Internal distribution code:

(A) [-] Publication in OJ
(B) [-] To Chairmen and Members
(C) [-] To Chairmen
(D) [X] No distribution

Datasheet for the decision of 4 April 2022

Case Number: T 0867/19 - 3.4.03

Application Number: 12701557.6

Publication Number: 2681769

IPC: H01L29/10

Language of the proceedings: EN

Title of invention:
SEMICONDUCTOR DEVICE HAVING HIGH PERFORMANCE CHANNEL

Applicant:
Wolfspeed, Inc.

Relevant legal provisions:
EPC Art. 52(1), 56, 123(2)
RPBA 2020 Art. 13(2), 25(1)

Keyword:
Late-filed main request - admitted (yes)
Amendments - added subject-matter (no)
Main request - inventive step - (no)
Late-filed auxiliary request - admitted (no)

Europäisches Patentamt
European Patent Office
Office européen des brevets

Beschwerdekammern

Boards of Appeal

Chambres de recours

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 0867/19 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 4 April 2022

Appellant: (Applicant)	Wolfspeed, Inc. 4600 Silicon Drive Durham, NC 27703 (US)
Representative:	FRKelly 27 Clyde Road Dublin D04 F838 (IE)
Decision under appeal:	**Decision of the Examining Division of the European Patent Office posted on 8 November 2018 refusing European patent application No. 12701557.6 pursuant to Article 97(2) EPC.**

Composition of the Board:

Chairman	T. Häusser
Members:	M. Ley
	C. Heath

Summary of Facts and Submissions

I. The appeal is against the decision of the examining division to refuse European patent application No. EP 12 701 557.6 pursuant to Article 97(2) EPC.

II. The impugned decision cited *inter alia* the following document:

D3 US 2008/0001158 A1

The examining division decided that the main request and the first auxiliary request then on file did not meet the requirements of Articles 123(2) and 84 EPC. The subject-matter of the independent claims of both requests was found to lack an inventive step (Article 56 EPC) over the disclosure of D3.

III. The appellant requests that the impugned decision be set aside and a European patent be granted on the basis of a main request or an auxiliary request, both filed with a letter dated 13 January 2022. In the alternative, it requests "that the decision be set aside and that the application be remitted to the Examination Division for further examination".

The appellant requests oral proceedings "in the event that the Board is minded to take any decision adverse to the Applicant".

IV. In a communication pursuant to Article 15(1) RPBA 2020, the board informed the appellant about its preliminary opinion that the independent claims according to the main and auxiliary requests then on file did not comply with Article 123(2) EPC and that the claimed subject-

matter lacked an inventive step (Article 56 EPC) over D3.

V. With its letter dated 13 January 2022, the appellant filed the present main and auxiliary requests and provided further arguments.

In a short letter dated 10 February 2022, the appellant informed the board that it would not be attending the oral proceedings on 18 February 2022.

The oral proceedings were cancelled by the board.

VI. Claim 1 according to the main request has the following wording (labelling added by the board):

A semiconductor device comprising:
(a) *a silicon carbide substrate of a first conductivity type;*
(b) *a source of a second conductivity type that is opposite to the first conductivity type and formed as a first well in the silicon carbide substrate;*
(c) *a drain of the second conductivity type formed as a second well in the silicon carbide substrate; and*
(d) *a surface diffused channel of the second conductivity type formed in the silicon carbide substrate* ***(d1)*** *between the source and the drain and* ***(d2)*** *extending to a depth that is less than or equal to 50 nanometers (500 Angstroms) from the surface of the silicon carbide substrate,* ***(d3)*** *the surface diffused channel having a doping concentration of at least* $5e17\ cm^{-3}$*,*
(e) *wherein the semiconductor device is configured to exhibit normally-off behaviour by conducting less than or equal to 1/10,000th of a rated current of the semiconductor device when a control voltage of zero*

volts is applied to a control contact of the semiconductor device.

Claim 1 of the auxiliary request has the following wording:

A method of fabrication of a semiconductor device on a silicon carbide substrate of a first conductivity type, comprising:
providing a source of a second conductivity type that is opposite to the first conductivity type and formed as a first well in the silicon carbide substrate;
providing a drain of the second conductivity type formed as a second well in the silicon carbide substrate;
providing an insulation layer on the SiC substrate between the first and second wells; and
diffusing a predetermined dopant into a surface of the silicon carbide substrate through the insulation layer by annealing the semiconductor device including the insulation layer in an environment rich with the predetermined dopant in order to form a surface diffused channel of the second conductivity type in the silicon carbide substrate between the source and the drain, wherein a depth and doping concentration of the surface diffused channel are such that a carrier mobility of the semiconductor device is significantly improved as compared to the semiconductor device without the surface diffused channel, wherein the depth of the surface diffused channel is less than or equal to 50 nanometers (500 Angstroms) and the surface diffused channel has a doping concentration of at least 5e17 cm^{-3}, wherein the semiconductor device is configured to exhibit normally-off behaviour by conducting less than or equal to 1/10,000th of a rated current of the semiconductor device when a control

voltage of zero volts is applied to a control contact of the semiconductor device.

VII. The appellant's relevant submissions can be summarised as follows:

(a) Document D3 did not disclose that
- the surface diffused channel extended to a depth that is less than or equal to 50 nanometers from the surface of the silicon carbide substrate and
- the semiconductor device was configured to exhibit normally-off behaviour.

In other words, D3 did not disclose features (d2) and (e).

(b) The claimed invention provided a high power SiC MOSFET with an increased electron mobility while being configured to exhibit a normally-off behaviour.

D3 aimed at exhibiting "reduced threshold voltages and/or higher on-state hole mobility compared to conventional silicon carbide p-channel MOS structures", whereas embodiments of the present invention attempted to provide devices with normally-off behaviour, i.e. high-threshold voltages, by the depth according to feature (d2). One goal of the claimed invention was to increase threshold voltages. The skilled person would not decrease the thickness of region 20 in D3.

(c) Document D3 repeatedly described that a benefit of the threshold adjustment layer 20 was to increase the mobility of carriers in the channel while also reducing the threshold voltage, see paragraphs

[0048] and [0049]. In contrast, paragraph [0032] of the application stated that for a depth of the surface diffused channel of less than 50 nm, the threshold voltage was "significantly less affected by changes in the doping concentration". The present application sought to increase the carrier mobility "without significantly altering the threshold voltage", which was a "different technical problem". The skilled person would have no reason to reduce the depth in the device of D3 below 100 nm.

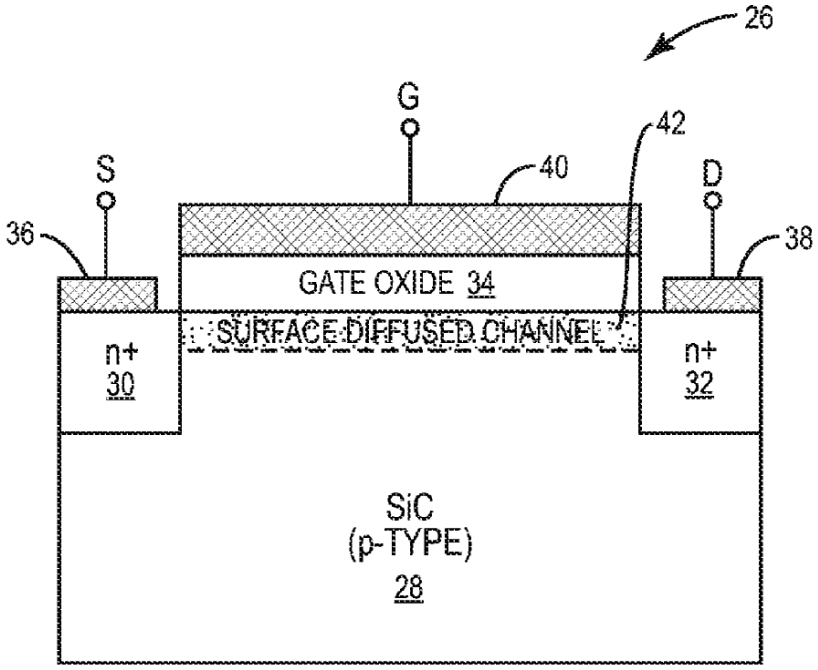
Moreover, D3 formed the surface diffused channel by ion implantation or epitaxial regrowth. Using these techniques, it would not be possible to obtain the claimed thickness, see also paragraph [0033] of the application. In paragraph [0004] of the application it was described that a substantial decrease of the threshold voltage would be obtained by ion implantation.

(d) Regarding the auxiliary request, the appellant stated that it sought "to further clarify differences between the present invention and the prior art references that relate to channels formed by ion implantation and/or epitaxial growth". The additional amendments further clarified how the surface diffused channel was formed, i.e. by diffusing a predetermined dopant into a surface of the silicon carbide substrate through the insulation layer and by annealing the semiconductor device including the insulation layer in an environment rich with the predetermined dopant.

Reasons for the Decision

1. The appeal is admissible.

2. The invention concerns an silicon carbide metal-oxide-semiconductor field effect transistor 26 having a surface diffused channel 42 formed in the silicon carbide substrate 28 between the source 30 and the drain 32, extending to a certain depth from the surface of the silicon carbide substrate 28 and having a doping concentration of at least 5 x 10^{17} cm^{-3}, see Figure 2 of the application reproduced below.



Compared to a conventional device without surface diffused channel (see e.g. Figure 1 of the application), a higher current when the transistor is in an ON-state is achieved (i.e. a lower ON-resistance) by increasing the electron mobility, while retaining a normally-OFF behaviour (i.e. a sufficiently high threshold voltage). The surface diffused channel thus solves issues with conventional transistors, see

paragraph [0004]. According to paragraph [0031], the surface diffused channel is thin (e.g. less than 100 nm) and has doping level of at least 5 x 10^{17} cm^{-3}. According to claim 1, its depth is less than 50 nm.

3. Procedural issues

The appellant's declaration of non-attendance at the oral proceedings is considered by the Board as equivalent to a withdrawal of its request for oral proceedings (see *Case Law of the Boards of Appeal of the European Patent Office*, 9th edition, 2019, III.C. 4.3.2) .

Taking into account the appellant's arguments provided in its letter dated 13 January 2022, the board concludes that the case is ready for decision without oral proceedings.

4. Main request

4.1 Admission

According to Article 13(2) RPBA 2020, which applies in the present case according to Article 25(1) RPBA 2020, any amendment to a party's appeal case made after notification of a summons to oral proceedings shall, in principle, not be taken into account unless there are exceptional circumstances, which have been justified with cogent reasons by the party concerned.

The set of claims according to the main request was filed after notification of the board's summons to oral proceedings.
The board accepts that the amendments made to the claims were a reaction to the board's objections under

Article 123(2) EPC raised for the first time in the communication pursuant to Article 15(1) RPBA 2020.

The main request is thus admitted into the appeal proceedings.

4.2 Added subject-matter - Article 123(2) EPC

The examining division objected that the omission of "the semiconductor device exhibits a normally-off behaviour" and the way how the independent claims defined the position of the source, the drain and the surface diffused channel relative to the silicon carbide substrate did not comply with Article 123(2) EPC.

The board is satisfied that the introduction of feature (e) renders moot the first objection. Moreover, features (d1), (d2) and (d3) correspond to the disclosure of Figure 2 and paragraphs [0030] to [0033] as originally filed. The second objection and the board's objections in the communication pursuant to Article 15(1) RPBA 2020 are thus overcome by the set of claims according to the main request.

4.3 Inventive step - Article 56 EPC

4.3.1 D3 discloses (in the wording of claim 1) a semiconductor device (Figure 1) comprising:
a silicon carbide substrate (11, 12, 14) of a first conductivity type (n, paragraph [0044]);
a source (well 16) of a second conductivity type (p, [0044]) that is opposite to the first conductivity type (n) and formed as a first well (Figure 1) in the silicon carbide substrate (11, 12, 14);

a drain (well 18) of the second conductivity type (p, [0044]) formed as a second well (Figure 1) in the silicon carbide substrate (11, 12, 14); and
a surface diffused channel (19, 20) of the second conductivity type (p, [0045]) formed in the silicon carbide substrate (11, 12, 14) between the source (16) and the drain (18) and extending to a depth that is 100 nm ~~less than or equal to 50 nanometers (500 Angstroms)~~ from the surface of the silicon carbide substrate ([0049]), the surface diffused channel having a doping concentration of at least 5el7 cm^{-3} (5 x 10^{18} cm^{-3}, [0049], [0020]),
wherein the semiconductor device is configured to exhibit normally-off behaviour (Figures 5 and 6) by conducting less than or equal to 1/10,000th of a rated current of the semiconductor device when a control voltage of zero volts is applied to a control contact (Figure 1, gate 30) of the semiconductor device.

4.3.2 With respect to the submission under section VII.(a) above, the board agrees with the appellant that D3 does not disclose the claimed channel depth of less than 50 nm. As also stated by the examining division, D3 mentions a depth between 100 and 500 nm, see paragraph [0049].

Figures 5 and 6 of D3 show the MOS hole mobility in the diffused p-type channel 20 as a function of the gate voltage. For a control voltage of 0 V, the hole mobility is zero, which means that the transistor is not conducting, i.e. is in its OFF state. Therefore, the semiconductor device is configured to "exhibit normally-off behaviour when a control voltage of zero volts is applied to a control contact of the semiconductor device".

D3 does not explicitly state that the transistor is conducting less than or equal to 1/10,000th of a rated current of the semiconductor device, when 0V is applied to the gate electrode. However, paragraph [0031] in combination with page 6, line 29 to page 7, line 1 of the application as originally filed makes it clear that a transistor having a surface diffused channel extending to a depth of 100 nm from the surface of a SiC substrate and having a doping concentration of 5 x 10^{17} cm^{-3} shows a "normally-off behaviour" as defined by feature (e). Thus, the transistor known from D3 inherently conducts less than or equal to 1/10,000th of its rated current, when 0V is applied to its gate electrode.

From the above, the board is of the view that the only distinguishing feature in claim 1 is feature (d2).

4.3.3 With respect to the appellant's submission in section VII.(b), the Board notes that claim 1 does not specify the specific conductivity type (n-type or p-type) of the surface diffused channel so that its doping level and/or its geometric arrangement would not necessarily change the *electron* mobility. For the sake of the argument, the board supposes that the appellant argued that the distinguishing features provided a high power SiC MOSFET with an increased (majority) carrier mobility in the surface diffused channel while being configured to exhibit a normally-off behaviour; the majority carriers being electrons for an n-type channel and holes for a p-type channel.

According to the application, the issues with conventional SiC MOSFETs (Figure 1 and paragraph [0004]) are overcome by providing a surface diffused channel having a depth of 100 nm (or less) and a doping

concentration of greater than 5 x $10^{17}cm^{-3}$, see paragraph [0031]. As document D3 describes a normally-off silicon carbide transistor (Figures 5 and 6) with a surface diffused channel having said depth of 100 nm and a doping concentration of 5 x 10^{18} cm^{-3}, the technical problems described in the paragraph [0004] of the application are considered to be solved in D3. Thus, it cannot be said that D3 "creates the exact problems that embodiments of the present application address" - as argued by the appellant - or that feature (d2) contributes to the solution of the problems mentioned in paragraph [0004] of the application.

In the claimed invention, the effect of the dopant concentration in the surface diffused channel is to provide a higher carrier mobility, see page 2, lines 28 to 31, page 6, lines 26 to 29, original claim 1 and paragraph [0031], which necessarily affects (i.e. reduces) the threshold voltage, see paragraph [0004] or page 9, lines 1 to 3. No passage in the application as originally filed states that "one goal of embodiments of the invention" would be "to increase a threshold voltage", contrary to what the appellant argued. Thus, the argument that feature (d2) provided an *increased* threshold voltage cannot be accepted.

Although paragraph [0032] of the application states that the threshold voltage might be "significantly less affected by changes in doping concentration" when the depth of the surface diffused channel is less than or equal to 50 nm, the skilled person would understand that, even for a depth of less than or equal to 50 nm, the threshold voltage decreases as a direct result of the increased carrier mobility. The term "significantly less affected" does not mean that the threshold voltage is not affected or altered at all, contrary to the

appellant's statement. Hence, the effect of feature (d2) is not an *unaltered* threshold voltage while still increasing the majority carrier mobility.

In the transistor of D3, as also pointed out by the appellant, dopants are provided into the channel region between source 16 and drain 18 to provide a threshold adjustment region 20 in order to increase the carrier mobility, with the additional and unsurprising result that the threshold voltage decreases, see paragraphs [0048], [0049] or [0083]. As shown by Figures 5 and 6 and as discussed before, the transistor of D3 keeps a "normally-off behaviour". As both the claimed semiconductor device and the one of D3 provide a normally-OFF silicon carbide transistor with increased carrier mobility in the channel, the objective technical problem solved by distinguishing feature (d2), i.e. a depth of 50 nm or less, is no more than to provide an alternative device.

4.3.4 D3 itself describes that the depth of the threshold adjustment region 20 is controlled by varying the ion implantation conditions, see paragraphs [0017] and [0049] and Figure 2B. The board is not convinced by the appellant's argument that it was technically not possible to manufacture a surface diffused channel having a depth of less that 50 nm for the device of D3. The board agrees with the examining division that it would be obvious for the skilled person to select the ion implantation conditions in D3 such that a depth of 50 nm or less is obtained.

Hence, the subject-matter of claim 1 of the main request lacks an inventive step (Articles 52(1) and 56 EPC).

5. Auxiliary request - admission

The set of claims according to the auxiliary request was filed after notification of the board's summons to oral proceedings.

The board understands that the auxiliary request was filed to overcome the objections under Article 56 EPC raised against the main request. However, a lack of inventive step in view of document D3 was already discussed during the examination phase, see e.g. the examining division's annex to the summons to attend oral proceedings, points 3.1. to 3.4. The appellant did not indicate any reasons justifying exceptional circumstances that would have prevented it to file the auxiliary request with the statement setting out the grounds of appeal or even during the examination procedure.

Moreover, according to the appellant, the amendments made to method claim 1 according to the auxiliary request were based on claims 24 and 25 as originally filed, see the appellant's letter dated 13 January 2022, first page, last sentence. Original claims 24 and 25 were not searched during the international phase and their subject-matter was removed from the claims after entry into the regional phase before the EPO. Admitting the auxiliary request into the appeal proceedings would be tantamount with examining unsearched subject-matter claimed for the first time after the entry into the regional phase before the EPO, which is manifestly contrary to the primary object of the appeal proceedings to review the decision under appeal in a judicial manner.

In view of these considerations, the Board does not admit the auxiliary request into the appeal proceedings (Articles 13(2) and 25(1) RPBA 2020)

6. As no admissible and 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. Häusser

Decision electronically authenticated