



(51) International Patent Classification:

H01S 5/028 (2006.01) C23C 14/56 (2006.01)

H01S 5/02 (2006.01) C30B 23/02 (2006.01)

H01S 5/323 (2006.01) C30B 29/48 (2006.01)

C23C 14/02 (2006.01) H01J 37/32 (2006.01)

(21) International Application Number:

PCT/EP2023/066794

(22) International Filing Date:

21 June 2023 (21.06.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

10 2022 118 351.3

22 July 2022 (22.07.2022)

DE

(71) Applicant: AMS-OSRAM INTERNATIONAL GMBH

[DE/DE]; Leibnizstraße 4, 93055 Regensburg (DE).

(72) Inventors: LANGER, Teresa; Am Bahndamm 7, 93173

Wenzenbach (DE). FUCHS, Peter; Zur Schönen Ge-

legenheit 1 A, 93047 Regensburg (DE). CHRZASCIEL,

Markus; Margaretenstraße 5, 93086 Woerth a.d. Donau

(DE). PUTZSCHKE, Solveig; Am Alten Pfarrhof 4, 84104

Rudelzhausen (DE).

(74) Agent: ENGELHARDT, Martin; c/o OSRAM GmbH,

Marcel-Breuer-Str. 4, 80807 München (DE).

(81) Designated States (unless otherwise indicated, for every

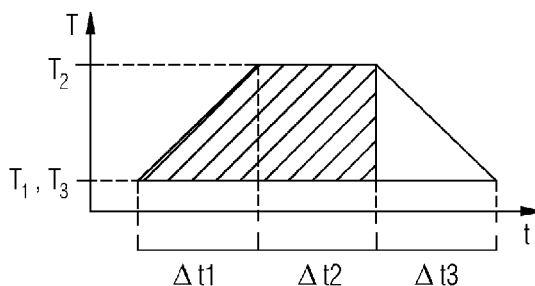
kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every

kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: METHOD FOR MANUFACTURING AN EDGE EMITTING SEMICONDUCTOR LASER DIODE

FIG 9



(57) Abstract: A method for manufacturing an edge emitting semiconductor laser diode comprising the following steps is provided: - providing an edge emitting semiconductor body (2) configured for generating electromagnetic laser radiation during operation in a chamber (12), the edge emitting semiconductor body (2) having two opposite facets (4, 4', 4''), - raising a temperature (T) of the edge emitting semiconductor body (2) from a first temperature (T1) to a second temperature (T2) during a first time interval (Δt_1), - treating the edge emitting semiconductor body (2) with the second temperature (T2) during a second time interval (Δt_2), - treating the edge emitting semiconductor body (2) with an ion plasma (16) in the chamber (12) during the first time interval (Δt_1) and the second time interval (Δt_2).

Published:

— *with international search report (Art. 21(3))*

- 1 -

Description

METHOD FOR MANUFACTURING AN EDGE EMITTING SEMICONDUCTOR LASER
DIODE

5

A method for manufacturing an edge emitting semiconductor laser diode is provided.

10 An improved method for manufacturing an edge emitting semiconductor laser diode is to be provided. In particular, an improved cleaning process for the facets of an edge emitting semiconductor laser diode is to be provided.

15 This problem is solved by a method with the method steps of claim 1.

Further developments and embodiments of the method are given in the dependent claims.

20 According to an embodiment of the method for manufacturing an edge emitting semiconductor laser diode, an edge emitting semiconductor body is provided in a chamber. In particular, the chamber has a closed volume, wherein a vacuum can be generated. The edge emitting semiconductor body is configured
25 for generating electromagnetic laser radiation during operation. In particular, the edge emitting semiconductor body comprises or consists of a semiconductor layer sequence having an active region, the active region being configured for generating electromagnetic radiation during operation of
30 the edge emitting semiconductor laser diode. Further, the edge emitting semiconductor body has two opposite facets. The facets are formed from side faces of the edge emitting semiconductor body. Further, the facets are arranged at two

opposite side faces of the edge emitting semiconductor body. The facets are perpendicular to a main extension plane of the active region. Over one facet, electromagnetic laser radiation is emitted by the edge emitting semiconductor laser diode during operation.

The facets, for example covered with a highly reflective coating on one facet and an antireflective coating on the other facet, form a resonator for the electromagnetic laser radiation. In particular, the active region acts as a laser active medium and is arranged within the resonator.

In the active region population inversion is generated in conjunction with the resonator during operation of the edge emitting semiconductor laser diode. Due to the population inversion, the electromagnetic radiation is generated in the active region by stimulated emission, which leads to the formation of electromagnetic laser radiation. Due to the generation of the electromagnetic laser radiation by stimulated emission, the electromagnetic laser radiation usually has a high coherence length, a narrow emission spectrum and/or a high degree of polarization, compared to electromagnetic radiation generated by spontaneous emission.

According to a further embodiment of the method, a temperature of the edge emitting semiconductor body is raised from a first temperature to a second temperature during a first time interval. For example, the temperature is raised from the first temperature to the second temperature continuously. In particular, a raise of the temperature from the first temperature to the second temperature is constant.

According to a further embodiment of the method, the edge emitting semiconductor body is treated with the second temperature during a second time interval. Particularly, the second temperature is constant during the second time interval as far as possible. However, it is possible that the second temperature unintentionally varies slightly due to process variations. For example, the variation of the second time interval does not exceed 3%, preferably 1%. Preferably, the second time interval immediately follows the first time interval.

According to a further embodiment of the method, an ion plasma is ignited in the chamber before or during the first time interval. Particularly, the ion plasma burns continuously during the whole first time interval and the whole second interval. For example, the ion plasma comprises or consists of hydrogen ions.

According to a further embodiment of the method, the edge emitting semiconductor body is treated with an ion plasma in the chamber during the first time interval and the second time interval. In other words, the edge emitting semiconductor body is treated with ion plasma not only when the second temperature is achieved by heating the edge emitting semiconductor body but also during heating the edge emitting semiconductor body to the second temperature. For example, the edge emitting semiconductor body is treated with ion plasma during the whole heating step. In such a way cleaning of the facets of the edge emitting semiconductor body can be improved.

According to a further embodiment of the method, at least one of the facets is cleaned by the ion plasma such that at least

- 4 -

one cleaned facet is achieved. In other words, cleaning of one or both facets takes place during burning of the ion plasma. Preferably, both facets are cleaned during the burning of the ion plasma. In particular, during cleaning of the facets by the ion plasma, impurities and contaminations are removed from one or both facets. Preferably, oxides are removed during cleaning.

According to a preferred embodiment, the method comprises the following steps:

- providing an edge emitting semiconductor body configured for generating electromagnetic laser radiation during operation in a chamber, the edge emitting semiconductor body having two opposite facets,
- raising a temperature of the edge emitting semiconductor body from a first temperature to a second temperature during a first time interval,
- treating the edge emitting semiconductor body with the second temperature during a second time interval,
- treating the edge emitting semiconductor body with an ion plasma in the chamber during the first time interval and the second time interval.

Preferably, the method steps given above are carried out in the given order.

Preferably, a plurality of edge emitting semiconductor bodies is treated in the same manner. In other words, the method is a batch process wherein the same method steps are carried out at several edge emitting semiconductor bodies in parallel. At present, the method steps are often described for only one edge emitting semiconductor body in singular for the sake of simplicity.

According to a further embodiment of the method, the ion plasma burns continuously during the first time interval and the second time interval. Particularly, the ion plasma
5 impinges continuously the facets of the edge emitting semiconductor body during the first time interval and the second time interval.

According to a further embodiment of the method, the
10 temperature of the edge emitting semiconductor body is lowered from the second temperature to a third temperature during a third time interval. Particularly, the third time interval follows the second time interval, preferably immediately. In particular, there is no further time interval
15 between the second time interval and the third time interval. For example, a decrease of temperature during the third time interval is constant. For example, the temperature decreases continuously down to the third temperature.

20 According to a further embodiment of the method, the decrease of temperature during the third time interval is between 2 °C/min and 40 °C/min, limits inclusive.

According to a further embodiment of the method, the ion
25 plasma is extinguished after the second time interval, particularly preferably immediately after the second time interval. In particular, the ion plasma does not burn during the third time interval when the temperature of the edge emitting semiconductor body is lowered from the second
30 temperature to the third temperature in this embodiment of the method. In this embodiment of the method, the edge emitting semiconductor body is not treated with the ion

plasma during the third time interval, when cooling of the edge emitting semiconductor body takes place.

Alternatively, it is also possible that the ion plasma is extinguished after the third time interval, particularly preferably immediately. In other words, the ion plasma burns in this embodiment of the method during the first time interval, the second time interval and the third time interval, preferably continuously.

According to a further embodiment of the method, a passivation layer is deposited on the facet, in particular after the second time interval or the third time interval. In other words, the passivation layer is deposited after cleaning the facet by the help of the ion plasma during the first time interval and the second time interval and optionally during the third time interval.

For example, the passivation layer is deposited by epitaxial growth on the facet. Particularly preferably, the passivation layer is in direct contact with the facet and covers the facet completely. Particularly, the passivation layer is grown on both facets of the edge emitting semiconductor body. For example, the passivation layer comprises or consists of ZnSe. For example, the passivation layer has a thickness between 10 nanometer and 100 nanometer, limits included.

According to a further embodiment of the method, the edge emitting semiconductor body is based on an arsenide compound semiconductor material. For example, the edge emitting semiconductor body comprises or consists of one or more arsenide compound semiconductor materials. Arsenide compound semiconductor materials are compound semiconductor materials

containing arsenic, such as the materials from the system $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{As}$ with $0 \leq x \leq 1$, $0 \leq y \leq 1$ and $x+y \leq 1$. In particular, an active region based on an arsenide compound semiconductor material generates electromagnetic radiation of the infrared spectral range.

According to a further embodiment of the method, the facet of the edge emitting semiconductor body comprises AlGaAs or consists of AlGaAs. In particular, if the edge emitting semiconductor body is based on an arsenide compound semiconductor material, the facet of the edge emitting semiconductor body comprises or consists of AlGaAs.

According to a further embodiment of the method, an oxide content of the facet is lowered. Particularly preferably, the facet is free of an oxide, in particular free of an oxide of As, such as As_2O_3 , of an oxide of Al and/or of an oxide of Ga. In particular, As_2O_3 exists at the facet, if the facet comprises or consists of AlGaAs. Particularly, oxides are removed by cleaning the facets with the ion plasma during the first time interval and the second time interval. Removing oxides from the facets particularly avoids a burning of the oxides within the facets during cleaning. Further, by removal of the oxides from the facets the oxygen content of the facet is reduced leading to less crystal defects in the vicinity of the active region.

For example, the facets are generated by cleaving adjacent edge emitting semiconductor bodies being part of a wafer. If the facets are exposed to ambient air after cleaving oxidation of the facets takes place such that oxides, for example As_2O_3 in the case of an edge emitting semiconductor body based on an arsenide compound semiconductor material, is

formed. Before further coatings, such as a passivation layer and/or a highly reflective coating and/or an antireflective coating are deposited, the oxide content has to be reduced in order to achieve high quality coatings and to ensure maximum passivation of dangling bonds at the semiconductor surface and to achieve improved interfaces. Particularly, the passivation layer has preferably crystal quality, if an oxide content is lowered before deposition of the passivation layer.

The method is based on the idea that for cleaning the facets with an ion plasma, the plasma burns already during heating the edge emitting semiconductor body to a process temperature and not only during a time interval with the process temperature. In such a way the cleaning can be enhanced and process time can be reduced. In particular, the oxide content of the facets is lowered by the method such that a passivation layer can be deposited on the facets with improved quality. Further, a high hydrogen pressure of the ion plasma might generate a back pressure and might avoid outgassing of material of the facet and also serves as protective gas to prevent oxidation during the first and the second time interval and, optionally, also during the third time interval in case of burning ion plasma.

According to a further embodiment of the method, the second temperature is between 250 °C and 500 °C, limits inclusive.

According to a further embodiment of the method, a duration of the second time interval does not exceed 100 minutes.

According to a further embodiment of the method, a raise of temperature during the first time interval is between 2 °C/min and 40 °C/min, limits inclusive.

- 5 According to a further embodiment of the method, the first temperature and/or the third temperature is between 50 °C and 200 °C, limits inclusive.

According to a further embodiment of the method, the edge
10 emitting semiconductor body is arranged such in the chamber that one facet faces away from an ion plasma source generating the ion plasma and the other facet faces the ion plasma source during treatment with the ion plasma. With the method it is possible to waive a flipping of the edge
15 emitting semiconductor laser body such that both facets face the ion plasma source during the treatment with the ion plasma for cleaning. This is possible due to the high efficiency of cleaning since the ion plasma already burns during heating the edge emitting semiconductor body to the
20 second temperature. In such a way process time can be reduced.

According to a further embodiment of the method, an antireflective coating being antireflective for the
25 electromagnetic laser radiation is deposited on the facet that faces the ion plasma source during treatment. In particular, the antireflective coating reflects at most 5 % of the electromagnetic radiation of the active region, preferably at most 2 % of the electromagnetic radiation of
30 the active region, particularly preferably at most 0,2 % of the electromagnetic radiation of the active region or at most 0,1 % of the electromagnetic radiation of the active region.

Further, a highly reflective coating being highly reflective for the electromagnetic laser radiation is deposited on the other facet that faces away from the ion plasma source during treatment. In particular, the highly reflective coating
5 reflects at least 90%, preferably at least 95%, particularly preferably at least 98% of the electromagnetic radiation of the active region.

In particular, the edge emitting semiconductor laser diode
10 manufactured by the method is an infrared high power laser.

The edge emitting semiconductor laser diode can, for example, be used for cutting, welding, soldering, hair removal or for defense purposes.

15

Further advantageous embodiments and developments of the method result from the exemplary embodiments described below in connection with the Figures.

20 Figure 1 shows a flow diagram of a method for manufacturing a semiconductor edge emitting laser diode according to an exemplary embodiment.

Figures 2 to 8 show schematically different stages of the
25 method of the exemplary embodiment of Figure 1.

Figure 9 shows schematically a temperature profile and an ion plasma profile during the method of the exemplary embodiment of Figure 1.

30

Figure 10 shows a flow diagram of a method for manufacturing a semiconductor edge emitting laser diode according to a further exemplary embodiment.

Figure 11 shows schematically a temperature profile and an ion plasma profile during a method of a further exemplary embodiment.

5

Figure 12 shows measurements of the optical output dependent on operation time of several edge emitting laser diodes manufactured with a common method.

10 Figure 13 shows measurements of the optical output dependent on operation time of several edge emitting laser diodes manufactured with a method according to an exemplary embodiment.

15 Figure 14 shows XRD-spectra of test samples cleaned with a method according to an exemplary embodiment before covered with a ZnSe passivation layer as well as a XRD-spectrum of test samples cleaned with a common method before covered with a ZnSe passivation layer.

20

Figure 15 shows a Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) analyses of a test sample cleaned with common methods before covered with a ZnSe passivation layer and cleaned with a method according to an exemplary
25 embodiment before covered with a ZnSe passivation layer.

Equal or similar elements as well as elements of equal function are designated with the same reference signs in the Figures. The Figures and the proportions of the elements
30 shown in the Figures are not regarded as being shown to scale. Rather, single elements, in particular layers, can be shown exaggerated in magnitude for the sake of better presentation and/or better understanding.

During the method of the exemplary embodiment of Figures 1 to 9, a wafer 1 comprising a plurality of edge emitting semiconductor bodies 2 is singulated in a first step S1 into
5 separate edge emitting semiconductor bodies 2 by cleaving in clean room air along separation lines 3 (Figure 2). By the cleaving facets 4 of the edge emitting semiconductor bodies are generated.

10 Figure 3 shows schematically a sectional view of an edge emitting semiconductor body 2 after cleaving. The edge emitting semiconductor laser body 2 comprises an epitaxial semiconductor layer sequence 5 with an active region 6 configured to generate electromagnetic radiation during
15 operation. On each of two opposite main surfaces of the epitaxial semiconductor layer sequence 5 an electrical contact layer 9 is deposited.

Side faces 10 of the edge emitting semiconductor bodies are
20 formed by the facets 4 generated by cleaving. The facets 4 are perpendicular to a main extension plane of the edge emitting semiconductor body 2.

The edge emitting semiconductor body 2 comprises a resonator
25 7 formed by the opposing facets 4. The resonator 7 has an optical axis 8 parallel to a main extension plane of the active region 6 and further perpendicular to the facets 4 of the edge emitting semiconductor body 2.

30 The edge emitting semiconductor body 2 of the present exemplary embodiment is based on an arsenide compound semiconductor material. In particular, the active region 6

- 13 -

comprises AlGaAs. After cleaving, oxides 11 are formed at the facets 4 by oxidation in clean room air.

In a next step S2, the singulated edge emitting semiconductor bodies 2 are transferred to a molecular beam epitaxy ultra-high vacuum plasma chamber 12 at a first temperature T1. For example, the first temperature T1 is about 150 °C. The first temperature T1 is also a transfer temperature at which the edge emitting semiconductor bodies can be transferred in the molecular beam epitaxy ultra-high vacuum plasma chamber 12.

The edge emitting semiconductor bodies 2 are fixed in a holder 13 with ring-like geometry. The holder 13 is in physical and/or radiation contact with a heater 14 configured for heating the edge emitting semiconductor bodies 2. Further, an ion plasma source 15 is provided in the chamber 12. The ion plasma source 15 is configured to produce an ion plasma 16 during operation. At present, the ion plasma source 15 produces a hydrogen ion plasma. The edge emitting semiconductor bodies 2 are arranged such in the chamber 12 that facets 4' faces the ion plasma source 15 while the other facets 4'' faces away from the ion plasma source 15 (Figure 4).

In a next step S3, the edge emitting semiconductor bodies 2 are heated during a first time interval Δt_1 by the heater 14 from the first temperature T1 of about 150 °C to a second temperature T2 of about 400 °C. During the first time interval Δt_1 , when the temperature of the edge emitting semiconductor bodies 2 is raised from the first temperature T1 to the second temperature T2, the ion plasma source 15 is ignited such that during the whole first time interval Δt_1 and the whole second time interval Δt_2 an ion plasma 16 is

- 14 -

present in the chamber 12. The ion plasma 16 cleans the edge emitting semiconductor bodies 2 and particularly the facets 4.

5 In a next step S4, the ion plasma 16 is extinguished within the chamber 12 and the edge emitting semiconductor bodies 2 are cooled down in a further step S5 to a third temperature T3 of about 150 °C during a third time interval Δt_3 . At present, the third temperature T3 is also the transfer
10 temperature.

In a next step S6, the edge emitting semiconductor bodies 2 are transferred to a flipping chamber, wherein the edge emitting semiconductor bodies 2 are flipped by rotating the
15 ring-shaped holder and transferred to the molecular beam epitaxy ultra-high vacuum plasma chamber 12 again (not shown). Due to the flipping of the edge emitting semiconductor bodies 2 in the ring-shaped holder 13, the facets 4'' facing away from the ion plasma source 15 during
20 steps S3, S4 and S5 now face the ion plasma source 15 (Figure 5).

Then, in step S7 steps S3 to S5 are repeated as already described.

25

Figure 6 shows schematically a sectional view of the edge emitting semiconductor body 2 after method step S7 of the method of the flow diagram of Figure 1. Compared to the edge emitting semiconductor body 2 of Figure 3 the facets 4 are
30 cleaned and in particular mostly free of oxides 11.

After cooling the edge emitting semiconductor bodies 2 to the third temperature T3 of about 150 °C in the second step S5

- 15 -

the edge emitting semiconductor bodies 2 are transferred to a growth chamber in step S8 (not shown).

5 In a further step S9, a passivation layer 17 comprising or consisting of ZnSe is deposited on the facets 4 of the edge emitting semiconductor bodies 2, which are intended to be covered with an antireflective coating 18 in step S12.

10 Then, in step S10 the edge emitting semiconductor bodies 2 are transferred to the flipping chamber wherein the edge emitting semiconductor bodies 2 are flipped such that facets 4 are accessible which are to be covered in step S13 with a highly reflective coating 19.

15 In a next step S11, a passivation layer 17 comprising or consisting of ZnSe is grown on the facets 4 to be covered with a highly reflective coating 19 in step S13. The ZnSe passivation layer 17 is deposited on the facets 4 by epitaxial growth.

20

Figure 7 shows schematically a sectional view of an edge emitting semiconductor body 2 after process step S11. On both facets 4 a passivation layer 17 comprising or consisting of ZnSe is deposited in direct contact with the epitaxial semiconductor layer sequence 5. The passivation layer 17 covers the facets 4 preferably completely.

25

In a next step S12, an antireflective coating 18 is deposited on one of the facets 4 in direct contact with the passivation layer 17.

30

- 16 -

In a further step S13, a highly reflective coating 19 is deposited on the other facet 4 also in direct contact with the passivation layer 17.

5 Figure 8 shows schematically a sectional view of an edge emitting semiconductor body 2 after the process step S13. In direct contact with the passivation layer 17 over one of the facets 4 an antireflective coating 18 being antireflective for the electromagnetic laser radiation generated within the
10 active region 6 is applied. On the other facet 4 a highly reflective coating 19 is applied on the passivation layer 17. The highly reflective coating 19 is highly reflective for the electromagnetic radiation of the active region 6.

15 Figure 9 shows schematically a temperature profile of the edge emitting semiconductor bodies 2 during process steps S3, S4 and S5 of the method according to the flow diagram of Figure 1. When the edge emitting semiconductor bodies 2 are provided within the chamber 12 comprising the ion plasma
20 source 15, the edge emitting semiconductor bodies 2 have a first temperature T_1 which corresponds at present to the transfer temperature of about 150 °C.

During a first time interval Δt_1 the edge emitting
25 semiconductor bodies 2 are heated to a second temperature T_2 of about 400 °C. In other words, the temperature T of the edge emitting semiconductor bodies 2 is raised to a second temperature T_2 during the first time interval Δt_1 , particularly preferably in a continuous manner. After heating
30 the edge emitting semiconductor bodies 2 to the second temperature T_2 , the temperature T of the edge emitting semiconductor bodies 2 is kept constant at the second temperature T_2 during a second time interval Δt_2 .

After the second time interval Δt_2 a third time interval Δt_3 follows immediately. During the third time interval Δt_3 the temperature T of the edge emitting semiconductor bodies 2 is decreased to a third temperature T_3 . At present, the third temperature T_3 is the transfer temperature of about 150 °C.

As indicated in Figure 9 by the shaded areas the ion plasma source 15 is ignited with starting raising the temperature T and the ion plasma 16 burns within the chamber 12 during the first time interval Δt_1 and the second time interval Δt_2 continuously.

During the method of the flow diagram of Figure 10, steps S1, S2 and S3 are carried out as already described in connection with Figure 1. Compared to the method of the exemplary embodiment of Figure 1 steps S5 and S4 are interchanged. In other words, according to the method of the flow diagram of Figure 10, the edge emitting semiconductor bodies 2 are cooled down to a third temperature T_3 , which is the transfer temperature of about 150 °C, before extinguishing the ion plasma 16. Therefore, the ion plasma 16 burns also during the third time interval Δt_3 , wherein the temperature T of the edge emitting semiconductor bodies 2 is decreased to the third temperature T_3 and not only during the first time interval Δt_1 and the second time interval Δt_2 .

Further, the method according to the flow diagram of Figure 10 does not comprise the steps S6 and S7. In other words, during the method of the flow diagram of Figure 10 the edge emitting semiconductor bodies 2 are not flipped such that all facets 4 face the ion plasma source 15 for cleaning.

However, steps S8 to S13 are carried out as already described in connection with the flow diagram of Figure 1.

In particular, with the method according to the flow diagram of Figure 10 a flipping of the edge emitting semiconductor bodies 2 can be avoided, since cleaning is improved. In particular, the facets 4 of the edge emitting semiconductor bodies 2 facing away from the ion plasma source 15 are cleaned efficiently such that flipping does not have to be carried out.

Figure 11 shows the temperature profile during the method of the flow diagram of Figure 10. Compared to Figure 9, the ion plasma 16 also burns during decreasing the temperature T of the edge emitting semiconductor bodies from the second temperature T2 to the third temperature T3.

For example, the temperature increase ΔT during the first time interval Δt_1 and the temperature decrease ΔT during the third time interval Δt_3 is about 20 °C/min. The second time interval T2 has for example a duration of about 50 minutes.

Figure 12 shows results of lifetime tests of edge emitting semiconductor laser diodes produced with a common method. During this method the ion plasma source 15 only produces ion plasma 16 during the second time interval Δt_2 , while the ion plasma 16 is extinguished during the first time interval Δt_1 and the third time interval Δt_3 . The edge emitting semiconductor laser diodes used for the lifetime test emitted electromagnetic laser radiation with a wavelength of about 920 nanometer. Further, a width of the resonator 7 of the edge emitting semiconductor laser diodes was about 200

micrometer and a length of the resonator 7 was about 4 millimeter.

In order to stress the edge emitting semiconductor laser diodes for simulating a whole lifetime, the edge emitting semiconductor laser diodes were driven under extreme overstress conditions with a very high electric current of about 29 A to 30 A.

10 The electrical output power P was measured of several edge emitting semiconductor laser diodes in dependency of the time t . As can be seen from Figure 12 showing the relative optical output power P in dependency of the operation time t , the output power P of the edge emitting semiconductor laser
15 diodes drops significantly after about 400 hours of operation. Therefore, edge emitting semiconductor laser diodes produced with a common method wherein the ion plasma
16 is only burning during the second time interval Δt_2 have a lifetime of about 400 hours under extreme overstress
20 conditions.

Figure 13 shows results of the same lifetime test of edge emitting semiconductor laser diodes produced with a method according to the exemplary embodiment of Figure 1. In other
25 words, the ion plasma 16 was also burning during the first time interval Δt_1 when the temperature T of the edge emitting semiconductor bodies 2 is raised to the second temperature T_2 and not only during the second time interval Δt_2 when the temperature T of the edge emitting
30 semiconductor bodies is kept constant at an elevated second temperature T_2 .

It can be seen from Figure 13 that the lifetime of the edge emitting semiconductor laser diodes produced with a method according to the flow diagram of Figure 1 is about 2500 hours for the same overstress conditions as the reference devices of Figure 12. Therefore, the present disclosed manufacturing method improves lifetime of the edge emitting semiconductor laser diodes significantly.

In order to investigate cleaning properties of the present method, measurements at test samples were performed. As test samples wafers were used having a surface of AlGaAs with an aluminum content of 2% to 40%. The surface of these test samples was covered with a ZnSe passivation layer 17 after cleaning the surface with the method described herein.

Figure 14 shows an x-ray diffraction diagram (XRD) of a test sample covered with the ZnSe passivation layer 17. The diagram shows the intensity I of the x-rays dependent on the special angle 2θ . Particularly, the diagram shows the peak resulting from the ZnSe of the passivation layer 17. This peak is indicated by a dotted circle in Figure 14.

In Figure 14, there are different XRD measurements shown. Curves C1 and C2 show the XRD-measurement at a test sample cleaned by a common method only during the second time interval Δt_2 . The second time interval Δt_2 of curve C1 had a duration of about 25 minutes, while the second time interval of curve C2 had a prolonged duration of 75 minutes. During both common methods the ion plasma 16 was only burning during the second time interval Δt_2 and not during heating and/or cooling of the edge emitting semiconductor bodies 2.

Further, Figure 14 shows curve C3 of a test sample cleaned by a method according to an exemplary embodiment, wherein the ion plasma 16 was not only burning during the second time interval Δt_2 with substantially constant second temperature T2, but also during the first time interval Δt_1 and the third time interval Δt_3 , hence during heating and cooling. It can be seen from Figure 14 that the ZnSe peak of the test sample cleaned with the present method is increased indicating a high crystal quality of the ZnSe-passivation layer 17.

Figure 15 shows ToF-SIMS analyses of test samples based on an AlGaAs semiconductor compound material, the surface of the test samples being covered with a ZnSe passivation layer 17. On the left axis the counts corresponding C, O₂ and H are shown (straight lines) while on the right axis the counts corresponding to O (dotted line) are applied.

Test samples were analyzed, wherein the AlGaAs-surface were cleaned with a common method before deposition of a ZnSe passivation layer 17 (left and middle values). During the common method the ion plasma 16 was only burning during the second time interval Δt_2 and not during the first time interval Δt_1 and the third time interval Δt_3 . The second time interval Δt_2 of the left values (circles) were 25 minutes and the second time interval Δt_2 of the middle values was 75 minutes (squares).

Further, Figure 15 shows values of test sample cleaned with an ion plasma 16 burning during the first time interval Δt_1 and the second time interval Δt_2 (right values, stars). A raise of temperature ΔT during the first time interval Δt_1

was 5 °C/min, while the duration of the first time interval Δt_1 together with the second time interval Δt_2 was 50 minutes. It can be seen that C, O₂, H and O at the interface ZnSe/AlGaAs are strongly reduced by the disclosed method.

5

The invention is not limited to the description of the embodiments. Rather, the invention comprises each new feature as well as each combination of features, particularly each combination of features of the claims, even if the feature or
10 the combination of features itself is not explicitly given in the claims or embodiments.

References

	1	wafer
	2	edge emitting semiconductor body
5	3	separation line
	4, 4', 4''	facet
	5	epitaxial semiconductor layer sequence
	6	active region
	7	resonator
10	8	optical axis
	9	electrical contact layer
	10	side face
	11	oxide
	12	chamber
15	13	holder
	14	heater
	15	ion plasma source
	16	ion plasma
	17	passivation layer
20	18	antireflective coating
	19	highly reflective coating
	T1	first temperature
25	Δt_1	first time interval
	T2	second temperature
	Δt_2	second time interval
	T3	third temperature
	Δt_3	third time interval
30	ΔT	temperature increase/decrease

Claims

1. Method for manufacturing an edge emitting semiconductor laser diode comprising the steps:

- 5 - providing an edge emitting semiconductor body (2) configured for generating electromagnetic laser radiation during operation in a chamber (12), the edge emitting semiconductor body (2) having two opposite facets (4, 4', 4''),
- 10 - raising a temperature (T) of the edge emitting semiconductor body (2) from a first temperature (T1) to a second temperature (T2) during a first time interval (Δt_1),
- treating the edge emitting semiconductor body (2) with the second temperature (T2) during a second time interval (Δt_2),
- 15 - treating the edge emitting semiconductor body (2) with an ion plasma (16) in the chamber (12) during the first time interval (Δt_1) and the second time interval (Δt_2).

2. Method according to the previous claim, wherein

- 20 at least one of the facets (4, 4', 4'') is cleaned by the ion plasma (16) such that at least one cleaned facet (4, 4', 4'') is achieved.

3. Method according to any of the previous claims, wherein

- 25 the ion plasma (16) burns continuously during the first time interval (Δt_1) and the second time interval (Δt_2).

4. Method according to any of the previous claims, wherein

- after the second time interval (Δt_2), the temperature (T) of
- 30 the edge emitting semiconductor body (2) is lowered from the second temperature (T2) to a third temperature (T3) during a third time interval (Δt_3).

5. Method according to the previous claim, wherein a decrease of temperature T during the third time interval (Δt_3) is between 2 °C/min and 40 °C/min, limits inclusive.

5

6. Method according to any of the previous claim, wherein the ion plasma (16) is extinguished after the second time interval (Δt_2).

10 7. Method according to claim 4 to 5, wherein the ion plasma (16) is extinguished after the third time interval (Δt_3).

8. Method according to any of the previous claims, wherein a passivation layer (17) is deposited on the facet (4, 4', 15 4'').

9. Method according to the previous claim, wherein the passivation layer (17) comprises ZnSe.

20 10. Method according to any of the previous claims, wherein the edge emitting semiconductor body (2) is based on an arsenide compound semiconductor material.

11. Method according to any of the previous claims, wherein 25 the facet (4, 4', 4'') of the edge emitting semiconductor body (2) comprises AlGaAs.

12. Method according to any of the previous claims, wherein an oxide content of the facet (4, 4', 4'') is lowered.

30

13. Method according to any of the previous claims, wherein the second temperature (T_2) is between 250 °C and 500 °C, limits inclusive.

14. Method according to any of the previous claims, wherein a duration of the second time interval (Δt_2) does not exceed 100 minutes.

5

15. Method according to any of the previous claims, wherein a raise of temperature (T) during the first time interval (Δt_1) is between 2 °C/min and 40 °C/min, limits inclusive.

10 16. Method according to any of the previous claims, wherein the first temperature (T1) and/or the third temperature (T3) is between 50 °C and 200 °C, limits inclusive.

15 17. Method according to any of the previous claims, wherein the edge emitting semiconductor body (2) is arranged such in the chamber (12) that one facet (4, 4', 4'') faces away from an ion plasma source (15) generating the ion plasma (16) and the other facet (4, 4', 4'') faces the ion plasma source (15) during treatment with the ion plasma (16).

20

18. Method according to the previous claim, wherein
- an antireflective coating (18) being antireflective for the electromagnetic laser radiation is deposited on the facet (4, 4', 4'') that faced the ion plasma source (15) during
25 treatment, and

- a highly reflective coating (19) being highly reflective for the electromagnetic laser radiation is deposited on the other facet (4, 4', 4'') that faced away from the ion plasma source (16) during treatment.

FIG 1

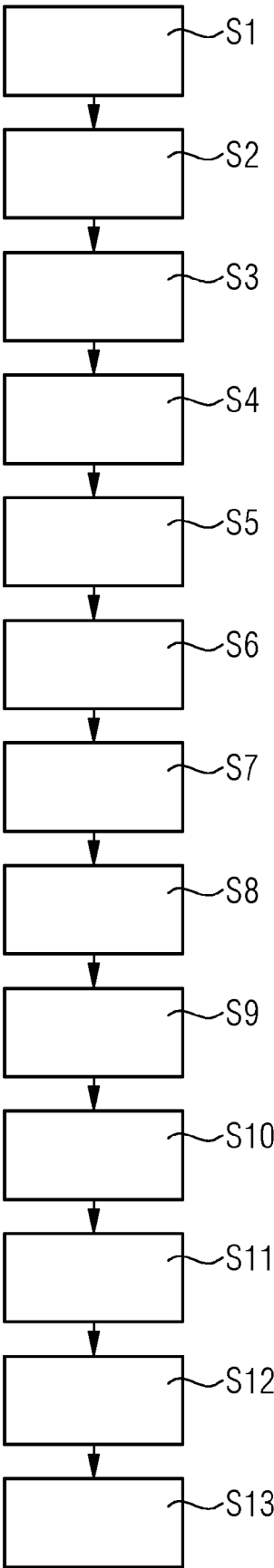


FIG 2

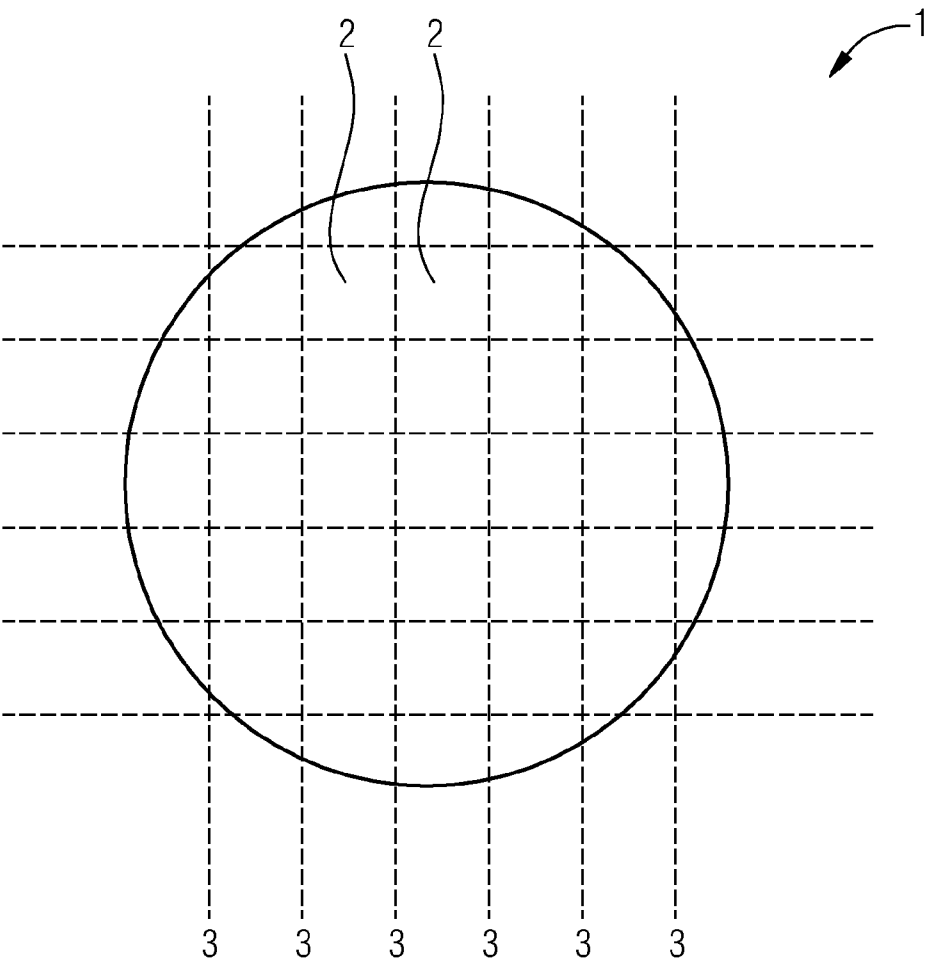


FIG 3

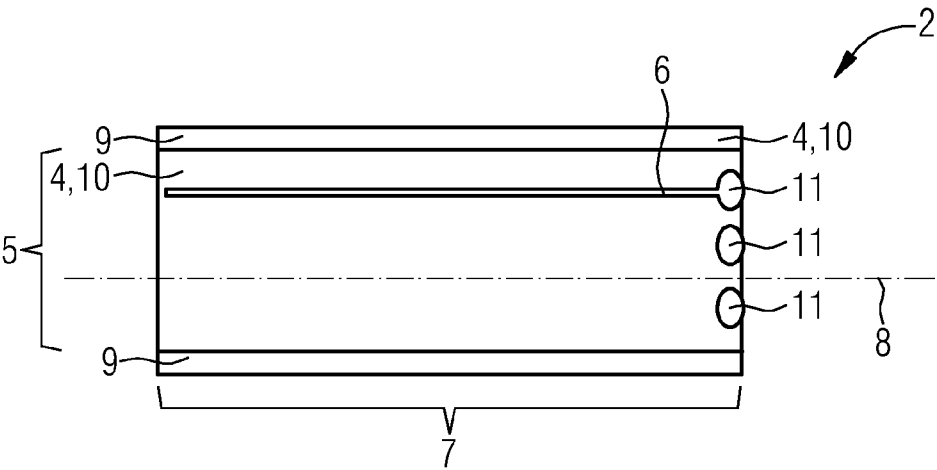


FIG 4

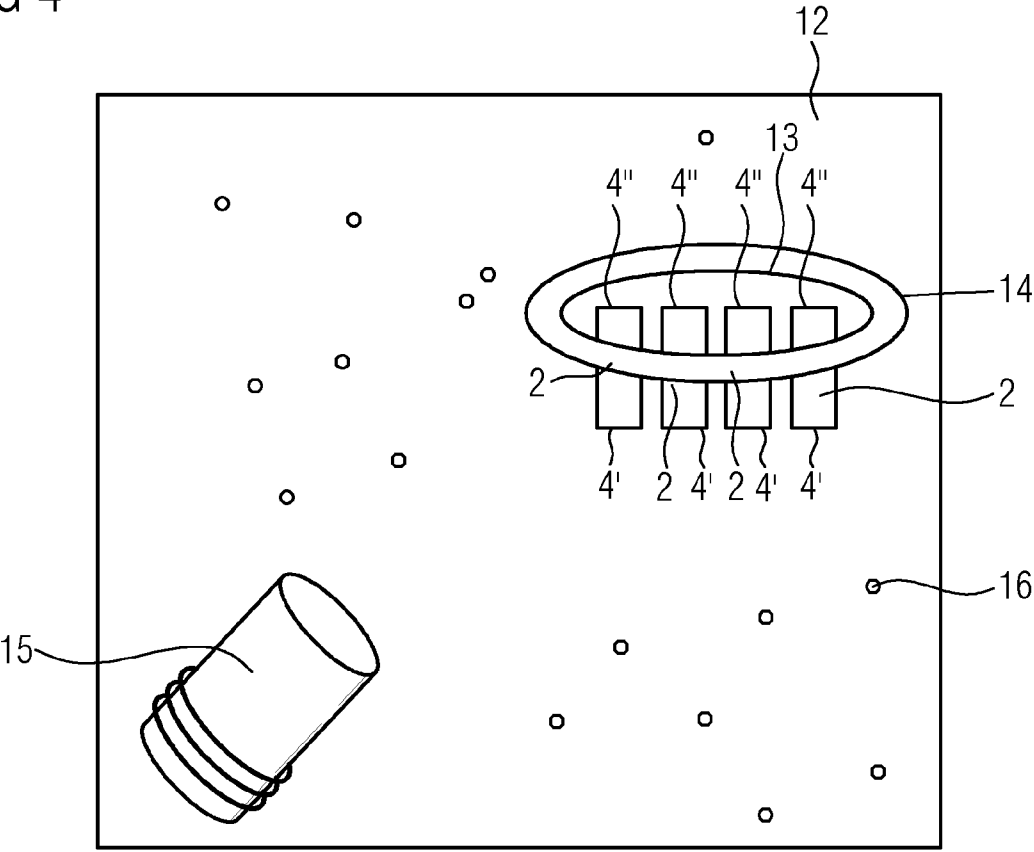


FIG 5

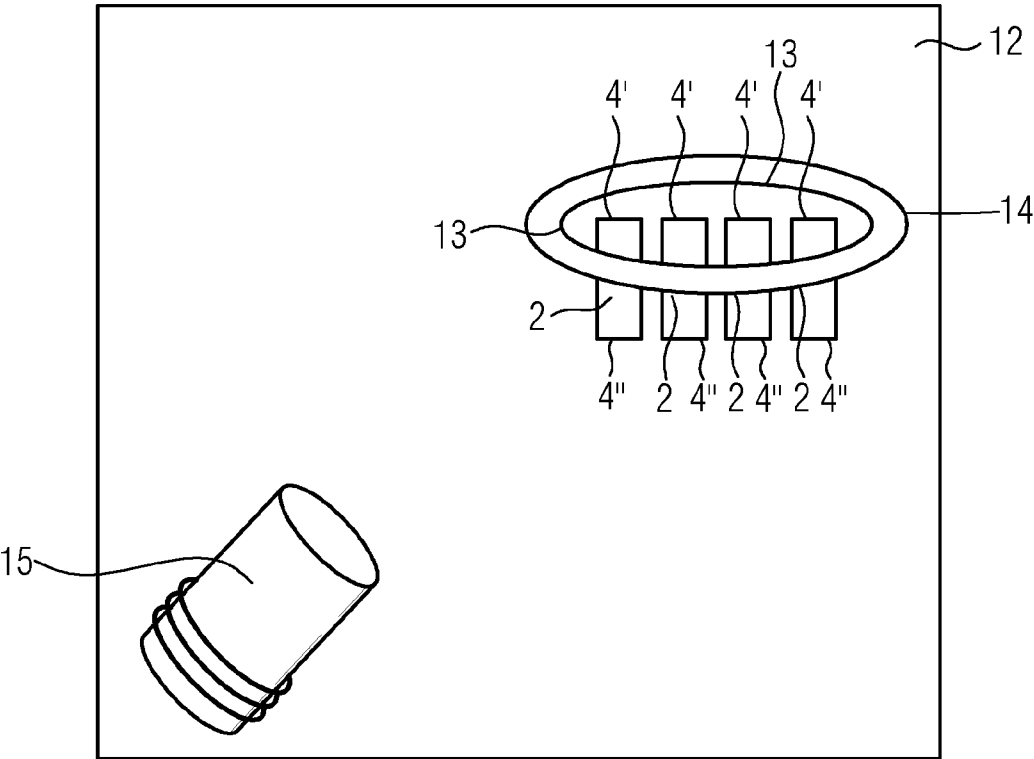


FIG 6

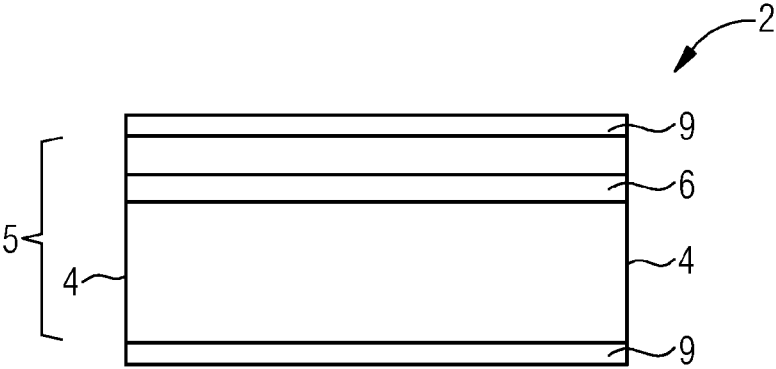


FIG 7

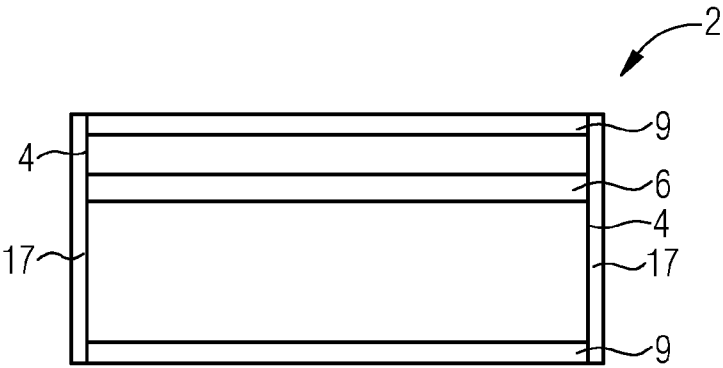


FIG 8

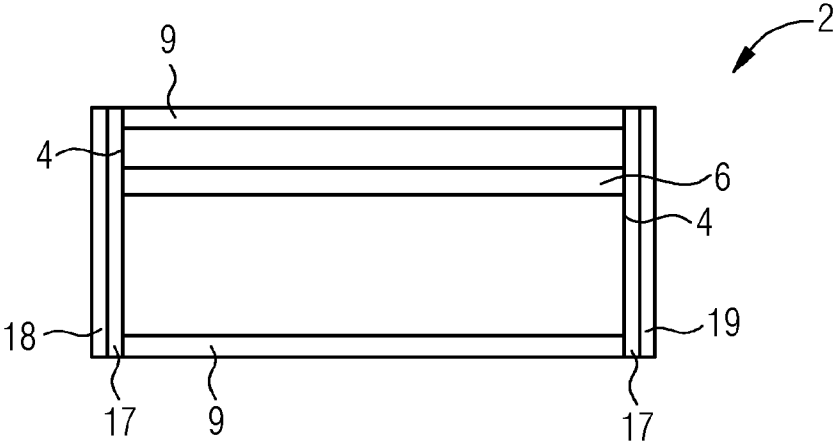


FIG 9

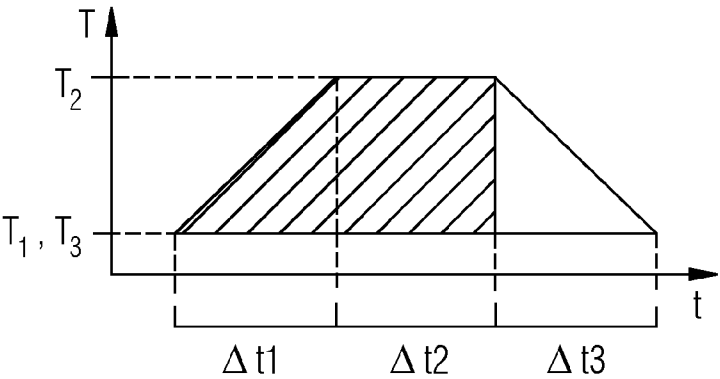


FIG 10

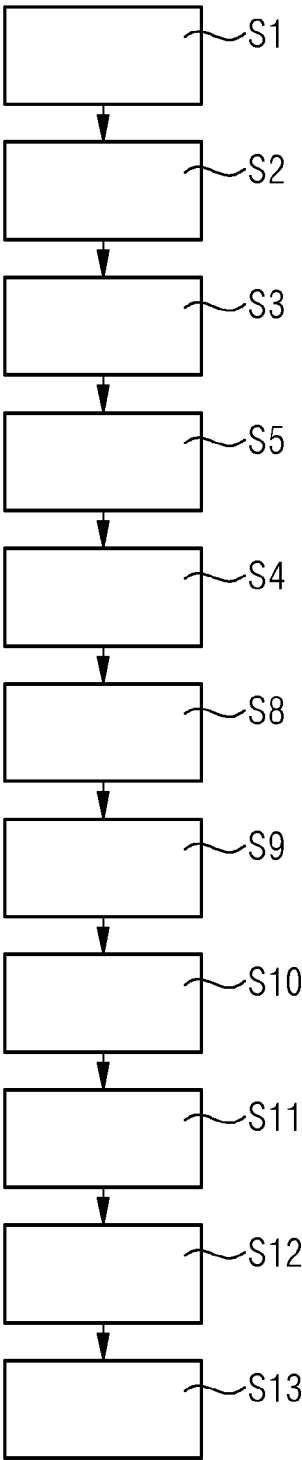


FIG 11

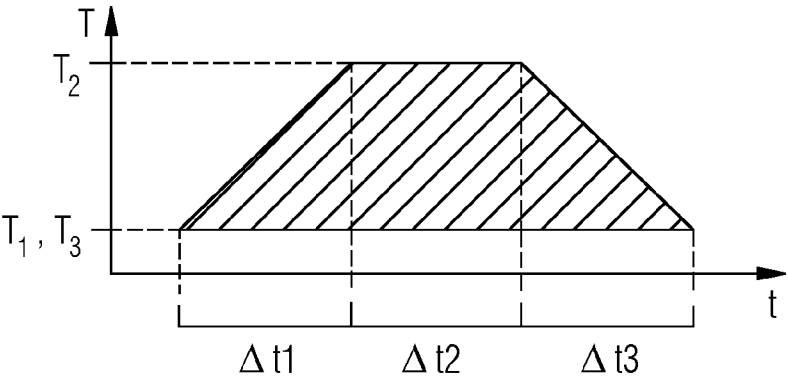
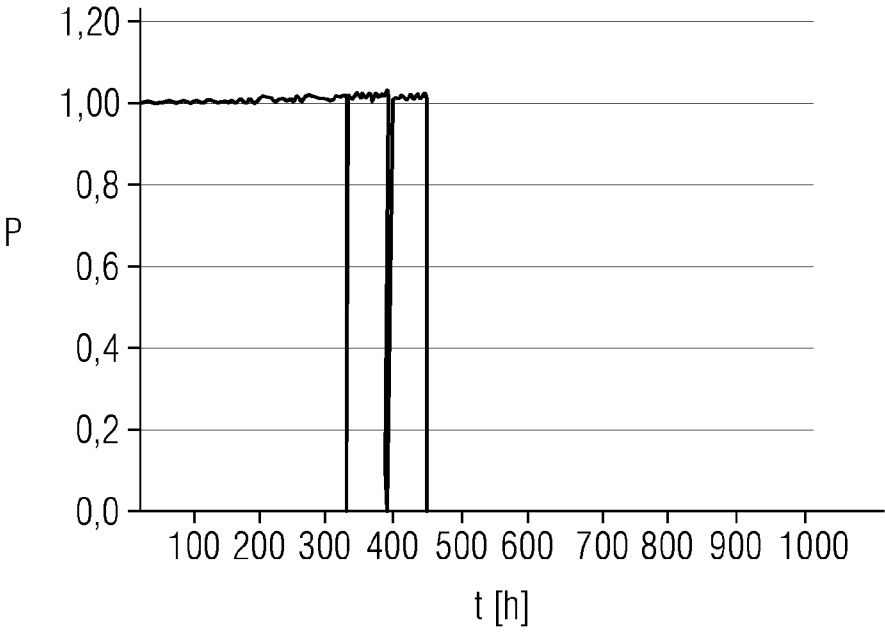


FIG 12



7/8

FIG 13

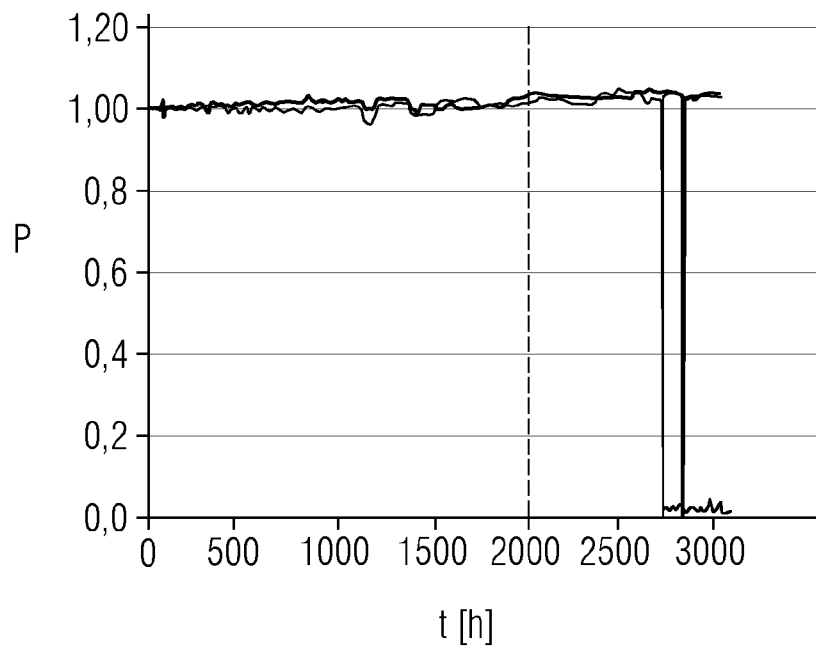


FIG 14

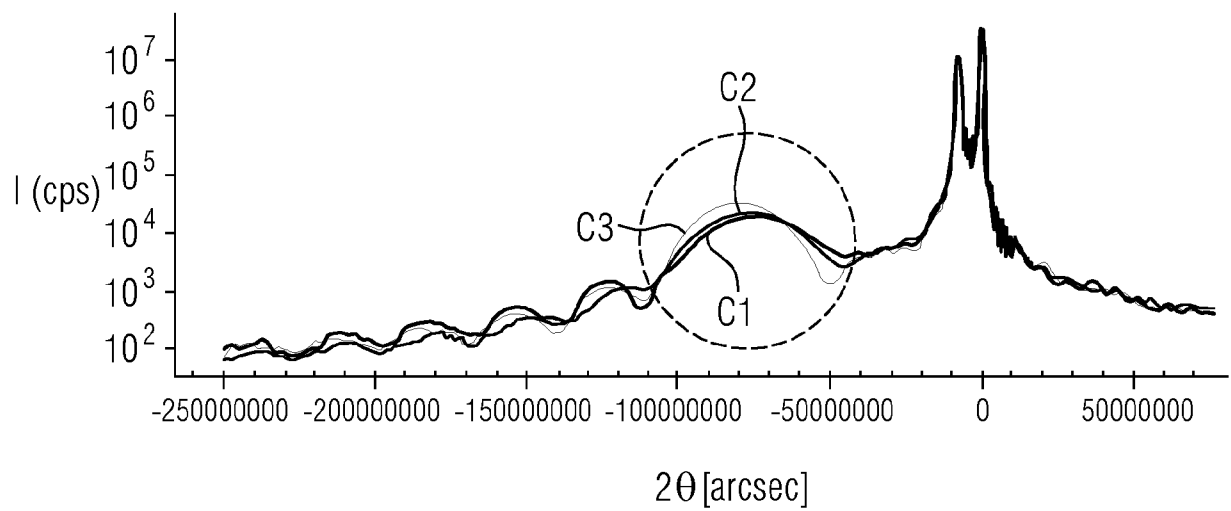
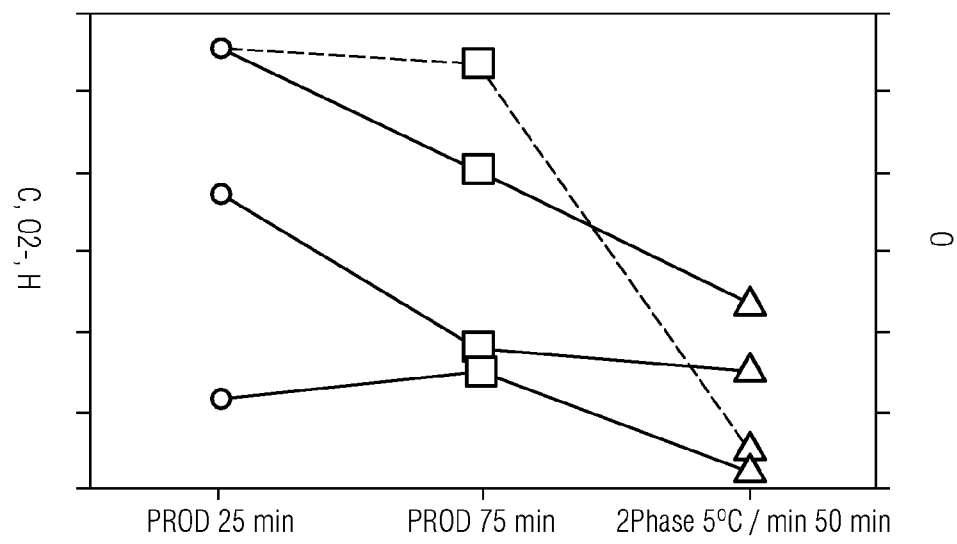


FIG 15



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/066794

A. CLASSIFICATION OF SUBJECT MATTER		
INV. H01S5/028		
ADD. H01S5/02	H01S5/323	C23C14/02
C30B29/48	H01J37/32	C23C14/56
		C30B23/02
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
H01S H01J C30B C23C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/310077 A1 (ZHANG QIANG [US] ET AL) 26 October 2017 (2017-10-26) paragraphs [0035] - [0081]; figures 1-7 -----	1-18
A	US 2005/287693 A1 (RESSEL PETER [DE] ET AL) 29 December 2005 (2005-12-29) paragraphs [0019] - [0026]; figure 1 -----	1
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
20 September 2023		29/09/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Riechel, Stefan

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/066794

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017310077 A1	26-10-2017	CN 109478765 A	15-03-2019
		EP 3446378 A2	27-02-2019
		JP 6934888 B2	15-09-2021
		JP 2019515490 A	06-06-2019
		KR 20180127654 A	29-11-2018
		US 2017310077 A1	26-10-2017
		WO 2017184569 A2	26-10-2017

US 2005287693 A1	29-12-2005	AU 2003233311 A1	11-11-2003
		DE 10221952 A1	27-11-2003
		EP 1514335 A2	16-03-2005
		JP 2005525704 A	25-08-2005
		US 2005287693 A1	29-12-2005
		WO 03096498 A2	20-11-2003
