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# D E C I S I O N
# of 25 October 2002

**Case Number:** T 0525/98 - 3.4.3

**Application Number:** 94113973.5

**Publication Number:** 0642175

**IPC:** H01L 29/812

**Language of the proceedings:** EN

**Title of invention:**
Semiconductor element with Schottky electrode and process for producing the same

**Applicant:**
MURATA MANUFACTURING CO., LTD.

**Opponent:**
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**Headword:**
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**Relevant legal provisions:**
EPC Art. 54(2), 56, 84

**Keyword:**
"Main request - clarity (no)"
"Process features in a product claim - no identifiable product features"
"Auxiliary request - clarity (yes) - inventive step (yes)"

**Decisions cited:**
T 0815/93, T 0141/93

**Catchword:**
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Beschwerdekammern | Boards of Appeal | Chambres de recours

**Case Number:** T 0525/98 - 3.4.3

**D E C I S I O N**
**of the Technical Board of Appeal 3.4.3**
**of 25 October 2002**

**Appellant:** MURATA MANUFACTURING CO., LTD.
26-10, Tenjin 2-chome
Nagaokakyo-shi
Kyoto-fu 226 (JP)

**Representative:** Specht, Peter, Dipl.-Phys.
Herrmann, Trentepohl, Grosse,
Bockhorni & Partner
Forstenrieder Allee 59
D-81476 München (DE)

**Decision under appeal:** **Decision of the Examining Division of the European Patent Office posted 14 January 1998 refusing European patent application No. 94 113 973.5 pursuant to Article 97(1) EPC.**

**Composition of the Board:**

**Chairman:** R. K. Shukla
**Members:** E. Wolff
M. B. Günzel

## Summary of facts and submissions

I. European patent application No. 94 113 973.5 was refused by the examining division on the grounds that claim 1 of the application was either not new (Article 54(2) EPC) or not inventive (Article 56 EPC). The decision is dated 14 January 1998.

The examining division also considered there to be a lack of clarity in claim 1 (Article 84 EPC) but in view of the refusal on the grounds of lack of novelty or inventive step did not pursue the matter further.

II. A notice of appeal was filed on 10 March 1998. The appeal fee was paid on the same day. The statement setting out the grounds of appeal was filed on 15 May 1998.

Oral proceedings were requested should the Board intend to dismiss the appeal.

III. In response to a communication annexed to the summons to the oral proceedings, the appellant filed on 25 September 2002 a main request and a first auxiliary request. Claims 1 to 11 according to the main request consist of an independent process claim 1 with dependent claims 2 to 4, and an independent device claim 5 with dependent claims 6 to 11.

Claim 1 of the main requests reads as follows:

"1. A process for the production of a semiconductor element having a Schottky junction, comprising the steps of
forming an active layer on a compound semiconductor

substrate and forming a Schottky electrode which forms a Schottky junction with said active layer,
wherein a modified layer is formed by plasma treatment in said active layer in at least a portion of a region comprising a region on which said Schottky electrode is to be formed and a vicinity of said region on which said Schottky electrode is to be formed,
and wherein said Schottky electrode is formed so that it is at least partially in contact with or adjacent to said modified layer,
characterised in that said plasma treatment is performed with a plasma source using $O_2$ or any combination of $O_2$ with $N_2$, Ar, $CF_4$, $CHF_3$ or/and $H_2$ and in that at least one oxide film which is formed through said plasma treatment is removed before forming said Schottky electrode."

Claim 5 of the main requests reads as follows:

"5. A semiconductor element comprising a Schottky electrode which forms a Schottky junction with an active layer formed on a compound semiconductor substrate, in which element a modified layer is formed in at least a portion of a region comprising a region of the active layer on which region the Schottky electrode is formed and a vicinity of said region characterized in that
the modified layer is formed by a plasma treating with a plasma source using $O_2$, or any combination of $O_2$ with $N_2$, Ar, $CF_4$, $CHF_3$ and/or $H_2$, and at least one oxide film - which is formed through said plasma treating - is removed.

IV. At the oral proceedings held on 25 October 2002, the appellant submitted a new auxiliary request based on

claims 1 to 4, replacing the first auxiliary request. The auxiliary request is for the grant of a patent with the following documents:

**Claims**: claims 1 to 4 as filed on 25 October 2002

**Description**: pages 1 to 37 as filed on 25 October 2002

**Drawings**: sheets 1/13 to 13/13 original drawings as filed on 6 September 1994

Claim 1 of the auxiliary request differs from claim 1 of the main request only in that "at least one oxide film" in the latter is replaced by "an oxide film".

Claims 2 to 4 are dependent claims.

V. The arguments put forward by the appellant in support of the main and auxiliary requests can be summarised as follows.

*Inventive Step*

The invention as claimed differs from the prior art by providing, in a region where a Schottky contact is to be formed, a modified region in an active layer by plasma treatment in the presence of oxygen, whether on its own or mixed with other specified gases. As can be seen from the experimental results provided by the appellant, plasma treatment in $O_2$ brings about a surprisingly low reverse bias current as compared with that obtained employing $N_2$ or $CF_4$ as a plasma source.

Because the prior art documents, read alone or in combination, contain no relevant disclosures either on plasma treatment with oxygen or the resulting advantages, it follows that the claimed invention is new and involves an inventive step.

In assessing the relevance of the prior art documents, it is important to distinguish between plasma treatment and ion implantation. Because ion implantation is a completely different process to plasma treatment, none of the documents relating to ion implantation are relevant as prior art for the claimed invention. In particular document D3, which is one of the documents concerned and which discloses that a thin layer having low carrier concentration can be formed by ion implantation of either $H^+$, $D^+$, $O^+$ or $B^+$, should therefore be disregarded.

*Clarity - Claim 5*

Concerning the clarity of claim 5, the established case law of the Boards of Appeal clearly permits product-by-process claims where a product cannot be adequately claimed in terms of structural elements. Because of the nature of the treatment, the modified layer cannot be adequately defined in terms of its structure. A product-by-process claim is therefore appropriate in the present circumstances. Moreover, the claim is clear in that it is limited to a semiconductor device which has undergone plasma treatment with oxygen or a gas mixture including oxygen.

## Reasons for the decision

1. The appeal is admissible.

*The main request*

2. *Clarity - claim 5*

2.1 Claim 5 relates to a semiconductor element and incorporates a process feature in its characterising clause to define the semiconductor element. It is the established case law of the Boards of appeal that where a product cannot be defined in terms of its properties or product features, it is permissible to incorporate process features in a product claim provided that the process features impart identifiable product features or properties to the claimed product (e.g. T 815/93 and T 141/93)

2.2 The characterizing clause of claim 5 purports to define the semiconductor element in terms of process-related features. The appellant has submitted experimental evidence that Schottky junctions which have undergone plasma treatment with oxygen as the plasma source exhibit much reduced reverse bias currents compared to similar junctions which have undergone either no plasma treatment or plasma treatment with $N_2$ or $CF_4$.

The appellant has also argued that plasma treatment with oxygen as the plasma source would result in identifiable traces in the finished product. Moreover, owing to the differences between ion implantation and plasma treatment, these traces would be clearly identifiable as being the result of the claimed plasma treatment. The Board accepts that this is plausible.

However, claim 5 is not limited to devices made using

plasma treatment with oxygen alone; instead, it also encompasses devices in which the source for the plasma treatment is a gas mixture of oxygen and other specified gases. The experimental evidence which the appellant supplied did not show whether there were improvements in the reverse bias current for devices that have been plasma treated with any of the claimed oxygen-containing gas mixtures. It is equally not clear which identifiable traces such gas mixtures would leave behind. There is no relevant disclosure in the application itself. Accordingly, it is not clear how a product which has undergone plasma treatment with the claimed gas mixtures could be identified and how the claimed product would differ, for example, from the product disclosed in document D1 if the gas mixture used is one of oxygen and $CHF_3$ as claimed in claim 1.

2.3 For the foregoing reasons the Board concludes that claim 5 of the main request lacks clarity.

*The auxiliary request*

3. *Clarity*

3.1 The Board is satisfied, in the light of the description referring to the modified layer as being a layer which has been modified to have a higher resistance (page 13 line 26 to page 14 line 4), that claim 1 sets out sufficiently clearly the steps which form the method claimed. The Board is also satisfied that the claim is concise and supported by the description, and accordingly fulfills all the requirements of Article 84 EPC, second sentence.

4. *Amendments*

Claim 1 corresponds to claim 9 of the application as originally filed and differs from the original claim 9 by the addition of the whole of the characterizing clause. The description as originally filed includes various examples of the conditions under which the plasma treatment is performed, and also includes specific reference to $O_2$ on its own and in combination with the other gases now specified in the claim (page 17, lines 21 and 22, page 22, lines 25 and 26). The amendments to the description of the application serve the purpose of making the description conform to the amended claims. The Board therefore concludes that the amended application does not contain any subject matter which goes beyond the contents of the application as filed and therefore complies with the requirements of Article 123(2).

5. *Novelty*

5.1 Novelty was not disputed in the decision under appeal. The Board, too, is satisfied that none of the cited documents discloses plasma treatment with oxygen or a gas mixture containing oxygen for the purpose of forming a modified layer prior to the formation of a Schottky contact. Accordingly, the claimed invention satisfies the requirements of Articles 52(1) and 54(1) and (2) EPC with respect to novelty.

6. *Inventive step* (Articles 52(1) and 56 EPC)

6.1 The present claim 1 relates to a process and documents D1, D2, D6, D7 and D8 relating to a plasma treatment were cited in the decision against both the product and the process claims regarding inventive step. In particular, the examining division considered

the description of the application in suit to establish that oxygen and oxygen-containing gas mixtures and other gases such as $N_2$, Ar, $CF_4$, $CHF_3$ and $H_2$ are equivalents for the purposes of plasma treatment, and that therefore the choice of oxygen and oxygen-containing gas mixtures did not require any inventive skill. In view of the specific properties which distinguish oxygen from other gases, in particular the formation of insulating oxides on surfaces exposed to oxygen, as well as for the reasons given below, the Board does not share this view.

6.2 The characterizing clause of claim 1 requires that "the modified layer is formed by a plasma treating with a plasma source using $O_2$, or any combination of $O_2$ with $N_2$, Ar, $CF_4$, $CHF_3$ and/or $H_2$, and at least one oxide film - which is formed through said plasma treating - is removed."The Board interprets this as a clear statement that the claim includes only methods in which an oxide layer is formed during the plasma treatment, either because the plasma source is pure oxygen or, in the case of oxygen-containing gases, because the oxygen content of the gas mixture is sufficiently high for such an oxide to form.

6.3 Document D1 discloses fabrication of a Schottky contact in which the region underneath the Schottky contact is modified before the contact is formed, by a Freon-based reactive ion etching process. This document is acknowledged in the application to be the closest prior art for considering whether a method of plasma treatment with oxygen and gas mixtures with oxygen involves an inventive step, and it forms the basis for the preamble of claim 1 of the auxiliary request.

6.4 Although document D1 relates to plasma treatment for the purpose of lowering the carrier concentration in a semiconductor material, the described process provides no incentive for the skilled person to use an ion species in addition to or instead of the disclosed Freon, since the etching properties of Freon are expressly required.

6.5 Document D6 relates to treating n-GaAs surfaces with hydrogen plasma prior to the formation of Schottky contacts on those surfaces. While document D6 also refers in the introduction to oxygen, it does so only as one of three gases used in sequence to passivate the surface of *n*-GaAs before the deposition of a $Ga_2O_3$ insulating layer (page 259, lefthand column, 2nd paragraph). There is no indication in document D6 that oxygen could be used in place of hydrogen for plasma treating the region on which the Schottky metal-to-semiconductor contact is to be formed. On the contrary, the document refers to any native oxide layer being removed by a dilute HCl etch **prior** to being loaded into the vacuum system. The Board accepts the appellant's argument that this, if anything, points away from using oxygen in the subsequent plasma treatment process taking place inside the chamber.

6.6 In the third paragraph of the left hand column on page 259, document D6 refers in connection with metal/GaAs interfaces only to investigation of $H_2$ and $N_2$ plasma treated surface layers. The remainder of the document describes solely the results of investigations into the use of $H_2$ as source for plasma treatment. It is also clearly stated that passivation of donors and acceptors in GaAs as a result of plasma treatment with $H_2$ had previously been attributed to indiffusion of

atomic hydrogen and the formation of a neutral complex between each dopant atom and H.

6.7 Oxygen, which is mentioned in document D6 only in connection with surface passivation prior to the deposition of a passivation, is therefore demonstrably excluded there from consideration as a possible candidate for forming low carrier concentration layers by plasma treatment, since in document D6 the experimental results are attributed not only to the indiffusion of atomic H and the formation of a neutral complex between each dopant and H but also to the known exceptionally high diffusion rates which distinguish hydrogen from other atomic species.

6.8 Thus, document D6 relates to plasma treatment for the purpose of lowering the carrier concentration in a semiconductor material, but on account of the stated reliance in the process on the exceptional diffusion properties of hydrogen ions provides no incentive for the skilled person to consider any other gas.

6.9 Like document D6, document D7 is concerned solely with exposing n-type GaAs to hydrogen plasma for the purposes of improving Schottky contacts formed on the n-type GaAs.

6.10 Document D2 discloses a method of shaping the depth profile of the electron-depleted layer under a Schottky contact by ion bombardment with $N_2$.

6.11 Document D8 concerns plasma treatment using an inert atmosphere such as Argon as the plasma source.

6.12 Document D11, which the examining division relied on as

prior art, particularly with respect to the product claim 11, relates to a plasma etching process which - unlike the invention - does not involve forming a modified layer. Instead, plasma etching is used in document D11 to etch away parts of a deposited metal layer not required for the formation of the Schottky contact so that, in contrast to the invention, the surface under the Schottky contact is at no time subject to a plasma treatment.

6.13 Concerning prior art documents relating to ion implantation, the appellant submitted that there are fundamental differences between plasma treatment and ion implantation.

(a) Plasma treatment is essentially a surface treatment, even if some of the ions penetrate a short distance below the surface. A plasma cloud is formed and a low voltage attracts the ions to the surface to be treated. The plasma ions react chemically with the target surface. Even if atoms penetrate below the surface, they will generally do so by diffusion without causing any damage to the crystal lattice; indeed, plasma treatment can be used to remove damage from a crystal lattice as described for example in last three lines of document D1, where it is explained that the low carrier concentration results from "restoring a crystal by plasma treatment by a Freon-based reactive ion etching operation of only the surface layer ..." .

(b) In contrast, ion implantation is a technique designed to place ion species into bulk material. An ion beam is generated and the ions are

accelerated until they have the required kinetic energy to penetrate the target material to the desired depth, where they generally replace atoms of the crystal lattice, thereby causing damage to the lattice structure. Even if the process is adjusted so that ions are implanted only near the surface, the distribution of ions and the effect on the crystal lattice will be noticeably different from the distribution resulting from plasma treatment on account of the lattice damage and, for example, because unlike plasma treatment, ion implantation results in an approximately Gaussian depth distribution of the ion species concerned.

6.14 If the argued for distinction between plasma treatment and ion implantation is accepted, as it is by the Board, it follows that the disclosures in documents D3 and D15, both of which disclose ion implantation with oxygen ions, fail to provide the skilled person with any indication that oxygen would be suitable as a plasma source for a method of plasma treatment, and for this reason are irrelevant prior art.

6.15 In the Board's judgment, none of the cited prior art documents would have provided the skilled person with any indication that oxygen or oxygen-containing gases would be worth trying as a plasma source to prepare a modified region prior to forming a Schottky contact on it, especially as the use of oxygen or the claimed oxygen-mixtures leads to the formation of undesirable oxides which must then be removed, and that therefore claim 1 of the auxiliary request involves an inventive step as required by Articles 52(2) and 56 EPC.

## Order

## For these reasons it is decided:

1. The decision under appeal is set aside.

2. The case is remitted to the Examining Division with the order to grant a patent with claims 1 to 4 and description, pages 1 to 37, of the auxiliary request filed at the oral proceedings, and figures 1 to 42, sheets 1/13 to 13/13, as filed.

The Registrar: The Chairman:

R. Schumacher R.K. Shukla