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D E C I S I O N
of 13 March 2003

Case Number: T 0327/00 - 3.4.3

Application Number: 94309644.6

Publication Number: 0664557

IPC: H01L 21/18

Language of the proceedings: EN

Title of invention:
Bonded semi-conductor device

Applicant:
Agilent Technologies, Inc. (a Delaware corporation)

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 113, 123(2), 56
EPC R. 67

Keyword:
"After amendments: admissibility of the amendments (yes)"
"Inventive step (yes)"
"Procedural violation (no)"
"Reimbursement of the appeal fee (no)"

Decisions cited:
-

Catchword:
-

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Case Number: T 0327/00 - 3.4.3

D E C I S I O N
of the Technical Board of Appeal 3.4.3
of 13 March 2003

Appellant: Agilent Technologies, Inc. (a Delaware corporation)
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 12 November 1999 refusing European patent application No. 94 309 644.6 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: R. K. Shukla
Members: M. Chomentowski
M. J. Vogel

Summary of Facts and Submissions

I. European patent application No. 94 309 644.6 (Publication No. 0 664 557) was refused by a decision of the examining division dated 12 November 1999 on the grounds that claim 1 of the applicant's main request introduced subject-matter which extended beyond the content of the application as filed and that the subject-matter of the claims of the applicant's auxiliary request did not involve an inventive step having regard to the prior art documents

D1: Applied Physics Letters, vol. 58, No. 18, May 1991, pages 1961 to 1963, Y.H.Lo et al., "Bonding by atomic rearrangement of InP/InGaAsP 1.5 μm wavelength lasers on GaAs substrates"; and

D2: Applied Physics Letters, vol. 62, No. 7, February 1993, pages 738 to 740, H. Wada et al., "Electrical characteristics of directly-bonded GaAs and InP".

Claim 1 of the auxiliary request was the only independent method claim of the request and had the following wording:

"1. A method of bonding at least two semiconductor surfaces (A, B) to form a bonded interface, at least one of the surfaces being bonded comprising a compound semiconductor (A), the two surfaces (A, B) having the same doping type, the method comprising the steps of: heating the two semiconductor surfaces (A, B); matching the crystallographic surface orientation (Φ) of the two semiconductor surfaces (A, B) to the extent that the magnitude of the difference between the surfaces' orientations (Φ) is less than 6 degrees;

matching the rotational alignment (Θ) of the two semiconductor surfaces (A, B) to the extent that the magnitude of the difference between the surfaces' rotational alignments (Θ) is less than 20 degrees; and applying uniaxial pressure to the heated, oriented and aligned surfaces (A, B)."

Claim 7 of the applicant's auxiliary request was an independent device claim and claim 8 was dependent from claim 7.

Contrary to claim 1 of the auxiliary request, claim 1 of the main request did not specify that the method comprised steps of heating the two semiconductor surfaces and applying uniaxial pressure to the heated, oriented and aligned surfaces.

II. The reasoning of the examining division can be summarized as follows:

Main request

The term "bonding" without any mention to a heating and pressing step could mean that an interlayer is used between the two surfaces to be bonded. The amendment introduced a generalisation for which no basis could be found in the application as filed, so that the main request infringed Article 123(2) EPC.

Auxiliary request

The method according to claim 1 contained the feature of matching the crystallographic surface orientation of the two semiconductor surfaces to the extent that the difference between the surfaces' orientations is less than 6 degrees, and was distinguished in this respect from the prior art according to document D1.

Hence, starting from this prior art, the objective problem underlying claim 1 was to reduce the crystalline defects at the interface between the lattices of the two semiconductor surfaces to be bonded. This problem was known from the same document which sought to achieve an excellent heteroepitaxy (cf. abstract) and defect-free epitaxy (cf. the caption of Figure 2 and page 1963, last paragraph). This known method is for bonding of a (100) InP substrate, i.e. a compound semiconductor substrate having a (100) surface orientation, on a GaAs substrate. It is generally known that GaAs and InP form crystals with the zinc-blende arrangement, which is a structure based on the cubic space group. The difference in the atomic distances on the (100) cubic faces of both GaAs and InP is about 3.6 to 3.8%. In document D1, a lattice mismatch between InP and GaAs of 3.7% is reported (cf. page 1962, left column), which is a further indication that the (100) InP is bonded to (100) GaAs.

It would be trivial and a matter of common sense to select the same surface crystallographic orientation of the lattices to be bonded. Each crystallographic surface has a particular atomic structure, for example, the (100) has a square atomic arrangement, the (111) a hexagonal, the (110) a rectangular, etc... A skilled person would not try to match a square arrangement to a rectangular or hexagonal one if he desired to reduce the crystalline defect density at the interface.

Even if it were considered that document D1 does not suggest the use of (100) surface orientation of the GaAs surface, the document D2 discloses that the wafers used in this work were commercially available mirror-polished (100) GaAs and InP substrates. In particular, document D2 reported on the electrical characterisation of bonded InP-GaAs wafers citing document D1.

Therefore, the feature distinguishing claim 1 from document D1 was known for the same technical purpose as in the present application from document D2. It was obvious for the skilled person to select in the method known from document D1 a (100) GaAs surface as known from document D2.

III. The applicant lodged an appeal against this decision on 14 January 2000, paying the appeal fee on the same day. A statement setting out the grounds of the appeal was filed on 14 March 2000 together with three-dimensional crystallographic models to illustrate the invention.

IV. With a telefax dated 25 February 2003 the appellant filed a new set of six claims. Independent claim 6 of the above set was withdrawn in a telephone consultation between the Rapporteur and the appellant on 27 February 2003, whereupon the oral proceedings scheduled on 28 February 2003 were cancelled.

Claim 1 reads as follows:

"1. A method of **direct** bonding at least two semiconductor surfaces to form a bonded interface **that exhibits low electrical resistance with a minimal accompanying voltage drop**, at least one of the surfaces being bonded comprising a compound semiconductor (A), the two surfaces having the same doping type, the method comprising the steps of:

heating the two semiconductor surfaces;

matching the crystallographic surface orientation (Φ) of the two semiconductor surfaces to the extent that the magnitude of the difference between the surfaces' orientations (Φ) is less than 6 degrees;

matching the rotational alignment (Θ) of the two semiconductor surfaces to the extent that the magnitude of the difference between the surfaces' rotational alignments (Θ) is less than 20 degrees; and

applying uniaxial pressure to the heated, oriented and aligned surfaces **so that the alignment of atoms across the bonded interface mimics as closely as possible that which is found in a bulk crystalline semiconductor,**

wherein the step of matching the rotational alignment includes the steps of discerning crystallographic directions for both semiconductors within the plane of the semiconductor surfaces and rotating the semiconductors in order that the angle between said crystallographic directions is less than 6 degrees,

wherein the said at least one semiconductor surface of the compound semiconductor (A) is a surface of a light emitting structure for emitting light, wherein the other semiconductor surface is a surface of an optically transparent substrate (B), and wherein the bonded interface exhibits substantially ohmic properties when passing current across the bonded surfaces to energize the light emitting structure and emit light through the transparent substrate."

Features added to claim 1 of the auxiliary request forming the basis of the decision under appeal are highlighted by the Board.

The further claims of the appellant's request, i.e., claims 2 to 5, are dependent method claims.

V. The appellant requested that the decision under appeal be set aside and that a patent be granted on the basis of the following patent application documents:

Description: Pages 1 to 15 as filed;

Claims: Nos. 1 to 5 filed with the appellant's telefax dated 25 February 2003;

Drawings: Sheets 1/6 to 6/6 as filed;

with the description to be adapted to the new claims.

VI. The appellant has argued in substance as follows in support of his request:

Document D1 does not disclose the simultaneous matching of two parameters as required by the claim, and in particular not the straightforward bonding of two semiconductor surfaces at all, but the heteroepitaxial growth of InP/InGaAsP layers on an InP (100) substrate, followed by the wafer bonding of these epitaxial layers onto a GaAs substrate; thus, the GaAs is not bonded directly to the nominally (100) InP surface, but rather to an epitaxial layer which has been grown on the nominally (100) InP surface.

Moreover, there is no disclosure of the crystallographic orientation of the epitaxial layer to be bonded, i.e. of matching the crystallographic orientation thereof.

In this known method, before heating, the InP and GaAs wafer which were put face to face whereby the cleavage planes of the wafers were carefully aligned with an error of less than 0.2°, were those of the p-GaAs substrate and of the InP substrate shown in Figure 1(a), and, with respect to InP, not the cleavage plane of the surface of p-InP to be bonded, i.e., of the epitaxial layer formed on a succession of epitaxial

layers of different materials on the InP substrate. The specific discerning and matching steps of the claimed method are not derivable from the document.

The three-dimensional crystallographic models provided by the appellant show that in compound semiconductors such as GaAs and InP, because the crystal lattice comprises more than one atom, the rotation of the crystallographic planes does not result automatically in the bonded surfaces being such that the alignment of atoms across the bonded interface mimics as closely as possible that which is found in a bulk crystalline semiconductor.

Document D2 concerns the investigation of electrical characteristics of directly-bonded commercially available GaAs and InP (100) wafers, whereby it is indicated that p-p wafers directly bonded at high temperature may show no rectification. Reference is made to document 1 for fabricating lasers using the direct-bonding method, but it is specified that the electrical characteristics of such bonded interface has not been clarified yet. However, there is no indication in document D2 about specifically discerning crystallographic orientations or matching such orientations.

As can be seen using the above-mentioned three-dimensional crystallographic models, bringing together the surfaces of commercially available wafers, even when using cleavage planes thereof, the operator may obtain by chance the matching mentioned in the claim, but he will not obtain it automatically in all cases. In such cases, he will not obtain an ohmic contact which, according to the disclosure in the patent

application, is obtainable only under specific orientation and alignment conditions, wherein discerning and matching the crystallographic orientations is necessary.

Therefore, the claimed method involves an inventive step in the sense of Article 56 EPC.

Reimbursement of the appeal fee

The decision under appeal has been based on grounds or evidence on which the applicant has not had an opportunity to present his comments.

Oral proceedings was the first time that an argument based on the interpretation of a microphotograph of Figure 2b of document D1 was raised and the new argument was relied upon to refuse the application in the decision under appeal (cf. paragraph 4 of the reasons). The purpose of oral proceedings should be to settle as far as possible all outstanding questions relevant to the decision. The representative of the appellant was not in a position without former briefing by the appellant to comment on the new arguments.

Moreover, a further document was cited in the annex to the summons and, even if it was not relied upon in the decision, the applicant should have been given a chance to lodge arguments in relation to this reference before being summoned to oral proceedings.

Both these instances appear to breach Guidelines E-III.5, which states that the purpose of oral proceedings should be to settle as far as possible all outstanding questions relevant to the decision.

Moreover, there would appear to be a breach of Article 113(1) EPC, in that a decision has been issued based on grounds/evidence on which the party concerned has not had an opportunity to present its comments.

In the circumstances, it is requested to consider whether a refund of the appeal fee would be equitable.

Reasons for the Decision

1. The appeal is admissible.

2. *Admissibility of the amendments and clarity*

The feature that the method of bonding at least two semiconductor surfaces is a method of direct bonding is directly and unambiguously derivable from the whole content of the application as filed (see Figures 1, 3 and 9 and the corresponding text). This feature also corresponds to the generally known terminology of bonding techniques wherein no interlayer is used during the bonding operation of the surfaces (see e.g. the title and abstract of document D2). Moreover, the features that the claimed method is to form a bonded interface that exhibits low electrical resistance with a minimal accompanying voltage drop, and that it comprises applying uniaxial pressure to the heated, oriented and aligned surfaces so that the alignment of atoms across the bonded interface mimics as closely as possible that which is found in a bulk crystalline semiconductor, are also disclosed in the application as filed (see page 3, fourth paragraph to page 4, first paragraph; page 12, last paragraph; claim 1).

The step of matching the rotational alignment including the steps of discerning crystallographic directions for both semiconductors within the plane of the semiconductor surfaces and rotating the semiconductors in order that the angle between said crystallographic directions is less than 6 degrees wherein the said at least one semiconductor surface of the compound semiconductor (A) is a surface of a light emitting structure is derivable from the whole content of the application as filed (see e.g. page 5, second paragraph, page 6, last paragraph to page 10, first paragraph and Figures 1 and 3; page 13, last paragraph to page 14, first paragraph).

Therefore, the Board is satisfied that the European patent application complies with the requirement of Article 123(2) EPC that a European patent application may not be amended in such a way that its contains subject-matter extending beyond the content of the application as filed.

Moreover, in the Board's judgment, the amendments in the claims meet the clarity objections expressed during the appeal proceedings (Article 84 EPC).

3. *Novelty*

The method known from document D1 (see the abstract) does not comprise all the steps of the claimed method and, moreover, as pointed out by the appellant , it is applied to the bonding of a surface of a material (GaAs) to build a structure (a laser) which is different from the light-emitting device with a transparent ohmic interface to be fabricated by the claimed bonding method. The same remark applies to document D2 (see the abstract). The other documents are less relevant.

Therefore, the Board is satisfied that the subject-matter of claim 1 is new in the sense of Article 54 EPC.

4. *Inventive step*

A method of bonding at least two semiconductor surfaces to form a bonded interface, at least one of the surfaces being bonded comprising a compound semiconductor (p-GaAs and p-InP), the two surfaces having the same doping type p, is known from document D1 (see page 1961, left-hand column, last paragraph to right-hand column, first paragraph; Figure 1); the method is derivable as being a method of direct bonding and comprises the steps of:

heating the two semiconductor surfaces; and

applying uniaxial pressure to the heated, oriented and aligned surfaces.

However, there is no information as to the crystallographic orientation of the p-GaAs substrate. Moreover, the document does not disclose the simultaneous matching of two parameters as required by the claim, and in particular not the straightforward bonding of two semiconductor surfaces at all, but the heteroepitaxial growth of InP/InGaAsP layers on an InP (100) substrate, followed by the wafer bonding of these epitaxial layers onto a GaAs substrate; thus, the GaAs is not bonded directly to the nominally (100) InP surface, but rather to an epitaxial layer which has been grown on the nominally (100) InP surface. Indeed, it is directly and unambiguously derivable that, on the surface of an InP substrate with a (100) surface, n-InGaAs, n-InP, I-InGaAsP and I-InGaAsP layers with different physical properties and then a p-InP of 2 µm layer are successively epitaxially grown

(cf. Figure 1(a)), that this compound structure is then turned upside down and the free surface of the 2 µm p-InP layer bonded on the surface of the GaAs substrate (cf. Figure 1 (b)).

Moreover, there is no disclosure of the crystallographic orientation of the InP epitaxial layer to be bonded, i.e. of matching the crystallographic orientation thereof.

Indeed, according to document D1 (see the same text locations), before heating, the InP and GaAs wafer were cleaned and put face to face, whereby the cleavage planes of the wafers were carefully aligned with an error of less than 0.2°. However, here again the derivable information is that the cleavage planes which are aligned are those of the p-GaAs substrate and of the InP substrate shown in Figure 1(a), and, with respect to InP, not the cleavage plane of the surface of p-InP to be bonded, i.e., of the epitaxial layer formed on a succession of epitaxial layers of different materials on the InP substrate. In particular, a method step of matching the rotational alignment of the two semiconductor surfaces to the extent that the magnitude of the difference between the surfaces' rotational alignments is less than 20 degrees, wherein the step of matching the rotational alignment includes the steps of discerning crystallographic directions for both semiconductors within the plane of the semiconductor surfaces and rotating the semiconductors in order that the angle between said crystallographic directions is less than 6 degrees, is not derivable from document D1.

In this respect, the appellant has provided with the statement setting out the grounds of the appeal three-dimensional crystallographic models showing that in compound semiconductors such as GaAs and InP, wherein because the crystal lattices comprise more than one

atom, the rotation of the crystallographic planes does not result automatically in the bonded surfaces being such that the alignment of atoms across the bonded interface mimics as closely as possible that which is found in a bulk crystalline semiconductor.

Document D2 (see the abstract; page 738, left-hand column, first paragraph, seventeenth line to right-hand column, first paragraph; the paragraph bridging pages 738 and 739; page 740, the last paragraph) concerns the investigation of electrical characteristics of directly-bonded commercially available GaAs and InP (100) wafers, whereby it is indicated that p-p wafers directly-bonded at high temperature may show no rectification. It is indicated that document 1 (reference 10) that it is known to fabricate lasers using the direct-bonding method. It is further specified that the electrical characteristics of such bonded interface is very important for the device design has not been clarified yet.

However, there is no indication in document D2 about specifically discerning crystallographic orientations or matching such orientations.

The following is to be noted with respect to these two prior art documents:

Both documents concern directly bonding semiconductor surfaces of the same conduction type, but contain only limited information about the matching of crystallographically compatible surfaces orientations and alignments. Document D2 indeed concerns electrical characteristics of such bonded surfaces, but only for a specific configuration, i.e., commercially available (100) GaAs and InP substrates.

As convincingly explained using the above-mentioned three-dimensional crystallographic models, bringing together the surfaces of commercially available wafers, even when using cleavage planes thereof, the operator may obtain by chance the matching mentioned in the claim, but he will not obtain it automatically in all cases. In such cases, he will not obtain an ohmic contact which, according to the disclosure in the patent application, is obtainable only under specific orientation and alignment conditions, thus necessitating discerning the crystallographic evaluation.

The further prior art documents are less relevant and, accordingly, they have not been cited in the reasoning of the decision under appeal.

Therefore, in the Board's judgment, to the skilled person, the method of claim 1 is not obvious having regard to the state of the art and thus involves an inventive step in the sense of Article 56 EPC.

Consequently, claim 1 is patentable (Article 52(1) EPC).

The description, however, requires amendments, in particular on page 6, second paragraph and page 14, lines 3 to 12 to exclude semiconductors such as GaAs (which are not transparent) for consistency with the amended claims.

5. *Reimbursement of the appeal fee*

The appellant has contended that the decision under appeal has been based on grounds or evidence on which the applicant has not had an opportunity to present his comments. In particular it was contended that technical arguments based on the interpretation of a

microphotograph (Figure 2b) of document D1 were presented for the first time during he oral proceedings. Consequently the representative was not briefed to address this technical point and was thus deprived of an opportunity to respond to the new arguments appropriately.

In this connection the Board first of all notes that document D1 was cited in the written proceedings before the examining division as the most relevant prior art in relation to the subject-matter of claim 1 before the examining division (cf. the official communication dated 22 September 1997, item 4). Also, according to the communication, the entire content of the document (which is a relatively short document with three pages) was relevant in relation to the claimed subject-matter. Although in the written proceedings there was no specific mention of the transmission electron micrographs of Figures 2(a) and 2(b), these TEMs are an essential part of the disclosure of document D1 as they demonstrate that excellent epitaxy is achieved by direct bonding. The conclusions derived from these TEMs are also mentioned in the abstract of document D1. Thus, the arguments based on the results shown in TEMs cannot be regarded as new evidence totally unrelated to what was already presented in the written proceedings. Consequently, there was no undue burden placed on the Representative to comment on the results shown in the TEMs during the oral proceedings.

The appellant's arguments concerning a further document are not relevant as this document has not been cited in the reasons for refusing the application.

Therefore, in the Board's judgment, there has been no infringement of the requirement of Article 113(1) EPC and, accordingly, a reimbursement of the appeal fee for reasons of equity is not justified (Rule 67 EPC).

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the first instance with the order to grant a patent on the following patent application documents:

   Description: Pages 1 to 15 as filed;

   Claims: Nos. 1 to 5 filed with the appellant's telefax dated 25 February 2003;

   Drawings: Sheets 1/6 to 6/6 as filed;

   with the description to be adapted to the new claims.

3. The request for the reimbursement of the appeal fee is rejected.

The Registrar: The Chairman:

M. Zawadzka R. K. Shukla