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D E C I S I O N
of 24 February 2005

Case Number: T 1167/02 - 3.4.3

Application Number: 96912752.1

Publication Number: 0826246

IPC: H01L 33/00

Language of the proceedings: EN

Title of invention:

Double heterojunction light emitting diode with gallium nitride active layer

Applicant:

CREE, INC.

Opponent:

-

Headword:

-

Relevant legal provisions:

EPC Art. 56

Keyword:

"Inventive step (no) "

Decisions cited:

-

Catchword:

-



Case Number: T 1167/02 - 3.4.3

D E C I S I O N
of the Technical Board of Appeal 3.4.3
of 24 February 2005

Appellant:

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Representative:

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Decision under appeal:

Decision of the Examining Division of the
European Patent Office posted 2 July 2002
refusing European application No. 96912752.1
pursuant to Article 97(1) EPC.

Composition of the Board:

Chairman: V. L. P. Frank
Members: G. L. Eliasson
T. Bokor

Summary of Facts and Submissions

- I. European patent application No. 96 912 752.1 was refused in a decision of the examining division dated 2 July 2002 on the ground that the subject matter of claim 1 according to a main request and an auxiliary request did not involve an inventive step.

The following prior art documents, among others, were cited in the examination procedure:

D1: Patent Abstracts of Japan, vol. 95, No. 1, & JP-A-7 007 182 and corresponding translation in English of JP-A-7 007 182;

D2: EP-A-0 599 224; and

D4: US-A-5 393 993.

- II. The appellant (applicant) lodged an appeal on 28 August 2002, paying the appeal fee the same day. A statement of the grounds of appeal was filed on 5 November 2002 together with new claims, as well as the following documents:

D5: US-A-5 679 965;

D6: R. L. Wells et al., "New Precursor Routes to Nanocrystalline Cubic/Hexagonal Gallium Nitride GaN" in Materials Research Society Symposium Proceedings vol. 468, page 39 (1997):

D7: Excerpt from
www.olympusmicro.com/primer/lightandcolor/sources;

D8: J. Andress, "Electromagnetic Wavelength Spectrum" from The Technology Interface Online Journal, vol. 1, No. 3, Spring 1997; and

D9: "The ALTA Spectrometer" from www.lpi.usra.edu.

III. In response to a communication of the Board accompanying summons to oral proceedings, the appellant submitted amended claims with a letter dated 4 February 2005.

IV. At the oral proceedings held on 24 February 2005, the appellant requested that the decision under appeal be set aside and a patent be granted on the basis of one of the following requests:

Main Request:

Claims 1 to 3 according to the main request filed with the letter dated 4 February 2005,
Claims 4 to 12 according to the main request filed with the statement of the grounds of appeal

Auxiliary Request:

Claims 1 to 11 according to the first auxiliary request filed with the letter dated 4 February 2005.

V. Claim 1 according to the main request reads as follows:

"1. A double heterostructure light emitting diode that emits in the blue portion of the visible spectrum and comprises:

a conductive silicon carbide substrate (21) having a first surface and a second surface;

a buffer layer (22) on said first surface of the substrate;

respective ohmic contacts (31, 32) to said second surface of the substrate and to the opposite end of the diode; said ohmic contacts (31, 32) defining a vertical structure for said diode and a vertical path for current flow through each layer between said ohmic contacts; and

a double heterostructure (24) on said buffer layer, the buffer layer providing a crystal and electronic transition between the substrate and the double heterostructure;

characterised in that:

the double heterostructure (24) on said buffer layer comprises:

an n-type layer of aluminum gallium nitride (25), having the formula $Al_xGa_{1-x}N$ where $1 > x > 0$, on said buffer layer;

a compensated n-type active layer of gallium nitride (26) on said n-type aluminum gallium nitride layer (25); and

a p-type layer of aluminum gallium nitride (27) having the formula $Al_xGa_{1-x}N$ where $1 > x > 0$ on said gallium nitride layer, said p-type layer of

aluminum gallium nitride and said n-type active layer forming a p-n junction."

VI. Claim 1 according to the auxiliary request reads as follows:

"1. A double heterostructure light emitting diode that emits in the blue portion of the visible spectrum and comprises:

a conductive silicon carbide substrate (21) having a first surface and a second surface;

a conductive buffer layer (22) on said first surface of said substrate, said buffer layer (22) selected from gallium nitride, aluminium nitride, indium nitride, ternary Group III nitrides having the formula $A_xB_{1-x}N$, where A and B are Group III elements and where x is zero, one, or a fraction between zero and one, quaternary Group III nitrides having the formula $A_xB_yC_{1-x-y}N$ where A, B, and C are Group III elements; x and y are zero, one or a fraction between zero and one, and 1 is greater than or equal to (x+y), and alloys of silicon carbide with such ternary and quaternary Group III nitrides;

respective ohmic contacts (31, 32) to said second surface of said substrate and to the opposite end of the diode; said ohmic contacts (31, 32) defining a vertical structure for said diode, and a vertical path for current flow through each layer between said ohmic contacts, and

a double heterostructure (24) directly adjacent said buffer layer;

characterised in that:

the double heterostructure (24) on said buffer layer comprises:

an n-type layer of aluminum gallium nitride (25) having the formula $Al_xGa_{1-x}N$ where $1 > x > 0$ and a net doping density of about $2 \times 10^{18} \text{ cm}^{-3}$ on said buffer layer (22);

a compensated n-type active layer of gallium nitride (26) having a net doping density of between $1 \times 10^{18} \text{ cm}^{-3}$ and $4 \times 10^{18} \text{ cm}^{-3}$; on said n-type aluminum gallium nitride layer (25); and

a p-type layer of aluminum gallium nitride (27) having the formula $Al_xGa_{1-x}N$ where $1 > x > 0$ and a net doping density of about $1 \times 10^{19} \text{ cm}^{-3}$ on said gallium nitride layer, said p-type layer of aluminum gallium nitride and said n-type active layer forming a p-n junction."

VII. The appellant's arguments in support of his requests can be summarized as follows:

- (a) Document D4 should be considered closest prior art since it discloses a vertical LED on a conductive substrate made of SiC. Document D1 on the other hand discloses a lateral operating LED on a non-conductive sapphire substrate.

- (b) The buffer layer disclosed in document D4 is specifically designed for growing GaN on it (cf. D4, column 4, lines 3 to 17). Therefore, the skilled person would not assume that it would be easier to grow the AlGaN layer cladding layer of document D1 on the buffer layer of document D4.
- (c) The heterostructure of document D1 is specifically for use in a lateral-operating device in which the only problem concerning band gap energy levels is the band gap difference between the cladding and active layers which is required for proper carrier confinement. However, in a vertical-operating device as disclosed in document D4, the band gap energy level of each layer must also be selected correctly to ensure proper vertical operation of the device. Thus, unlike in the case of a lateral operating device, the person skilled in the art has to consider two separate problems: Firstly, the bandgap between the active and cladding layers has to result in proper carrier confinement to yield high luminescence. Secondly, the relative band gaps of each layer must result in proper flow of carrier between the layers to provide correct vertical operation.
- (d) The device of document D1 has a peak emission at 490 nm, and therefore the emitted light has greenish-blue colour (cf. document D6 to D9). It is furthermore disclosed in document D1 that by increasing the aluminium content in the active layer, the emitted light will have a deeper blue colour (cf. paragraph 0014). Therefore, a skilled person faced with the problem of producing a blue

light emitting diode would have no reason to replace the active layer of $\text{Al}_{0.01}\text{Ga}_{0.99}\text{N}$ of the device of document D1 with a GaN layer, since he would expect such a replacement to push the emitted light further into the green portion of the spectrum. The claimed invention has the surprising effect that the wavelength of the emitted light is shorter than that emitted by the device of document D1 although the bandgap of the active layer is smaller than that of the known device. Furthermore, the device according to the claimed invention emits light at higher power than the known device.

- (e) Regarding the auxiliary request, it is submitted that the general method of optimising the doping concentrations of the heterostructure of document D2 relates to a lateral device. Therefore, the skilled person would not consider this for a vertical device, such as the claimed device, since the type of substrate affects the performance.

Reasons for the Decision

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

At the oral proceedings, the Board informed the representative that the feature in claim 1 according to the main request specifying that the n-type aluminum gallium nitride layer of the double heterostructure

formed "on the buffer layer" has no basis in the application as filed, contrary to the requirements of Article 123(2) EPC. In particular, the device depicted in Figure 1 of the application in suit has an n-type GaN layer 23 between the buffer layer 22 and the n-type aluminium gallium nitride layer 25. The same applies to the feature "a double heterostructure directly adjacent said buffer layer" in claim 1 according to the auxiliary request.

Since the representative indicated willingness to omit the above features, these features are not taken into consideration in the assessment of inventive step. In other words, the embodiment of Figure 1 mentioned above falls within the scope of claim 1.

3. *Inventive step - Main Request*

It is common ground that novelty is not an issue in the present appeal.

- 3.1 Document D1 discloses an $\text{Al}_y\text{Ga}_{1-y}\text{N}/\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{Al}_z\text{Ga}_{1-z}\text{N}$ double heterostructure LED formed on a sapphire substrate (cf. abstract). The n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}$ active layer 5 is formed between an n-type $\text{Al}_y\text{Ga}_{1-y}\text{N}$ cladding layer 4 and a p-type $\text{Al}_z\text{Ga}_{1-z}\text{N}$ cladding layer 6, such that $0 \leq x < 1$, $x < y$, and $x < z$, where the specific values $x=0.01$, $y=0.2$ and $z=0.2$ are disclosed (cf. paragraphs 0019 to 0021). In order to increase the luminance and the emission output, the active layer 5 made of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ is compensated n-type and doped with Si and Zn (cf. Figure 2; paragraphs 0013 and 0014). The maximum luminance is obtained when the net doping density of

the active layer 5 is about 10^{19} cm^{-3} (cf. Figure 1; paragraphs 0020, 0024 and 0031).

On the sapphire substrate 1 of the device of document D1, a buffer layer 2 of GaN and an n-type GaN layer 3 are formed (cf. Figure 2). The n- $\text{Al}_y\text{Ga}_{1-y}\text{N}$ /n- $\text{Al}_x\text{Ga}_{1-x}\text{N}$ /p- $\text{Al}_z\text{Ga}_{1-z}\text{N}$ double heterostructure 4, 5, 6 is formed on the n-type GaN layer 3. An upper electrode 8 is formed over the p-type $\text{Al}_z\text{Ga}_{1-z}\text{N}$ cladding layer 6 and a lower electrode 9 is formed in contact with the n-type GaN layer 3.

The peak emission wavelength is between 480 to 490 nm where the luminous power is up to 400 μW at 20 mA (cf. paragraph 0024 and 0031).

3.1.1 The device of claim 1 according to the main request differs from that of document D1 in that:

- (a) The substrate is made of SiC and is conductive; whereas in document D1 the substrate is made of sapphire, an insulator; and
- (b) the active layer is made of compensated n-type GaN, whereas in document D1 the active layer is made of compensated n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}$, $0 \leq x < 1$. The only value of x disclosed in the examples of document D1 is $x=0.01$.

3.2 Document D4 was considered closest prior art in the decision under appeal and discloses a double heterostructure vertical LED comprising a SiC substrate 61 onto which a conductive buffer layer structure 62 is formed (cf. Figure 4). The diode structure made of a

GaN/ $\text{In}_x\text{Ga}_{1-x}\text{N}$ /GaN double heterostructure 63/64/65 is formed on the buffer layer structure 62. Electrodes 66, 67 are formed over the heterostructure 63/64/65 and on the bottom surface of the SiC substrate 61, respectively.

3.2.1 In contrast to the device according to claim 1, document D4 does not disclose an $\text{n-Al}_x\text{Ga}_{1-x}\text{N}/\text{n-GaN}/\text{p-Al}_x\text{Ga}_{1-x}\text{N}$ double heterostructure where the n-type GaN layer is compensated doped.

3.3 The Board considers document D1 to represent the closest prior art, since it discloses an AlGaN-based double heterostructure diode where the active layer is compensated doped.

The appellant argued that document D4 should be considered the closest prior art, since it discloses a vertical device where the current flows through each layer between the ohmic contacts formed on the bottom surface of the conductive substrate and the opposite end of the diode (cf. item VII(a) above). The Board finds, however, that the claimed device and that of document D1 have not only the same type of materials for the light emitting double heterostructure ($\text{Al}_x\text{Ga}_{1-x}\text{N}$) in common, but also a compensated n-type active layer. The device of document D4, on the other hand, has only the type of substrate (conductive SiC) and the vertical electrode structure in common with the claimed device, i.e. features which do not concern the light emitting region of the LED. As to the light emitting double heterostructure, document D4 neither discloses the same type of materials as in the claimed device, nor a compensated n-type active layer.

3.4 The device of document D1 has the disadvantage that it is grown on a sapphire substrate so that it is not possible to form a vertical device having ohmic contacts placed at opposite ends of the device. The technical problem having regard to document D1 thus relates to modifying the known device to have a vertical electrode structure.

3.5 Regarding feature (a) referred to under item 3.1.1 above, i.e. the use of a conducting substrate, the skilled person faced with the above problem would in the Board's opinion consider the teaching of document D4, since it addresses the same problem of avoiding an insulating substrate for GaN-based devices, in particular GaN-based LEDs (cf. D4, column 2, lines 18 to 34; column 3, lines 1 to 7). The Board also finds that the replacement of the sapphire substrate 1 and buffer layer 2 of the device of document D1 with the conductive SiC substrate 61 and buffer layer structure 62 of document D4 also does not require any inventive skills (cf. D4, Figure 4; column 5, lines 41 to 55).

3.6 The appellant argued in this connection that the buffer layer of the device of document D4 was specifically designed for acting as an intermediary between the SiC substrate and an n-type GaN layer, and it would therefore not be expected that this buffer layer would be suitable for an AlGaIn cladding layer (cf. item VII(b) above).

The Board is not convinced by the above argument, since document D1 discloses an n-doped GaN layer 3 on the buffer layer 2 for the purpose of ensuring high quality

crystal growth of the light emitting AlGaN/GaN/AlGaN heterostructure (cf. paragraph 0008). Therefore, the skilled person would consider growing a corresponding GaN layer on the buffer layer of document D4 before the n-type AlGaN cladding layer is grown in order to ensure high quality crystal growth.

3.7 The arguments relating to problems of conduction across the buffer layer also do not convince the Board (cf. item VII(c) above), since as mentioned above, a skilled person seeking to apply the teaching of document D4 to the device of document D1 would deposit an n-type GaN layer on the buffer layer before growing the light-emitting double heterostructure. The buffer layer in the device of document D4 is designed to be positioned between a SiC substrate and a GaN layer and would therefore allow adequate current flow between the substrate and the GaN layer.

3.8 As to feature (b), an active layer made of GaN, the appellant pointed out that the peak wavelength of the emitted light from the device of document D1 is about 480 to 490 nm which is arguably in the blue-green spectrum of visible light. Therefore, the appellant argued, the skilled person seeking to produce a reliable blue-emitting LED would be deterred from making alterations to the structure of document D1 which may increase the wavelength, such as decreasing the aluminium content, thereby decreasing the bandgap, in the active layer (cf. item VII(d) above).

3.8.1 The band gap of GaN is about 3.4 eV (cf. application in suit, sentence bridging pages 3 and 4), whereas the peak emitted light of 490 nm corresponds to a photon

energy of 2.5 eV. It is also noted that in document D2 the same emission peak wavelength 490 nm is obtained as in document D1, by using an active layer made of compensated n-type $\text{In}_{0.14}\text{Ga}_{0.86}\text{N}$ doped with Si and Zn, a material which has a considerably smaller bandgap than $\text{Al}_{0.01}\text{Ga}_{0.99}\text{N}$ or GaN (cf. D2, Examples 19 and 20 in column 23). Therefore, the skilled person recognises from the above that the peak intensity of the emitted light emitted by the device of document D1 cannot be the result of band-to-band recombination but rather results from transitions between states induced by the dopants, zinc and silicon, defects or other impurities. Consequently, it would be expected that a slight change of the aluminium content in the active layer would have little or no effect on the peak wavelength of the emitted light.

Furthermore, since a GaN layer is less complicated to grow than an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer and document D1 discloses the alternative $x=0$ for the active layer, the skilled person would as a matter of routine consider replacing the $\text{Al}_{0.01}\text{Ga}_{0.99}\text{N}$ active layer of the device of document D1 with a corresponding layer made of GaN.

3.9 For the above reasons, in the Board's judgement, the subject matter of claim 1 according to the main request does not involve an inventive step within the meaning of Article 56 EPC.

4. *Inventive step - Auxiliary Request*

With respect to the main request, claim 1 according to the auxiliary request specifies that the doping densities of the layers of the double heterostructure

are about $2 \times 10^{18} \text{ cm}^{-3}$ for the n-type AlGa_N layer, between $1 \times 10^{18} \text{ cm}^{-3}$ and $4 \times 10^{18} \text{ cm}^{-3}$ for the active n-type compensated GaN layer, and about $1 \times 10^{19} \text{ cm}^{-3}$ for the p-type AlGa_N layer. In document D1, the net doping density of the compensated Al_{0.01}Ga_{0.99}N active layer is about 10^{19} cm^{-3} (cf. paragraph 0020). The doping densities for the cladding layers are not disclosed in document D1.

4.1 As held in the decision under appeal, the ranges specified in claim 1 for the cladding layers lie in the range which is known to be employed for the same type of device, as shown in document D2 (cf. D2, column 13, line 37 to column 14, line 14; Figure 9 and 10). Furthermore, document D1 discloses a very broad range for the net doping density of the active layer (10^{17} to 10^{22} cm^{-3}), where the optimum net doping density lies in a narrower range around 10^{19} cm^{-3} , i.e. close to the claimed range (cf. D1, Figure 1; paragraph [0014]). Therefore, the claimed doping densities are considered as falling within the ranges which would routinely be contemplated by the skilled person seeking to optimize the performance of a double heterostructure LED emitting blue light.

4.2 The Board is also not able to follow the argument that the skilled person would not consider the teaching of document D2 regarding suitable doping densities (cf. item VII(e) above), since document D2 discloses the same type of device as document D1, i.e. an LED having a double heterostructure made of gallium nitride-based materials formed on a sapphire substrate where the active layer is compensated n-type (cf. e.g. D2, abstract).

4.3 For the above reasons, therefore, the subject matter of claim 1 according to the auxiliary request does not involve an inventive step within the meaning of Article 56 EPC.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar:

The Chairman:

M. Patin

V. L. P. Frank