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**Datasheet for the decision
of 30 November 2007**

Case Number: T 0459/05 - 3.4.03

Application Number: 01116726.9

Publication Number: 1178538

IPC: H01L 29/737

Language of the proceedings: EN

Title of invention:

Heterojunction bipolar transistor with reduced thermal resistance

Applicant:

NORTHROP GRUMMAN CORPORATION

Opponent:

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Headword:

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Relevant legal provisions:

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Relevant legal provisions (EPC 1973):

EPC Art. 52(1), 54, 56, 123(2)

Keyword:

"Novelty (yes) - main request"

"Inventive step (no) - all requests"

"Added subject-matter (yes) - first auxiliary request"

Decisions cited:

-

Catchword:

-



Case Number: T 0459/05 - 3.4.03

D E C I S I O N
of the Technical Board of Appeal 3.4.03
of 30 November 2007

Appellant: NORTHROP GRUMMAN CORPORATION
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Decision under appeal: Decision of the Examining Division of the
European Patent Office posted 12 October 2004
refusing European application No. 01116726.9
pursuant to Article 97(1) EPC.

Composition of the Board:

Chairman: R. G. O'Connell
Members: R. Bekkering
J. Van Moer

Summary of Facts and Submissions

- I. This is an appeal against the refusal of application 01 116 726 for lack of novelty (main request), added subject-matter (first auxiliary request) and lack of inventive step (second auxiliary request).
- II. At oral proceedings before the board the appellant applicant requested that the decision under appeal be set aside and a patent granted on the basis of the main, first or second auxiliary requests as refused.
- III. Independent claim 1 according to the main request reads as follows:

*"1. An HBT with low thermal resistance comprising:
a substrate (514, 614, 714);
a collector (518, 618, 718);
a base (520, 620, 720) formed on the collector (518, 618, 718); and
an emitter (522, 622, 722) formed on the base (520, 620, 720);
wherein the substrate (514, 614, 714) consists essentially of InP and wherein the base contains material having a lower thermal conductivity than InP, characterized in that a sub-collector (516, 616, 716) is arranged between the substrate (514, 614, 714) and the collector (518, 618, 718), wherein the sub-collector (516, 616, 716) and the collector (518, 618, 718) all consist essentially of InP, so that heat generated in the collector (518, 618, 718) during operation of the HBT is dissipated through the collector (518, 618, 718) and the sub-collector (516, 616, 716) into the substrate (514, 614, 714)."*

Independent claim 8 is directed to a corresponding method of fabricating an HBT.

- IV. Independent claims 1 and 8 according to the first auxiliary, compared to the main request, contain the following additional feature:

"the collector (518, 618, 718) has a collector area of 175 μm^2 or less".

- V. Independent claims 1 and 8 according to the second auxiliary, compared to the main request, contain the following additional feature:

"and wherein an etch stop layer (532, 632, 732) having a thickness below 10nm is formed between the collector (518, 618, 718) and the sub-collector (516, 616, 716)".

- VI. Reference is made to the following documents:

D1: US-A-6 049 099

D4: H. Kroemer, "Heterostructure Bipolar Transistors and Integrated Circuits," Proceedings of the IEEE, vol. 70, no. 1, January 1982

D5: D. T. Cheung et al., "A Simplified Model for Graded-Gap Heterojunctions", Solid State Electronics, Elsevier Science Publishers, Barking, GB, March 1975, vol. 18, no. 3, pages 263 to 266

D6: US-A-5 734 193

Reasons for the Decision

1. The appeal is admissible.

2. *Main request*

2.1 *Novelty*

2.1.1 In the decision under appeal the subject-matter of claim 1 of the main request was held to lack novelty with respect to the embodiment of document D1 relating to a double heterojunction bipolar transistor.

Document D1 discloses two embodiments, the first relating to a single heterojunction bipolar transistor (SHBT) and the second one relating to a double heterojunction bipolar transistor (DHBT). The first embodiment is disclosed with reference to figures 2a and 2b, providing a band diagram and a schematic cross section, respectively, of the device. The second embodiment relating to the DHBT is disclosed with reference to figures 3a and 3b, again providing a band diagram and a schematic cross section. However, figure 3b provided in document D1 is a duplicate of figure 2b and the correct figure showing the cross section of the DHBT is evidently missing.

Still, concerning the DHBT embodiment in the description the following is disclosed:

- the device is a CdS emitter InP-based DHBT,
- the sub-collector, collector, and base are sequentially grown epitaxially on an InP substrate,
- the collector is InP, and

- the base is $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ (see column 4, lines 47 to 58).

Furthermore figure 3a depicts the band diagram of the CdS emitter InP-based DHBT according to the second embodiment, showing in particular a CdS emitter, an InGaAs base and an InP collector.

The base, thus, contains material (InGaAs) having a lower thermal conductivity than InP (cf figure 4 of the application) as per claim 1.

2.1.2 The appellant disputed that in this second embodiment the base was formed **on** the collector as required by claim 1. In particular, he argued that the second embodiment included the same transition layer between collector and base as in the first embodiment.

The board notes, however, that there is no mention of a transition layer between collector and base in document D1. A "*collector to base transition*" is depicted in figure 2a pertaining to the first embodiment (and obviously in figure 3a). This transition is, however, not further specified in the description.

What is disclosed in the description in a discussion of the prior art, is that "*a drawback of the DHBT is the conduction band discontinuity, which reflects electrons back into the base. The band structure can be modified to reduce the undesirable effect of the conduction band discontinuity by grading the transition between materials over a finite distance during epitaxial growth*" and reference is made to document D4 (see document D1, column 1, lines 61 to 64).

Document D4 (see page 22, left-hand column, third paragraph), and document D5 referred to therein, disclose that with a graded transition from one material to the other of the heterojunction over a few hundred Angstrom, the discontinuity in the conduction band is entirely eliminated (see document D5, page 265, left-hand column, second paragraph).

Yet, figure 3a of document D1, pertaining to the DHBT embodiment, shows an abrupt junction between collector and base with the corresponding discontinuity in the conduction band and, thus, a device without any substantial grading.

In this respect, the appellant argued that figure 3a was only schematic and no conclusions could be drawn from the discontinuity shown.

In the board's view, however, figure 3a shows directly and unambiguously a base formed on the collector. There are no concrete instructions in D1 to include a transition layer in the DHBT. Document D1 merely indicates that the band structure might be modified to reduce the undesirable effect of the conduction band discontinuity by grading.

It, thus, follows that document D1 discloses a base formed on the collector as per claim 1.

2.1.3 Incidentally, it is noted that the expression "*formed on*" *per se* would, moreover, not exclude the presence of a (relatively thin) intervening transition layer.

As far as the appellant argued that claim 1 should be read - possibly with some clarification of the claim wording - to exclude the presence of any transition between the collector and base, it is noted such reading would not be warranted as some unsubstantial grading between the differing materials of collector and base will inevitably be present in document D1 as well as in the application, since both use the same materials.

2.1.4 Similarly, in document D1 the emitter is formed on the base as per claim 1.

2.1.5 On the other hand, contrary to the finding in the decision under appeal, as far as the material of the sub-collector is concerned, the board agrees with the appellant that document D1 does not disclose that the sub-collector in the DHBT embodiment consists essentially of InP as required by claim 1.

There is no specific disclosure in respect to the DHBT embodiment of the sub-collector material. The only information provided is that "*the sub-collector, collector, and base, labeled as in FIG. 2b, of an InP-based HBT are sequentially grown epitaxially on InP substrate 10*" (column 4, lines 50 to 52). The labelling however typically concerns the reference numerals used and not necessarily the materials of the various layers as indicated. In figure 2a the sub-collector is indicated to be made of InP, like the underlying substrate and the overlying collector. Since in the DHBT embodiment the substrate and the collector are both made of InP, the use of InP for the sub-collector would be a natural choice. Nonetheless, in principle

other materials for the sub-collector are conceivable. It follows that document D1 cannot be held to disclose directly and unambiguously that the sub-collector consists essentially of InP.

The subject-matter of claim 1 is, therefore, novel over document 1 by virtue of the feature that the sub-collector consists essentially of InP (Articles 52(1) and 54(1) and (2) EPC).

2.2 *Inventive step*

2.2.1 In view of the above difference, the objective problem to be solved relative to document D1 can be formulated as choosing an appropriate sub-collector material.

InP is evidently suitable as a sub-collector material since it is used in the SHBT embodiment of document D1. Furthermore, since both the underlying substrate and the overlying collector of the DHBT are made of InP, it would be straightforward for the skilled person to choose InP for the sub-collector as well. Forming the sub-collector of a different material would only complicate the manufacturing process and introduce difficulties in terms of lattice mismatch etc.

2.2.2 The appellant argued that InP was difficult to contact due to its large band gap. For this reason InGaAs was generally used as a cap layer on top of the emitter to improve the ohmic contact resistance to the emitter, as indicated in the application (page 3, lines 13 to 16). Absent any considerations in the prior art as to heat dissipation through the sub-collector, the skilled person would rather select other materials such as

InGaAs. Moreover, the use of InP for the sub-collector would render the structuring of the collector more difficult, making the use of etch stop layers necessary.

These arguments do not persuade the board. Both in document D1, first embodiment, as well as the application itself, eg figure 3B, showing a typical InP based HBT, InP sub-collectors are used. The InP sub-collector is heavily doped and contacted with a metal forming an ohmic contact. With a sufficiently high doping of the sub-collector semiconductor layer, low resistance ohmic contacts can be made without difficulty also to semiconductors with wider band gaps such as InP. Moreover, any heat-dissipation advantages would inevitably be obtained as a result of the above choice of InP for the sub-collector in D1. As far as the structuring is concerned, D1 shows that the skilled person knew how to manufacture a device with an InP sub-collector with an overlying InP collector (see figure 2b).

Accordingly, InP would be an obvious choice for the skilled person for the sub-collector of the DHBT of D1.

As a consequence, the heat generated in the collector during operation is dissipated through the collector and the sub-collector into the substrate as per claim 1.

The subject-matter of claim 1, thus, lacks an inventive step (Articles 52(1) and 56 EPC).

The main request is, therefore, not allowable.

3. *First auxiliary request*

3.1 Claim 1 of the first auxiliary request, compared to the main request, contains the additional feature that the collector has a collector area of $175 \mu\text{m}^2$ or less. There is, however, no basis in application as originally filed for this area range and in particular for collector areas down to zero, it being clear from figure 8 that such small collector areas are not envisaged as the thermal resistance rises steeply. The claim as amended, thus, contains subject-matter extending beyond the content of the application as filed (Article 123(2) EPC).

3.2 Moreover, even if assuming, for the sake of argument, that a range of collector areas disclosed in the application as originally filed, and in particular in figure 8, were to be claimed, this would not render the subject-matter of claim 1 inventive (Articles 52(1) and 56 EPC).

The appellant argued that areas below $175 \mu\text{m}^2$ were smaller than those available in the prior art and that the skilled person would have no incentive to go to such small areas with the low thermal conductivity materials used in the prior art.

However, as can for instance be seen from document D6, cited as prior art starting point for the invention in the application as filed, emitter areas of the order of several square microns to several hundred square microns, and hence collector areas of the same order of magnitude, were conventional for HBT devices (see column 14, table 1 and figures 2a to 2c). In fact, at

the filing date of the present application device dimension down to microns and below were easily feasible in the semiconductor industry, so that the skilled person had the option to design collector areas down to a few square microns depending on the desired electrical characteristics such as the power rating of the device, the required level of integration and the like. Moreover, contrary to what is argued by the appellant, the use of low thermal conductivity materials for the collector would as such not prevent the skilled person from designing small collector areas, but at most limit the power rating of the device. With InP as collector material as suggested in D1, such limitations would not even arise.

For the reasons above, the first auxiliary request is not allowable.

5. *Second auxiliary request*

Claim 1 according to the second auxiliary, compared to the main request, contains the additional feature that an etch stop layer having a thickness below 10nm is formed between the collector and the sub-collector.

Etch stop layers *per se* are comprised in the common general knowledge in the semiconductor art to be used where etching the layer to be structured would otherwise also etch the underlying layer, eg where both layers are of the same material.

This problem of etching a layer in an HBT stack overlying a layer of the same material is addressed in document D2.

In this document, in order to structure the second emitter (7) over the underlying first emitter (5), both emitters being of InGaP, an etch stop layer (6) is used between the two layers stopping the etch of the second emitter (see figures 1, 2 and column 4, line 38 to column 5, line 24). According to document D2, if a uniform composition layer, not a composition gradient layer, is used, it is preferable to set the total thickness to be about 10 nm or less (column 16, lines 34 to 36).

It would accordingly, be obvious for the skilled person, faced with the problem of structuring the collector over the underlying sub-collector in the device suggested by D1, in particular where both collector and sub-collector are made of InP, to use an etch stop layer of about 10 nm or less as suggested in D2.

The appellant argued that since the etch stop layer in document D2 also had a function as emitter passivation layer, this latter function, however, being incompatible with document D1, the skilled person would discard D2. Furthermore, the etch stop layer proposed would only work with the specified materials.

In the board's reading of document D2, however, the function of the layer as etch stop is disclosed distinctly from its function as passivation layer, so that the skilled person would readily recognise its suitability for solving the etch related problem posed relative to document D1. As far as the materials are concerned, being aware of the underlying principle of etch stop layers (ie a low etch rate for the etch stop

layer compared to that of the overlying layer to be structured), it would be straightforward for the skilled person to apply the principle to different materials to be etched and to select the etch stop layer material accordingly.

The subject-matter of claim 1, thus, lacks an inventive step (Articles 52(1) and 56 EPC).

The second auxiliary request is, therefore, not allowable either.

Order

For these reasons it is decided that:

The appeal is dismissed.

Registrar:

Chair:

S. Sánchez Chiquero

R. G. O'Connell