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Datasheet for the decision of 14 June 2021

Case Number: T 1094/17 - 3.4.03

Application Number: 01957415.1

Publication Number: 1307903

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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
RPBA Art. 12(4)

Keyword:
Inventive step - (no)
Auxiliary request could have been filed before the Examining Division (yes)

Decisions cited:

Catchword:

Boards of Appeal of the
European Patent Office
Richard-Reitzner-Allee 8
85540 Haar
GERMANY
Tel. +49 (0)89 2399-0
Fax +49 (0)89 2399-4465

Case Number: T 1094/17 - 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)	The Regents of the University of California 1111 Franklin Street, 12th Floor Oakland, CA 94607 (US)
Representative:	Ward, David Ian Marks & Clerk LLP Alpha Tower Suffolk Street Queensway Birmingham B1 1TT (GB)
Decision under appeal:	**Decision of the Examining Division of the European Patent Office posted on 5 December 2016 refusing European patent application No. 01957415.1 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. 01957415 which is based on published International application No. WO 02/13245 A1 (PCT application No. PCT/US01/24347).

II. The decision is based on a main request and three auxiliary requests. The decision comprises objections with respect to Article 56 EPC taking D4 as closest prior art combined with the teaching of D5 for all requests.

III. The appellant requests that the decision under appeal be set aside in its entirety (notice of appeal) and that a patent be granted on the basis of a main request or on the basis of one of four auxiliary requests. All requests were filed with the grounds of appeal.
The independent claims of the main request and of auxiliary request 1 correspond to the independent claims of the main request and auxiliary request 1, respectively, on which the decision is based.

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:

D4: 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 comments 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 semiconductor structure, comprising:*

b) *a silicon substrate; and*

c) *a graded nitride layer comprising aluminium and gallium on the substrate having a graded composition varying continuously from an initial composition to a final composition,*

d) *wherein the initial composition is an aluminium composition having an aluminium content of at least 20% and the final composition is an aluminium composition having an aluminium content of less than 20%,*

e) *the graded layer having a net compressive stress.*

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

c') *a graded nitride layer comprising aluminium and gallium on the substrate having a graded composition varying continuously from an initial composition which is adjacent to the substrate to a final composition,*

VIII. Independent claim 1 of auxiliary request 2 differs from independent claim 1 of the main request in that feature c) is replaced by feature c'') and in that it comprises, at the end, feature f), as follows:

c'') *a film comprising a graded nitride layer comprising aluminium and gallium on the substrate having a graded composition varying continuously from an initial composition which is adjacent to the substrate to a final composition,*

f) *and wherein the grade of the graded nitride layer is carried out over a thickness of 20-80% of the total thickness of the film.*

IX. Independent claim 1 of auxiliary request 3 differs from independent claim 1 of auxiliary request 2 in that feature f) is replaced by feature f') as follows:

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

X. Independent claim 1 of auxiliary request 4 reads as follows:

g) *A method of producing a semiconductor structure, comprising:*

h) *providing a silicon substrate;*

i) *using metalorganic chemical vapour deposition (MOCVD) depositing a graded nitride layer by:*

j) *depositing a silicon layer on the heated surface of the silicon substrate using a silicon precursor;*

k) *introducing an aluminium precursor so as to form an aluminium silicide;*

l) *progressively removing the silicon precursor so as to form a film of aluminium;*

m) *introducing a nitrogen precursor so as to complete the transition to aluminium nitride; and introducing a gallium precursor, thereby forming*

c) *a graded nitride layer comprising aluminium and gallium on the substrate having a graded composition varying continuously from an initial composition to a final composition*

n) *and being formed from a supply of precursors in a growth chamber without any interruption in the supply during the deposition,*

d) *wherein the initial composition is an aluminium composition having an aluminium content of at least 20% and the final composition is an aluminium composition having an aluminium content of less than 20%,*

e) *the graded layer having a net compressive stress.*

Auxiliary request 4 does not comprise any independent claim directed at a semiconductor structure.

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

(a) D4 provided its own solution to the problem of cracking of GaN layers grown on silicon by means of an AlN nucleation layer between the Si substrate and the GaN layer (grounds of appeal, page 4, section 1.).

(b) D5 was concerned with a different problem than D4 and the invention. D5 related to the growth of GaN on SiC. The main problem addressed was the large mismatch between AlN and GaN (grounds of appeal, page 5, section 2.).
Si and SiC were not equivalent substrate materials and the growth of GaN on Si could not be compared with growth of GaN on SiC because of the greater thermal mismatch between Si and GaN compared to that between SiC and GaN (grounds of appeal, page 7, first paragraph). It could not be assumed that a graded layer that was capable of mitigating cracking in the case of GaN/SiC was also capable of solving the problem for GaN/Si (grounds of appeal, page 7, last paragraph).

(c) Even if the skilled person had considered the teachings of both D4 and D5, they would not have had any reason to select the particularly graded AlGaN layer where x varies from 1 at the SiC/buffer interface to 0 at the buffer/GaN interface; no teachings in D5 said that the embodiment of figure 8 was the best way of working the invention. On the contrary, the text explicitly stated that the preferred modes for carrying out the invention had a different layer structure (grounds of appeal, page 6, fourth to penultimate paragraph).

(d) Further, they would have been aware of the benefits of an AlN layer between an SiC substrate and a graded AlGaN layer from the embodiment of figure 9 of D5 as well as from D6, as supported by the Nakamura declaration. Thus, starting from D4, the skilled person would have retained the AlN nucleation layer. They would not have *replaced* the AlN layer of D4 by the graded layer of D5. If anything, they would have placed the graded layer of D5 *on top* of the discrete AlN layer of D4 (grounds of appeal, page 7, second to fourth paragraph).

(e) The skilled person would further have been deterred from placing a graded layer wherein the AL content *decreased from the substrate/graded layer interface* directly onto Si due to the large mismatch between Si and AlN (grounds of appeal, page 7, third paragraph).

(f) The inventors had surprisingly found that cracking of a GaN film could be prevented in the absence of an AlN buffer by a graded layer grown without interruptions, thereby creating a large amount of compressive strain sufficient to counteract the tensile stress caused by the lattice and thermal mismatch (grounds of appeal, page 7, penultimate paragraph). Compressive stress was not mentioned in the paragraph spanning columns 18 and 19 of D5 (grounds of appeal, page 5, last paragraph).

Reasons for the Decision

1. The appeal is admissible.

2. Main request

2.1 D4 as closest prior art

The appellant considers D4 to be the closest prior art (grounds of appeal, page 3, first paragraph under the heading "Inventive step of claim 1 based on D4 combined with D5"). The contested decision also discusses this approach (section II A 2 and the corresponding subsections).

D4 is directed at semiconductors structures including an Si substrate and a nitride layer and addresses the same problem as the application, i.e. the cracking of GaN films grown on Si substrates (see abstract).

The Board thus concurs with the appellant concerning the selection of D4 as the closest prior art.

2.2 Distinguishing features

The Examining Division found that the subject-matter of claim 1 of the main request differed from D4 in that the nitride layer was a layer according to features c), d) and e) as defined above (contested decision, point II A 2.1). The appellant essentially agreed therewith (grounds of appeal, page 3, penultimate paragraph).

The Board sees no reason to disagree.

2.3 Technical effect

The Examining Division and the appellant also concur that the technical effect of the distinguishing features is that the GaN films grown on Si do not exhibit cracking, even if they are relatively thick (contested decision, point II A 2.2 and grounds of appeal, page 3, last paragraph).

Again, the Board sees no reason to disagree.

2.4 Objective technical problem to be solved

A plausible objective technical problem can then be formulated as being

- *how to avoid cracking of thick GaN films grown on Si substrates*

This objective technical problem corresponds essentially to the objective technical problems identified by both the Examining Division (contested decision, point II A 2.3) and the appellant (grounds of appeal, page 4, first paragraph)

2.5 Inventive step

2.5.1 Solution proposed in D4 (see section XI.(a) above)

No cracking of GaN films grown on Si with a 30 nm thick intermediate AlN layer was observed in D4 as long as the thickness of the GaN film was less than 0.7 micrometers (page 736, left-hand column, last sentence, and right-hand column, lines 15 to 19). D4 further suggests that thicker crack-free GaN films may be grown if a thinner intermediate AlN layer was used (page 738, left-hand column, last paragraph). This could be seen as D4's own solution for the cracking problem, as argued by the appellant.

However, the limited thickness of the GaN films obtained with this particular solution generally limits the usability of the obtained films, not only in terms of reduced electrical isolation caused by possibly thinner AlN layers as argued by the Examining Division (contested decision, point II A 2.2).

Consequently, the skilled person would, starting from D4, continue to look for (further) solutions of the cracking problem, despite the solution proposed in D4 itself.

2.5.2 Combining D4 with the teaching of D5 (see section XI. (b) above)

The Board accepts that Si and SiC are different substrate materials, as submitted by the appellant.

However, D4 mentions that TCE mismatch causes problems when growing GaN on SiC, in a similar, albeit less severe, manner than when growing GaN on Si (page 736, right-hand column, lines 7 to 12). Thereby, the skilled person would have assumed that solutions that were capable of mitigating cracking in the case of GaN/SiC would also be capable of solving the problem for GaN/Si, contrary to the argument of the appellant.

Starting from D4, they would thereby have considered to apply solutions found for the case of GaN/SiC to solve the objective technical problem as defined above.

The Board accepts that D5 mentions mismatch between AlN and GaN in column 18, lines 29 to 38 as submitted by

the appellant. The same passage, however, also refers to TCE differences between other materials ("...differences in the TCE between GaN and AlN or SiC").
The skilled person would thus not understand from D5 that the main problem for GaN growth on SiC using a buffer layer was the mismatch between AlN and GaN, contrary to the argument of the appellant.

Further, 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 D4, as submitted by the appellant. However, D5 concerns a problem that is mentioned in D4 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 substrates when trying to solve the objective technical problem starting from D4, in line with the argumentation of the Examining Division under points II A 2.5 and 2.6 of the contested decision.

2.5.3 Solutions suggested in D5 (see section XI.(c) 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 6, fourth paragraph).
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 line with the argument of the appellant.

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 at the buffer/GaN interface. Such a buffer is even listed under the "Preferred modes of carrying out the invention" (column 28, lines 54 to 64), as noted by the appellant (grounds of appeal, page 6, fifth paragraph).

However, no buffer layer 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 undesired 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 have had reasons to select, as a buffer layer, the type of compositionally graded AlGaN buffer layer disclosed in the paragraph bridging columns 18 and 19 and Example V, contrary to the arguments of the appellant.
This type of buffer layer fulfills the requirements defined by features c) and d).

2.5.4 Options for an 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 c) and d).

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 D4 and trying to solve the objective technical problem as defined above would in principle have considered to apply any of these two options without the exercise of an inventive step.

2.5.5 The first option (see section XI.(d) above)

The Board accepts that document D4 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 that document).

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 32 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 (see column 18, lines 29 to 32) AlN buffer layer, 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 the AlN buffer layer disclosed in D4, contrary to the argument of the appellant (see grounds of appeal, page 7, paragraphs 3 and 4).

Instead, within that context, D5 suggests to replace that AlN layer by an AlGaN buffer layer graded over its entire thickness according to features c) and d).

2.5.6 Deposition of AlN on Si (see section XI.(e) above)

D4 discloses an AlN buffer layer placed directly on an Si substrate. The skilled person would thus not have been deterred by the large mismatch between Si and AlN from placing a graded layer with an Al content decreasing from the substrate directly onto Si, contrary to the argument of the appellant.

2.5.7 Compressive stress (see section XI.(f) above)

The Board accepts that D5 does not describe compressive stress in the paragraph bridging columns 18 and 19, as noted by the appellant. D5 also does not explicitly mention any compressive stress caused by an uninterrupted growth of the graded AlGaN layer.

However, the type of graded AlGaN buffer layer disclosed in D5 - which the skilled person would have selected to replace the AlN buffer disclosed in D4 as set out above - is 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). The skilled person would have had no reason to grow that layer in a different manner when using the Si substrate of D4.

The appellant submits that uninterrupted growth of this type of graded AlGaN buffer layer on an Si substrate causes compressive stress. If that is the case, such compressive stress will inevitably also be present when the AlN buffer layer of D4 is replaced by an AlGaN buffer layer grown continuously as described in Example V of D5.

It must be concluded that a graded layer grown in that manner has a compressive stress to the same extent as required by feature e).

2.5.8 Conclusion

To summarize the above, the skilled person, starting from D4 disclosing features a) and b) as well as an AlN nitride layer and being faced with the objective technical problem of how to avoid cracking of thick GaN films grown on Si substrates would have considered to apply solutions found for similar problems when growing GaN on SiC instead of on silicon.

They would thereby have consulted D5 and would have been incited by the teaching of D5 relating to figure 8 to replace the AlN buffer layer on the Si substrate of D4 by an AlGaN layer arranged directly on the substrate and thereby adjacent to it, the AlGaN layer being continuously compositionally graded over its entire thickness as required by feature c), 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 feature d).

They would thereby have arrived at a graded ALGaN layer grown in the same manner as the one proposed in the present application. The resulting graded AlGaN layer inevitably would have had a net compressive stress to the same extent as disclosed in the application and required by feature e).

Hence, the subject-matter of independent claim 1 of the main request is not inventive under Article 56 EPC 1973 in view of D4 combined with the teaching of D5 relating to figure 8.

3. Auxiliary request 1

In the foregoing, independent claim 1 of the main request was narrowly interpreted such that the graded buffer layer was, with its initial composition, adjacent to the substrate. Thus, the above arguments for the main request apply to independent claim 1 of auxiliary request 1 as well.

Hence, the subject-matter of that claim is not inventive under Article 56 EPC 1973.

4. Auxiliary request 2

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 with respect 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 D4 would have been incited by the teaching of D5 relating to figure 9 to replace the AlN buffer layer on the Si substrate of D4 by a buffer film consisting of an AlN buffer region followed by a compositionally graded AlGaN buffer region as required by feature c'').

The Board notes that Document D6 cited by the appellant and commented upon in the declaration of Professor Nakamura also discloses in paragraphs [14] to [19] a two-region buffer film consisting of an AlN region and a graded AlGaN region (see also grounds of appeal, page 7, third and fourth paragraph).

The ranges given in D5 for the preferred thicknesses of the two buffer regions 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 (e.g. 300 nm AlN and 700 nm AlGaN) as required by feature f) of independent claim 1 of the second auxiliary request.

Therefore, the skilled person, starting from D4 and applying the teaching of figure 9 of D5, would have arrived at a buffer film according to this claim by a non-inventive selection of the thickness values for the two buffer regions suggested in D5 in relation to figure 9.

Hence, the subject-matter of independent claim 1 of auxiliary request 2 is not inventive under Article 56 EPC, either (see also the part of point III A of the contested decision relating to claim 8 of the main request).

5. Auxiliary request 3

In view of the preferred thickness ranges given in D5 for the thicknesses of the two buffer regions mentioned above and in the apparent absence of any particular technical effect achieved by the thickness range of 20 to 80% of the total film thickness and a particular total film thickness of one micrometer, the arguments brought forward above for claim 1 of auxiliary request 2 also apply to independent claim 1 of auxiliary request 3.

The subject-matter of that claim is thus not inventive under Article 56 EPC 1973, either.

6. Auxiliary request 4

Features j), k), l) and m) of claim 1 of auxiliary request 4 relate to additional layers at the substrate/ buffer interface and details of the deposition process thereof. Such additional layers and details were never discussed during the proceedings before the Examining Division. Further, they have been taken exclusively from paragraph [32] of the description and were never claimed before.
An independent claim comprising these features thus not only could, but should have been filed in the proceedings before the Examining Division.

The Board decides not to admit auxiliary request 4 into the proceedings under Article 12(4) RPBA 2007 in conjunction with Article 25(2) RPBA 2020.

7. The independent semiconductor structure claims of the main request and of auxiliary requests 1 to 3 are not inventive. Auxiliary request 4 is not admitted into the procedure.

In the absence of any allowable request the appeal must fail, and it is not necessary to discuss the other issues raised in the contested decision and the Board's communication.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated