DESCRIPTION

SOI WAFER AND MANUFACTURING METHOD THEREOF

TECHNICAL FIELD

[0001]

The present invention relates to an SOI (Silicon on Insulator) wafer suitable for a process of manufacturing a semiconductor device in which an extremely-short thermal treatment is conducted for no more than 0.1 seconds at a maximum temperature of 1200°C or more, and manufacturing method thereof.

This application claims priority from Japanese Patent Application No. 2007-071800 filed on March 20, 2007, the disclosure of which is incorporated by reference herein.

BACKGROUND ART

[0002]

Since devices have been highly integrated and consumption of electric power needed to work such devices has been decreased, an extremely-short thermal treatment no more than 0.1 seconds at a maximum temperature of 1200°C or more, such as laser annealing, has been applied for a process of manufacturing a device. Particularly, in the case that only one side of an SOI wafer is heated in a laser annealing furnace, not only an active layer in the SOI wafer, but also a part of an insulated oxide film layer and a support layer are sometimes heated in spite of the treatment being conducted for an extremely short time.

[0003]

It has been found that, if the support layer is heated even for such a short time, a large amount of stress is generated near an interface between the support layer and the insulated oxide film layer, because oxygen precipitates near the interface obstruct a heat conduction, and thus a slip dislocation is generated at a high density, thereby causing plastic deformation at the region just below the insulated oxide film layer.

[0004]

Such plastic deformation causes a defocus when the exposure is conducted in the process of manufacturing a device, and deteriorates the yield ratio.

[0005]

Patent Document

Japanese Unexamined Patent Application, First Publication No. 2006-237042

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0006]

The present invention takes the above circumstances into consideration, with an object of providing an SOI wafer which does not generate slip dislocation, even if laser annealing is conducted at a maximum temperature of 1200°C or more for no more than 0.1 seconds.

MEANS FOR SOLVING THE PROBLEMS

[0007]

The present invention is an SOI wafer used for a process of manufacturing a semiconductor device in which a laser annealing is conducted at a maximum temperature of 1200°C for no more than 0.1 seconds, which includes an active layer, a support layer of a monocrystaline silicon, and an insulated oxide film layer between the active layer and the support layer, wherein light-scattering defect density measured by 90° light-scattering method at the depth region of 260 μm toward the support layer side from an interface between the insulated oxide film layer and the support layer is no more than $2\times10^{8}/cm^{3}$.

EFFECTS OF THE INVENTION

[0008]

In the present invention, since the light-scattering defect density measured by a 90° light-scattering method at the depth region of 260 μm toward the support layer side from the interface between the insulated oxide film layer and the support layer is no more than $2\times10^{8}/cm^{3}$, slip dislocation is not generated even if laser annealing is conducted at a maximum temperature of 1200°C or more for no more than 0.1 seconds.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 is a drawing showing a pattern (pattern 1) of a heat treatment in the Examples.

FIG. 2 is a drawing showing a pattern (pattern 2) of a heat treatment in the Examples.

FIG. 3 is a drawing showing a pattern (pattern 3) of a heat treatment in the Examples.

FIG. 4 is a drawing showing a pattern (pattern 4) of a heat treatment in the Examples.

FIG. 5 is a sectional view showing a structure of an SOI wafer.

BEST MODE FOR CARRYING OUT THE INVENTION

[0010]

In the following examples, it is confirmed that slip dislocation is not generated even if laser annealing is conducted at a maximum temperature of 1200°C for no more than 0.1 seconds, when the light-scattering defect density measured by a 90° light-scattering method at the depth region of 260 μm toward the support layer side from the interface between the insulated oxide film layer and the support layer is no more than $2\times10^{8}/cm^{3}$.

EXAMPLES

[0011]

Example 1

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter was heated up to 650°C, then oxygen ions with the acceleration energy of 200 keV and the dose amount of $5\times10^{17}/cm^{2}$ were implanted into the wafer. As a result, the oxygen ions reacted with the monocrystaline silicon wafer, thereby forming an embedded SiO_2 layer (insulated oxide film layer) inside the monocrystaline silicon wafer. On the embedded SiO_2 layer, that is, on the surface of the monocrystaline silicon wafer, a residual silicon layer with the implantation damage was formed.

[0012]

Subsequently, the monocrystaline silicon wafer was heated at 1325°C for 8 hours in a mixed atmosphere of Ar and O_2. By performing the high-temperature thermal treatment, precipitates other than the embedded SiO_2 were removed from the monocrystaline silicon wafer, and a monocrystaline silicon layer (an active layer) in which silicon atoms were rearranged was formed on the surface of the monocrystaline silicon wafer. The thickness of the active layer and the embedded SiO_2 layer were measured by using a transmission microscope, and the result was that the thickness of the active layer was 200 nm, and the thickness of the embedded SiO_2 layer was 125 nm.

[0013]

The SOI wafer obtained above was subjected to a thermal treatment of pattern 3 shown in FIG. 3. The thermal treatment included the steps of: leaving the SOI wafer at 600°C for 1 hour; heating it to 650°C at a heating rate of 1°C/minute (50 minutes); leaving it at 650°C for 2 hours; heating it to 950°C at a heating rate of 5°C/minute (60 minutes); and leaving it at 950°C for 12 hours.

[0014]

The defect density near the interface between the insulated oxide film layer and the support layer induced by the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). The measurement of the light-scattering defect (light-scattering body) in the 90° light-scattering method was conducted by irradiating a light with a wavelength of 1.06 μm (near-infrared) and the output power of 100 mW from the upper surface of the silicon wafer, thereby detecting the 90° scattered light which was detected from a cleavage surface of the wafer. The 90° scattered light was attenuated by passing through a filter.

[0015]

The measured region was up to the depth of 260 μm from the interface between the insulated oxide film layer and the support layer, as shown in FIG. 5. The light-scattering defect density was measured at the 10 points determined randomly in the radial direction of the wafer, wherein 2 mm in the radial direction of the wafer was referred to as a point.

[0016]

The result is shown in Table 1. The light-scattering defect density was $1.1\times10^{8}/cm^{3}$.

[0017]

Subsequently, the SOI wafer of Example 1 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in a condition of a maximum temperature of 1200°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, the slip dislocation was not observed, as shown in Table 1.

[0018]

Example 2

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^3 (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1, was heated to 650°C, and then oxygen ions with the acceleration energy of 200 keV and the dose amount of $5\times10^{17}/cm^{2}$ were implanted into the silicon wafer.

[0019]

Subsequently, similarly to Example 1, the monocrystaline silicon wafer was thermally treated at 1325°C for 8 hours in a mixed atmosphere of Ar and O_2, thereby producing an SOI wafer. The thickness of the active layer and the embedded SiO_2 layer formed by the above thermal treatment were checked using a transmission microscope.

As a result, the thickness of the active layer was 200 nm, and the thickness of the embedded SiO_2 layer was 125 nm.

[0020]

The SOI wafer obtained in this way was subjected to a thermal treatment of pattern 3 shown in FIG. 3, and then defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $1.9\times10^8/cm^3$.

[0021]

Subsequently, the SOI wafer of Example 2 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1300°C. Then, whether there was slip dislocation migrated to the surface of the wafer or not was checked using an X-ray topography method. As a result, slip dislocation was not observed, as shown in Table 1.

[0022]

Example 3

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^3 (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1, was heated to 650°C, and then oxygen ions with the acceleration energy of 200 keV and the dose amount of $5\times10^{17}/cm^2$ were implanted into the silicon wafer.

[0023]

Subsequently, similarly to Example 1, the monocrystaline silicon wafer was thermally treated at 1325°C for 8 hours in a mixed atmosphere of Ar and O_2, thereby producing an SOI wafer. The thickness of the active layer and the embedded SiO_2 layer formed by the above thermal treatment were checked using a transmission microscope. As a result, the thickness of the active layer was 200 nm, and the thickness of the embedded SiO_2 layer was 125 nm.

[0024]

Furthermore, the SOI wafer was subjected to a thermal treatment at 1100°C in a mixed atmosphere of Ar and O_2, thereby performing a sacrificial oxidation. The oxide film produced by performing the sacrificial oxidation was stripped in a fluorinated acid solution. Then, the thickness of the active layer was checked using a transmission microscope. As a result, the thickness of the active layer was 100 nm.

[0025]

The SOI wafer obtained in this way was subjected to a thermal treatment of pattern 3 shown in FIG. 3, and then defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $1.8\times10^{8}/cm^{3}$.

[0026]

Subsequently, the SOI wafer of Example 3 was subjected to a extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace of a maximum temperature of 1300°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, slip dislocation was not observed, as shown in Table 1.

[0027]

Example 4

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1, was thermally oxidized at 1100°C, thereby forming a oxide film of 300 nm. Then, hydrogen ions with the acceleration energy of 50 keV and the dose amount of $6\times10^{17}/cm^{2}$ were implanted into the silicon wafer through the oxide film from the upper surface of the SOI wafer, thereby forming an ion-implanted layer in the wafer (the wafer used as an active layer).

[0028]

Subsequently, the wafer used as the active layer was stuck with a silicon wafer (the wafer used as the support layer: oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1, through the oxide film. Then, they were subjected to a thermally stripping treatment at 600°C, thereby stripping the wafer used as the active layer into a thin film by using the ion-implanted layer as the boundary. Furthermore, a thermal treatment was performed at 1100°C to strengthen the adhesion, thereby obtaining an SOI wafer in which these two wafers were rigidly bonded. Here, in order to remove the damage generated on the surface, sacrificial oxidization was performed in which the vicinity of the surface was oxidized by a thermal treatment in the oxygen atmosphere.

[0029]

The thickness of the active layer and the embedded SiO_2 layer of the SOI wafer were checked using a transmission microscope. As a result, the thickness of the active layer was 100 nm, and the thickness of the embedded SiO_2 layer was 150 nm.

[0030]

The SOI wafer obtained above was then subjected to a thermal treatment of pattern 4 shown in FIG. 4. The thermal treatment included the steps of: leaving the SOI wafer at 800°C for 4 hours; heating it to 950°C at a heating rate of 1.5°C/minute (100 minutes); heating it to 1000°C at a heating rate of 2°C/minute (25 minutes); and leaving it at 1000°C for 8 hours.

[0031]

Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $1.7\times10^8/cm^3$.

[0032]

Subsequently, the SOI wafer of Example 4 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1300°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, slip dislocation was not observed, as shown in Table 1.

[0033]

Comparative Example 1

The SOI wafer (the thickness of the active layer was 200 nm, and the thickness of the embedded SiO_2 layer was 125 nm) obtained by the same condition as Example 1 was subjected to a thermal treatment of pattern 2 shown in FIG. 2. The thermal treatment included the steps of: leaving the SOI wafer at 600°C for 1 hour; heating it to 650°C at a heating rate of 1°C/minute (50 minutes); leaving it at 650°C for 2 hours; heating it to 950°C at a heating rate of 3°C/minute (100 minutes); and leaving it at 950°C for 12 hours.

[0034]

Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1,

the light-scattering defect density was $3.2\times10^{8}/cm^{3}$.

[0035]

Subsequently, the SOI wafer of Comparative Example 1 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1200°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, slip dislocation was observed, as shown in Table 1.

[0036]

Comparative Example 2

The SOI wafer (the thickness of the active layer was 100 nm, and the thickness of the embedded SiO_2 layer was 125 nm) obtained by the same condition as Example 3 was subjected to a thermal treatment of pattern 2 shown in FIG. 2.

[0037]

Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $3.5\times10^{8}/cm^{3}$.

[0038]

Subsequently, the SOI wafer of Comparative Example 2 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1200°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, a large amount of slip dislocation was observed, as shown in Table 1.

[0039]

Comparative Example 3

The SOI wafer (the thickness of the active layer was 200 nm, and the thickness of the embedded SiO_2 layer was 125 nm) obtained by the same condition as Example 1 was subjected to a thermal treatment of pattern 2 shown in FIG. 2

[0040]

Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1,

the light-scattering defect density was $4.4\times10^{8}/cm^{3}$.

[0041]

Subsequently, the SOI wafer of Comparative Example 3 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1300°C. Then, it was checked using a X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, a large amount of slip dislocation was observed, as shown in Table 1.

[0042]

Reference Example

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 nm in diameter, which is the same as that of Example 1, was thermally oxidized at 1100°C, thereby forming a silicon dioxide film of 200 nm.

[0043]

Subsequently, the wafer obtained above (the wafer used as the active layer), which was covered with a silicon dioxide film of 200 nm, was stuck at room temperature with a silicon wafer (the wafer used as the support layer: oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1 and not oxidized, thereby producing a laminated substrate (wafer). Then, they were subjected to thermally adhesive treatment at 1100°C to strengthen the adhesion.

[0044]

Subsequently, grinding or etching was performed to the peripheral surface of the wafer used as the active layer, thereby removing defective parts of adhesion which lie on the peripheral surface of the laminated substrate.

[0045]

Then, the wafer for the active layer was subjected to surface grinding or surface etching, thereby forming an active layer with the thickness of about 1000 nm. In this manner, a laminated SOI wafer was obtained.

[0046]

The SOI wafer (the thickness of the active layer was 1000 nm, and the thickness of the insulated oxide film layer was 200 nm) was subjected to a thermal treatment of pattern 1 shown in FIG. 1. The thermal treatment included the steps of: leaving the SOI wafer at 700°C for 4 hour; heating it to 950°C at a heating rate of 5°C/minute (50 minutes); heating it to 1000°C at a heating rate of 2°C/minute (25 minutes); and leaving

it at 1000°C for 8 hours.

[0047]

Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the substrate layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $3.2\times10^{9}/cm^{3}$.

[0048]

Subsequently, the SOI wafer of Reference Example 1 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1200°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, slip dislocation was not observed, as shown in Table 1.

[0049]

Reference Example 2

A silicon wafer (oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1, was thermally oxidized at 1100°C, thereby forming a silicon dioxide film of 200 nm.

[0050]

Subsequently, the wafer (wafer used as the active layer) obtained above, which was covered with a silicon dioxide film of 200 nm was stuck with a silicon wafer (a wafer for a support: oxygen concentration of 11.5×10^{17} to 13.6×10^{17} atoms/cm^{3} (Old-ASTM)) sliced from a monocrystaline silicon ingot of 200 mm in diameter, which is the same as that of Example 1 and not oxidized, at room temperature, thereby producing a laminated substrate (wafer). Then, they were subjected to thermally adhesive treatment at 1100°C to strengthen the adhesion.

[0051]

Subsequently, grinding or etching was performed to the peripheral surface of the wafer used as the active layer, thereby removing defective parts of adhesion which lie on the peripheral surface of the laminated substrate.

[0052]

Then, the wafer used as the active layer was subjected to surface grinding or surface etching, thereby forming an active layer with the thickness of about 1000 nm. In this manner, a laminated SOI wafer was obtained.

[0053]

The SOI wafer (the thickness of the active layer was 1000 nm, and the thickness of the insulated oxide film layer was 200 nm) obtained in this manner was subjected to a thermal treatment of pattern 1 shown in FIG. 1. Similarly to Example 1, the defect density induced by the thermal treatment near the interface between the support layer and the insulated oxide film layer of the SOI wafer after the thermal treatment was evaluated by a 90° light-scattering method, using MO-441 (manufactured by Mitsui Mining & Smelting Co. Ltd.). As shown in Table 1, the light-scattering defect density was $3.5\times10^{9}/cm^{3}$.

[0054]

Subsequently, the SOI wafer of Reference Example 2 was subjected to an extremely-short thermal treatment (laser annealing) which was performed in a process of manufacturing a device, in a laser spike annealing furnace in the condition of a maximum temperature of 1300°C. Then, it was checked using an X-ray topography method whether there was slip dislocation migrated to the surface of the wafer or not. As a result, slip dislocation was not observed, as shown in Table 1.

[0055]

Table 1

	Characteristics of a wafer				Laser annealing	Result
	Method of manufacturing a SOI wafer	Thickness of an active layer (nm)	Level of a thermal treatment	light-scattering defect density at the depth of 260 μm from the interface ($/cm^3$)	Maximum temperature (°C)	Slip dislocation
Example 1	SIMOX	200	Level 3	1.1E+08	1200	No
Example 2	SIMOX	200	Level 3	1.9E+08	1300	No
Example 3	SIMOX	100	Level 3	1.8E+08	1300	No
Example 4	Adhesion (smart cut)	100	Level 4	1.7E+08	1300	No
Comparative Example 1	SIMOX	200	Level 2	3.2E+08	1200	Yes
Comparative Example 2	SIMOX	100	Level 2	3.5E+08	1200	Extremely much amount
Comparative Example 3	SIMOX	200	Level 2	4.4E+08	1300	Much amount
Reference Example 1	Adhesion (grinding)	1000	Level 1	3.2E+08	1200	No
Reference Example 2	Adhesion (grinding)	1000	Level 1	3.5E+08	1300	No

[0056]

From the results of Examples 1 to 4, Comparative Examples 1 to 3, and

Reference Examples 1 and 2, the following is clarified. When an extremely-short annealing treatment is performed, it is thought that only the surface of a wafer is heated. Therefore, if the active layer has enough thickness, such as the cases of Reference Example 1 and 2, slip dislocation of the support layer is not generated, since the region heated in the wafer is restricted to the active layer. However, it is thought that, particularly if the active layer has the thickness of no more than 200 nm, a part of the insulated oxide film layer and the support layer is also heated. Therefore, the infrared radiation (IR) light scattering defect generates densely in the rapidly heated region. The defect obstacles to heat conduction, and high stress is generated near an interface between the support layer and the insulated oxide film layer, thereby generating slip dislocation.

INDUSTRIAL APPLICABILITY

[0057]

The SOI wafer of the present invention does not generate slip dislocation even if laser annealing is conducted at a maximum temperature of 1200°C or more for no more than 0.1 seconds, since the light-scattering defect density measured by a 90° light-scattering method at the depth region of 260 μm toward the support layer side from the interface between the insulated oxide film layer and the support layer is no more than $2\times10^{8}/cm^{3}$. Therefore, it is consequently extremely useful industrially.

CLAIMS

1. An SOI wafer used for a process of manufacturing a semiconductor device, in which a laser annealing is conducted for no more than 0.1 seconds at a maximum temperature of 1200°C or more, the SOI wafer comprising:

an active layer;

a support layer of a monocrystaline silicon; and

an insulated oxide film layer between the active layer and the support layer,

wherein light-scattering defect density measured by a 90° light scattering method at the depth region of 260 μm toward the support layer side from an interface between the insulated oxide film layer and the support layer is $2\times10^8/cm^3$ or less, and

the thickness of the active layer is 200 nm or less.

2. A method of manufacturing an SOI wafer, comprising:

producing a SOI wafer having a insulated oxide film layer between a support layer of a monocrystaline silicon and an active layer, and

thermally-treating the SOI wafer so that light-scattering defect density measured by a 90° light scattering method at the depth region of 260 μm toward the support layer side from an interface between the insulated oxide film layer and the support layer is $2\times10^8/cm^3$ or less,

wherein the thickness of the active layer is 200 nm or less.