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Datasheet for the decision of 17 December 2020

Case Number: T 1939/16 - 3.4.03

Application Number: 06124388.7

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Language of the proceedings: EN

Title of invention:
Nitride based transistors for millimeter wave operation

Applicant:
Cree, Inc.

Relevant legal provisions:
EPC Art. 123(2), 54(1), 54(2), 56
RPBA 2020 Art. 13(2)

Keyword:
Amendments - extension beyond the content of the application as filed (yes) - main request, first to fourth auxiliary requests
Novelty - (no) - fifth auxiliary request
Inventive step - (no) - fifth auxiliary request
Amendment after summons - taken into account (no) - sixth to thirteenth auxiliary requests

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Case Number: T 1939/16 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 17 December 2020

Appellant: Cree, Inc.
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted on 7 April 2016 refusing European patent application No. 06124388.7 pursuant to Article 97(2) EPC.**

Composition of the Board:

Chairman T. Bokor
Members: M. Ley
M. Papastefanou

Summary of Facts and Submissions

I. The appeal concerns the decision of the examining division to refuse European patent application No. EP 06 124 388.7.

The examining division cited the following documents:

D1 XP 0109303545
D2 XP 011108466
D3 XP 011136381
D4 XP 012032976

and decided that:

- the subject-matter of claim 1 according to the main request lacked novelty (Article 52(1) EPC, Article 54(1) and (2) EPC 1973),
- the subject-matter of claim 1 according to the first auxiliary request lacked novelty (Article 52(1) EPC, Article 54(1) and (2) EPC 1973) and an inventive step (Article 56 EPC 1973),
- claim 1 according to the second auxiliary request did not comply with Article 123(2) EPC and its subject-matter lacked novelty (Article 52(1), Article 54(1) and (2) EPC 1973),
- the subject-matter of claim 1 according to the third auxiliary request lacked novelty (Article 52(1) EPC, Article 54(1) and (2) EPC 1973) and an inventive step (Article 56 EPC 1973)
- the subject-matter of claim 1 according to the fourth auxiliary request lacked an inventive step (Article 56 EPC 1973).

II. The appellant requests that the decision be set aside and a European patent be granted based either on a main request or on one of the first to fourth auxiliary requests filed with the statement of grounds of appeal or on one of the fifth to thirteenth auxiliary requests filed with letter dated 17 November 2020.

The main request and the first to fourth auxiliary requests correspond to those underlying the contested decision.

III. In a communication pursuant to Article 15(1) RPBA 2020, the Board informed the appellant about its provisional view that claim 1 according to the main request and according to the first to fourth auxiliary requests did not comply with the requirements of Article 123(2) EPC (see points 4.1, 4.2, 5. and 6.) and that, in addition, the subject-matter of claim 1 according to the third and fourth auxiliary requests was not novel over D1 (see points 7.2.2 and 8.4) or did not involve an inventive step over D2 in combination with D1 (see points 7.2.1, 7.3.1, 7.3.2 and 8.5). The Board pointed out that the provisional findings with respect to novelty/inventive step were equally valid for claim 1 of the main request and of the first and second auxiliary requests (see point 7.4).

IV. Oral proceedings took place on 17 December 2020 via video conference at the request of the appellant, at the end of which the Chairman announced the Board's decision.

V. Claim 1 according to the the **main** request has the following wording:
A field effect transistor comprising a
Group III-nitride first sublayer (16A) and a

Group III-nitride channel (16B) on the first sublayer, the first sublayer comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$, the channel layer comprising GaN and characterised in that the channel layer has a concentration of Fe dopants therein that decreases with distance from the first sublayer.

Claim 1 according to the **first** auxiliary request has the following wording:
A field effect transistor comprising:
a Group III-nitride first sublayer (16A) comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$;
a Group III-nitride channel layer (16B) on the first sublayer, the channel layer comprising GaN;
a spacer layer (62) on the channel layer;
a gate contact (24) on the channel layer and configured to modulate a conductivity of the channel layer in response to a voltage applied to the gate contact,
the gate contact having a gate length that is sufficient to permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz;
source and drain contacts (20,22) on the channel layer; and
a lower field plate (64) electrically connected to the gate contact and extending across the space layer a distance L_{FD} toward the drain contact, wherein L_{FD} is at least 0.1 µm;
characterised in that the channel layer has a concentration of Fe dopants therein that decreases with distance from the first sublayer.

Claim 1 according to the **second** auxiliary request has the following wording:
A field effect transistor comprising:

a Group III-nitride first sublayer (16A) comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$;
a Group III-nitride channel layer (16B) on the first sublayer, the channel layer comprising GaN;
a Group III-nitride barrier layer (18) on the channel layer, wherein the barrier layer and the channel layer cooperatively induce a two-dimensional electron gas in the channel layer near an interface between the barrier layer and the channel layer;
characterised in that the channel layer has a concentration of Fe dopants therein that decreases with distance from the first sublayer.

Claim 1 according to the **third** auxiliary request has the following wording :
A field effect transistor comprising:
a Group III-nitride first sublayer (16A) comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$;
a Group III-nitride channel layer (16B) on the first sublayer,the channel layer comprising GaN;
a spacer layer (62) on the channel layer;
a gate contact (24) on the channel layer and configured to modulate a conductivity of the channel layer in response to a voltage applied to the gate contact,
the gate contact having a gate length that is sufficient to permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz;
source and drain contacts (20,22) on the channel layer; and
a lower field plate (64) electrically connected to the gate contact and extending across the space layer a distance L_{FD} toward the drain contact, wherein L_{FD} is at least 0.1 µm;

a Group III-nitride barrier layer (18) on the channel layer, wherein the gate contact and the spacer layer are on the barrier layer, and the barrier layer and the channel layer cooperatively induce a two-dimensional electron gas in the channel layer near an interface between the barrier layer and the channel layer; characterised in that the channel layer has a concentration of Fe dopants therein that decreases with distance from the first sublayer.

Claim 1 according to the **fourth** auxiliary request corresponds to claim 1 of the **third** auxiliary request and further requires the field effect transistor being configured to exhibit a power density of greater than 5 W/mm when operated at a frequency of at least 30 GHz and L_{FD} being 0.25 µm.

Claim 1 according to the **fifth** auxiliary request has the following wording:
A field effect transistor configured to exhibit a power density of greater than 5 W/mm when operated at a frequency of at least 30 GHz comprising:
a Group III-nitride channel layer (16) comprising a Group III-nitride first channel sublayer (16A) and a Group III-nitride second channel sublayer (16B) on the first channel sublayer, the first channel sublayer comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$, the second channel sublayer comprising GaN and characterised in that the second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first channel sublayer,
a spacer layer (62) on the channel layer;
a gate contact (24) on the channel layer and configured to modulate a conductivity of the channel layer in response to a voltage applied to the gate contact, the

gate contact having a gate length (L_G) that is sufficient to permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz; source and drain contacts (20,22) on the channel layer; and a lower field plate (64) electrically connected to the gate contact and extending across the spacer layer a distance L_{FD} toward the drain contact, wherein L_{FD} is at least 0.1 µm.

Claim 1 according to the **sixth** auxiliary request corresponds to claim 1 of the **fifth** auxiliary request, wherein the field effect transistor comprises a substrate (12), a buffer layer (14) on the substrate and the Group-III channel layer (16) on the buffer layer.

Claim 1 according to the **seventh** auxiliary request corresponds to claim 1 of the **sixth** auxiliary request, wherein the buffer layer comprises AlN.

Claim 1 according to the **eighth** auxiliary request corresponds to claim 1 of the **seventh** auxiliary request, wherein it is further specified that the Group III-nitride channel is on and distinct from the buffer layer.

Claim 1 according to the **ninth** auxiliary request corresponds to claim 1 of the **fifth** auxiliary request, wherein the first channel sublayer has a thickness of 0.1 - 0.8 µm and the second channel sublayer has a thickness of 0.2 - 2.0 µm.

Claim 1 according to the **tenth** auxiliary request corresponds to claim 1 of the **sixth** auxiliary request, wherein the first channel sublayer has a thickness of

0.1 - 0.8 µm and the second channel sublayer has a thickness of 0.2 - 2.0 µm.

Claim 1 according to the **eleventh** auxiliary request corresponds to claim 1 of the **eighth** auxiliary request, wherein the first channel sublayer has a thickness of 0.8 µm and the second channel sublayer has a thickness of 0.8 µm.

Claim 1 according to the **twelfth** auxiliary request corresponds to claim 1 of the **eleventh** auxiliary request, wherein it is further specified that the channel layer (16), the first and second channel sublayers (16A) and (16B) are a GaN channel layer (16), a GaN first channel sublayer (16A) and a GaN second channel sublayer (16B), respectively.

Claim 1 according to the **thirteenth** auxiliary request corresponds to claim 1 of the **twelfth** auxiliary request wherein the field effect transistor further comprises a Group III-nitride barrier layer (18) comprising a first barrier sublayer (18A) on the second channel sublayer and a second barrier sublayer (18B) on the first barrier sublayer, wherein the gate contact and the spacer layer are on the barrier layer, and the barrier layer and the channel layer cooperatively induce a two-dimensional electron gas in the channel layer near an interface between the barrier layer and the channel layer, the spacer layer (62) is on the second barrier sublayer, the gate contact (24) is on the second barrier sublayer and wherein the first barrier sublayer comprises AIN and has a thickness of 0.8 µm, and wherein the second barrier sublayer comprises $Al_xGa_{1-x}N$, wherein $0.15 < x < 0.45$, and has a thickness of 25 µm.

VI. The appellant's relevant arguments are as follows:

(a) Basis in the application as originally filed for the amendments :

In its letter dated 16 February 2016, the appellant indicated paragraphs [0014], [0015], [0016] and original claims 1 to 3, 6 and 7 as a basis for the amendments made to claim 1 of the main and first to fourth auxiliary requests. No further passages related to these requests were indicated in the statement of grounds of appeal, in the letter dated 17 November 2020 or during oral proceedings.

(b) Novelty with respect to D1 and D2:

D1 did not explicitly mention Fe doping in the device, see e. g. the statement of grounds of appeal, pages 1 and 2.

D2 did not provide any further details about the Fe doped GaN buffer layer, i. e. its location, thickness, etc. D2 lacked a channel layer (or sublayer) comprising GaN and having a concentration of Fe dopants that decreased with distance from the first sublayer. For the appellant, the GaN channel in D2 was the region with the 2DEG region near the interface between the GaN layer and the AlN/AlGaN barrier layer as shown in figure 1. The doping properties of this layer were not disclosed in D2, see e. g. the statement of grounds of appeal, pages 2 and 3.

D2 made reference to document D4, which disclosed Fe doping used "for growth of semi-insulating GaN films" used "beneath the device structure" in HEMT devices, see e. g. the letter dated 17 November 2020, page 3. D4 disclosed a 2.6 µm thick GaN layer with the "first 0.3 µm of the film" doped with Fe, see page 441, left column. D4 further disclosed an additional region of 0.8 µm having a decrease in Fe as a result of "memory effects". Hence, D4 only disclosed 1.1 µm of the GaN layer doped with Fe; the remaining portions of 1.5 µm were free of Fe. Therefore, D2 (in view of D4) would be interpreted by one of ordinary skill in the art as describing Fe doping to form a "buffer layer" in the GaN film beneath the device structure (e. g. the channel layer). While one of ordinary skill in the art might understand that the lower portions of the GaN film in D2 to include Fe so as to act as a buffer, there was no disclosure that the channel portions (i. e. the upper portions comprising the 2DEG) of the device would also incorporate Fe. The memory effect described in D4, which resulted in a decrease in the concentration of Fe dopants, did not imply that the channel in D2 was doped with Fe.

On the contrary, the invention according to the present application concerned a field effect transistor with channel layer 16 having a Fe dopant throughout its entire thickness, see the letter dated 17 November 2020, page 4. In the embodiment of paragraph [0070] as an example, the first sublayer 16A had a thickness of 0.8 µm and a Fe concentration of 10^{18} cm^{-3}, and the second sublayer 16B had a thickness of 0.8 µm with a decreasing Fe concentration throughout its entire thickness in view of the disclosure of D4, page 441, left column. This was "strikingly different from the GaN structure of the cited prior art in which a majority of the GaN layer" was "free of Fe", see letter dated 17 November 2020, page 4.

Hence, in the wording of claim 1 according to the fifth auxiliary request, neither D1 nor D2 did disclose "a Group III-nitride channel layer comprising a Group III-nitride first channel sublayer and a Group III-nitride second channel sublayer on the first channel sublayer, the first channel sublayer comprising GaN and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$, the second channel sublayer comprising GaN and characterised in that the second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first channel sublayer", see the letter dated 17 November 2020, page 3.

The appellant also argued that D2 did not disclose the claimed operation frequency of greater than 30 GHz.

(c) Inventive step

According to the statement of grounds of appeal, pages 4 and 5, the alleged distinguishing features, i. e. a GaN channel layer having the claimed Fe dopants concentration decreasing with distance from the first sublayer, would provide an "improved field effect transistor" due to the "surprising observation" of "improved power capability, reduced gate-to-drain feedback capacitance (as described in paragraph 0039) and improved power performance for wide bandgap field effect transistors at millimetre wave frequencies (paragraph 0080)". The "improved characteristics" were demonstrated in figures 2 to

4 and paragraphs [0075] to [0079], see also the letter dated 17 November 2020, page 4.

According to the "inventors of the application", unintentional doping of the channel region could "cause problems in the device", which "need to be balanced against undesiderable high frequency performance degradation that can occur when the thickness of certain layers are increased to reduce the impact of dopant memory effects on the channel", see statement of grounds of appeal, page 6. According to the appellant's statement in the letter dated 17 November 2020, page 4, and during oral proceedings, the "ability to move the Fe-doped portions of the GaN channel layer closer to the barrier layer would result in a device having a thinner GaN film over those devices, such as D1 and D2, which incorporate an Fe-doped GaN buffer portion and a non-Fe doped GaN channel portion above the buffer portion".

The skilled person would not be motivated by D4 to dope the region with the 2DEG of D2 and would keep the channel layer free of Fe in order to improve carrier mobility.

(d) Admission of the sixth to thirteenth auxiliary requests:

In its letter dated 17 November 2020, page 1, the appellant argued that the sixth to thirteenth auxiliary request were filed "in response to the Added Matter and Clarity objections, which are raised in the Preliminary Opinion for the first time, and the Novelty and Inventive Step objections, which are expanded compared to those raised by the Examining Division".

During the oral proceedings, the appellant added that the sixth to eight auxiliary requests addressed the objections of lack of novelty and inventive step by specifying that a buffer layer was present between a substrate and the channel layer. Neither D1 nor D2 disclosed a buffer layer. D4 required the GaN to be formed directly onto a sapphire substrate, with no further buffer layer needed. According to paragraph [0042] of the application, an additional buffer layer would "provide an appropriate crystal structure transition between the silicon carbide substrate and the remainder of the device" and an AlN buffer layer would provide a compressive stress, see paragraph [0046].

During the oral proceedings, the appellant argued that the ninth to thirteenth auxiliary requests should be admitted as they better clarified that iron dopants were present throughout the whole channel layer including the first and second sublayers, contrary to what was disclosed in D1 or D2 in view of D4.

Reasons for the Decision

1. The appeal is admissible.

2. The invention concerns a field effect transistor configured to exhibit a power density of greater than 5 W/mm when operated at a frequency of at least 30 GHz, see paragraph [0001].

The transistor includes a Group III-nitride channel layer and a spacer layer on the Group III-nitride channel layer. A gate contact is on the Group III-nitride channel layer and is configured to modulate a conductivity of the channel layer when a sufficient voltage is applied to the gate contact. The gate contact has a gate length that is sufficient to permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz. A lower field plate is electrically connected to the gate contact and extends across the spacer layer a distance L_{FD} of at least 0.1 µm toward the drain contact. Source and drain contacts are on the Group III-nitride channel layer.

In the transistors as claimed, the channel layer has two sublayers, both comprising GaN. The first channel sublayer has a concentration of iron dopants of at least $1x10^{17}$/cm3. The second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first channel sublayer.

A typical example of the claimed transistor is a high-electron-mobility-transistor (HEMT), see paragraph [0005].

3. Main request

In the contested decision, the examining division stated that claim 1 according to the main request was derivable from paragraphs [0014] and [0018] of the description as originally filed (point 1 of the Grounds).

For the Board, the requirements of Article 123(2) EPC are not met for the reasons as follows.

3.1 Throughout the application as originally filed, the Group III-nitride channel layer (16) comprises a first channel sublayer (16A) and a second channel sublayer (16B) on the first channel sublayer, the first channel sublayer comprising GaN and having a concentration of Fe dopants of at least about $1x10^{17}/cm^3$, the second channel sublayer comprising GaN and having a concentration of Fe dopants therein that decreases with distance from the first channel sublayer, see paragraph [0014] in combination with paragraph [0018] or original claims 1, 2 and 6 or paragraphs [0046] to [0050] in combination with figure 1 or paragraph [0070].
On the other hand, the wording of claim 1 does not require the "Group-III first sublayer" having a Fe dopants concentration equal or greater than $1x10^{17}/cm^3$, being a part of a channel layer, i. e. a layer whose conductivity might possibly be modulated in response to a voltage applied to a gate contact. This arrangement is not disclosed in or derivable from the application as originally filed.

3.2 Moreover, a field effect transistor with a channel having a Fe dopants concentration that decreases with distance from a first sublayer always has the following features according to the application as originally filed:
(i) a spacer layer (62) on the Group III-nitride channel layer (16);
(ii) a gate contact (24) on the Group III-nitride channel layer (16) and configured to modulate a conductivity of the channel layer (16) in response to a voltage applied to the gate contact (24), the gate contact (24) having a gate length (L_G) that is sufficient to permit modulation of the conductivity of the channel layer (16) at frequencies exceeding 30 GHz;

(iii) source and drain contacts (20, 22) on the Group III-nitride channel layer (16); and
(iv) a lower field plate (64) electrically connected to the gate contact (24) and extending across the spacer layer (62) a distance, L_{FD} toward the drain contact (22), wherein L_{FD} is at least 0.1 µm.
(v) the field effect transistor being configured to exhibit a power density of greater than 5 W/mm when operated at a frequency of at least 30 GHz.

From paragraphs [0014] and [0018], claims 1, 2 and 6 as originally filed or figure 1 and the related description, a field effect transistor according to the present application must comprise the above mentioned features in order to be operational at frequencies exceeding 30 GHz (i. e. in order to be suitable for millimeter wave operation). A field effect transistor according to the present application, i. e. operating at a frequency above 30 GHz, without gate, source and drain contacts as defined by features (i) to (v) above constitutes technical information for the person skilled in the art, which is not present in the application as originally filed.

4. First auxiliary request

The amendments made to claim 1 according to the first auxiliary request do not overcome the objections raised under Article 123(2) EPC against claim 1 of the main request, see points 3.1 and 3.2 above.

In addition, according to claim 1 in its present wording, the gate contact is "configured to modulate the conductivity" of a channel layer, which is limited to a channel layer having a concentration of Fe dopants that decreases with distance from the first sublayer, whereas in the application as originally filed, the channel (16) comprises both a first channel sublayer (16A) and a second channel sublayer (16B), see e. g. claim 6 or paragraph [0018].

With respect to the feature (v), the Board does not share the examining division's view that paragraph [0022] justifies the omission of the features of original claim 1, see the contested decision, point 5 of the grounds. Claim 1 as originally filed and paragraph [0014] make it clear that the field effect transistor according to the invention is necessarily configured such that it has a power density > 5 W/mm when it is operated at a frequency of at least 30 GHz. As no upper limit for L_{FD} is defined in claim 1, its present wording encompasses transistors having a smaller power density, when operated at 30 GHz.

5. Second auxiliary request

The amendments made to claim 1 according to the second auxiliary request do not overcome the objections raised under Article 123(2) EPC against claim 1 of the main request and of the first auxiliary request, see sections 3.1, 3.2 and 4. above.

In addition, the Board agrees with the examining division that a barrier layer according to claim 1 is only disclosed in the application as originally filed for the gate contact layer (24) and the spacer layer (62) on the barrier layer 18, 18A, 18B, see e. g. original claim 3 and figure 1.

Moreover, according to claim 1 in its present wording, the two-dimensional electron gas (2DEG) is induced in the channel layer, i. e. the layer having a concentration of Fe dopants therein that decreases with distance from the first sublayer. There is no basis in the application for this kind of device. Claims 1 to 3 and 6 as originally filed or the example of figure 1 merely disclose that the 2DEG is induced in the channel layer 16, said channel layer comprising both a first channel sublayer 16A (having an Fe dopant concentration $\geq 1 \times 10^{17}$ cm^{-3}) and a second sublayer 16B (having a decreasing Fe concentration). The set of original claims or paragraphs [0014] to [0018] or figure 1 in combination with [0055] (" ... through a 2DEG channel 26 induced in the channel layer 16 near the interface between the channel layer 16 and the barrier layer 18 ...") leave it open at which position within the channel 16, i. e. in which one of the sublayers 16A or 16B forming the channel 16, the 2DEG is exactly formed. A skilled person would not be able to derive from the application as originally field that the 2DEG is necessarily formed in the second sublayer 16B.

6. Third and fourth auxiliary requests

The amendments made to claim 1 according to the third and the fourth auxiliary requests do not overcome the objections raised under Article 123(2) EPC against claim 1 of the higher ranking requests, see sections 3.1, 4. and 5. above, and, in addition, section 3.2 for the third auxiliary request.

7. Fifth auxiliary request

7.1 Admission - Article 13(2) RPBA 2020

The set of claims according to the fifth auxiliary request was filed after the notification of the summons to oral proceedings and, hence, is an amendment to the appellant's appeal case that shall, in principle, not be taken into account unless there are exceptional circumstances, which have been justified with cogent reasons by the party concerned (Article 13(2) RPBA 2020 in combination with Article 25(1) RPBA 2020).

The appellant justified the filing of the fifth auxiliary request *inter alia* as a response to the added subject-matter objection raised for the first time in the Board's communication pursuant to Article 15(1) RPBA 2020.

The Board accepts that the amendments made to claim 1 according to the fifth auxiliary request address only the issues with respect to Article 123(2) EPC and do not introduce new aspects. The amendments made were already anticipated and considered in the Board's preliminary opinion on novelty and inventive step, see points 7.2, 7.3, 8.4 and 8.5 of the Board's communication.

Thus, the Board used its discretion to admit the fifth auxiliary request into the appeal procedure.

7.2 Novelty - Articles 52(1) EPC and 54(1) and (2) EPC 1973

The subject-matter of claim 1 according to the fifth auxiliary is known from D1 for the reasons as follows.

7.2.1 Figure 1 of D1 shows a AlGaN/GaN high-electron-mobility-transistor (HEMT) configured to exhibit a power density of 8.6 W/mm when operated at a frequency of 40 GHz (abstract). The HEMT comprises a GaN/AlN/AlGaN stack on a silicon carbide substrate, source/drain contacts, a gate contact with a gate length L_g and a field plate extending towards the drain contact by a distance L_f, see figure 1. The stack in D1 includes a Group III-nitride barrier layer (AlN/AlGaN) on a GaN channel layer (figure 1), wherein the gate contact and a silicon nitride spacer layer are on the barrier layer (figure 1). In operation, the AlN/AlGaN barrier layer and the GaN channel layer cooperatively induce a two-dimensional electron gas (2DEG) in the GaN channel layer (figure 1) near an interface between the barrier layer and the channel layer (figure 1).

The GaN/AlN/AlGaN stack of D1 is the same as used in D2, see section "Device Fabrication", first sentence, "The epi-design of AlGaN/GaN HEMTs in this study was reported before[1]."; reference sign "[1]" referring to document D2.

7.2.2 D2 discloses (figure 1) a HEMT on a silicon carbide substrate and comprising a GaN layer including a GaN channel with a two-dimensional electron gas (2DEG), source, drain contacts, an AlN/AlGaN barrier layer, a gate contact and a field plate in contact with the gate contact.

D2 states that iron doping according to document D4 is used in the GaN layer (see page 118, left column, first paragraph below figure 2: "Additionally, Fe doping of the GaN buffer was used [10]"; reference sign [10] concerning document D4).

D4 discusses the inclusion of Fe dopants in the GaN layer of an AlGaN/GaN HEMT close to the growth substrate at a concentration larger than $1x10^{17}/cm^3$, see page 441, left column, second paragraph. Therefore, the statement "Fe doping of the GaN buffer was used" in D2 makes it clear that the same Fe dopant concentration in D2 is present in a region close to the SiC/GaN interface of figure 1 of D2.

Moreover, D4 teaches that iron doped GaN layers are grown by metalorganic chemical vapor deposition using ferrocene as the Fe precursor, which is also the method used in the present application, see paragraph [0049]. D4 describes an iron doping level of larger than 10^{17} per cm^3 (page 441, left column, second paragraph: 1.7 x 10^{18} cm^{-3}) and that a decrease of Fe concentration is created when interrupting the ferrocene flow, see figure 3 for the example of GaN:Fe:Si/GaN. This teaching of D4 implies for D2 that, when the ferrocene flow is stopped during the growth of the GaN layer shown in figure 1 of D2 and before growing the AlN barrier, a decrease in Fe concentration is necessarily formed within the GaN layer, e. g. close to the GaN/AlN interface.

7.2.3 In view of the above, a skilled person, who reads D2 and, in particular, the sentence "Additionally, Fe doping of the GaN buffer was used [10]" understands that the GaN layer shown in figure 1 of D2 has a concentration of Fe dopants of at least $1x10^{17}/cm^3$ in a first sublayer close to the GaN/substrate interface and has a Fe concentration that necessarily decreases towards the GaN/AlN interface within a second sublayer.

In other words, using the wording of claim 1, document D2 discloses a Group III-nitride channel layer (figure 1, "GaN") comprising a Group III-nitride first channel sublayer (lower part of GaN, figure 1) and a Group-III nitride second channel layer (upper part of the GaN, figure 1) on the first channel sublayer (figure 1), the first channel sublayer comprising GaN (figure 1) and having a concentration of Fe dopants of at least $1x10^{17}$

/cm^3, the second channel sublayer (figure 1) comprising GaN (figure 1) and the second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first sublayer.

7.2.4 As the GaN layer in D1 is the same as the one of D2, the GaN layer of the field effect transistor of D1 comprises the first and second channel sublayers in the sense of claim 1. In particular, the GaN layer of D1 comprises the iron doping in accordance with documents D2 and D4. Hence, the Board does not agree with the appellant's view that D1 lacked a disclosure of Fe dopants.

In other words, document D1 discloses (in the wording of claim 1 according to the fifth auxiliary request) a field effect transistor (figure 1, section "Device Fabrication") comprising:
a Group III-nitride channel layer (figure 1, "GaN") comprising a Group III-nitride first channel sublayer (lower part of GaN) comprising GaN (figure 1) and having a concentration of Fe dopants of at least $1x10^{17}$ /cm^3 (see 7.2.2 and 7.2.3 above) and Group III-nitride second channel layer (figure 1, upper part of GaN layer closer to the GaN/AlN interface) on the first channel sublayer (figure 1), the second channel sublayer comprising GaN (figure 1) and characterised in that the second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first channel sublayer (see 7.2.2 and 7.2.3 above);
a spacer layer (SiN) on the channel layer (figure 1);
a gate contact (figure 1) on the channel layer (figure 1) and configured to modulate a conductivity of the channel layer in response to a voltage applied to the gate contact (figure 1), the gate contact having a gate length (L_G = 0.15 to 0.18 µm) that is sufficient to

permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz (abstract, 40GHz, 8.6 W/mm);
source and drain contacts (S, D, figure 1) on the channel layer (figure 1);
a lower field plate (figure 1) electrically connected to the gate contact and extending across the spacer layer (SiN) a distance L_f toward the drain contact, wherein L_F is at least 0.1 µm (see figure 1, L_F = 0.3 µm).

7.2.5 The appellant's arguments (see section VI (b) above) have not convinced the Board.

Both the present invention as defined in claim 1 and documents D1 or D2 concern field effect transistors with a GaN layer on a substrate. According to claim 1, said GaN layer is called "channel layer" and comprises two "channel sublayers". For the reasons given above, the portion of the GaN layer close to the silicon carbide substrate in D1 or D2 is called "GaN buffer" and has a Fe dopant concentration higher than $1x10^{17}/cm^3$ so that it is a "first channel sublayer" in the sense of claim 1. In view of D4, the GaN layer of D1 or D2 necessarily includes a portion with a concentration of Fe decreasing towards the barrier layer (AlN/AlGaN) i. e. with a distance from the first sublayer. Hence, the GaN layer known from D1 or D2 also has a second sublayer according to claim 1. In other words, the wording of claim 1 and the technical content of D1 or D2 regarding the GaN layer differ only by the terminology used.

The open language of claim 1 ("a Group III-nitride channel layer comprising ...", "the second channel sublayer has ...") does not exclude that the second channel sublayer further comprises a region completely free of Fe or that the channel layer 16 comprises additional GaN sublayers free of Fe, see also the present application, paragraph [0030], third sentence. In view of paragraph [0031] of the present application, the wording of claim 1 does not even exclude additional sublayers between the first and second sublayers of claim 1. Thus, the wording of claim 1 encompasses field effect transistors with a majority of the GaN layer or with the portion of the GaN layer having the 2DEG completely free of Fe dopants. Therefore, the Board does not agree with the appellant that the wording of claim 1 is limited to a channel layer having Fe dopants throughout its entire thickness.

Moreover, the Board is of the view that this type of GaN layer is not disclosed in the application as originally filed. Neither original claim 6, paragraph [0018], paragraphs [0047] to [0049] nor paragraph [0070] explicitly disclose the thickness of the portion of the GaN channel layer with the decrease in Fe concentration. As the application is silent about the experimental conditions used when growing the first channel sublayer 16A by chemical vapor deposition using ferrocene as metalorganic source gas, a skilled person cannot directly and unambiguously derive from the application as originally filed the thickness of the portion with the decreased in Fe concentration. In particular, as there are no indications that the same conditions as in D4 are used, a skilled person cannot conclude that this depth is necessarily 0.8 µm.

As both the GaN layers known from D1 and D2 comprise the claimed first and second sublayers, they clearly have to be considered as "Group III-nitride channel layer" in the sense of claim 1 according to the fifth auxiliary request.

7.3 Inventive step - Article 56 EPC

Although the subject-matter of claim 1 according to the fifth auxiliary request lacks novelty over D1, it does not involve an inventive step in view of a combination of D2 with D1, either. The reasons are the following.

7.3.1 Document D2 discloses (in the wording of claim 1) a field effect transistor (figure 1, section "II. Device Design and Fabrication") comprising:
a Group III-nitride channel layer (figure 1, "GaN") comprising a Group III-nitride first channel sublayer (lower part of GaN, figure 1) and a Group-III nitride second channel layer (upper part of the GaN, figure 1) on the first channel sublayer (figure 1), the first channel sublayer comprising GaN (figure 1) and having a concentration of Fe dopants of at least $1x10^{17}/cm^3$ (see 7.2.2, 7.2.3 and 7.2.5 above), the second channel sublayer (figure 1) comprising GaN (figure 1) and characterised in that the second channel sublayer has a concentration of Fe dopants therein that decreases with distance from the first sublayer (see 7.2.2, 7.2.3 and 7.2.5 above);
a spacer layer (SiN) on the channel layer (figure 1);
a gate contact (figure 1, "Gate") on the channel layer (figure 1) and configured to modulate a conductivity of the channel layer in response to a voltage applied to the gate contact (figure 1, 2DEG), the gate contact having a gate length (L_G) that is sufficient to permit modulation of the conductivity of the channel layer at frequencies of 8 GHz;
source and drain contacts (figure 1) on the channel layer;

a lower field plate (figure 1, "Field plate") electrically connected to the gate contact (see section II.) and extending across the spacer layer a distance L_F toward the drain contact, wherein L_F is at least 0.1 µm (see figure 2, L_F = 0.1, 0.2, ..., 1.1µm).

In addition, D2 discloses a Group III-nitride barrier layer (AlN/AlGaN) on the channel layer (figure 1), wherein the gate contact and the spacer layer are on the barrier layer (figure 1), and the barrier layer and the channel layer cooperatively induce a two-dimensional electron gas (2DEG) in the channel layer (figure 1) near an interface between the barrier layer and the channel layer (figure 1). The gate length is 0.5 to 0.6 µm so that the transistor is operated at 8 GHz (abstract).

Hence, as also argued by the examining division, the subject-matter of claim 1 differs from D2 by a gate length L_G that is sufficient to permit modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz. As a consequence, the field effect transistor according to D2 is not configured to operate at a frequency of at least 30 GHz so that it is not "configured to exhibit a power density of greater than 5 W/mm when operated at a frequency of at least 30 GHz".

7.3.2 As explained in section 7.2 above, the Board takes the view that the "GaN channel layer" according to claim 1 is already disclosed in both D1 and D2. Hence, the Board is not convinced by the appellant's argument that neither D1 nor D2 disclosed a channel layer that has a concentration of Fe dopants therein that decreases with distance of the first sublayer and that the objective technical problem solved by this distinguishing feature would be to provide "an improved field effect transistor", see section VI (c) above.

The Board notes that - contrary to the appellant's statement - there is no indication in the application as originally filed that a decrease in Fe concentration would have any (positive or negative effect) on the device's performance, see paragraphs [0047], [0049], [0070]. It appears from paragraph [0047] that it is immaterial for the functioning of the claimed field effect transistor whether the channel layer 16 comprises iron doping or not.

The appellant referred to figures 2 - 4, and paragraphs [0039] and [0075] to [0080] and mentioned "improved power capability", "reduced gain-to-drain feedback capacitance" and "improved power performance for wide bandgap field effect transistors at millimetre wave frequencies". The Board does not share the appellant's view, because there is no indication in the application as originally filed that the alleged improvements are a result of the concentration of Fe dopants in the channel layer decreasing with distance from the first sublayer. For the Board, the effects mentioned in those paragraphs are related to the general structure of the HEMT according to claim 1, e. g. the gate length L_G, the distance L_{FD}, etc. Paragraphs [0047], [0049], [0070] rather appear to suggest that the Fe doping has neither a beneficial nor a detrimental effect on the device performance.

Finally, the Board is of the opinion that none of the features in present claim 1 would allow to obtain a GaN layer that is necessarily thinner than that of the cited prior art, contrary to the appellant's statements, see section VI (c) above. As discussed in section 7.2 above, neither claim 1 requires the presence of iron doping throughout the whole thickness of the channel layer nor is this type of channel layer derivable from the application as originally filed by a skilled person using its common general knowledge. Hence, the Board is not convinced that the problem of an "undesirable high frequency performance degradation" would be addressed by the features of claim 1.

The Board takes the view that the objective technical problem is to modify the device of D2 such that a higher operation frequency is possible.

7.3.3 From D2, section "I. Introduction", the skilled person knows about the general trend to increase the operation frequencies of HEMTs. As mentioned before, a HEMT operating at frequencies of 30 and 40 GHz is known from D1 and has a gate length of 0.15 to 0.18 µm, which is smaller than the one of D2 (0.5 to 0.6 µm). The gate length of D1 is in the range of 0.15 to 0.25 µm mentioned in paragraph [0057] of the present application and thereby allows the field effect transistor operating at higher frequencies.

It would be obvious for the skilled person to modify the device of D2 by selecting the gate length known from D1, which permits "modulation of the conductivity of the channel layer at frequencies exceeding 30 GHz".

Therefore, taking D2 as the closest prior art, the skilled person would arrive without any inventive skill at a field effect transistor having a gate length L_G between 0.15 and 0.18 µm and configured to operate at 30 GHz. As document D2 discloses a field effect transistor having all the remaining structural features of claim 1, said field effect transistor with a reduced gate length between 0.15 and 0.18 µm is necessarily "configured to operate at a power density greater than 5 W/mm when operated at a frequency of at least 30 GHz".

8. Admission of the sixth to thirteenth auxiliary requests

The Board, using its discretion, decides not to admit the sixth to thirteenth auxiliary requests into the procedure (Article 13(2) RPBA 2020 in combination with Article 25(1) RPBA 2020) for the reasons as follows.

8.1 The set of claims according to the sixth to thirteenth auxiliary requests were filed after the notification of the summons to oral proceedings and, hence, are amendments to the appellant's appeal case that shall, in principle, not be taken into account unless there are exceptional circumstances, which have been justified with cogent reasons by the party concerned (Article 13(2) RPBA 2020 in combination with Article 25(1) RPBA 2020).

8.2 While the Board considers the amendments made to the claims according to the fifth auxiliary as a response to the Board's objections under Article 123(2) EPC raised against the main and the first to fourth auxiliary requests, this is not the case for the other auxiliary requests.

The amendments made to the sixth to eighth auxiliary requests concern the substrate onto which the GaN channel layer is positioned; those made to the ninth to thirteenth auxiliary requests concern the thickness of the first and second channel sublayers, the thirteenth auxiliary request introducing in addition a barrier layer including first and second barrier sublayers.

In its communication, the Board did not raise any new or different objections regarding novelty or inventive step with respect to the objections of the examining division. Therefore, the Board does not find convincing the appellant's argument that the sixth to thirteenth auxiliary requests should be admitted as a response to "Novelty and Inventive Step objections, which are expanded compared to those raised by the Examining division", seepoint VI.(d) above.

The amendments made to the auxiliary requests introduce new aspects that have never been discussed in an independent claim before the examining division. Hence, the auxiliary requests could and should have been submitted earlier as a reply to the examining division's summons to attend oral proceedings or, at the latest, with the statement of the grounds of appeal. The Board notes that the appellant decided not to attend the oral proceedings before the examining division, which were hold in its absence.

8.3 Regarding the sixth to eighth auxiliary requests, the Board notes that the application as originally filed appears to be limited to an AlN buffer layer 14, i. e. a buffer layer composed of aluminum nitride, see paragraph [0042] and [0070], so that a "buffer layer" made of any material or merely "comprising" AlN appears not to be disclosed in the application as originally filed. Moreover, the application itself states that substrates having a AlN buffer layer for receiving a GaN layer grown thereon to form a HEMT are already known from the prior art, see paragraphs [0008]. Contrary to the appellant's statement, the application does not describe that a "compressive stress" is a result of the presence of a buffer layer, see paragraphs [0043] and [0046].

Hence, *prima facie*, the amendments made to the sixth to eighth auxiliary request do not overcome the issues raised by the Board without raising newones.

8.4 With respect to the ninth to thirteenth auxiliary requests, the Board takes the view that the wording of claim 1 according to none of these requests requires that the entire channel layer has iron dopants and/or that the second channel sublayer has a decrease in Fe concentration throughout its entire thickness. Hence, as for the fifth auxiliary request, it is not excluded that the part of the channel layer having the 2DEG in the claimed field effect transistors is completely free of iron dopants. The Board repeats its view that a channel layer doped with iron throughout its entire thickness including the 2DEG channel region cannot be directly and unambiguously derived from the application as originally filed. Hence, prima facie, the amendments made to the ninth to thirteenth auxiliary requests do not overcome the issues raised by the Board.

The Board also notes that the issue of the iron doping in the channel layer was addressed during the examination procedure and under points 2.3 to 2.5 of the grounds for the decision. The Board cannot acknowledge any cogent reasons as to why the ninth to thirteenth auxiliary requests could not have been filed during the examining procedure or with the statement of grounds of appeal.

9. As no allowable request is on file, the appeal must fail.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

S. Sánchez Chiquero T. Bokor

Decision electronically authenticated