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D E C I S I O N
of 5 August 2003

Case Number:	T 0203/01 - 3.4.3
Application Number:	95105817.1
Publication Number:	0678945
IPC:	H01S 3/19
Language of the proceedings:	EN

Title of invention:
Gallium nitride group compound semiconductor laser diode and method of manufacturing the same

Patentee:
TOYODA GOSEI CO., LTD., et al

Opponent:
Siemens AG

Headword:
-

Relevant legal provisions:
EPC Art. 56

Keyword:
"Inventive step (no)"

Decisions cited:
-

Catchword:
-

Case Number: T 0203/01 - 3.4.3

DECISION
of the Technical Board of Appeal 3.4.3
of 5 August 2003

Appellant: (Proprietor of the patent)
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Decision under appeal: **Decision of the Opposition Division of the European Patent Office posted 23 November 2000 revoking European patent No. 0678945 pursuant to Article 102(1) EPC.**

Composition of the Board:

Chairman: R. K. Shukla
Members: G. L. Eliasson
J. P. B. Seitz

Summary of Facts and Submissions

I. This appeal lies from the decision of the opposition division dated 23 November 2000 revoking European patent No. 0 678 945 pursuant to Article 102(1) EPC. The ground for revoking the patent was that the patent in suit did not meet the requirement of inventive step pursuant to Article 100(a) EPC having regard inter alia to the prior art documents

E1: US-A-5 247 533; and

E4: S. M. Sze, "Semiconductor Devices, Physics and Technology" (J. Wiley and Sons, New York, 1985), pages 268 to 278.

II. Independent claims 1 and 4 as granted have the following wording:

"1. A compound semiconductor laser diode (10) having: a double hetero-junction structure with said double hetero-junction structure sandwiching an active layer (5) by an n-type layer (4) and a p-type layer (6) respectively having wider band gaps than said active layer (5), said compound semiconductor laser diode respectively satisfying the formula $(Al_xGa_{1-x})_yIn_{1-y}N$, including $0 \leq x \leq 1$ and $0 \leq y \leq 1$, and electrodes for applying a current to the double hetero-junction structure,

characterized in that

said active layer (5) is a p-type conductive layer doped with magnesium such that the threshold current of the laser diode is reduced in comparison with the same laser diode whose active layer is not doped with any impurities and whereby laser light is radiated by recombination of electrons and holes between conduction band and valence band."

"4. A compound semiconductor laser diode (10) having: a double hetero-junction structure with said double hetero-junction sandwiching an active layer (5) by an n-type layer (4) and a p-type layer (6) respectively having wider band gaps than said active layer (5), said compound semiconductor laser diode respectively satisfying the formula $(Al_xGa_{1-x})_yIn_{1-y}N$, including $0 \leq x \leq 1$ and $0 \leq y \leq 1$, and electrodes for applying a current to the double hetero-junction structure,

characterized in that

said active layer (5) is an n-type conductive doped with silicon such that the threshold current of the laser diode is reduced in comparison with the same laser diode whose active layer is not doped with any impurities,

subject to the proviso that if $x = 0$ for the active layer then $y \neq 1$ for the n-type and the p-type sandwiching layers."

III. In the decision under appeal, the opposition division reasoned essentially as follows:

(a) Document E4 discloses a double heterojunction (DH) laser diode having p-type active layer sandwiched between an n-type and a p-type cladding layer, where all layers are made of materials satisfying the formula $Al_xGa_{1-x}As$. Equation 19 in document E4 shows that the threshold current density is reduced by increasing the quantum efficiency η. It is also known that one of the parameters which influences the quantum efficiency is the doping concentration in the active layer.

(b) The device of claim 1 differs from that of document E4 only in the choice of semiconductor compound material, and in the use of Mg as p-type dopant.

(c) A skilled person who is concerned with the use of new III-V semiconductor material, as disclosed in document E1, when blue emission is required, would considered it obvious to use the basic laser diode structure known from other III-V type material systems, such as the GaAs system disclosed in document E4.

IV. The appellant (patent proprietor) lodged an appeal on 23 January 2001, paying the appeal fee the same day. A statement of the grounds of appeal was filed on 23 March 2001.

V. The following documents were cited by the opponent and the patent proprietor, respectively, during the appeal proceedings:

E6: S. M. Sze, "Physics of Semiconductor Devices, 2nd Edition" (J. Wiley and Sons, New York, 1981), pages 704 to 725; and

E7: H. R. Zappe, "Introduction to Semiconductor Integrated Optics" (Artech House, Boston, 1995), pages 248 to 253, 222 to 223, 359 and 238 to 245.

VI. In a communication annexed to a summons to oral proceedings, the Board introduced further pages of the same text-book which furnished document E6:

E6a: S. M. Sze, "Physics of Semiconductor Devices, 2nd Edition" (J. Wiley and Sons, New York, 1981), pages 681 to 725.

VII. At the oral proceedings held on 5 August 2003, the parties made the following requests:

The appellant (patent proprietor) requested that the decision under appeal be set aside and that the patent in suit be maintained as granted.

The respondent (opponent) requested that the appeal be dismissed.

VIII. The patent proprietor (appellant) presented essentially the following arguments in support of his request:

(a) Document E1 and not document E4 should be considered closest prior art, since document E1 relates to a double-heterojunction laser diode made of the same material system as that of the claimed devices.

(b) Contrary to the view held in the decision under appeal, none of the parameters of equation 19 in document E4 (or equation 55 in document E6a) for the threshold current density relate to the presence of impurities in the active layer. The quantum efficiency η depends on the quantity of electrons and holes which are injected from the n- and p-type layers, respectively (unbalanced carrier concentration), and it is not disclosed in document E4 whether the quantum efficiency η may depend on the carrier concentration in a stationary state.

Although document E6a discloses that the quantum efficiency is directly related to the radiative lifetime, Equation 20 describes the radiative lifetime for an LED and not a laser diode, and is furthermore only valid for "weak excitations", a condition which is not met in a laser diode at the threshold of lasing. Rather, it appears that the radiative lifetime would be independent of doping concentration for very strong excitations.

(c) Document E7 is a more recent textbook on lasers and indicates more accurately what was common technical knowledge at the priority date of the patent in suit than the much older text-books from which documents E4 and E6a are excerpts. In contrast to the devices disclosed in document E6a having doped active layers, document E7 only discloses DH layers diodes having undoped active layers (cf. E7, Figure 9.13; paragraph bridging pages 242 and 243). Furthermore, according to document E7 the quantum efficiency in laser diodes is "typically very close to unity", and may be reduced by defects (cf. E7, page 252, second paragraph). Thus, an efficiency value which is already close to unity cannot be significantly increased by doping. This is also reflected in the equation 9.63 for the threshold current density, which corresponds to equation 55 of document E6a, where the quantum efficiency has been set equal to one. The main parameters influencing the threshold current voltage are, according to document E7, structural parameters such as the thickness d of the active layer and the confinement factor Γ (cf. E7, pages 248 to 250; Figure 9.18).

Furthermore, it is commonly known in the art that doping in III-V semiconductors materials influences the quality of the crystal structure, and therefore, document E7 teaches against using a doped active layer in a double heterojunction laser diode.

(d) The basic laser diode design disclosed in documents E4 and E6a is not as easily applicable to other material systems as asserted in the decision under appeal. This is also evidenced by the fact that the discussion in document E6a is explicitly limited to GaAs/AlGaAs-systems only (cf. E6a, page 721, last paragraph). In particular, it is difficult to obtain lattice matching between the active layer and the surrounding clad layers in GaN/AlGaN type systems.

IX. The opponent (respondent) presented essentially the following arguments:

(a) The opponent shares the view of the opposition division that it was well-known that all the parameters in equation 19 in document E4 depend, among others, on the doping density.

(b) Since GaN laser devices, as well as the methods of doping GaN-type materials, were known in the art, there was no reason why a skilled person would not be able to transfer knowledge from GaAs-type devices to GaN. It is also noted that document E1, which relates to laser diodes made of GaN/AlGaN-type materials, also makes references to the corresponding devices made of GaAs/AlGaAs (cf. column 7, line 62 to column 8, line 20).

(c) Document E7 was published after the priority date of the patent in suit and therefore cannot be used as evidence of the common general knowledge at the priority date of the patent in suit.

Reasons for the Decision

1. The appeal complies with Articles 106 to 108 and Rule 64 EPC and is therefore admissible.

2. *Inventive step*

The only issue in the present appeal is that of inventive step.

2.1 Document E1 discloses a double heterojunction (DH) laser diode having an active layer 4 made of undoped GaN sandwiched between an n-doped layer 3 and a p-doped layer 5, both made of a material satisfying the formula $Al_xGa_{1-x}N$, where $0 < x \leq 1$, in the following referred to as "AlGaN-type materials" (cf. E1, Figure 1, column 2, line 64 to column 3, line 42). The p-type layer 5 is doped with magnesium.

2.1.1 The device according to claim 1 differs from that of document E1 in that the active layer is doped with magnesium so as to reduce the threshold current density, whereas in the device of document E1, the active layer is undoped, or is at least not intentionally doped.

2.2 Documents E4 and E6 where introduced by the opponent as evidence of common general knowledge at the priority date of the patent in suit. The documents are excerpts from two respective text-books written by the same author, S. M. Sze. It is common ground that the disclosure of document E6 is more complete than that of document E4, which was referred to in the decision under appeal.

In order to resolve questions relating to the relevance of having a doped active layer, the Board has introduced document E6a which is a more extensive excerpt from the same chapter of the text-book which furnished document E6.

2.3 Document E6a discloses, among others, a double hetero-junction laser diode having a p-type active layer made of GaAs sandwiched between an n-type and a p-type layer, where the n-type and p-type layers are made of materials satisfying the formula $Al_xGa_{1-x}As$, where $0 < x \leq 1$, in the following referred to as "AlGaAs-type materials" (cf. E6a, Figures 27(c) and 36 with accompanying texts).

2.3.1 In Section 12.4.3 ("Threshold Current Density"), the different mechanisms contributing to the threshold of lasing are discussed, and an expression for the threshold current density J_{th} is derived in Equation 55 in terms of the quantum efficiency η, the confinement factor Γ, the reflectance R of the ends of the cavity, the width d of the active region, and the loss α per unit length of the cavity (cf. page 723, where Equation 55 of document E6a corresponds exactly to Equation 19 of document E4 referred to in the decision under appeal). It is also pointed out that in order to reduce the threshold current density, one can, for example, increase the quantum efficiency η (cf. page 723, last paragraph).

2.3.2 Section 12.2.2 ("Luminescent Efficiency") defines the quantum efficiency in terms of recombination rates or lifetimes (cf. pages 686 and 687; equations 7 to 10). It is in particular pointed out that in order to obtain high quantum efficiency, the radiative lifetime should be small (cf. page 687, sentence after equation 10). On pages 702 to 703, expressions for the radiative recombination rate and the radiative lifetime in a doped semiconductor layer are derived, and it is shown in equation 20 that for a p-type material, the radiative lifetime is approximately inversely proportional to the p-type doping density, when the excitation is sufficiently weak, i.e. when the density of holes in the active region is approximately equal to the p-type doping density of the active region.

Although the patent proprietor correctly observes that Equation 20 is derived under the condition for weak excitation (cf. item VIII(b) above), a condition which is not valid at threshold for lasing, it is nevertheless readily derivable from Equation 20 that the radiative life time is inversely proportional to the total density of holes, i.e. the sum of density of injected holes and the p-type dopant density. Thus, it follows that by increasing the dopant density, the radiative life time will decrease, and thereby the quantum efficiency will increase.

As mentioned above, the quantum efficiency is discussed in the framework of light emitting diodes (LED), which is consistent with the fact that a laser diode operates as an LED before reaching the threshold for lasing (cf. E6a, page 722, last paragraph).

2.3.3 Therefore, contrary to the submissions of the patent proprietor (cf. item VIII(b) above), document E6a contains an indication to the skilled person that the quantum efficiency in a laser diode can in principle be increased by doping the active layer.

2.3.4 The device according to claim 1 differs thus from that of document E6a in that (i) the layers of the double heterojunction satisfy the formula $(Al_xGa_{1-x})_yIn_{1-y}N$, including $0 \leq x \leq 1$ and $0 \leq y \leq 1$, whereas in the device of document E6a, the corresponding layers satisfy the formula $Al_xGa_{1-x}As$; and (ii) the p-type active layer is doped with magnesium, whereas in document E6a, the dopant is not specified.

2.4 Document E7 was published in 1995, which is after the priority date of 20 April 1994 of the patent in suit. It therefore does not belong to the state of the art as defined in Article 54(2) EPC and cannot be used for the assessment of inventive step.

2.5 The patent proprietor argued that document E1, and not document E6a (or E4 as in the decision under appeal), should be considered the closest prior art (cf. item VIII(a) above). The Board agrees that document E1 represents the closest prior art, since a skilled person faced with the task of producing a laser diode emitting light in the blue to ultraviolet frequency range would consider a prior art document, such as document E1, disclosing such a device as relevant. Furthermore, it is also noted that document E1 was cited as the closest prior art in the application as filed.

2.6 As mentioned in the patent in suit, the device of document E1 has the disadvantage that the threshold current density, i.e. the minimum current density required for bringing the laser diode to emit laser light, is rather high (cf. patent in suit, column 1, lines 13 to 19). Thus, the patent in suit relates to solving the technical problem of reducing the threshold current density in a double heterojunction laser diode made of $(Al_xGa_{1-x})_yIn_{1-y}N$-type (AlGaInN-type) materials.

2.7 The Board follows the arguments of the opponent that a skilled person faced with the task of reducing the threshold current density of the device of document E1 would consider doping the active layer with a p-type dopant, since such doped active layers are disclosed in document E6a (cf. E6a, Figures 27c and 36), and document E6a discloses that the quantum efficiency can be increased by introducing dopants in the active layer (cf. item IX(a) above). As to the choice of dopant for the active layer, document E1 uses magnesium for the p-type layer 5, and therefore, the skilled person would use this dopant for the active layer as well.

2.8 In this respect, the patent proprietor argued that

(i) the skilled person would refrain from introducing dopants into the active layer, since they may induce defects in the active layer which will severely degrade device performance. In this respect, reference was made to document E7 which discloses that in modern DH laser diodes, the active layer is usually undoped (cf. item VIII(c) above).

(ii) Furthermore, it is known from document E7 that the quantum efficiency is close to unity, so that there would be little room for improvement by introducing dopants (cf. item VIII(c) above).

(iii) Finally, since document E6a is solely concerned with AlGaAs-type materials, and due to the particular technological difficulties with AlGaN-type materials, document E6a would not be considered by a skilled person concerned with the task of improving a laser diode made of AlGaN-type materials (cf. item VIII(d) above).

2.8.1 Regarding the question of defects induced by dopants (item (i) above), the Board agrees with the patent proprietor that this phenomenon is well-known in the art (cf. for example, E6a, Figure 4; page 687). Therefore, the skilled person would have to weigh the known advantages of introducing dopants into the active layer (can in principle increase the quantum efficiency) against its known disadvantages (may produce defects) in each individual case, taking into account that the number of defects introduced by dopants crucially depends on which dopant is used and whether any treatment of the doped semiconductor layer was carried out in order to activate the dopants.

2.8.2 As to the argument that according to document E7, the quantum efficiency is typically about unity (item (ii) above), apart from the fact that document E7 does not belong to the state of the art, and therefore cannot be used as evidence of the common general knowledge at the priority date of the patent in suit (cf. item 2.4 above), this statement in document E7 can in the Board's opinion only be considered in the context of conventional devices, i.e. laser diodes made of materials such as GaAs/AlGaAs or InP/InGaAsP. It is well-known in the art to produce semiconductor layers of the above materials with extremely low defect density in the bulk and at the layer interfaces (cf. E7, page 242, Figure 9.13). For producing GaN/AlGaN devices, on the other hand, considerable technological difficulties in producing layers having satisfactory quality were known to exist in the art. Therefore, for GaN/AlGaN systems, it could not be assumed that the quantum efficiency would be close to unity, as the case might be for other III-V semiconductor materials. The patent proprietor was also not able at the oral proceedings to provide any information as to the quantum efficiency values which were achievable for GaN at the priority date of the patent in suit.

2.8.3 Finally, as to the question whether a text-book on AlGaAs-type laser diodes would be considered as relevant by the skilled person faced with the task of improving a AlGaN-type device (item (iii) above), the Board notes that both AlGaAs- and AlGaN-type materials are III-V compound semiconductor materials, and therefore have many properties, such as crystal structure, in common. Therefore, once it is established that it is possible to form n- and p-doped layers of AlGaN-type materials with sufficiently high quality, it is reasonable to expect that device designs known to be successful for AlGaAs-type devices would also work for AlGaN, taking due account of the differences between AlGaN and AlGaAs, such as the much larger bandgap of AlGaN-type materials. As also pointed out by the opponent, document E1 also makes such references to the corresponding devices made of AlGaAs-type materials (cf. item IX(b) above; document E7, column 7, line 62 to column 8, line 20).

2.9 Therefore, in the Board's judgement, the subject matter of claim 1 does not involve an inventive step within the meaning of Article 56 EPC. The grounds of opposition under Article 100(a) EPC therefore prejudice maintenance of the patent in suit.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar:

U. Bultmann

The Chairman:

R. K. Shukla