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**Datasheet for the decision
of 14 June 2021**

Case Number: T 2310/16 - 3.4.03

Application Number: 10013685.2

Publication Number: 2276059

IPC: H01L21/20, H01L21/205, C30B25/02, C30B29/40, H01L29/778

Language of the proceedings: EN

Title of invention:
Method of controlling stress in gallium nitride films deposited on substrates

Applicant:
The Regents of the University of California

Headword:

Relevant legal provisions:
EPC 1973 Art. 56

Keyword:
Inventive step - (no)

Decisions cited:

Catchword:

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Beschwerdekammern

Boards of Appeal

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Case Number: T 2310/16 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 14 June 2021

Appellant: (Applicant)
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Decision under appeal:
Decision of the Examining Division of the European Patent Office posted on 21 April 2016 refusing European patent application No. 10013685.2 pursuant to Article 97(2) EPC.

Composition of the Board:

Chairman G. Eliasson
Members: M. Stenger
T. Bokor

Summary of Facts and Submissions

I. The appeal concerns the decision of the Examining Division to refuse European patent application No. 10013685, being a a divisional application of European patent application No. 01957415, which is based on published International application No. WO 02/13245 A1.

II. The decision is based on a main request and two auxiliary requests. The decision comprises objections with respect to Article 56 EPC (all requests), and Articles 84 and 123(2) EPC (auxiliary request 1). All objections with respect to Article 56 EPC relate to D3 as closest prior art combined with the teaching of D5.

III. The appellant requests that the decision be set aside and that a patent be granted on the basis of a main request or one of auxiliary request 1 or 2.
The main request and auxiliary request 2 are the main request and auxiliary request 2 referred to in the contested decision. Both were filed with letter dated 2 March 2016. Auxiliary request 1 was filed with the grounds of appeal (grounds of appeal, page 1, second paragraph).

IV. With the notice of appeal and the grounds of appeal, the appellant had requested oral proceedings. In reply to the Board's communication preparing oral proceedings scheduled for 6 November 2020, the appellant indicated with letter dated 30 September 2020 that neither it nor its representative would be attending, that they had no further submissions and asked to issue a decision on the basis of the documents on file.
Hence, the oral proceedings were cancelled.

V. The following documents will be referred to:

D3: Schremer A. et al.: "High electron mobility AlGaN/GaN heterostructure on (111) Si", Applied Physics Letters, American Institute of Physics, 2 Huntington Quadrangle, Melville, NY 11747, Vol. 76, No. 6, 7 February 2000 (2000-02-07), pages 736 - 738, XP012025829

D5: US 5 874 747 A

D6: JP 09-083016

Document D6 was cited by the appellant with the grounds of appeal. A declaration in which Professor Shuji Nakamura commented on D6 was also filed with the grounds of appeal.

VI. Independent claim 1 of the main request has the following wording (labeling a), b),... added by the Board):

a) *A field effect transistor including a film comprising a nitride layer,*

b) *the nitride layer comprising*
b1) *aluminum and*
b2) *gallium and*

c) *being on a silicon substrate, the nitride layer having a first side adjacent to the silicon substrate and a second side opposite the first side, wherein*

d) *the nitride layer is a continuously graded nitride layer having a higher aluminum fraction* *adjacent to the first side than adjacent to the second side,*

e) *the aluminum fraction of the nitride layer is at least 20% adjacent to the first side and is less than 20% adjacent to the second side, and*

f) *the grade of the nitride layer is carried out over a thickness of 20-100% of the total thickness of the film.*

VII. Independent claim 1 of auxiliary request 1 differs from independent claim 1 of the main request in that feature f) is replaced by feature f') as follows (label f') added by the Board):

f') *wherein the film has a thickness of one micrometer and the grade of the nitride layer is carried out over a thickness of 20-80% of a one micrometer thick film.*

VIII. Independent claim 1 of auxiliary request 2 differs from independent claim 1 of the main request in that feature e) is replaced by feature e') as follows (label e') added by the Board):

e') *the nitride layer is AIN or $Al_{0.5}$ $Ga_{0.5}$ N adjacent to the first side and GaN or $Al_{0.2}$ $Ga_{0.8}$ N adjacent to the second side, and*

IX. The relevant arguments of the appellant may be summarised as follows:

(a) Problems addressed in D3 and D5

D3 related to the problem of thermal mismatch between GaN layers and Si substrates and solved this problem by means of an AlN buffer layer.
D5 was concerned with the problem of thermal mismatch between GaN and AlN buffer layers on SiC substrates and solved this problem by means of a graded AlGaN buffer layer. D5 thus addressed a different problem than D3 (grounds of appeal, page 3, sixth to fifth paragraph from the bottom, and page 3, penultimate paragraph, first two sentences).

(b) Graded buffer layer

Since D5 addressed a different problem than D3, the skilled person would have had no reason to believe that a graded AlGaN buffer layer would overcome the large thermal mismatch between GaN and Si (grounds of appeal, page 3, penultimate paragraph, last sentence).

(c) Applying the teaching of D5

The skilled person would further have had no reason to consider *replacing* the AlN buffer layer of D3 by the graded buffer layer of D5 (grounds of appeal, page 3, antepenultimate paragraph).
If anything, they would have considered placing the graded layer of D5 *on top* of the AlN layer of D3, in particular because of the benefits of the AlN layer taught by D3. The benefit of an AlN intermediate layer was also apparent from D6 (grounds of appeal, page 3, last paragraph to page 4, second paragraph).

(d) Uninterrupted growth

The present inventors had surprisingly found that an AlN buffer layer was not required on top of a silicon substrate in order to prevent cracking of a GaN film. Instead, a graded AlGaN layer could be grown directly on a Si substrate *without interruption* to introduce sufficient compressive stress to overcome the large thermal and lattice mismatch between Si and AlN. This was not suggested in D3 or D5 (grounds of appeal, page 4, third paragraph).

(e) Multiple discrete layers

Even when the grade of the nitride layer according to the invention was not necessarily carried out over a thickness of 100 % of the film such that the layer had a graded region as well as one or more non-graded regions, these regions were not *multiple discrete* layers as may be derived from the combination of D3 and D5, due to the continuous growth of the graded AlGaN layer according to the invention (grounds of appeal, page 4, fourth paragraph).

Reasons for the Decision

1. The appeal is admissible.

2. D3

D3 concerns a field effect transistor (see title and page 736, left-hand column, first paragraph) with a nitride layer (30 nm AlN nucleation layer, see page 736, left-hand column, last paragraph) on an Si substrate (see title), as defined in the independent claims of the main request.
D3 further relates, like the application, to the problem of cracking of the GaN layer due to mismatch of the thermal coefficient of expansion (TCE) between Si

and GaN (page 736, right-hand column, second paragraph).

3. Main request

3.1 D3 as closest prior art

The appellant accepts the closest prior art (D3) identified by the Examining Division (point II.A.1.1 of the contested decision as well as page 1, penultimate paragraph to page 2, first paragraph of the grounds of appeal).
D3 discloses subject-matter aiming at the same objective as the present application and has the most relevant technical features in common therewith (see above).

The Board thus concurs with the appellant and the Examining Division that D3 is suitable to represent the closest prior art.

3.2 Distinguishing features

The Examining Division argues that the subject-matter of claim 1 of the main request differs from D3 by features b2), d), e) and f) as defined above (see point II.A.1.1 of the contested decision). The appellant essentially agrees therewith (page 2, second paragraph of the grounds of appeal).

The Board sees no reason to disagree with the appellant and the Examining Division concerning their analysis with respect to the distinguishing features.

3.3 Objective technical problem to be solved

The appellant also accepts the objective technical problem to be solved as defined by the Examining Division: *how to mitigate film cracking for III-nitrides on silicon* (see page 4, first two paragraphs of the contested decision and page 2, paragraphs 3 and 4 of the grounds of appeal).
The Board sees no reason to disagree with the appellant and the Examining Division concerning the definition of the objective technical problem to be solved.

3.4 Inventive step

3.4.1 Considering solutions found for SiC substrates / D5 (see section IX.(a) above)

To avoid cracking of GaN films grown on Si, D3 proposes a limitation of the thickness of the GaN film (page 736, right-hand column, lines 15 to 19). This could be seen as a solution for the objective technical problem as defined above. However, this particular solution also limits the usability of the GaN film. Thus, the skilled person would, starting from D3, continue to look for further solutions of this problem.

D3 further mentions that TCE mismatch causes problems when growing GaN on SiC, in a similar, although less severe manner than when growing GaN on Si (page 736, right-hand column, lines 7 to 12).
Thereby, the skilled person would have considered to apply solutions found for similar problems arising when GaN is grown on SiC, when looking for further solutions to the objective technical problem defined above.

The Board accepts that D5 mentions that mismatch between AlN and GaN is a problem, as submitted by the appellant (see column 18, lines 29 to 38 of D5). However, this is not the only problem mentioned in D5.

For instance, the same passage also refers to problems caused by TCE differences between other materials ("...differences in the TCE between GaN and AlN or SiC"), and D5 explicitly mentions that TCE mismatch between GaN and SiC often causes cracking when GaN films are grown on SiC substrates (column 4, lines 52 to 58).

D5 therefore might not directly concern the objective technical problem as defined above and referred to in D3, as submitted by the appellant (see section IX.(a) above). However, D5 concerns a problem that is mentioned in D3 as being similar to the objective technical problem as defined above.

Thereby, the skilled person would have considered to apply the solutions suggested in D5 for the case of growing GaN films on SiC substrate when trying to solve the objective technical problem starting from D3, in line with the argumentation of the Examining Division under point II A 1.1 of the contested decision.

3.4.2 Solutions suggested in D5 (see section IX.(b) above)

D5 discloses that the problem of cracking of the GaN layer grown on an SiC substrate can be resolved by using a compositionally graded AlGaN buffer layer (column 18, lines 53 to 56). D5 discloses a (small) number of different types of such graded buffer layers, as submitted by the appellant (grounds of appeal, page 2, sixth paragraph from the bottom).
The skilled person could in principle have considered to use any of these different types of graded buffer

layers in order to solve the objective technical problem as defined above.

In some of the graded buffer layers disclosed in D5, the Al content is graded from 0 at the SiC/buffer interface to 1 at the buffer/GaN interface. Such a buffer is even listed as a preferred mode of carrying out the invention (column 28, lines 54 to 64).

However, no buffer with such a grading is used in any of the examples of D5. Further, the skilled person would have been aware that such a grading would lead to an undesirable lattice mismatch at the buffer/GaN interface. Therefore, the skilled person reading D5 would not have considered to actually use a buffer layer of that type.

D5 further explicitly states that a graded buffer layer where the Al content is graded from 1 at the SiC/buffer interface to 0 at the buffer/GaN interface successfully enabled the growth of crack-free GaN epi-layers several microns thick (paragraph bridging columns 18 and 19, see also example V). In addition, the skilled person would have been aware that with this type of buffer grading, lattice mismatch at the buffer/GaN interface would be eliminated.

Thus, the skilled person, in view of the overall teaching of D5 and their common general knowledge, would preferably have considered the type of compositionally graded AlGaN buffer disclosed in the paragraph bridging columns 18 and 19 and Example V. This type of buffer layer fulfills the requirements defined in features b2), d) and e).

They would thereby have had a reason to believe that such a graded AlGaN buffer would overcome the large thermal mismatch between Si and GaN, contrary to the arguments of the appellant (see section IX.(b) above).

3.4.3 Options for a AlGaN buffer layer with AlN at the substrate/buffer interface disclosed in D5

Two options are disclosed in D5 for a compositionally graded AlGaN buffer with a grading from AlN at the substrate/buffer interface to GaN at the buffer/GaN interface, i.e. a buffer comprising features b2), d) and e) as set out above.

The first option is changing the composition of the graded buffer layer directly adjacent to the substrate, resulting in a buffer layer that is graded over its entire thickness. This option is disclosed in the part of D5 relating to figures 8 and 20.

The second option consists of a buffer layer consisting of two regions, a thin AlN region directly adjacent to the substrate followed by a compositionally graded AlGaN region. This option is described in D5 with respect to figure 9.

The skilled person, starting from D3 and trying to solve the objective technical problem as defined above, would in principle have considered to apply any of these two options without an inventive step.

3.4.4 The first option (see section IX.(c) above)

The Board accepts that document D3 mentions the benefits of an AlN buffer layer between the Si substrate and the GaN layer, as submitted by the appellant. The Board also accepts that D6 discloses that an AlN layer placed between an SiC substrate and a graded AlGaN layer is beneficial in that it improves the crystallinity of both the graded layer and the nitride layer on top of the graded layer (see paragraph [11]) of D6).

However, with respect to the first option mentioned above, D5 discloses that using a compositionally graded AlGaN buffer with a grading from AlN at the substrate/ buffer interface to GaN at the buffer/GaN interface *instead* of an AlN buffer layer reduces cracking of the GaN epi-layer (column 18, lines 29 to 34 and column 18, line 64 to column 19, line 7; see also examples IV and V in comparison).
Further, in the embodiment shown in figure 8 relating to the first option (see also column 19, lines 16 to 22), the compositionally graded AlGaN layer *replaces* the previously used AlN buffer layer (see column 18, lines 29 to 32), leading to a thick GaN layer without cracks (column 19, lines 30 to 35).

Within the context of the first option, D5 does therefore not suggest to place a compositionally graded AlGaN buffer *on top* of an AlN buffer layer, contrary to the arguments of the appellant.

Instead, within that context, D5 suggests to replace an AlN layer by an AlGaN buffer layer that is graded over its entire thickness as required by feature f).

3.4.5 Uninterrupted growth/compressive stress (see section IX.(d) above)

The Board notes that claim 1 of the main request does not require that the graded AlGaN layer is grown in a continuous manner without interruption.

Further, D5 might not explicitly mention any compressive stress caused by an uninterrupted growth of the graded AlGaN layer. Nevertheless, the graded AlGaN buffer layer according to D5 is actually grown in a continuous manner starting from AlN (see figure 20 and the part of the description relating to Example V in columns 24 and 25). Thus, if an uninterrupted growth of a graded AlGaN layer on Si causes compressive stress as submitted by the appellant, such a stress will also be present in the graded layer which the skilled person would grow on Si, when starting from D3 and following the teaching of D5.

For these reasons, the Board cannot accept the argument of the appellant summarised above in section IX.(d).

3.4.6 Conclusion

To summarize the above, the skilled person, starting from D3 (which discloses features a), b), b1) and c)) and being faced with the objective technical problem of how to mitigate film cracking for III-nitrides on silicon would have considered to apply solutions for similar problems when growing GaN on SiC instead of on silicon.
They would thereby have consulted D5 and would have been incited by its teaching relating to figure 8 to replace the AlN buffer layer on the Si substrate of D3 by

- an AlGaN layer arranged directly on the substrate as required by feature b2) in combination with features b) and b1),

- [the AlGaN layer] being compositionally graded over its entire thickness as required by feature f), and

- starting with an initial composition of AlN (i.e. an Al content of 100 %) at the substrate/buffer interface and ending with a final composition of GaN (i.e. an Al content of 0 %) at the buffer/GaN interface in line with the requirements of features d) and e),

thereby arriving at the subject-matter of claim 1 of the main request without an inventive step.

Consequently, the subject-matter of independent claim 1 of the main request is not inventive within the meaning of Article 56 EPC 1973 in view of D3 combined with the teaching of D5 relating to figure 8.

4. Auxiliary request 1 (see section IX.(e) above)

As mentioned above, D5 discloses two options for a compositionally graded AlGaN buffer with a grading from AlN at the substrate/buffer interface to GaN at the buffer/GaN interface and the skilled person would have considered to apply any of these two options in order to solve the objective technical problem as defined above.

The second option, described in D5 in relation to figure 9, relates to a buffer structure or buffer film consisting of two regions, a thin AlN region with a preferred thickness of 10 nm to 1000 nm grown directly on the SiC substrate followed by a compositionally graded AlGaN region which has a preferred thickness of 50 nm to 1000 nm (see column 7, lines 21 to 38; see also figure 9 and column 19, lines 23 to 29).

Hence, the skilled person starting from D3 would have been incited by the teaching of D5 relating to figure 9 to replace the AlN buffer layer on the Si substrate of D3 by a buffer film consisting of an AlN buffer region followed by a compositionally graded AlGaN buffer region.

Further, as noted above, the graded AlGaN buffer according to D5 is grown in a *continuous* manner starting from AlN (see figure 20 and the part of the description relating to Example V). That is, the skilled person would have had no reason to interrupt the growth process when a first region of the buffer film were to consist of AlN only. Instead, they would have simply maintained the flow rates of TMAl and TMGa at their initial levels for the required time to grow an AlN region of the desired thickness, before adjusting them continuously to grow the graded layer. Thus, a combination of D3 and D5 would not have provided *multiple discrete* layers even when a thin AlN region were to be grown before a graded region, contrary to the argument of the appellant.

The Board notes that document D6 cited by the appellant and commented upon in the declaration of Professor Nakamura also discloses a two-region buffer consisting of an AlN region and a graded AlGaN region grown by a continuous process (see paragraphs [14] to [19] of D6; see also grounds of appeal, page 4, second paragraph).

The preferred thickness ranges given in D5 for the two buffer regions (see column 7, lines 21 to 38; see also figure 9 and column 19, lines 23 to 29 as mentioned above) comprise buffer films consisting of an AlN region and a graded AlGaN region where the graded region accounts for 20% to 80% of the total thickness of the buffer film which may be one micrometer (e.g. 300 nm AlN and 700 nm AlGaN) as required by feature f') of independent claim 1 of auxiliary request 1.

Therefore, the skilled person would have arrived at a field effect transistor with a buffer film according to this claim starting from D3, applying the teaching of figure 9 of D5 and selecting thickness values of the two regions of the buffer film in a non-inventive manner, as argued by the Examining Division (contested decision, point II B 3).

Hence, the subject-matter of independent claim 1 of the first auxiliary requests is not inventive within the meaning of Article 56 EPC 1973 in view of D3 combined with the teaching of D5 and the common general knowledge of the skilled person.

5. Auxiliary request 2

As set out above, D5 discloses a graded layer, the composition of which is AlN on the substrate side and GaN on the GaN side (see column 7, lines 21 to 31 and column 18, line 64 to column 19, line 4). This corresponds to one of the combinations of compositions defined in feature e'). D5 thus discloses this feature as well.
The Board notes that D5 further suggests to use other compositions at the two sides of the buffer also falling into the ranges defined by feature e') (*starting composition* and *end composition*, see column 19, lines 42 to 54).

Thus, the subject-matter of independent claim 1 of the second auxiliary request is not inventive within the meaning of Article 56 EPC 1973 in view of D3 combined with the teaching of D5, either, in line with the argumentation of the Examining Division (contested decision, point II C).

6. Since none of the requests on file fulfills the requirements of Article 56 EPC 1973, the appeal must fail.

It is therefore not necessary to discuss the other issues raised in the contested decision and the Board's communication preparing the oral proceedings.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated