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HIGH-ELECTRON-MOBILITY TRANSISTORS

Applicant:
Power Integrations, Inc.

Relevant legal provisions:
EPC Art. 83

Keyword:
Sufficiency of disclosure - undue burden (yes)

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Case Number: T 0623/22 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 9 January 2025

Appellant: (Applicant)	Power Integrations, Inc. 5245 Hellyer Avenue San Jose, CA 95138 (US)
Representative:	Fish & Richardson P.C. Highlight Business Towers Mies-van-der-Rohe-Straße 8 80807 München (DE)
Decision under appeal:	**Decision of the Examining Division of the European Patent Office posted on 25 October 2021 refusing European patent application No. 15202460.0 pursuant to Article 97(2) EPC.**

Composition of the Board:

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

Summary of Facts and Submissions

I. The appeal is against the decision of the examining division to refuse European patent application No. 15 202 460 pursuant to Article 97(2) EPC.

II. The following documents were cited in the impugned decision:

D1 EP 2 779 947 A2

D2 EP 2 772 940 A2

D3 1200-V Normally Off GaN-on-Si Field Effect Transistors With Low Dynamic ON-Resistance, 2011

D4 Electric Field Control in AlGaN/GaN HEMTs Operating in the kV Regime, 2016

D5 GaN-based HEMT Improvement Using Advanced Structures, 2013

D6 High Performance Enhancement-Mode AlGaN/GaN MIS-HEMT with Selective Fluorine Treatment, 2015

D7 A novel double field-plate power high electron mobility transistor based on AlGaN/GaN for performance improvement, 2011

D8 Simulation of AlGaN/GaN HEMT's Breakdown Voltage Enhancement Using Gate Field-Plate, Source Field-Plate and Drain Field Plate, 2019

D9 RESURF AlGaN/GaN HEMT for High Voltage Power Switching, 2001

D10 Enhancement of breakdown voltage in AlGaN/GaN high electron mobility transistors using a field plate, 2001

D11 A two-dimensional fully analytical model with polarization effect for off-state channel potential and electric field distributions of GaN-based field-plated high electron mobility transistor, 2014

D12 Analytical Study on the Breakdown Characteristics of Si-Substrated AIGaN/GaN HEMTs With Field Plates, 2020

D13 Breakdown-Voltage-Enhancement Technique for RF-Based AIGaN/GaN HEMTs With a Source-Connected Air-Bridge Field Plate, 2012

For the sources of the cited documents, reference is made to the impugned decision.

Documents D4 to D13 were submitted by the appellant during the examination proceedings. D4, D11 and D12 have been published after the priority date of the present application.

During the appeal proceedings, the appellant submitted the following documents:

D14 Data sheet "Sentaurus TCAD Industry - Standard Process and Device Simulators", © 2012, Synopsys Inc., available at: https://www.synopsys.com/content/dam/synopsys/silicon/datasheets/sentaurus_ds.pdf

D15 Listing of the first thirty results of a Google Book search conducted on 5 December 2024 for the exact phrase "gate swing" in conjunction with HEMT

III. At the end of the oral proceedings before the board, the appellant requested that the impugned decision be set aside and a European patent be granted on the basis of a main request or one of the first to fifth auxiliary requests, all filed with the statement setting out the grounds of appeal.

IV. Claim 1 of the **main request** has the following wording (board's feature labelling):

A HEMT comprising:
(a) *a first semiconductor material (105) and* **(b)** *a second semiconductor material (110) disposed to form a heterojunction (115) at which a two-dimensional electron gas (120) arises;*
(c) *a source electrode (125),* **(d)** *a drain electrode (130), and* **(e)** *a gate electrode (135),* ***(e1)*** *the gate electrode disposed to regulate conduction in the heterojunction between the source electrode and the drain electrode,* **(e2)** *the gate having a drain-side edge (150);*
(f) *a gate-connected field plate (140) disposed above the drain-side edge of the gate electrode and extending laterally toward the drain; and*
(g) *a second field plate (145, 310) disposed above a drain-side edge (160) of the gate-connected field plate and extending laterally toward the drain,*
(g1) *wherein the second field plate is source-connected or gate-connected,*
(h) *wherein the HEMT is configured such that, in the OFF state and at a potential difference between the source and the drain in excess of the absolute value of a gate swing amplitude,* **(h1)** *charge carriers are depleted from a portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate,* **(h2)** *the depletion of charge carriers effective to saturate a lateral electric field in the heterojunction in a vicinity of the drain-side edge of the gate electrode at potential differences between the source and the drain in excess of the absolute value of a gate swing amplitude,*
(i) *wherein the HEMT is configured such that, in the OFF state*

(i1) *a first electric field in the heterojunction extends drain-ward from the drain-side edge of the gate-connected field plate,*
(i2) *a second electric field in the heterojunction extends source-ward from a drain-side edge of the second field plate, and*
(i3) *the first electric field first overlaps with the second electric field only at potential differences between the source and the drain that exceed a potential difference between the source and the drain at which a local maximum in electric field in a portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate begins to saturate;*
(j) *wherein the gate swing amplitude is an available operational range between limits of potential differences between the gate and the source for the HEMT for operation of the HEMT.*

Claim 1 of the **first auxiliary request** differs from claim 1 of the main request in that feature **(i3)** is formulated in a way similar to claim 1 according to the main request underlying the impugned decision:

($i3_{AR1}$) *the first electric field first overlaps with the second electric field only at potential differences between the source and the drain that exceed a potential difference between the source and the drain at which charge carriers are completely depleted from a portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate;*

Claim 1 according to the **second auxiliary request** corresponds to claim 1 according to the first auxiliary request underlying the impugned decision. It differs from claim 1 of the main request in that feature **(i3)** is amended as follows:

($i3_{AR2}$) *the first electric field first overlaps with the second electric field only at potential differences between the source and the drain that exceed a potential difference between the source and the drain at which charge carriers are depleted from the heterojunction beneath the drain-side edge of the gate-connected field plate and the electric field beneath the drain-side edge of the gate-connected field plate saturates, wherein without overlap of the first electric field and the second electric field, a portion (805) of the heterojunction between the drain-side edge of the gate-connected field plate and the drain-side edge of the second field plate remains as conductive as in the ON state*

Claim 1 according to the **third auxiliary request** is based on claim 1 according to the second auxiliary request, with the additional specification that charge carriers are "completely" depleted. Feature **(i3)** reads:

($i3_{AR3}$) *the first electric field first overlaps with the second electric field only at potential differences between the source and the drain that exceed a potential difference between the source and the drain at which charge carriers are completely depleted from the heterojunction beneath the drain-side edge of the gate-connected field plate and the electric field beneath the drain-side edge of the gate-connected field plate saturates, wherein without overlap of the first electric field and the second electric field, a portion (805) of the heterojunction between the drain-side edge of the gate-connected field plate and the drain-side* *edge of the second field plate remains as conductive as in the ON state*

Claim 1 according to the **fourth and fifth auxiliary requests** is based on claim 1 according to the second and third auxiliary request, respectively, with the additional specification in feature **(g1)** that the second field plate is gate-connected. The fourth auxiliary request also corresponds to the third auxiliary request underlying the impugned decision.

V. The appellant argued that the skilled person, using its common general knowledge, being confronted with the content of the present application and being familiar with the available software tools, was in a position to carry out the invention, see point 2.2 below. The requirements of Article 83 EPC were thus met.

Reasons for the Decision

1. The invention concerns a high-electron-mobility transistor (HEMT).

A HEMT is a field-effect transistor that includes a heterojunction which acts as the transistor channel. The conduction of a two-dimensional electron gas in the heterojunction channel is regulated by a gate electrode, see paragraph [0003] of the application.

Field plates are conductive elements that have commonly been used to modify the profile of electric fields in semiconductor devices. In general, field plates are designed to reduce the peak values of electric fields in semiconductor devices, hence improving the breakdown voltage and lifespan of the devices that include field plates, see paragraph [0005] of the application.

In HEMTs, field plates reduce a parasitic effect commonly referred to as "dc-to-rf dispersion" or "drain current-collapse." as explained in paragraphs [0006] and [0007] of the application.

According to the invention, the HEMT includes a gate electrode, a gate-connected field plate and at least a second source-connected or gate-connected field plate (see Figures 1 to 3 of the application) and is configured according to functional features **(h)** to **(j)**, see Figure 8 of the application.

2. Main request - sufficient disclosure (Article 83 EPC)

2.1 The main request substantively corresponds to the main request underlying the impugned decision. The appellant only replaced the feature objected to by the examining division under Article 123(2) EPC by the formulation according to feature **(i3)**. Page 24, lines 8 to 13 and 20 to 24 were indicated as a basis for this amendment.

The board accepts that both features have the same meaning, under the assumption that a "complete" depletion was meant by the expression "at which charge carriers are depleted from a portion ..." in claim 1 according to the main request underlying the impugned decision. Therefore, the board does not question the admittance of the main request filed for the first time with the statement setting out the grounds of appeal.

2.2 The appellant argued that HEMTs were well-known since the late 1970s. A junction between two materials with different band gaps (i.e. a "heterojunction”) acted as the channel. Electrons accumulated along the junction inside the material with the narrower band gap (as a two-dimensional electron gas, [0003] and [0030] of the application) and could carry current with a very high mobility/low resistivity. In an ON state, only a small voltage drop would appear across the HEMT channel as shown in figures 5A and 5B.

By applying negative voltages to gates and field plates that were in the vicinity of the channel, the energy level of electrons in the heterojunction could be changed, electrons could be depleted, and the conductivity of the heterojunction could be decreased ("OFF state"). Electrons were preferentially depleted beneath negatively biased structures, i.e. these were locations where the channel became locally depleted.

The location and extent of the depletions (and the resultant electric fields) depended not only on the relationship between the band gaps of the materials, but also on the properties and the geometry of many different materials in the HEMT as well as on the momentary potential differences between the source, the drain, and the gate, see e.g. page 16, lines 6 to 17 and page 19, line 24 to page 21, line 23, Figures 6A and 6B of the application. In the regions of the channel where electrons were depleted, the channel became more resistive. Because of this higher resistance, any potential difference between the source and the drain would drop across the depleted regions of the channel and an electric field would be present in these regions. See e.g. Figures 4A and 4B with regions 425, 435, 445 having a decreased number of free electrons and thus an increased resistance. With sufficiently high negative biases, the repulsion could be complete, i.e. all free electrons were repulsed from a location in the channel. Once a location along the channel was fully depleted of electrons, no further electrons could be repulsed from that location and that location had effectively reached its upper-most resistance and its upper-most electric field, see paragraphs [0069] and [0076] of the application.

These concepts were known to the skilled person. The appellant indicated several passages to support the conclusion that a detailed understanding of the extent of depletion and electric fields that arose in a HEMT channel belonged to the common general knowledge and was well known before the filing date of the present application: D5, Figure 2 of D10, Figure 2(b) of D9. Both D9 and D10 used commercially available software ("Atlas" provided by Silvaco Inc.). Other simulation software was known from D13 ("APSYS-TCAD"), D6 ("Sentaurus TCAD" from Synopsys), D12 ("Sentaurus TCAD" from Synopsys), D11 (new analytical model compared to "Atlas"), D8 ("Atlas"), D7 ("commercial simulation tool"). D14 showed that Sentaurus TCAD was available before the priority date of the present application.

Regarding features **(h)**, **(h1)**, **(h2)** and **(j)**, the appellant argued that these features reflected the dependency of the location and extent of depletion on the parameters mentioned above. Feature **(h)** was essential, because the potential difference between the drain and the source must be large enough to obtain the desired effects. The appellant also argued that the term "saturates" meant that further depletion of the current-carrying electrons from the heterojunction was not possible.

Regarding features **(i)**, **(i1)**, **(i2)** and **(i3)**, the appellant made reference to Figures 7 and 8 and paragraphs [0074] to [0082] of the present application and argued that distance d_3 in Figure 8 appeared larger than d_3 in Figure 7 so that there was no overlap in the curves labelled "V_{D4}" and "V_{D5}" in Figure 8. The skilled person would know that in the HEMT of e.g. D1, the distance corresponding to distance d_3 had to be enlarged, thereby easily carrying out the invention.

However, according to the appellant, the separation distance d_3 was not the only parameter that influenced the shapes of those curves, as reflected by features **(i)**, **(i1)**, **(i2)** and **(i3)**. The evolution of the electric fields depended not only on the properties and geometry of the materials, but also on the potential differences between the source and the drain. "Pre-university physics students" would understand that the dielectric constants and the thicknesses of layers 155 and 165 would influence the shapes and evolution of the curves.

Regarding the term "overlap", the appellant conceded that it was true that "electric fields in reality converge asymptotically towards zero without actually arriving at zero". However, using this understanding to interpret the claimed overlap of electric fields was a "pedantic construction" that ignored the standpoint of skilled practitioners, as shown e.g. in D10, page 1517, left column, page 1516, left column or D9, page 374, left column or D12, page 1033, left column. Moreover, Figures 5A and 5B and paragraphs [0052] to [0055] of the present application also "set a standard" (according to the appellant) for determining when the electric fields in portion 805 did not overlap. When depletion of electrons by the electric fields extending into portion 805 increased the resistance as compared to the inherent ON state resistance, then there was an overlap of the claimed electric fields, see page 24, lines 8 to 16. Hence, there was an overlap, when the conductivity of portion 805 was reduced.

The wording in functional terms, i.e. features **(h)** to **(j)**, rendered claim 1 more clear and more concise than a wording based on specific physical parameters.

Skilled practitioners had been routinely taking into account a high number of parameters using commercially-available software tools when designing HEMT devices since at least 2001. It was undisputed that a large number of parameters interacted to influence the behaviour of a HEMT, but taking these parameters into account could hardly be considered a research program.

The appellant argued that a skilled practitioner had had access to the above mentioned commercially available software that obtained the claimed electric fields and their evolution for more than a decade prior to the filing of the present application. In the field of HEMT devices, simulating the operation of a HEMT with commercially available software involved no "undue experimentation", even if it was undeniably impressive what the skilled person could achieve using these software tools. Given the difficulty of semiconductor device fabrication, simulation with commercially available software was the easiest, least burdensome way to determine the characteristics of a device.

The claimed features - including the electric fields and their evolution and overlap - were verifiable technical features of a device that allowed the solving of the underlying technical problems, see e.g. page 24, lines 20 to 29 of the original application, e.g. to reduce or prevent the ionization of the deep centers in the semiconductor materials that formed the heterojunction. Slide 19 of D4 (although published only in 2016) supported the conclusion that skilled practitioners understood that lateral electric fields evolved in the heterojunction of a HEMT device as a function of drain voltage, see also figure 2 of D10.

In summary, a skilled person, using its common general knowledge, being confronted with the content of the present application and knowing the available software tools, was in a position to carry out the invention.

2.3 The board holds that the requirements of Article 83 EPC are not met.

2.3.1 It is undisputed that the skilled person would be able to determine if a given HEMT has structural features **(a)** to **(g1)** or not.

In a section entitled "III. Additional Observations" that does not form part of the impugned decision, the examining division argued that e.g. document D1 disclosed a HEMT with features **(a)** to **(g1)**. The board agrees. In particular, Figure 2 of D1 shows a plurality of gate-connected field plates 27, each having its own drain-side edge. It is noted that the application does not exclude a direct electrical contact between the gate electrode and a gate-connected field plate, see paragraph [0033] of the application. E.g. the gate electrode and the gate-connected field plate can be formed by a unitary member having a generally L-shaped cross-section, as is the case for Figure 2 of D1.

The appellant also argued that D1 was an "enabling disclosure" of a HEMT, while not every element of said HEMT was described in detail in D1. This was additional evidence that the application was not less enabling.

2.3.2 The board has doubts whether the skilled person would be in a position to configure without undue burden a HEMT having structural features **(a)** to **(g1)** so that the conditions according to features **(h)** to **(j)** were met.

2.3.3 As a first step, it will be explained how the wording of claim 1 is understood by the board.

(a) "gate-connected field plate"

The board notes that the wording of claim 1 alone leaves it open if the "gate connected field plate" in features **(h1)**, **(i1)**, **(i3)** is the field plate according to feature **(f)** or the field plate according to feature **(g)** when gate-connected according to feature **(g1)**.

However, from the context of the application, it is clear that the gate-gate connected field plate (140 in figures 1 to 3) is meant, as also argued by the appellant. Thus the board accepts this interpretation.

(b) "absolute value of a gate swing amplitude"

According to claim 1, the HEMT is configured such that the effects of features **(h1)** and **(h2)** take place at a potential difference between the source and the drain in excess of the absolute value of a gate swing amplitude (feature **(h)**). The gate swing amplitude is "an available operational range between limits of potential differences between the gate and the source for the HEMT for operation of the HEMT" (feature **(j)**).

In operation, HEMTs are switched between the ON state and the OFF state by biasing the respective gate electrodes. In general, depletion mode HEMT devices conduct when the potential difference between the gate and the source is zero. To switch depletion mode devices into the OFF state, the gate is negatively biased with respect to the source. The ON state resistance of the HEMT is sought to be as low as practically possible in order to avoid e.g. that the power losses in the HEMT become undesirably high or the HEMT heats up excessively. The gate is generally biased positively with respect to the source, for reducing the ON state resistance, see application paragraph [0051].

As explained in paragraph [0052], excessive potential differences between the gate and the source can lead to degradation and/or dielectric breakdown of the intervening materials having a particular thickness and density, electron spill-over to and trapping in second semiconductor layer 110, and hot electron trapping in first layer of insulating material 155.

These effects define the limits of the range of potential differences between the gate and source within which the HEMT can operate without degradation. Said range can be on the order of 10's of volts, see paragraph [0052].

However, the claim wording also permits the interpretation that the "available gate swing amplitude" as defined by feature **(j)** is "between" said limits of potential differences, i.e. is a sub-range of the range described in paragraph [0052], as also pointed out by the examining division, point 2.1 of the section "III. Additional Observations". Neither claim 1 nor the application provides further details which sub-range could be meant.

The board accepts the appellant's position that despite the use of the indeterminate article "an" in feature **(j)**, the skilled person would understand that the gate swing amplitude is "the" available operational range between "the" limits of potential differences between the gate and the source for the HEMT for operation of the HEMT. This is the meaning commonly given to this term (see e.g. document D15) as also disclosed in the description of the present application.

(c) "a local maximum .... begins to saturate"

The subject-matter of claim 1 according to the main request concerns the example of Figure 8, which is described in paragraphs [0079] to [0082] of the application as originally filed. Indeed, it can be seen from Figures 6B, 7 and 9 that the first and second electric fields overlap at drain voltages (e.g. V_{D3} in figure 6B or V_{D4} in figure 7) at which the local maximum at 440 is not yet saturated, contrary to what is required by feature **(i3)**.

In the example of Figure 8, reference sign 150 is the drain-side edge of the gate electrode 135, reference sign 160 is the drain-side edge of the gate-connected field plate 140 and reference sign 170 is the drain-side edge of the second field plate 145, 310. Hence, in this example, the first electric field according to feature **(i1)** corresponds to the portion of the electric field between abscissa d_0+d_1 and region 805 and the second electric field is the portion of the electric field between region 805 and abscissa $d_0+d_1+d_3$. The local maximum in electric field mentioned in feature **(i3)** is the maximum at 440 (at abscissa d_0+d_1).

It is at least questionable whether it can be said that two (i.e. first and second) electric fields are present, because Figure 8 (as well as Figures 4A, 4B, 5A, 5B, 6A, 6B, 7 and 9) shows the electric field across the region between source and drain as a function of the distance to the source, see e.g. paragraphs [0024] to [0029] and the respective first sentence of paragraphs [0054], [0060], [0066], [0072], [0079] and [0083] of the application as originally filed. For the benefit of the appellant, the board understands that the first and second electric fields according to features **(i1)**, **(i2)** and **(i3)** are sub-portions of said electric field, as explained by the appellant.

Feature **(i3)** requires that the first electric field first overlaps with the second electric field only at potential differences between the source and the drain that exceed a specific potential difference between the source and the drain. At said specific potential difference, named ΔV_{SDx} in the following, according to claim 1, a local maximum in electric field in a portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate "begins to saturate".

From the appellant's explanations and the application, the board understands that, when the potential difference between the source and the drain ΔV_{SD} is below ΔV_{SDx}, the local maximum 440 of the electric field at the drain-side edge 160 of the gate-connected field plate changes when ΔV_{SD} changes, i.e. the local maximum increases when increasing ΔV_{SD}. When the potential difference between the source and the drain ΔV_{SD} is equal to or higher than ΔV_{SDx}, the local maximum 440 no longer changes when further increasing the potential difference between the source and the drain, see also the last sentence of paragraph [0076], "saturation or 'cut-off' of the incremental change in local maximum 440 of the electric field" in the context of Figure 7. According to features **(i1)**, **(i2)** and **(i3)**, the first and second electric fields "first" overlap when $\Delta V_{SD} > \Delta V_{SDx}$. This implies that the first and second electric fields do not overlap when $\Delta V_{SD} \leq \Delta V_{SDx}$.

According to the appellant, this is disclosed in paragraphs [0081] and [0082] of the application as originally filed. The board notes that the second sentence of paragraph [0081] states that the electric field that extends laterally towards the drain from bottom, drain-side edge 160 of gate-connected field plate 140 (i.e. the "first electric field") "does not reach" the electric field that extends laterally towards the source from bottom, drain-side edge 170 (i.e. the "second electric field") until the local maximum 440 in the electric field in the vicinity of bottom, drain-side edge 160 of gate-connected field plate 140 "begins to saturate" at the higher potential differences between the source and the drain ΔV_{SD}. The wording "does not reach" might be interpreted as "does not overlap". In Figure 8 (with V_S= 0V), this might correspond to voltage $\Delta V_{SD} = V_{D4}$ and $\Delta V_{SD} = V_{D5}$. In accordance with claim 1, the electric fields visibly overlap at a "relatively higher potential differences ΔV_{SD}", see Figure 8 when $\Delta V_{SD} \geq V_{D6}$.

Hence, one could argue that the first and second electric fields of figure 8 "first" overlap when $\Delta V_{SD} = \Delta V_{SDx}$, which does not exactly correspond to feature **(i3)**. Following the appellant's explanations, the board accepts that the electric fields begin to overlap at the same specific potential difference ΔV_{SDx}

at which the local maximum in electric field 440 does no longer change when increasing ΔV_{SD}. In other words, the term "exceed" in feature **(i3)** encompasses an arbitrarily small difference between ΔV_{SDx} and the potential difference ΔV_{SD} causing the claimed overlap.

The local maximum (e.g. 440 in Figure 8) saturates, because it does not further change when increasing the potential difference between the source and the drain of the HEMT. When this is the case, charge carriers are completely depleted from the portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate, as pointed out by the appellant. Saturation thus corresponds to a complete depletion of charge carriers.

However, neither claim 1 nor the application appear to define what is meant by the expression "begins to saturate". This expression suggests that the local maximum had not yet saturated (completely), but is close to reaching the saturation when the potential difference ΔV_{SD} defined by feature **(i3)** is (slightly) below ΔV_{SDx}. From the appellant's explanations, the term "the local maximum begins to saturate" should be understood as "the local maximum saturates", i.e. effectively reaches a saturated state.

(d) "overlap"

As acknowledged by the appellant, electric fields in reality asymptotically converge without however arriving at zero, as also pointed out by the examining division. The appellant argued that the first electric field did not overlap the second electric field in a specific region when the conductivity of this region of the channel corresponded to the ON-state of the transistor. For the board, this definition is not directly and unambiguously derivable from the application as a whole.

However, the board accepts that the skilled person would be in a position to decide if first and second electric fields are strong enough in a specific region so that they can be said to overlap.

2.3.4 It is undisputed that the electric field across the channel of an HEMT in the OFF state (i.e. the location and extent of depleted regions within said channel) depends on a multitude of parameters: the band gaps of the materials, the properties and geometry (e.g. distances, thicknesses, etc.) of the different (insulating and conductive) materials used in the HEMT, the temperature, the operating conditions such as the potential differences between the source, the drain and the gate, see paragraphs [0054], [0068], [0070] of the application. Examples of possible materials are disclosed in paragraphs [0038] and [0039], examples of possible geometric configurations are disclosed in paragraphs [0041] and [0047].

2.3.5 As pointed out in point II.2.1 of the impugned decision, functional features **(h)** to **(j)** are not a direct consequence of structural features **(a)** to **(g1)**. In other words, functional features **(h)** to **(j)** impose additional limitations on the claimed HEMT. Hence, the board agrees with the appellant that a device with features **(a)** to **(g1)**, e.g. the HEMT of D1, would not necessarily include the remaining functional features of claim 1.

2.3.6 It is undisputed that software tools and analytical models were available to the skilled person to perform simulations e.g. of the electric field by changing the above mentioned parameters.

2.3.7 However, in view of the high number of parameters to be taken into account, the board is of the view that the skilled person is unable to determine which limitations are implied by said functional features. Even using available software tools, the skilled person would not easily determine whether a given HEMT comprising features **(a)** to **(g1)** would also have the specific behaviour (spatial distribution and evolution with ΔV_{SD}) of the electric field across its channel according to claim 1 and would not be able to modify said given HEMT so as to show the claimed behaviour.

2.3.8 Turning to the description of the present application, the board notes that paragraphs [0070], [0071], [0077], [0078], [0082] only state that the geometric and material properties of the HEMT can be tailored such that features **(h)** to **(j)** are fulfilled. However, the application as a whole does not provide any specific example how this tailoring should be performed. In view of the numerous parameters and the absence of any indications in the application, the skilled person is forced to start a research program. The board is not convinced that the skilled person using its common general knowledge would be capable of carrying out the invention without undue experimentation, the term "experimentation" also including performing simulations using the available software tools mentioned by the appellant.

2.3.9 Hence, the skilled person is not in a position to configure a HEMT with features **(a)** to **(g1)** so that the result according to features **(h)** to **(j)** is achieved.

2.3.10 In particular, the application does not disclose how to configure a HEMT such that the first electric field begins to overlap with the second electric field not only at some point, but **exactly** at the potential difference ΔV_{SDx} between the source and the drain at which a local maximum in electric field in a portion of the heterojunction in a vicinity of the drain-side edge of the gate-connected field plate saturates, i.e. how to achieve feature **(i3)**. The application does not explicitly mention that a configuration according to feature **(i3)** could be achieved by using a sufficiently high distance d_3 between the drain-side edge (160) of the gate-connected field plate (140) and the drain-side edge (170, 320) of the second field plate (145, 310) in figures 1 to 3, as argued by the appellant. Instead, paragraph [0041] of the application only provides possible value ranges for the distances shown in figures 1 to 3.

Paragraphs [0077] and [0078] suggest that the distance d_3 may have an influence on the presence or not on the claimed "overlap" between the first and the second electric fields. However, they clearly state that other parameters ("geometric and material properties of the HEMT") have an influence on said overlap and that they have to be tailored accordingly, see also the first sentence of paragraph [0082], as also explained by the examining division.

As pointed out by the appellant, document D1 provides an enabling disclosure of a HEMT. However, D1 does not require a configuration according to features **(h)** to **(j)**, and it is thus understandable that this prior art document does not provide any technical details concerning how these functional features could be achieved. Instead, D1 includes sufficient information for the skilled person to carry out the device shown e.g. in figure 2 of D1. The board does not agree that merely increasing the distance corresponding to distance d_3 (in the device of D1 or other similar devices) would be sufficient to arrive at the claimed HEMT, contrary to the appellant's submissions during the oral proceedings.

2.3.11 The board points out that the way the first and second electric fields evolve by increasing the potential difference between the source and the drain of the HEMT depends on the values of the negative bias applied to the gate electrode, the gate-connected field plate and the second field plate.

The wording of claim 1 however does not impose any limitations with respect to these voltages and the description does not provide any teaching which negative voltages (within the gate swing amplitude) are to be used. The board does not believe that feature **(i3)** could be achieved for any voltages applied to said three electrodes. In particular, in case the second field plate is source-connected (feature **(g1)**, first alternative), it is not trivial, if possible at all, to configure the HEMT in a particular way to obtain feature **(i3)**, and this for all reasonable voltages.

2.3.12 Consequently, the application does not disclose the invention in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art so that the requirements of Article 83 EPC are apparently not met.

3. Auxiliary requests 1 to 5

As pointed out before, the board accepts that a complete depletion (feature **(i3$_{AR1}$)**) corresponds to the saturation of a local maximum of the electric field, i.e. the local maximum no longer increasing when increasing the potential difference ΔV_{SD} between the source and the drain. Insofar, features **(i3)** and **(i3$_{AR1}$)** have the same meaning. Features **(i3$_{AR2}$)** and **(i3$_{AR3}$)** both include the behaviour of the first and second electric fields according to feature **(i3$_{AR1}$)**.

It follows that the requirements of Article 83 EPC are not met for auxiliary requests 1 to 5 as well, the reasons being the same as for the main request. The appellant gave no counter-arguments in this respect.

4. As no allowable request is on file, a patent cannot be granted and the appeal must fail.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

S. Sánchez Chiquero M. Stenger

Decision electronically authenticated