

OPTICAL DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical device composed of a substrate and a light emitting layer formed on the front surface of the substrate.

Description of the Related Art

In a fabrication process for an optical device such as a laser diode (LD) and a light emitting diode (LED), a light emitting layer (epitaxial layer) is formed by epitaxial growth, for example, on the upper surface (front surface) of a crystal growing substrate of sapphire, SiC, or the like, thereby manufacturing an optical device wafer for forming a plurality of optical devices. The light emitting layer formed on the crystal growing substrate of the optical device wafer is partitioned by a plurality of crossing division lines to define a plurality of separate regions where the plural optical devices such as LDs and LEDs are formed. The optical device wafer is divided along these division lines to obtain the individual optical devices as chips.

As a method of dividing the optical device wafer along the division lines, there are known methods as described in Japanese Patent Laid-open No. Hei 10-305420

and Japanese Patent Laid-open No. 2008-006492. The dividing method described in Japanese Patent Laid-open No. Hei 10-305420 includes the steps of applying a pulsed laser beam having an absorption wavelength to the wafer along the division lines to form a laser processed groove along each division line and next applying an external force to the wafer to thereby break the optical device wafer along each division line where the laser processed groove is formed as a division start point.

On the other hand, the dividing method described in Japanese Patent Laid-open No. 2008-006492 is intended to improve the luminance of the optical device and it includes the steps of applying a pulsed laser beam having a transmission wavelength to the optical device wafer along the division lines in the condition where the focal point of the pulsed laser beam is set inside the wafer, thereby forming a modified layer inside the wafer along each division line and next applying an external force to each division line where the modified layer is formed to be reduced in strength, thereby dividing the optical device wafer along each division line.

SUMMARY OF THE INVENTION

In each of the dividing methods described in Japanese Patent Laid-open No. Hei 10-305420 and Japanese

Patent Laid-open No. 2008-006492, the laser beam is directed to the optical device wafer substantially perpendicularly thereto to form the laser processed groove or the modified layer and then divide the optical device wafer along the laser processed groove or the modified layer as a division start point, thereby obtaining the individual optical devices. Each optical device has a rectangular boxlike shape such that each side surface is substantially perpendicular to the light emitting layer formed on the front surface of the substrate. Accordingly, of the light emitted from the light emitting layer of the optical device, the proportion of the light striking each side surface at an incident angle greater than the critical angle is large. As a result, the proportion of the light totally reflected on each side surface is large, so that there is a possibility that the light repeating the internal total reflection in the substrate may finally become extinct in the substrate. Accordingly, the light extraction efficiency of the optical device is reduced to cause a reduction in luminance.

It is therefore an object of the present invention to provide an optical device which can improve the light extraction efficiency.

In accordance with an aspect of the present

invention, there is provided an optical device including a substrate and a light emitting layer formed on the front surface of the substrate; both the front surface and the back surface of the substrate being parallel to each other and having substantially the same rectangular shape; the substrate having four side surfaces connecting the front surface and the back surface of the substrate; each side surface of the substrate being formed with a plurality of projecting portions arranged in the direction of extension of the corresponding side of the front surface; each projecting portion being formed with a plurality of alternating projections and depressions arranged in the direction of thickness of the substrate.

With this configuration, each side surface of the substrate has the plural projecting portions and each projecting portion is formed with the alternating projections and depressions arranged in the direction of thickness of the substrate. Accordingly, of the light emitted from the light emitting layer and striking each side surface, the proportion of the light striking each side surface at an incident angle less than or equal to the critical angle can be increased. As a result, the proportion of the light totally reflected on each side surface and returned to the light emitting layer can be reduced to thereby increase the proportion of the light

emerging from each side surface. That is, the light extraction efficiency can be improved.

The above and other objects, features and advantages of the present invention and the manner of realizing them will become more apparent, and the invention itself will best be understood from a study of the following description and appended claims with reference to the attached drawings showing a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic perspective view of an optical device according to a preferred embodiment of the present invention;

FIG. 2A is a schematic sectional view taken along the line A-A in FIG. 1;

FIG. 2B is a schematic elevational view of the optical device shown in FIG. 1;

FIG. 3 is a schematic sectional view for illustrating a manner of emission of light from the optical device shown in FIG. 1;

FIG. 4 is a schematic sectional view for illustrating a manner of emission of light from a conventional optical device as a comparison;

FIG. 5A is a perspective view of a laser processing

apparatus to be used in manufacturing the optical device shown in FIG. 1;

FIG. 5B is a sectional side view for illustrating the application of two laser beams in the laser processing apparatus shown in FIG. 5A;

FIG. 6 is a sectional view for illustrating an attaching step;

FIG. 7A is a sectional view for illustrating a condition before forming modified layers in a modified layer forming step;

FIG. 7B is a plan view for illustrating the focal points of the two laser beams;

FIG. 7C is a plan view for illustrating a division line where the modified layers have been formed;

FIG. 7D is a sectional view for illustrating a condition after forming the modified layers;

FIG. 8A is a schematic perspective view of an optical device wafer;

FIG. 8B is a cross section taken along the line B-B in FIG. 8A for illustrating a condition after forming the modified layers inside the optical device wafer shown in FIG. 8A;

FIG. 8C is a view similar to FIG. 8B, illustrating a condition after breaking the optical device wafer shown in FIG. 8B;

FIG. 9 is a schematic perspective view for illustrating the modified layer forming step; and

FIG. 10 is a sectional view for illustrating a dividing step.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

There will now be described a preferred embodiment of the present invention with reference to the attached drawings. FIG. 1 is a schematic perspective view of an optical device 1 according to this preferred embodiment. FIG. 2A is a schematic sectional view taken along the line A-A in FIG. 1, and FIG. 2B is a schematic elevational view of the optical device 1 shown in FIG. 1. FIG. 3 is a schematic sectional view for illustrating a manner of emission of light from the optical device 1 shown in FIG. 1.

As shown in FIGS. 1, 2A, and 2B, the optical device 1 is composed of a substrate 21 and a light emitting layer 22 formed on the front surface 21a of the substrate 21. Preferably, the substrate 21 is transparent. The substrate 21 is a crystal growing substrate selected from a sapphire substrate (Al_2O_3 substrate), gallium nitride substrate (GaN substrate), silicon carbide substrate (SiC substrate), and gallium oxide substrate (Ga_2O_3 substrate), for example. As shown in FIG. 3, the optical device 1 is

adapted to be mounted on a base 11 by wire bonding or flip chip bonding.

The light emitting layer 22 is formed by the epitaxial growth of an n-type semiconductor layer (e.g., n-type GaN layer) in which electrons function as majority carrier, a semiconductor layer (e.g., InGaN layer), and a p-type semiconductor layer (e.g., p-type GaN layer) in which holes function as majority carrier. These layers are epitaxially grown in this order on the front surface 21a of the substrate 21. The light emitting layer 22 is formed with two electrodes (not shown) each connected to the n-type semiconductor layer and the p-type semiconductor layer. A voltage from an external power source is applied to the two electrodes to thereby emit light from the light emitting layer 22.

As shown in FIGS. 1, 2A, and 2B, both the front surface 21a and the back surface 21b of the substrate 21 have substantially the same rectangular shape as viewed in plan and they are parallel to each other. The substrate 21 has four side surfaces 21c each connecting the four sides of the front surface 21a and the four sides of the back surface 21b. Each side surface 21c is formed with a plurality of projecting portions 26 arranged in the direction of extension of the corresponding side of the front surface 21a. Accordingly,

each side surface 21c has a corrugated sectional shape as viewed in a plane (cross section taken along the line A-A in FIG. 1) parallel to the front surface 21a of the substrate 21 as shown in FIG. 2A.

Further, as shown in FIGS. 1 and 2B, each projecting portion 26 of each side surface 21c is formed with a plurality of alternating projections and depressions arranged in the direction of thickness of the substrate 21 (in the vertical direction). Accordingly, as viewed in elevation of the substrate 21 (see FIG. 2B), each projecting portion 26 has a corrugated shape formed by the alternating projections and depressions. In this preferred embodiment, the pitch of the plural projecting portions 26 arranged in the direction of extension of each side of the front surface 21a is smaller than the pitch of the alternating projections and depressions arranged in the vertical direction. However, the pitch of the plural projecting portions 26 may be equal to or larger than the pitch of the alternating projections and depressions. Further, each projecting portion 26 and each of the alternating projections and depressions have a gently curved shape in this preferred embodiment. However, each projecting portion 26 and each projection may have a trapezoidal sectional shape (isosceles trapezoid) or a triangular sectional shape.

The luminance improving effect by the optical device 1 shown in FIG. 3 will now be described in comparison with a conventional optical device 3 shown in FIG. 4. FIG. 4 is a schematic sectional view for illustrating a manner of emission of light from the optical device 3 as a comparison. The optical device 3 shown in FIG. 4 is similar to the optical device 1 shown in FIG. 3 except the shape of each side surface 21c of the substrate 21. More specifically, the optical device 3 shown in FIG. 4 is composed of a substrate 31 and a light emitting layer 32 formed on the front surface 31a of the substrate 31. Both the front surface 31a and the back surface 31b of the substrate 31 have substantially the same rectangular shape as viewed in plan. The optical device 3 is mounted on a base 33. The substrate 31 has four side surfaces 31c, each of which is a flat surface perpendicular to the front surface 31a and the back surface 31b.

As shown in FIG. 3, the light generated in the light emitting layer 22 of the optical device 1 according to this preferred embodiment is emitted mainly from the front surface 22a and the back surface 22b. The light emitted from the front surface 22a of the light emitting layer 22 (e.g., optical path A1) is extracted through a lens member (not shown) or the like to the outside. On

the other hand, the light emitted from the back surface 22b of the light emitting layer 22 and propagating along an optical path A2 strikes the interface between the side surface 21c of the substrate 21 and an air layer at an incident angle θ_1 . Since the side surface 21c is corrugated (more specifically, each projecting portion 26 of the side surface 21c has the alternating projections and depressions arranged in the direction of thickness of the substrate 21), the incident surface at each projecting portion 26 which the light propagating along the optical path A2 strikes is oriented (inclined) toward the light emitting layer 22 as compared with a vertical flat surface. Accordingly, the incident angle θ_1 of the light propagating along the optical path A2 is so small as to be less than or equal to the critical angle of the substrate 21. Accordingly, the light propagating along the optical path A2 is partially transmitted through the side surface 21c to the air layer (optical path A3), and the remaining part is reflected on the side surface 21c (optical path A4).

The light propagating along the optical path A3 is next reflected on the upper surface of the base 11 and extracted to the outside. The light propagating along the optical path A4 travels in the substrate 21 in a nearly horizontal direction as viewed in FIG. 3 because the

incident angle θ_1 is small as mentioned above. The light thus traveling in the substrate 21 strikes the opposite side surface 21c (right side surface as viewed in FIG. 3) and is next emerged to the air layer.

In contrast thereto, the light is emitted from the optical device 3 as a comparison shown in FIG. 4 to propagate along optical paths B1 and B2. The optical paths B1 and B2 of the light emitted from the optical device 3 are similar to the optical paths A1 and A2 of the light emitted from the optical device 1. However, since each side surface 31c of the substrate 31 is a flat surface perpendicular to the front surface 31a and the back surface 31b, an incident angle θ_2 of the light propagating along the optical path B2 and striking the interface between the side surface 31c and the air layer is larger than the incident angle θ_1 shown in FIG. 3. Accordingly, the incident angle θ_2 is larger than the critical angle of the substrate 21, so that the light propagating along the optical path B2 is totally reflected on the interface between the side surface 31c and the air layer (optical path B3). The light propagating along the optical path B3 is reflected on the upper surface of the base 33 (optical path B4). The light propagating along the optical path B4 travels in the substrate 31 in a nearly vertical direction as viewed in

FIG. 4 in comparison with the optical path A4. Accordingly, the light propagating along the optical path B4 strikes the light emitting layer 32 and is absorbed by the light emitting layer 32, so that the light cannot be extracted to the outside.

According to the optical device 1 shown in FIG. 3, each side surface 21c of the substrate 21 is corrugated, that is, each side surface 21c of the substrate 21 is formed with the plural projecting portions 26, and each projecting portion 26 has the alternating projections and depressions, so that the light emitted from the light emitting layer 22 and propagating in the substrate 21 along optical paths similar to the optical path A2 can be extracted to the outside along optical paths similar to the optical paths A3 and A4. Accordingly, as compared with the light propagating along optical paths similar to the optical path B2 shown in FIG. 4, the proportion of the light totally reflected on each side surface 21c to the light propagating along optical paths similar to the optical path A2 can be reduced. Accordingly, the proportion of the light repeatedly reflected in the substrate 21 and returned to the light emitting layer 22 can be reduced and the proportion of the light emerging from the substrate 21 can be increased to thereby improve the light extraction efficiency, resulting in the

improvement in luminance.

There will now be described a manufacturing method for the optical device 1 according to this preferred embodiment. The manufacturing method for the optical device 1 according to this preferred embodiment includes an attaching step, a modified layer forming step by a laser processing apparatus, and a dividing step by a dividing apparatus. In the attaching step, an adhesive sheet (protective tape) is attached to the front side of an optical device wafer on which a light emitting layer is formed. In the modified layer forming step, a plurality of modified layers are formed inside the optical device wafer along each division line. In the dividing step, the optical device wafer is divided along each division line where the modified layers are formed as a division start point, thereby obtaining a plurality of individual optical devices. These steps of the manufacturing method will now be described in more detail.

Referring to FIG. 5A, there is shown a perspective view of a laser processing apparatus 100 for forming the modified layers inside the optical device wafer in this preferred embodiment. FIG. 5B illustrates the application of two laser beams in the laser processing apparatus 100 shown in FIG. 5A. The configuration of the laser processing apparatus usable in the present invention is

not limited to that shown in FIG. 5A. That is, any configuration capable of forming the modified layers inside the optical device wafer may be adopted as the laser processing apparatus.

As shown in FIG. 5A, the laser processing apparatus 100 includes a laser processing unit 102 for applying the laser beams to an optical device wafer W held on a chuck table (holding means) 103, wherein the laser processing unit 102 and the chuck table 103 are relatively moved to process the optical device wafer W.

The laser processing apparatus 100 has a boxlike base 101. There is provided on the upper surface of the base 101 a chuck table moving mechanism 104 for feeding the chuck table 103 in the X direction extending along an X axis shown in FIG. 5A and also indexing the chuck table 103 in the Y direction extending along a Y axis shown in FIG. 5A. A wall portion 111 stands from the base 101 at its rear end behind the chuck table moving mechanism 104. An arm portion 112 projects from the front surface of the wall portion 111. The laser processing unit 102 is supported to the arm portion 112 so as to be opposed to the chuck table 103.

The chuck table moving mechanism 104 includes a pair of parallel guide rails 115 provided on the upper surface of the base 101 so as to extend in the X

direction and a motor-driven X table 116 slidably supported to the guide rails 115. The chuck table moving mechanism 104 further includes a pair of parallel guide rails 117 provided on the upper surface of the X table 116 so as to extend in the Y direction and a motor-driven Y table 118 slidably supported to the guide rails 117.

The chuck table 103 is provided on the upper surface of the Y table 118. Nut portions (not shown) are formed on the lower surfaces of the X table 116 and the Y table 118, and ball screws 121 and 122 are threadedly engaged with these nut portions of the X table 116 and the Y table 118, respectively. Drive motors 123 and 124 are connected to the end portions of the ball screws 121 and 122, respectively. Accordingly, when the ball screws 121 and 122 are rotationally driven by the drive motors 123 and 124, respectively, the chuck table 103 is moved in the X direction and the Y direction along the guide rails 115 and 117, respectively.

The chuck table 103 is a circular member and it is rotatably provided on the upper surface of the Y table 118 through a θ table 125. A suction holding member (not shown) of a porous ceramic material is formed on the upper surface of the chuck table 103. Four clamps 126 are provided on the outer circumference of the chuck table 103, wherein each clamp 126 is supported through a pair

of arms to the chuck table 103. The four clamps 126 are driven by an air actuator (not shown) to thereby fix a ring frame F supporting the optical device wafer W through an adhesive sheet S.

The laser processing unit 102 has a processing head 127 provided at the front end of the arm portion 112. An optical system is provided in the arm portion 112 and the processing head 127 to constitute the laser processing unit 102. More specifically, a laser oscillator (not shown) is provided in the arm portion 112, and the processing head 127 includes separating means (not shown) such as a birefringent crystal for separating a laser beam oscillated from the laser oscillator into two laser beams LB1 and LB2 of ordinary light and extraordinary light (see FIG. 5B) and focusing lens (not shown) for focusing each of the separate laser beams LB1 and LB2 to the optical device wafer W held on the chuck table 103, thereby processing the optical device wafer W. In this case, the laser beams LB1 and LB2 have a transmission wavelength to the optical device wafer W, and the focal points of the laser beams LB1 and LB2 are adjusted by the optical system so that the laser beams LB1 and LB2 are focused inside the optical device wafer W. As the separating means for obtaining the separate laser beams LB1 and LB2, a corresponding part of the apparatus

disclosed in Japanese Patent Laid-open No. 2007-000931 may be adopted.

By the application of the laser beams to the optical device wafer W, a plurality of modified layers (reformed layers) R (see FIGS. 7D and 8B) as a division start point are formed inside the optical device wafer W along each division line. Each modified layer R is a region different from its ambient region in density, refractive index, mechanical strength, or any other physical properties in the optical device wafer W irradiated with the laser beams, causing a reduction in strength as compared with the ambient region. Examples of each modified layer R include a melted and rehardened region, cracked region, breakdown region, and refractive index changed region. These regions may be mixed.

The optical device wafer W is a substantially disk-shaped member. As shown in FIGS. 6 and 8A, the optical device wafer W is composed of a substrate W1 and a light emitting layer W2 formed on the front side (upper surface as viewed in FIG. 6) of the substrate W1. The light emitting layer W2 of the optical device wafer W is partitioned by a plurality of crossing division lines (streets) ST to define a plurality of separate regions where a plurality of respective optical devices 1 are formed. As shown in FIG. 5A, the optical device wafer W

to be held on the chuck table 103 is attached to the adhesive sheet S supported to the ring frame F in the condition where the light emitting layer W2 is oriented downward, i.e., the substrate W1 is oriented upward.

The optical device manufacturing method by processing the optical device wafer W according to this preferred embodiment will now be described with reference to FIGS. 6 to 10. The steps shown in FIGS. 6 to 10 are merely illustrative and the steps of the optical device manufacturing method applicable in the present invention are not limited to those shown in FIGS. 6 to 10. The attaching step shown in FIG. 6 is first performed. As shown in FIG. 6, the optical device wafer W is positioned inside the ring frame F in the condition where the light emitting layer W2 formed on the front side of the substrate W1 is oriented upward. Thereafter, the front side (upper surface) of the optical device wafer W (i.e., the light emitting layer W2) and the upper surface of the ring frame F are attached to the adhesive sheet S. Accordingly, the optical device wafer W is supported through the adhesive sheet S to the ring frame F in the condition where the substrate W1 of the wafer W is exposed.

After performing the attaching step, the modified layer forming step shown in FIGS. 7A to 7D is performed.

FIG. 7A illustrates a condition before forming the modified layers, FIG. 7B illustrates the focal points of the two laser beams as viewed in plan, FIG. 7C illustrates the division line where the modified layers have been formed as viewed in plan, and FIG. 7D illustrates a condition after forming the modified layers. As shown in FIG. 7A, the optical device wafer W supported through the adhesive sheet S to the ring frame F is held on the chuck table 103 in the condition where the adhesive sheet S is in contact with the upper surface of the chuck table 103 and the ring frame F is fixed by the clamps 126. Thereafter, a predetermined one of the division lines ST of the optical device wafer W is positioned directly below the processing head 127. Further, the focal point Pa of the laser beam LB1 of ordinary light to be applied from the processing head 127 and the focal point Pb of the laser beam LB2 of extraordinary light to be applied from the processing head 127 are set at the same vertical position inside the optical device wafer W (see FIG. 5B). As shown in FIG. 7B, the focal point Pa of the laser beam LB1 and the focal point Pb of the laser beam LB2 are shifted from each other by a distance Xa in the X direction and by a distance Yb in the Y direction.

Thereafter, the laser beams LB1 and LB2 having a

transmission wavelength to the optical device wafer W are applied from the processing head 127. As applying the laser beams LB1 and LB2, the optical device wafer W is moved in the X direction to thereby form the modified layer R inside the optical device wafer W along the predetermined division line ST as shown in FIG. 7C. The modified layer R along the predetermined division line ST is composed of plural modified spots Ra formed by the laser beam LB1 and plural modified spots Rb formed by the laser beam LB2, wherein the modified spots Ra are shifted from the modified spots Rb by the distance Xa in the X direction and by the distance Yb in the Y direction. Further, the modified spots Ra are arranged in a line extending in the X direction with the pulse pitch P according to the laser beam LB1. Similarly, the modified spots Rb are also arranged in a line extending in the X direction with the pulse pitch P according to the laser beam LB2.

FIG. 8A is a schematic perspective view of the optical device wafer W, FIG. 8B is a cross section taken along the line B-B in FIG. 8A for illustrating a condition after forming the modified layers R inside the optical device wafer shown in FIG. 8A, and FIG. 8C is a view similar to FIG. 8B, illustrating a condition after breaking the optical device wafer W shown in FIG. 8B. FIG.

9 is a schematic perspective view for illustrating the modified layer forming step. As shown in FIGS. 7D, 8B, and 9, the formation of the modified layer R by the laser beams LB1 and LB2 along the predetermined division line ST is repeated plural times by changing the vertical position of the focal points of the laser beams LB1 and LB2 along the thickness of the substrate W1. More specifically, the first modified layer R1 is formed by setting the vertical position (in the Z direction) of the focal points to a position below the back side Wa (upper surface) of the optical device wafer W toward the front side (lower surface) thereof by a predetermined defocus amount DF1 and then applying the laser beams LB1 and LB2 along the predetermined division line ST. The formation of the first modified layer R1 composed of the plural modified spots Ra and Rb is repeated for all of the division lines ST. Thereafter, a defocus amount DF2 smaller than the defocus amount DF1 is set for the formation of the second modified layer R2. That is, the vertical position of the focal points in forming the second modified layer R2 is set to a position above the first modified layer R1 (below the back side Wa by the defocus amount DF2) as horizontally shifted therefrom along the width of each division line ST (in the Y direction) by an index In. Thereafter, the third modified

layer R3 is similarly formed above the second modified layer R2 by setting a defocus amount DF3 smaller than the defocus amount DF2 and also shifting the focal points along the width of each division line ST by the index In in the direction opposite to that in the case of the second modified layer R2. Thereafter, the fourth modified layer R4 is similarly formed above the third modified layer R3 by setting a defocus amount DF4 smaller than the defocus amount DF3 and also shifting the focal points along the width of each division line ST by the index In in the direction opposite to that in the case of the third modified layer R3. Thusly, the plural modified layers R (the first to fourth modified layers R1 to R4 in this preferred embodiment) are formed along each division line ST in such a manner that the plural modified layers R are vertically juxtaposed from the front side (lower surface as viewed in FIG. 8B) of the optical device wafer W to the back side (upper surface as viewed in FIG. 8B) thereof and horizontally staggered along the width of each division line ST. In this manner, the plural modified layers R are formed as a division start point inside the optical device wafer W along each division line ST.

After performing the modified layer forming step, the dividing step shown in FIG. 10 is performed. As shown

in FIG. 10, the substrate W1 of the optical device wafer W is placed on a pair of parallel support beds 35 constituting a breaking apparatus (not shown), and the ring frame F supporting the optical device wafer W through the adhesive sheet S is placed on an annular table 36. The ring frame F placed on the annular table 36 is fixed by four clamps 37 provided on the annular table 36. The pair of parallel support beds 35 extend in one direction (perpendicular to the sheet plane of FIG. 10), and imaging means 38 is located between the support beds 35 on the lower side thereof. The imaging means 38 functions to image the back side (lower surface as viewed in FIG. 10) of the optical device wafer W, i.e., the back side of the substrate W1 from between the support beds 35.

A pressure blade 39 for pressing the optical device wafer W from the upper side thereof is provided above the support beds 35 at a horizontal position therebetween. That is, an external force is applied from the pressure blade 39 to the optical device wafer W held on the support beds 35. The pressure blade 39 extends in one direction (perpendicular to the sheet plane of FIG. 10), and it is vertically movable by a pressure applying mechanism (not shown). When the back side of the optical device wafer W is imaged by the imaging means 38, a predetermined one of the division lines ST is positioned

between the support beds 35 and directly below the pressure blade 39 according to an image obtained by the imaging means 38. Thereafter, the pressure blade 39 is lowered to abut against the optical device wafer W through the adhesive sheet S, thereby applying an external force to the optical device wafer W to divide the wafer W along the predetermined division line ST where the plural modified layers R as a division start point are formed. At this time, a crack K (see FIG. 8C) is formed between any adjacent ones of the plural modified layers R juxtaposed along the thickness of the wafer W and staggered along the width of the predetermined division line ST. By the formation of the crack K, the optical device wafer W is divided along the predetermined division line ST so as to form a corrugated sectional shape corresponding to the shape of each side surface 21c shown in FIGS. 1 to 3, i.e., the corrugated sectional shape such that the plural projecting portions 26 are arranged along the predetermined division line ST and each projecting portion 26 has the alternating projections and depressions arranged in the thickness of the substrate W1. At this time, the plural modified layers R along the predetermined division line ST form the projecting portions 26 of one of the optical devices 1 adjacent to each other with the predetermined division

line ST interposed therebetween, and simultaneously form the projecting portions 26 of the other optical device 1 (see FIG. 8C). This dividing step is similarly performed along all of the division lines ST to thereby divide the optical device wafer W into the individual optical devices 1.

Examples of the laser processing conditions in the modified layer forming step are shown below as Examples 1, 2, and 3. Examples 1, 2, and 3 are shown in Tables 1, 2, and 3, respectively. In all of Examples 1 to 3, the common conditions are set as follows:

Number of modified layers R along each division line ST: 4

Work feed speed: 600 mm/second

Pitch P (width of each projecting portion 26): 3 μ m

Plane size of each optical device: 0.65 mm $\times$ 0.65 mm

Table 1

Modified Layer	Power (W)	Defocus Amount (mm)	Index In
Modified Layer R1	0.20	DF1:0.0425	9 μ m each
Modified Layer R2	0.20	DF2:0.0325	
Modified Layer R3	0.20	DF3:0.0225	
Modified Layer R4	0.20	DF4:0.0125	

Table 2

Modified Layer	Power (W)	Defocus Amount (mm)	Index In
Modified Layer R1	0.15	DF1:0.0425	7 μm each
Modified Layer R2	0.15	DF2:0.0325	
Modified Layer R3	0.15	DF3:0.0225	
Modified Layer R4	0.20	DF4:0.0125	

Table 3

Modified Layer	Power (W)	Defocus Amount (mm)	Index In
Modified Layer R1	0.15	DF1:0.0425	9 μm each
Modified Layer R2	0.15	DF2:0.0325	
Modified Layer R3	0.15	DF3:0.0225	
Modified Layer R4	0.20	DF4:0.0125	

By using the optical devices 1 obtained in Examples 1 to 3, the total intensity (power) of light radiated was measured (total radiant flux measurement). As compared with the conventional optical device having the flat side surfaces as shown in FIG. 4, the luminance of each optical device 1 according to this preferred embodiment was improved by 1 to 2%.

According to the optical device manufacturing method in this preferred embodiment, the plural projecting portions 26 can be formed on each side surface 21c of the substrate 21 in such a manner that each projecting portion 26 has the alternating projections and depressions arranged in the direction of thickness of the substrate 21 even in the case that the thickness of the optical device wafer W is small. Further, the plural modified layers R juxtaposed along the thickness of the wafer W are staggered in the direction of width of each

division line ST in the modified layer forming step. Accordingly, the wafer W can be divided so as to form a corrugated shape along the thickness of the wafer W by simply applying an external force to the wafer W in the dividing step. As a result, complication of each step and elongation of the time of each step can be suppressed to thereby manufacture the optical devices 1 efficiently.

The present invention is not limited to the above preferred embodiment, but various modifications may be made. The size, shape, etc. of the parts in the above preferred embodiment shown in the attached drawings are merely illustrative and they may be suitably changed within the scope where the effect of the present invention can be exhibited. Further, the above preferred embodiment may be suitably modified without departing from the scope of the object of the present invention.

For example, while the dividing step is performed by using a breaking apparatus in the above preferred embodiment, the dividing step in the above preferred embodiment may be performed by using any apparatus capable of dividing the optical device wafer W along the division lines ST to obtain the individual optical devices 1. Further, the steps of the optical device manufacturing method in the above preferred embodiment may be performed by using separate apparatuses or by

using the same apparatus.

The present invention is not limited to the details of the above described preferred embodiment. The scope of the invention is defined by the appended claims and all changes and modifications as fall within the equivalence of the scope of the claims are therefore to be embraced by the invention.

WHAT IS CLAIMED IS:

1. An optical device comprising a substrate and a light emitting layer formed on a front surface of said substrate;

both the front surface and a back surface of said substrate being parallel to each other and having substantially the same rectangular shape;

said substrate having four side surfaces connecting the front surface and the back surface of said substrate;

each side surface of said substrate being formed with a plurality of projecting portions arranged in the direction of extension of the corresponding side of said front surface;

each projecting portion being formed with a plurality of alternating projections and depressions arranged in the directions of the side and thickness of said substrate.