂ to form a nitride film of refractory metal on said GaAs substrate, wherein a partial pressure of N₂ in said inert gas atmosphere is selected to be substantially 10%, thereby producing a WSi-N_x/GaAs wafer; and

annealing said WSi-N_x/GaAs wafer at 800° C for a predetermined period of time so as to restore damage caused thereto in the depositing step."

Claims 6, 12, 13, 14, 17, and 23 according to the second auxiliary request are further independent claims, all directed to a method for manufacturing a semiconductor device.

IX. The appellant presented essentially the following arguments in support of his requests:

- (a) The claimed process provides a method of forming a semiconductor device having a Schottky contact where the individual process steps have been modified in order to optimize the properties of

the produced device. In particular with respect of the Schottky barrier height and the reverse bias leakage current, the claimed method produces superior devices than prior methods.

- (b) In the decision under appeal, the examining division had to select features from no less than four prior art documents (D1, D4, D6, and D7) in order to arrive at the claimed method. Such selective picking out of features from a large number of prior art documents, each which provides a variety of different possibilities, can only be based on an ex-post-facto analysis without a realistic assessment of the prior art.

- (c) As to the main request and the first auxiliary request, document D4 does not disclose sputtering of a WSi-Nx having the tungsten/silicon ratio equal to 1:0.6. It is also not likely that the skilled person using the teaching of document D4 would be able to arrive at the claimed tungsten/silicon ratio, in particular since there is not incentive for him to seek this particular ratio. The claimed ratio of 1:0.6 provides a higher Schottky barrier than the prior art electrodes and is therefore advantageous, as shown in Table I of the application in suit.

Reasons for the decision

- 1. The appeal complies with Articles 106 to 108 and Rule 64 EPC and is therefore admissible.

- 2. *Main request - Inventive step:*

2.1 The application in suit relates to a process of forming a Schottky electrode on GaAs, such as a gate electrode of a MESFET. Schottky contacts to GaAs, i.e. a metal/semiconductor contact, are known to be very sensitive to the presence of residual oxides on the GaAs surface prior to the deposition of the electrode layer. The presence of residual oxides and other impurities deteriorate device properties such as the Schottky barrier height and the reverse bias leakage current. This technical problem is solved by performing a chemical clean of the GaAs substrate, followed by a sputter etching. Subsequently, sputter deposition of $WSi_{0.6}N_x$ in an Ar/N ambient is carried out in the same sputter processing chamber, so that no oxide can form after the cleaning is completed. The electrode layer is made of tungsten silicide-nitride which has a high Schottky barrier with respect to GaAs.

2.2 Document D1 which is considered the closest prior art, discloses a method of forming a Schottky electrode on GaAs (cf. Abstract and page 3091 "II. Experimental details"). The method of document D1 includes the steps of implanting Si in a surface of a GaAs substrate and annealing the GaAs substrate to form n-type regions. The GaAs substrate is put in a sputtering processing chamber and subjected to a sputter cleaning by Ar of the GaAs surface, immediately followed by Ar-N sputtering of a W target to form a Schottky electrode layer made of WN_x .

2.3 The method according to claim 1 differs from that of document D1 in that

(a') a film of WSi is formed having a composition ratio of tungsten and silicon in the deposited silicide

film is 1:0.6, whereas in document D1, the film is made of WN_x ;

- (b) chemical cleaning is performed prior to sputter cleaning, whereas document D1 does not mention any cleaning step before the sputter etching; and
- (c) prior to sputter etching, a shutter for shielding the target for the reactive sputtering is closed, whereas document D1 does not mention any shutter.

2.4 With respect to claim 1 forming the basis of the decision under appeal, claim 1 according to the main request further specifies the composition ratio of tungsten and silicon to be 1:0.6, whereas the former claim defined a film of $WSi-N_x$ without any specified composition ratio (cf. feature (a) referred to in item II(A) above). In its assessment of inventive step, the examining division held that none of the differences (a) to (c) were functionally interdependent. Therefore, each feature solving a separate technical problem could be considered on its own merit for inventive step. In this connection the Board agrees with the examining division, since there is no evidence or even suggestion that the above features (a) to (c) support each other in their effect to provide a new technical result. The modification of feature (a) into feature (a') in claim 1 according to the main request presently under consideration does not change this situation. Although the appellant argued that the claimed process was modified in each step in order to optimize the properties of the produced device, the appellant has failed to show that the device properties are improved beyond what one would expect from a mere addition of the effects that each of the individual measures (a')

to (c) would provide in the final product (cf. item IX(a) above). The Board, however, agrees with the appellant that each of these measures individually contributes in obtaining a Schottky contact with desired electrical characteristics.

2.5 Consequently, the features (a'), (b), and (c) listed above relate to the solution of three separate technical problems:

A: The partial technical problem addressed by employing measure (a') is to find an alternative to WN_x as material for the Schottky electrode which, among other properties, has a high Schottky barrier with respect to GaAs.

B: As to feature (b), it is known in the art that sputter etching is a slow process. It therefore takes long time to remove a native oxide layer on a GaAs substrate using only sputter etching. On the other hand, sputter etching *in situ*, i.e. in the same sputter processing chamber as where the deposition of the Schottky electrode takes place, has the advantage that the substrate surface will remain absolutely clean until the deposition of the electrode material begins. The partial technical problem related to feature (b) thus relates to shortening the total time for cleaning the GaAs substrate prior to deposition of the Schottky electrode, without compromising the quality of the cleaned surface.

C: Regarding feature (c), the effect of having a shutter in the sputter processing apparatus is that during cleaning of the substrate or the

target by sputter etching, the other parts not being subject to sputter etching will be protected from being contaminated from the cleaning process. The partial technical problem related to feature (c) thus relates to protecting the target from being contaminated during the step of cleaning the substrate by sputter etching.

2.6 Document D4 is considered relevant for feature (a'), since it discloses a process of forming a Schottky electrode made of WSi-Nx on a GaAs substrate using reactive sputtering in an Ar/N₂ and a target made of WSi (cf. abstract). When the recommended process parameters of having a mixture of 10% N₂ and annealing the substrate at 800°C for 20 min after deposition are followed (cf. English translation, page 7, line 14; page 14, first paragraph), it is shown in Figure 5 (amended numbering) that a Schottky barrier height of about 0.79 V is obtained.

2.6.1 In the decision under appeal, the examining division argued that a skilled person would consider the replacement of the W target known from document D1 by a target made of WSi as a matter of routine, in particular since the same Ar/N₂ ambient is used for the reactive sputtering in both the methods of documents D1 and D4, and therefore no major modifications other than a change of target would be required.

2.6.2 The appellant, who in the appeal stage has amended claim 1 to specify the composition ratio of tungsten to silicon to be 1:0.6, mainly argued that a skilled person using the teaching of document D4 on the method of document D1 would not be able to arrive at the claimed composition ratio, since document D4 does not

disclose any composition of the deposited film. A layer having the composition ratio of 1:0.6 has a particularly high Schottky barrier when compared to prior art devices, as can be seen from Table I of the application in suit (cf. item IX(c) above).

- 2.6.3 The Board is however not convinced by the above arguments for the following reasons: Firstly, the Board is not able to find any disclosure in the application in suit attributing any favorable properties or technical effect to the particular composition ratio of 1:0.6, and it is therefore appears to be a more or less arbitrary choice.

As to the disclosure in Table I referred to by the appellant, the results shown in Table I are clearly inconsistent with the discussion of the results in the description (cf. page 3, last paragraph) according to which the Schottky diode characteristics in the example according to the invention (where sputter deposition is carried out after sputter etching in the vacuum chamber) **are improved** over the comparative example where no sputter etching is carried out prior to deposition. Table I on the other hand does not show any etching for the example according to the invention having a higher barrier height of 0.798.

Even when the results in Table I are interpreted in the light of the description, the fact nevertheless remains that the results presented in Table I only show that a device subjected to the step of sputter etching the substrate prior to electrode deposition has a higher Schottky barrier height and a lower reverse bias leak current compared to a device where no sputter etching took place (cf. application, page 6, line 23 to page 7,

line 15). Both the samples of Table I have the same composition ratio 1:0.6, so that the only information gained from Table I regarding about the claimed composition ratio is that a Schottky barrier height of 0.798 volt can be achieved.

2.6.4 Furthermore, although document D4 does not disclose any composition ratio of the deposited electrode layers, it appears that a skilled person following the teaching of document D4 would inevitably arrive at a composition ratio having a value very close to the claimed value of 1:0.6, since the process parameters disclosed in document D4, i.e. sputtering with 10% N₂ in Ar using a WSi target and annealing in 800°C for 20 minutes, are almost the same as all the parameters disclosed in the application in suit (cf. D1, page 7, line 14; page 14, first paragraph; application in suit, page 3, lines 27 to 31; page 4, lines 33 to 36). The only difference in parameters of the two methods is that in document D4, the post-deposition anneal is carried out at 800°C for 20 minutes, whereas in the application in suit, the anneal is carried out at the same temperature but for only 10 minutes.

The reported Schottky barrier heights, about 0.79 V in document D4 (Figure 5) and 0.798 in the application in suit (Table I), also support the assumption that the method of document D4 using the disclosed process parameter would yield a device having about the same composition ratio as claimed.

2.6.5 Therefore, the Board finds that the modification of the method known from document D1 by feature (a') does not involve an inventive step.

2.7 Regarding feature (b), it is was argued in the decision under appeal that, although sputter etch has the advantage of being carried out in the same process chamber as the subsequent deposition step, it is well-known in the art that argon sputter etching is a very slow process. It is therefore known in the art that argon sputter etch alone is impractical, and it would therefore be obvious to a skilled person to carry out a chemically cleaning step prior to the sputter etching step in order to shorten the overall process time.

As an evidence of this conventional knowledge, reference was made in the decision under appeal to document D7 which discloses a process of cleaning a semiconductor substrate prior to metal deposition by reactive sputtering, i.e. the same type of method for depositing the electrode material as in document D1. A method of cleaning which is described in document D7 as being conventional comprises the step of cleaning the substrate in a hydrofluoric acid dip followed by argon sputter etch (cf. column 1, lines 54 to 65).

2.7.1 The Board therefore agrees with the opinion of the examining division that it would be obvious to a skilled person to include a chemically cleaning step prior to the sputter etching step, in order to speed up the etching process. It is also noted that the appellant has not contested the examining division on this point.

2.8 As to feature (c), it is was held in the decision under appeal that most conventional sputter processing apparatuses are provided with a shutter, and that it belongs to the basic knowledge of an average practitioner that a shutter serves the purpose of

shielding the target from contamination during sputter etching of the substrate. As evidence of this conventional knowledge, reference was made to document D6 which contains excerpts from a textbook on sputtering techniques (cf. D6, Figure 6-12, page 197, section "Shutters"). Therefore, the skilled person would consider it is too obvious to engage the shutter during the step sputter etching the substrate.

The appellant has not provided any counter-argument on this point, and the Board sees no reasons to depart from finding of the examining division on this issue.

2.9 The appellant submitted that the examining division had to combine the teaching of four different prior art documents in order to arrive at the claimed method. Since the different documents on their own provide teachings which point in different directions, the combination of features given in the decision under appeal can only be obtained by picking out particular features from each document, an approach which relies on hindsight (cf. item IX(b) above).

2.9.1 Although the boards of appeal exercise great caution with respect to any inventive step argument which relies on a combination of a large number of documents, the Board is in the present case not convinced by the appellant's argument of hindsight: The relatively large number of documents (four) was a result of the finding that the claimed method solves three partial technical problems which are not interrelated, and therefore, each partial technical problem could be considered separately. Consequently, it should be expected that the number of documents would increase with the number of partial technical problems to be solved.

2.10 For the foregoing reasons, in the Board's judgement, the subject matter of claim 1 according to the main request does not involve an inventive step within the meaning of Article 56 EPC.

3. *First auxiliary request - inventive step*

With respect to claim 1 according to the main request, claim 1 according to the first auxiliary request contains the further specifications that (i) a Schottky electrode is produced; (ii) the partial pressure of N₂ is 10 %; (iii) a WSi-Nx layer is formed in the reactive sputtering step; and (iv) the WSi-NX/GaAs wafer is annealed at 800°C for a predetermined period of time so as to restore damage caused thereto in the depositing step. All the above features (i) to (iv) are however known from document D4, as already discussed under item 2.6 above. Therefore, the subject matter of claim 1 according to the first auxiliary request does not involve an inventive step within the meaning of Article 56 EPC for the same reasons as given under item 2 above for claim 1 according to the main request.

4. *Second auxiliary request*

4.1 The second auxiliary request contains seven independent claims all directed to a method of producing a semiconductor device, in contrast to the main request and the first auxiliary request each of which contains one independent claim. Since there are no special reasons given for having such high number of independent claims, the claims according to the second auxiliary request are not concise, contrary to the requirements of Article 84 EPC.

- 4.2 Furthermore, the subject matter of claim 1 according to the second auxiliary request does not involve an inventive step for the same reasons as given for claim 1 according to the main request: Although a partial pressure of 10% N₂ and an annealing step are specified, neither the composition ratio nor the presence of a shutter are specified. The particular value of 10% nitrogen partial pressure is disclosed in document D4, as mentioned under item 2.6 above.
5. For the foregoing reasons, in the Board's judgement, none of the appellant's requests meets the requirement of inventive step according to Articles 52(1) and 56 EPC.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar:

The Chairman:

D. Spigarelli

R. K. Shukla