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DECISION
of 1 September 1994

Case Number: T 0203/93 - 3.4.1

Application Number: 83307967.6

Publication Number: 0115204

IPC: H01L 33/00

Language of the proceedings: EN

Title of invention:
Epitaxial wafer for use in the production of an infrared LED

Patentee:
MITSUBISHI MONSANTO CHEMICAL CO.LTD.

Opponent:
Siemens AG
TEMIC TELEFUNKEN microelectronic GmbH
KABUSHIKI KAISHA TOSHIBA

Headword:
MITSUBISHI/Wafer

Relevant legal provisions:
EPC Art. 56

Keyword:
"Inventive step (yes)"
"Use of known means not foreseeable to solve objective problem"
"Known means **could** have been used, but **would not** have been used"
"Time factor of over ten years an additional indication supporting conclusion that claimed use of known means was not obvious"

Decisions cited:
-

Catchword:
-

Europäisches Patentamt
Beschwerdekammern

European Patent Office
Boards of Appeal

Office européen des brevets
Chambres de recours

Case Number: T 0203/93 3.4.1

DECISION
of the Technical Board of Appeal 3.4.1
of 1 September 1994

Appellant:
(Opponent I)

Siemens AG
Postfach 22 16 34
D-80506 München (DE)

Representative:

Rabold, Rudolf (authorised employee)
Siemens AG

Appellant:
(Opponent III)

KABUSHIKI KAISHA TOSHIBA
72 Horikawa-cho
Saiwai-ku, Kawasaki-shi
Kanagawa-ken/Japan (JP)

Representative:

Wagner-Zerlauth, Bernhard
Patentanwälte
Henkel, Feiler, Hänzel & Partner
Möhlstrasse 37
D-81675 München (DE)

Respondent:
(Proprietor of the patent)

MITSUBISHI MONSANTO CHEMICAL CO. LTD.
5-2, Marunouchi 2-chome
Chiyoda-ku
Tokyo (JP)

Representative:

Paget, Hugh Charles Edward
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

Other party: (Opponent II)	TEMIC TELEFUNKEN microelectronic GmbH Postfach 35 35 D-74025 Heilbronn (DE)
Representative:	Kolb, Georg (authorised employee) TEMIC TELEFUNKEN microelectronic GmbH Postfach 35 35 D-74025 Heilbronn (DE)
Decision under appeal:	**Decision of the Opposition Division of the European Patent Office dated 22 December 1992 rejecting the opposition filed against European patent No. 0 115 204 pursuant to Article 102(2) EPC.**

Composition of the Board:

Chairman: G. D. Paterson
Members: H. J. Reich
U. G. O. Himmler

Summary of Facts and Submissions

I. The Respondent is owner of European patent No. 0 115 204.

Independent Claims 1 and 5 of this patent read as follows:

"1. An epitaxial wafer for use in the production of an infrared light-emitting diode comprising:

a single crystalline semiconductor substrate consisting of N-type GaAs;

an N-type GaAs epitaxial layer consisting of N-type GaAs doped with Si and formed on said single crystalline semiconductor substrate; a P-type GaAs epitaxial layer consisting of P-type GaAs doped with Si and formed on said N-type GaAs epitaxial layer; and

a mixed crystal layer consisting of P-type $Ga_{1-x}Al_xAs$ mixed crystal, formed on said P-type GaAs epitaxial layer, and having a thickness of from 5 µm to 90 µm and a carrier concentration of from $1.0 \times 10^{17} cm^{-3}$ to $5.0 \times 10^{18} cm^{-3}$, the mixed crystal ratio (x) of $Ga_{1-x}Al_xAs$ being in the range of from 0.03 to 0.8 at least in a region of the mixed crystal layer, which region is at least 2 µm thick and extends from the interface between said mixed crystal layer and said P-type GaAs epitaxial layer, said N-type GaAs epitaxial layer having a thickness of from 20 µm to 100 µm and a carrier concentration in the range of from $1.0 \times 10^{17} cm^{-3}$ to $2.0 \times 10^{18} cm^{-3}$ and said P-type GaAs epitaxial layer having a thickness of from 10 µm to 80 µm and a carrier concentration in the range of from $1.0 \times 10^{17} cm^{-3}$ to $5.0 \times 10^{18} cm^{-3}$.

5. An infrared light emitting diode comprising a chip formed from a wafer according to any one of the preceding claims."

Claims 2 to 4 are dependent on Claim 1.

II. Opponents Siemens AG (OI), "Temic Telefunken microelectronic GmbH (OII)" and Kabushiki Kaisha Toshiba (OIII) filed Notices of Opposition against this patent on the grounds of lack of novelty and inventive step having regard to the following documents:

D1: Japanese Journal of Applied Physics, Vol. 16, No. 3, March 1977, pages 465-477,
D2: FR-A-2 296 271,
D3: US-A-4 008 485,
D4: Patent Abstract of Japan, 22 May 1981, Vol. 5, No. 78 (E-58) [750], concerning JP-A-5624987,
D5: FR-A-1 529 040,
D6: DE-A-2 600 319,
D7: Journal of Applied Physics, Vol. 42, No. 2, February 1971, pages 654-656,
D8: Solid State Electronics, Vol. 14, Pergamon Press 1971, pages 1265-1273,
D9: Journal of Applied Physics, Vol. 39, No. 4, March 1968, page 2006,
D10: National Technology Report (Japan) Vol. 18, No. 3, June 1972, pages 249-258 with translation,
D11: JP-A-518883 with translation,
D12: Journal of Applied Physics, Vol. 52, No. 1, January 1981, pages 412-418,
D13: Applied Physics Letters, Vol. 9, No. 6, 15 September 1966, pages 221-223,
D14: Journal of Applied Physics, Vol. 49, No. 9, June 1978, pages 3565-3570, and
D15: Solid State Electronics, Vol. 22, Pergamon Press 1979, pages 115 and 116.

III. With a letter dated 23 November 1992 the patent Proprietor filed three auxiliary requests:

The wording of Claim 1 of the **first** auxiliary request corresponds to granted Claim 1 with an amendment of the thickness of the P-type GaAs layer from 10 µm to 80 µm into "10 µm to 60 µm". Claim 1 of the **second** auxiliary request corresponds to granted Claim 1 with the amendment of the thickness of the mixed crystal P-type $Ga_{1-x}Al_xAs$ layer from 5 µm to 90 µm into "15 µm to 90 µm". Claim 1 of the **third** auxiliary request corresponds to granted Claim 1 but with both of the above amendments.

IV. The Opposition Division rejected the oppositions. It held that Claim 1 of the patent as granted involves an inventive step for the following reasons:

Documents D1, D4, D8 and D14 disclose conventional "single heterostructure" wafers, i.e. wafers comprising an N-GaAs substrate, an N-GaAs epitaxial layer, a P-GaAs epitaxial layer and a P-$Ga_{1-x}Al_xAs$ mixed crystal layer, wherein the P-GaAs epitaxial layer is not doped by Si as claimed, but by Zn or Ge and has a thickness **below** the claimed region. On the other hand, the conventional "homostructure" diodes as disclosed in documents D3, D5, D10 and D13 comprise an N-GaAs substrate, a silicon doped N-GaAs epitaxial layer and a P-GaAs epitaxial layer which is doped by Si and has a thickness within the claimed region. However, no document has been put forward to prove that the use of a window layer to obtain a certain distance between P-N junction and the electrode is known in the art. In making use of the advantage of the amphoteric nature of the dopant Si in a conventional "single heterostructure" wafer, the longer mean free path of electrons in a Si-doped and not Zn-doped P-GaAs epitaxial layer, would be no incentive to simultaneously increase the conventional P-GaAs layer thickness in the single heterostructure diode, since the potential well formed in the interface between P-GaAs (active) layer and P-$Ga_{1-x}Al_xAs$ (window) layer confines the electrons to the active P-layer. Using his common general knowledge the skilled person would rather be led to decrease the thickness of the P-GaAs layer compared to known homostructure diodes in view of the required current density and the volume reabsorption of the generated photons. As disclosed in the description, the use of a $Ga_{1-x}Al_xAs$ mixed crystal (window) layer on top of a conventional Si-doped homostructure diode produces a high increase in power output which would not have been predictable from knowledge of the prior art. Since a plurality of parameters had to be considered, a skilled person could not have obtained the claimed wafer from his routine knowledge or from routine experiments.

V. Opponents OI and OIII filed separate appeals against this decision, and Opponent OII also participated in the appeal proceedings. The Opponents based their submissions in the appeal procedure additionally on general knowledge which was evidenced by the following documents:

D16: "The Bell System Technical Journal", Vol. 58, No. 7, September 1979, pages 1579 to 1591,
D17: H. Kressel et al: "Semiconductor Lasers and Heterojunction LEDs", Academic Press, New York 1977, pages 250 and 251,
D18: H.C. Casey Jr. et al: "Heterostructure Lasers" Academic Press, 1978, pages 16 and 17,
D19: E.S. Yang: "Fundamentals of Semiconductor Devices" McGraw-Hill Inc. (USA), 1978, pages 167 to 169,
D20: G. Winstel et al: "Optoelektronik 1, Lumineszenz- und Laserdioden", Springer Verlag Berlin, 1980, pages 81, 84 to 87 and 92 to 100, and

D24: "Semiconductor Heterostructure", published 1 September 1974.

The Respondent relied in his submissions during the appeal procedure additionally on documents:

D21: JP-A-60-202 184 with translation,
D22: Experimental data of the Patentee (3 pages) filed 19 October 1993; and
D25: C. Kittel: "Introduction to Solid State Physics" Fifth edition, John Wiley & Sons, Inc., New York 1976, pages 155 to 181,.

VI. In a communication annexed to a summons to oral proceedings, the Board informed the parties of its provisional view that the crucial question to be discussed is whether a skilled person is able to foresee that the use of a conventional $Ga_{1-x}Al_xAs$ mixed crystal layer such as for instance disclosed in document D8, on top of the active P-GaAs layer of a conventional silicon doped homostructure GaAs diode such as for instance disclosed in document D5, would increase the emission efficiency of the resulting diode, in view of the non-radiative recombination of minority carriers in the surface of the active region, the absorption recycling produced photon within the volume of the active region, and current crowding leading to absorption in the metal contacts. Such effects are for instance known from document D20 to limit the emission efficiency of a conventional homostructure diode. Since document D8 discloses that there is no volume absorption in a mixed crystal window layer, non-radiative recombination in the interface of active and window layer is negligible and its potential barrier confining electrons to the active layer, the Board might regard a skilled person as able to foresee that these properties of the window layer, in particular the confining potential barrier, would enable it to function as a reflecting electron mirror, and would allow, in addition to the elimination of surface recombinations, the shortening of the absorption lengths of produced photons without decreasing the number of photons produced in the active layer, since for complete radiative recombination the thickness of the active layer only needs to be half the free path length of the injected electrons (became of the reflection). Reference was made in the respect to:

D23: W.H. Westphal: "Physikalisches Wörterbuch",
Springer Verlag, Berlin, 1952, page 321,

VII. Oral proceedings were duly held on 1 September 1994.

The Opponents requested that the decision under appeal be set aside and that the European patent No. 0 115 204 be revoked.

The Patentee requested that the appeal be dismissed and that the patent be maintained in accordance with the main, first, second or third Auxiliary requests as before the Opposition Division.

VIII. In support of his request Opponent OI argued essentially as follows:

Since document D1, Figure 1 and Table I on page 466, discloses the identical sequence of layers claimed in Claim 1 of the opposed patent and also dopant concentrations which fall into the claimed regions, it would represent the nearest prior art. Nothing inventive can be seen in selecting the claimed layer thicknesses, because the skilled person is guided to such appropriate values by the diffusion lengths indicated in document D1 on page 474 and the effect of photon recycling indicated in document D1 on page 476.

IX. Opponents OII and OIII based their arguments on the same technical facts and made the following submissions.

(a) According to the translation of document D10, page 2, paragraph 1 and the translation of document D4, page 7, lines 16 to 20, it is known since the publication of documents D5 and D13 that a homostructure diode which is Si-doped has a higher emission efficiency than a Zn-doped one. Hence, in view of the problem disclosed in the opposed patent, which is to increase the emission efficiency, the closest prior art is document D5. In further improving the emission efficiency, the skilled person will maintain the optimal thickness of 50 µm for an Si-doped active layer in order to allow the radiative recombination of all injected electrons in the active layer as disclosed in document D5, page 5, left column, paragraphs 2 and 3, and D13, page 223, left column, paragraphs 1 and 2. The skilled person will regard the 2 µm active layer thickness as disclosed in D8 as not relevant with regard to the very short diffusion length of an electron in Zn-doped GaAs. A thickness of an active layer which falls into the claimed region is as well disclosed in documents D3, D7, D10 and D13.

(b) Document D20 shows the principal effects which limit the emission efficiency of the homostructure diode such as photon recycling in the active layer (volume absorption), current crowding leading to photon absorption by contacts and non-radiative surface recombination, are basic general knowledge. It is also known to the expert that the shortening of the active layer does not only reduce the volume absorption but also the emission rate of photons. Thus, on the basis of the indication in document D5, left column, last 10 lines, that only "a great majority of electrons recombines within an active layer thickness of about 50 to 60 µm", the skilled person will recognise that the emission efficiency of the homostructure diode disclosed in document D5 is still limited by non-radiative recombination losses in the free surface of the active layer.

(c) On the other hand, document D8, page 1266, right column, lines 11 to 15, and page 1272, left column, last paragraph; document D19, page 168, paragraph 5 to page 169, paragraph 1; and the translation of document D4 page 6, paragraph 2, teach that in a heterostructure diode the problem of non-radiative surface recombination is avoided by the mixed crystal (window) layer. Moreover, the window layer exercises a double function, in that it is transparent for photons and provides in its interface with the active layer a potential well which reflects and thus confines electrons to the active layer. These facts make it obvious to the skilled person that a window layer will further increase the emission efficiency of a homostructure diode and hint to a skilled person to aggregate the teaching of documents D5 and D8, so that he arrives at the subject-matter of Claim 1 without exercising an inventive step.

(d) The effect of the potential well in the interface of the active and window layer to confine electrons to the active layer mentioned in document D8, Figure 1; the translation of document D4, page 6, paragraph 2; and document D17, page 250, means that the direction of the drift velocity of the electrons in the active layer toward the window layer is converted by the potential well so that the electrons turn back to the pn-junction. This direction-converting effect of the potential well in the interface of active and window layer was known to the skilled person as the bent arrows in Figure 5.21 of document D24 demonstrate, and may be understood as a reflection of electrons. Moreover, the generally known electron-reflecting effect of a potential well can not only be explained classically but follows as well from the known amplitude distribution of electron wave functions in a quantum mechanical description of a semiconductor. The pages of document D25 cited by the Respondent deal with the free electron Fermi gas and are thus only relevant for metals. Thus, whenever the active layer thickness is half the diffusion length of the electron, the electron travels twice through the active layer. Therefore, in the obvious use of a window layer on top of the monostructure disclosed in document D5, a skilled person expects a maximal emission rate for half the optimal active layer thickness disclosed in document D5 and is not surprised by the experimental results in Table 4 of the opposed patent and in Figure 1 filed by the Patentee on 16 August 1990.

(e) P^+-layer 14 is only provided in Figure 1 of document D5, but not in Figure 2 of document D5, forming the basis of the obvious aggregation of documents D5 and D8 mentioned above. Moreover, it reduces the contact resistance without having an influence on the emission efficiency of photons.

(f) The numerical regions claimed for the carrier concentrations would not be inventive. From document D5, right column, lines 12 to 15, the skilled person would derive for the active layer a carrier concentration of $10^{18}cm^{-3}$, i.e. a value within the claimed region. The claimed range of

$1.10^{17}cm^{-3}$ to $5.10^{18}cm^{-3}$ for the mixed crystal (window layer) would be normal in view of reproducibility on the low limit and semiconductor degeneration at the high limit.

(g) Document D5 was published in 1968; document D8 in 1971. The period of 11 years between the publication of document D8 and the priority date of the opposed patent in 1982 is not indicative of an inventive step, since a satisfactory method for manufacturing the claimed three-layer structure was only developed later.

X. The above arguments were contested by the Patentee, who made essentially the following submissions:

(a) Document D1 would not be relevant since the photoluminescent device described therein does not emit in the infrared region, is not Si but Ge-doped (page 468, left column, paragraph 2) and has thicknesses for all layers which fall outside the claimed regions.

(b) The claimed invention was not obvious having regard to a combination of documents D5 and D8.

Document D5, page 3, right column, lines 12 to 21 discloses an upper limit of $10^{19}cm^{-3}$ for the **global** impurity content, whereas the carrier concentration in the active layer should always stay below the claimed lower limit of 1.10^{17}. Document D5 is the only one which discloses a numeric value for the carrier concentration in a Si-doped active layer and teaches moreover to decrease it in order to improve the emission efficiency. Document D8 is totally silent about the carrier concentration in the window layer. None of the cited further documents hints at the carrier concentration claimed. In particular the cited prior art gives no guidance to the combination of all three carrier concentrations claimed.

(c) The Opponent's line of argument would be a classical case of hindsight, wherein document D8 was selected in the knowledge of the present claim. It generalises the prior art inadmissibly and ignores special indications. The active and mixed crystal (window) layers disclosed in documents D2, D4, D8, d14 and D19 are all Zn-doped and do not hint at the window layer thickness claimed. On the other hand, the homostructure diodes disclosed in documents D3, D5, D6, D7, D9, D10 and D13 have all Si-doped active layers. Hence, there must be drawn a distinction between a Si-doped homostructure diode and the Zn-doped heterostructure diodes.

(d) The efficiency measurements in Table 2 of document D8 and the disclosure of document D5, in particular page 4, right column, line 8 to page 5, left column, line 8, demonstrates that in the Si-doped homostructure diode no problems with regard to emission efficiency are present. In particular document D5, page 1, right column, paragraph 2 to page 2, left column, paragraph 1; page 3, right column, last paragraph and page 4, right column, paragraph 1, indicates that due to the low carrier concentration in the active layer, the volume absorption of emitted photons is low. Contrary to the Opponent's opinion in paragraph IX-(b), the skilled person derives from document D5, page 5, left column, paragraphs 2 and 3 that the great majority of electrons recombines within the active layer, so that non-radiative surface recombination losses can be neglected. The dependence of the external efficiency from the active layer thickness disclosed in Figure 6-20 of document D19 concerns a Zn-doped active layer and has no relevance to describe the influence of surface recombination in the Si-doped active layer of document D5. D19 states a window layer to be only an alternative measure to avoid surface recombinations. Moreover, non-radiative surface recombinations are in particular avoided in the embodiment of Figure 1 of document D5, wherein p^+ layer 14 according to D5, page 5, left column, lines 2 to 8 and 28 to 39 converts electrons which reach the surface region of the active layer into photons. A diffusion of Zn into GaAs is feasible within a depth of 2 µm, so that the active layer thickness must remain smaller than the average diffusion length of electron in Zn-doped GaAs (10 µm). In such a case the extremely costly manufacture of an additional mixed crystal (window layer) would be justified in view of the fact that almost all electrons reach the free active layer surface and would be lost in a non-radiative transition. However a Si-doped GaAs layer can be produced practically without thickness limitation. Hence, the skilled person would rather avoid non-radiative surface recombinations by an appropriate value of the active layer thickness than use a window layer. Therefore, the technical solutions suggested to the skilled person in documents D5 and D8, point in opposite directions.

(e) From Figure 10 of document D10 a linear increase of the output power of a Si-doped homostructure diode is derivable, which demonstrates that there is no need to compensate for the volume absorption of the produced photons when increasing the emission efficiency of the diode by enlarging the thickness of the active layer. Document D5 discloses that the volume absorption may be kept very small by a small carrier (hole) concentration (page 5, left column, lines 13 to 20) such as below $1.10^{17} cm^{-3}$ (page 3, right column, lines 15 to 21) and for obtaining a useful power output, teaches to optimise the internal quantum efficiency of the active layer, i.e. to select an appropriate thickness of the active layer, so that all electrons injected into the active layer are able to recombine with a hole within the volume of the active layer (page 5, left column, lines 20 to 28). Thus, also in view of an efficiency loss by volume absorption, the prior art discloses no technical need to provide a window layer on top of the free surface of the active layer in the homostructure diode of document D5. An addition of a window layer would only unnecessarily increase the resistance of the diode.

(f) Electron reflection is a purely classical effect of an individual electron. However, from document D25 it follows that in order to describe the effects of a p-p-heterojunction, electrons are viewed not individually but statistically from the quantum mechanical point of view. A skilled person will not associate statistical electron densities to the more simplistic concept of reflection. The submitted translation of document D24 is not relevant since it concerns the reflection of light in a laser resonator. Moreover, as can be seen from Figure 1 of document D8, no electrical field is present in an active layer provided with a window layer. The functioning submitted by the Opponents as set out in paragraph IX-(d) is not disclosed in any cited document. It is beyond a skilled person's routine to foresee that, by the use of a window layer, absorption lengths of produced photons may be shortened without decreasing the internal quantum efficiency of the active layer.

(g) The period of 11 years between the publication of document D8 and the priority date of the present invention is a clear indication that the large increase of output power disclosed in Table 4 of the present patent, in document D22 and in Figure 1 filed on 16 August 1990, was not expected by the skilled person. The high current saturation level, allowing to realise a linear output power dependence from the current at high current densities, the small half-width of the output energy and a longer output power peak wavelength are surprising additional advantages underlining the presence of an inventive step. Since current crowding is only effective in thin layers, a smaller photon absorption by the contact layer does not explain the higher output power of curve A in Figure 1 of document D22 with regard to curve D.

XI. At the conclusion of the oral proceedings the decision was announced that the appeal is dismissed.

Reasons for the Decision

1. *Inventive step - Claim 1 - Main request*

1.1 The only substantive issue raised in this appeal is that of inventive step.

1.2 The Board agrees with the Patentee that the sequence of layers disclosed in document D1 is Ge-doped and has no specified thicknesses. Consequently, the Board does not regard document D1 as the closest prior art, as submitted by Opponent OI. The Board agrees with Opponents OII and OIII that, having regard to the technical aim underlying the claimed invention, namely to increase the output power of an infrared light emitting diode to make it usable in the field of optical communication (description page 1, lines 24 to 26), the closest prior art is formed by the Si-doped homostructure diode disclosed in document D5.

1.3 Document D5 discloses, with reference to the wording of Claim 1 of the main request:

"An epitaxial wafer for use in the production of an infrared light-emitting diode (see D5, page 3, left column, lines 13-18) comprising: a single crystalline semiconductor substrate consisting of N-type GaAs (page 2, left column, lines 37-43); an N-type GaAs epitaxial layer consisting of N-type GaAs doped with Si and formed on said single crystalline semiconductor substrate (page 2, left column, lines 43-47); a P-type GaAs epitaxial layer (region 12 in Figures 1 and 2) consisting of P-type GaAs doped with Si and formed on said N-type GaAs epitaxial layer (page 2, left column, lines 47-55); ...; said N-type GaAs epitaxial layer having a thickness of from 20 µm to 100 µm (see D5, page 6, right column, lines 10 to 13, disclosing 20-30 µm) ... and said P-type GaAs epitaxial layer having a thickness of from 10 µm to 80 µm (see page 5, left column, paragraph 3, disclosing a range from 10 µm to 60 µm)."

The assessment of the carrier concentration in the P-type GaAs epitaxial layer of the wafer disclosed in document D5 as set out in paragraph IX-(f) above is not accepted by the Board in view of the explicit statement in document D5, page 3, right column, lines 18 to 20, that in region 12 the concentration of carriers (holes in excess) is below $1.10^{17}cm^{-3}$, i.e. outside the lower limit claimed. Document D5 does not specify the carrier concentration in the N-type GaAs epitaxial layer.

1.4 Starting from the closest prior art, namely document D5, the objective problem underlying the claimed invention is to provide a wafer for an infrared LED (light emitting diode) and an infrared LED which may exhibit an output power higher than that of the conventional infrared LED which is made of a GaAs epitaxial wafer produced by LPE (liquid-phase-epitaxy) of GaAs doped with Si; see the description of the patent under appeal, page 1, lines 29 to 31. The manufacture of the homostructure diode of document D5 is disclosed in document D5, page 6, left column, last paragraph to right column, paragraph 2.

1.5 The above problem is solved according to the remaining wording of Claim 1 of the main request in that:

(a) said N-type GaAs epitaxial layer has "a carrier concentration in the range of from $1.0 \times 10^{17}cm^{-3}$ to $2.0 \times 10^{18}cm^{-3}$" and said P-type epitaxial layer has "a carrier concentration in the range of from $1.0 \times 10^{17}cm^{-3}$ to $5.0 \times 10^{18}cm^{-3}$", and

(b) the wafer comprises

"a mixed crystal layer consisting of P-type $Ga_{1-x}Al_xAs$ mixed crystal, formed on said P-type GaAs epitaxial layer, and having a thickness of from 5 μm to 90 μm and a carrier concentration of from $1.0 \times 10^{17}cm^{-3}$ to $5.0 \times 10^{18}cm^{-3}$, the mixed crystal ratio (x) of $Ga_{1-x}Al_xAs$ being in the range of from 0.03 to 0.8 at least in a region of the mixed crystal layer, which region is at least 2 μm thick and extends from the interface between said mixed crystal layer and said P-type GaAs epitaxial layer."

1.6 In the infrared LED with a Zn-doped single heterostructure as disclosed in document D8 is known, following the wording of distinguishing feature (b) mentioned in paragraph 1.5 above:

"a mixed crystal layer consisting of P-type $Ga_{1-x}Al_xAs$ mixed crystal, formed on a P-type GaAs ... layer (see D8, Figure 1 on page 1266), and having a thickness of from 5 µm to 90 µm (30 µm to 70 µm according to D8, page 1269, left column, lines 8 and 9), ... the mixed crystal ratio (x) being in the range of from 0.03 to 0.8 at least in a region of the mixed crystal, which region is at least 2 µm thick and extends from the interface between said mixed crystal layer and said P-type GaAs ... layer (about 0.6 at the interface according to D8, page 1267, right column, lines 10 to 17)".

Such a mixed crystal layer is known to be practically transparent (i.e. a window) for the infrared photons produced by electron-hole recombination in the underlying P-type GaAs (active) layer (D8, page 1266, line 4), to confine electrons to the active layer by a potential well in the GaAs-$Ga_{1-x}Al_xAs$ interface (D8, text under Figure 1) and to prevent non-radiative recombination of electrons injected into the active layer (D8, page 1266, right column, lines 11 to 15).

Hence, the question to be examined is whether it was obvious for a skilled person to make use of the above known properties of this window layer disclosed in document D8, in order to increase the emission efficiency of the Si-doped homostructure diode disclosed in document D5, and to select for this purpose the claimed carrier concentrations for the window layer (see distinguishing feature (b)) and for the active (P-GaAs) layer and the electrons injecting (N-GaAs) layer (see distinguishing feature (a)).

1.7 The fact that the inherent properties of a technical means are known to the skilled person, so that he has the intellectual possibility to apply this means in a conventional device, merely establishes the **possibility** of using such technical means in such a manner; i.e. that the skilled person **could** have used it. However, if it is to be established that such intellectual possibility was also a technical measure which was obvious for the skilled person to use, it is necessary to show that there was a recognisable pointer in the state of the art to combine such known means and such conventional device for achieving the intended technical aim; i.e. that the skilled person **would** have made such a combination. The existence of such a technical reason is dependent on the known properties not only of the means but also of those of the device.

1.7.1 Hence, in assessing the question of obviousness it is necessary inter alia to examine whether at the priority date of the invention the skilled person was able to recognise the following facts:

(a) that the chosen device is an appropriate technical starting point and is really technically suited and convertible for the intended technical aim (i.e. in the present case that it is technically possible to further improve the output power of a Si-doped homostructure diode);

(b) that the known properties of the means are able to convert the functioning of the resulting entity of device and means into a subject which satisfies the intended technical aim (i.e. in the present case that - via its transparency, its potential well and its interface without non-radiative recombinations - the window layer will increase the output power of a Si-doped homostructure diode), and

(c) that the state of the art offers the skilled person no alternative measures which, in view of the intended aim, are technically more advantageous, simple or promising in industrial development or manufacture, so that the skilled person gives no superior alternative measure preference over said particular means for practical reasons (i.e. in the present case there are no known measures which allow an increase in the output power of a Si-doped homostructure diode more easily than an additional coating with a window layer).

1.8 In answering the question whether the Si-doped homostructure diode is a suitable technical starting point (see paragraph 1.7.1-(a) above), in the Board's view a skilled person would have interpreted the total technical information derivable from document D5, to mean that this conventional Si-doped homostructure diode, when produced with its disclosed optimal parameters, already produces the possible maximum of output power, for the following reasons:

1.8.1 Any active layer which is thicker than 50 µm allows electrons injected into the active layer to recombine with holes within the volume of the active layer (see D8, page 5, left column, lines 20-28 and 50-55 and page 3, right column, lines 35-41). Hence, the conventional active layer already provides an ideal internal quantum efficiency. From the fact that all electrons recombine with holes before they reach the free surface of the active layer, a skilled person easily concludes that non-radiative surface recombination losses are negligible. Contrary to the Opponents' submission in paragraph IX-(b) above, in the Board's view, avoidance of a **negligible** quantity of non-radiative surface recombination is no technical reason to coat the free surface of the Si-doped active layer with a mixed crystal window layer.

1.8.2 Due to the low carrier concentration in the active layer of the homostructure diode disclosed in document D5, below $1.10^{17}cm^{-3}$, its volume absorption is low and practically no photons are recycled to electrons and thus lost on their way to the free surface of the active layer (see D5, page 3, right column, lines 18-20 and page 4, right column, lines 3-13). Such negligible volume absorption of photons is not a technical reason either to shorten the absorption length of photons in the semiconductor material of the homostructure diode or to provide a partial optical path in its semiconductor material which is transparent. Therefore, the Board does not accept the Opponents arguments in paragraph IX-(c) above.

1.9 Having regard to whether a skilled person who was interested in converting negligible losses by volume absorption and non-radiative surface recombinations into useful photon emission, would consider a window layer as a technically superior means which he would prefer to other known measures (see paragraph 1.7.1-(c) above), the Board takes the following view: a skilled person would be primarily guided by the existing functioning of the Si-doped homostructure diode and the optimisation rules of its parameters as disclosed in document D5 - i.e. to lower volume absorption by a lower carrier concentration and to decrease non-radiative surface losses by a thicker active layer - before he consults a neighbouring field such as Zn-doped heterostructure diodes for a solution to his problem. Moreover, in order to diminish volume absorption in the active layer, a further reduction of the carrier concentration can more easily be realised than window layer coating. Residual non-radiative losses are more easily reduced by enlarging the active layer in the motion direction of the injected electrons than by window layer coating. Hence, following the recommendations disclosed in document D5, an additional manufacturing step such as would result from an application of the teaching of document D8 would not have been obvious.

1.9.1 It is evident that the P^+-layer 14 in Figure 1 of document D5 is not relevant to the question whether the combination of the embodiment of Figure 2 without such layer and the window layer of document D8 is obvious; see paragraph IX-(e) above. However, from document D5, page 3, right column, lines 41 to 47 and page 5, left column, lines 34 to 39, a skilled person is able to derive that the increased carrier concentration in layer 14 increases the recombination rate in the surface region of the active layer and thus reduces non-radiative recombinations. Since a doping step is more easily realised than the manufacture of a GaAs-$Ga_{1-x}Al_xAs$ interface, in the Board's view, the skilled person would be more likely to produce a P^+-layer within the active layer than to coat its surface with an additional mixed crystal window layer in order to avoid residual surface losses.

1.9.2 For these reasons, the Board is satisfied that a skilled person would not consider the mixed crystal window layer of a heterostructure diode as an obvious technical solution for solving the objective problem underlying the present invention.

1.10 With regard to the question whether a skilled person would reasonably expect that a window layer on top of a

Si-doped homostructure diode would increase the output power of the resulting device (see paragraph 1.7.1-(b) above), the Board concludes as follows:

1.10.1 Document D4, at page 6, lines 14 to 19 of the translation discloses that the effect of the potential well at the GaAs-$Ga_{1-x}Al_xAs$ interface to confine electrons, prevents the injected electrons from non-radiative recombinations in this interface which correspond to the non-radiative surface losses of the homostructure diode. None of the cited documents hints to a skilled person to technically apply the known property of a potential well to convert the drift velocity direction of electrons and to make use of the potential well in order to shorten the active layer thickness necessary for maximal internal quantum efficiency. The Zn-doped active layer thickness of the heterostructure diode disclosed in document D8 (2 µm) is a limit given by the method for manufacturing, and is five times smaller than the free path length of injected electrons (see also paragraph X-(d) above). Hence, in the conventional use of a window layer there was no technical need to shorten the active layer volume. Though the effect of electron reflection by a potential well is generally known, in the Board's view it was not obvious for a skilled person to make use of this known effect in order to compress the volume of an Si-doped active layer which is necessary for a total radiative recombination of all injected electrons to half its size. The Board follows the Opponents submissions as set out in paragraphs IX-(a) and IX-(d) above only insofar as the skilled person would maintain maximal internal quantum efficiency, i.e. radiative recombination of **all** injected electrons. Furthermore, it might also be possible that a skilled person would be able to understand why the active layer thickness for maximal output power is shifted from 50 µm in the closest prior art (see D5, page 5, lines 45-55) to 25 µm in the invention (see the description, example 6 in Tables 3 and 4). But there is no hint in the prior art that such compression of the emissive diode parts would increase its output power. Since document D5 teaches that volume absorption and non-radiative surface losses are negligible, in the Board's view, a skilled person would not expect that a substitution of half an optical way in low absorbing material by half an optical way in transparent material actually results in an experimentally observable increase of the output power.

1.10.2 In the Board's view, a skilled person - on the basis of his general knowledge - would expect that a compression of the emissive volume of the Si-doped homostructure diode disclosed in document D5 by a window layer, combined with a greater carrier density results in a **lower** output power of the corresponding device, since it causes an enlarged photon absorption within the compressed emissive volume. The Board has no reason to doubt that the use of a window layer according to distinguishing feature (b) in paragraph 1.5 above) combined with an increased carrier concentration in the active layer (according to distinguishing feature (a) in paragraph 1.5 above) leads to an **increased** power output with regard to a comparative example formed by a Si-doped homostructure diode with a carrier concentration below $1.10^{17}cm^{-3}$ in the active layer and a double active layer thickness. Hence, in the Board's view the combined use of a window layer and an increased carrier concentration in the active layer provides a surprising synergistic effect. This also supports the conclusion that such a combination was not obvious to a skilled person.

1.11 As follows from Figure 2 of document D8 and the corresponding description on page 1267, GaAs-$Ga_{1-x}Al_xAs$

.../...

interfaces were carried out before the publication date of document D8 in 1971. For this reason the Appellant's submission in paragraph IX-(g) above does not explain why such interface was applied to a Si-doped homostructure only 11 years later, i.e. at the priority date of the present invention in 1982. Since - as generally known - the technical development of optical communication system started before 1971, during the whole period of 11 years a need for an infrared LED which is usable in this field, existed. Therefore, the Board regards a period of 11 years in a technical field wherein intensive development efforts were made, as a relevant further indication supporting the conclusion that the combination of constructional elements of a Si-doped homostructure diode (document D5) and a Zn-doped heterostructure diode (document D8) for solving the objective problem underlying the present invention was not obvious for the skilled person.

1.12 For the reason set out in detail in paragraphs 1.1 to 1.11 above, the Board finds that the subject-matter of Claim 1 of the main request involves an inventive step within the meaning of Article 56 EPC.

2. Hence, it follows that granted Claim 1 can be maintained unamended. Dependent Claims 2 to 4 concern particular embodiments of the wafer claimed in Claim 1. Independent Claim 5 is directed to a diode comprising a chip formed from the wafer claimed in Claim 1. Therefore Claims 2 to 5 can be likewise maintained as granted.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar:	The Chairman:
M. Beer	G. D. Paterson