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DESCRIPTION



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EMITTER, EMITTER MANUFACTURING METHOD, AND COLD-ELECTRON
EMITTING ELEMENT MANUFACTURING METHOD

TECHNICAL FIELD

The present invention relates to an emitter for emitting a cold-electron which is employed as an electron source of diverse electron beam utilization devices such as flat-type image display devices, various types of sensors, high-frequency oscillators, ultra-fast devices, electron microscopes, electron beam exposure apparatus, and an emitter manufacturing method.

BACKGROUND ART

As an electron source for cold electrons of a conventional electric-field-emission display device or the like, a source in which many conical submicroscopic emitters each having a nearly 1 μ m of height and a nearly 1 μ m of bottom diameter are formed at the cathode side is employed. The above-mentioned emitter can emit an electron by concentrating the electric field on its tip portion. This basic structure is known by the method suggested by C. A. Spint et al. (Journal of Applied Physics, Vol. 47, No.12, p.5248, 1976). Since the electron emission characteristics depend on the shape of the tip portion of the emitter, in order to equalize the electron emission

characteristics of respective emitters, it is desired that the shapes of emitters manufactured in plurality, particularly shapes of the tip portions, are formed uniform.

In addition, as a biggest problem for this emitter, the electron emission amount varies with time. The emitter manufacturing methods to solve this problem will be divided broadly into the following two.

One is a method for forming a metal emitter on a glass substrate and connecting a large electrical resistance to this emitter in series, thereby to stabilize the emission current amount. The other is a method for forming an emitter and a transistor by semiconductors, and controlling the emission current amount actively by this transistor. This method is feasible with low power consumption and a high operation speed, and is expected to achieve a further development.

In cases where the emitters are formed employing the semiconductor as described above, the following three kinds of emitter material films are conceivable. The first one is a monocrystalline film having no grain boundary and having crystal axes which are uniform in a fixed direction at all parts. The second one is a polycrystalline film which is formed by that crystalline grains having disparate crystal axes are gathered. The third one is an amorphous film having no crystal structure. Among the three kinds of cold-electron emitting element materials as described above, the

monocrystalline film or the polycrystalline film are preferable in view of forming the transistor of excellent characteristics.

In cases where the monocrystalline film is employed, since there is no grain boundary and the crystal axis is uniform in a fixed direction, the isotropic etching rate of wet etching or the anisotropic etching rate of reactive ion etching is uniform, whereby an emitter superior in uniformity can be manufactured. However, since the monocrystalline film requires a high manufacturing cost and cannot be manufactured on a large-area substrate such as a glass substrate, it lacks in practicability in the present state.

On the other hand, the manufacturing costs when employing the polycrystalline film is inexpensive as compared with the monocrystalline film and the polycrystalline film can be manufactured on a large-area substrate at a low temperature, and this film is suitable for a minute electron source of display devices and the like.

Figure 10 is a cross sectional view of the conventional polycrystalline film substrate as mentioned above. Figure 11 is a cross sectional view of an emitter manufactured by employing the polycrystalline film in figure 10.

In figure 10, numeral 1 denotes a substrate such as a glass, on which a polycrystalline film 14 composed of micro crystalline grains 13 of different crystal orientation and grain diameter is formed. In the polycrystalline film 14,

since there are present crystalline grains 13 of various sizes and directionalities on the substrate 1, numerous grain boundaries exist therein.

Further, an emitter 15, shown in figure 11, which is manufactured by employing the polycrystalline film 14 can be formed by etching the polycrystalline film 14 composed of micro crystalline grains 13 having different crystal axes and grain diameters on the substrate 1 of a glass or the like.

As described above, in the prior art, since the emitter is manufactured by forming the polycrystalline film 14 on the substrate, a transistor and a cold-electron emitting element of favorable characteristics can be manufactured at a low process temperature, and therefore an inexpensive large-area glass substrate can be used. Accordingly, the manufacturing cost of the emitter 15 can be lowered.

However, there is a problem that the emitter 15 formed by employing the above-mentioned polycrystalline film 14 has variations in the electron emission characteristics. This is because crystalline grain diameters in the polycrystalline film to be etched vary largely as well as the crystal axis and crystal orientation surface of the respective crystalline grains vary largely, and therefore, the isotropic or anisotropic etching rate differs for each crystalline grain with the grain boundary as a boundary, while the emitter 15 is formed by etching.

More particularly, since in the conventional polycrystalline film 14 the isotropic or anisotropic etching rate differs for each crystalline grain, numerous irregular unevenness are formed on the surface of the emitter 15, as shown in figure 11, resulting in variations in the electron emission characteristics. Moreover, no reproducibility is obtained in the formation of the emitter 15 by etching. Therefore, when employing such irregular polycrystalline film 14, it is difficult to form a large number of uniform emitters 15 on a large-area substrate with good reproducibility, and the manufacturing cost of a device employing the emitter 15 becomes expensive.

The present invention is made to solve the problems described above, and has an object to provide an emitter and its manufacturing method, which can obtain the uniformity of the emitter shape with good reproducibility as well as suppress variations in the electron emission characteristics due to variations in the emitter shape, even when many emitters are formed.

DISCLOSURE OF THE INVENTION

An emitter of one form of the present invention is formed by depositing columnar crystalline grains on a

substrate along a same crystal axis, and thereafter patterning a first insulator on the columnar polycrystalline film, and performing etching to the columnar polycrystalline film employing the patterned first insulator. Thereby, even when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

An emitter as claimed in claim 2 of the present invention is formed by forming a second insulator on a substrate and forming a columnar polycrystalline film by depositing columnar crystalline grains on the second insulator along a same crystal axis, and thereafter forming a patterned first insulator on the columnar polycrystalline film, and performing etching to the columnar polycrystalline film employing the patterned first insulator. Thereby, even when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 3 of the present invention, in the emitter as claimed in claim 1 or claim 2, the columnar crystalline grains constituting the columnar polycrystalline film have crystal axes and crystal faces, which are uniform in a fixed direction with respect to the substrate. Thereby, even

when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 4 of the present invention, in the emitter as claimed in any one of claims 1 to 3, the columnar polycrystalline film includes at least silicon. Thereby, the columnar polycrystalline film can be realized by a low-temperature process at 500°C or lower. Therefore, the columnar polycrystalline film can be etched into a uniform shape on a large-area substrate, thereby obtaining the uniformity of the emitter shape with good reproducibility as well as suppressing variations in the electron emission characteristics due to variations in the emitter shape even when a large number of emitters are formed.

According to claim 5 of the present invention, in the emitter as claimed in any one of claims 1 to 4, the set of orientation faces in the columnar polycrystalline film is {110}. Therefore, the crystal axis and the crystal face are easy to be aligned, thereby enabling uniform shape etching. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 6 of the present invention, in the emitter as claimed in any one of claims 1 to 4, an orientation surface of the columnar polycrystalline film is {100}. Thereby, the crystal orientation and the crystal face are easy to be aligned which enables etching of the columnar polycrystalline film into a uniform shape. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed. Further, the barriers produced by the grain boundary can be suppressed as well as the trap levels formed at the interface of the insulator are lowered. Therefore, the mobility of the running electron is increased, thereby realizing the efficient emitters.

According to claim 7 of the present invention, in the emitter as claimed in any one of claims 1 to 6, the curvature radius of a tip portion of the emitter formed by performing etching to the columnar polycrystalline film is 50nm or less. Therefore, the concentration of the electric field on the tip portion of the emitter is increased, thereby enabling the emission of the electrons at low voltages.

According to claim 8 of the present invention, in the emitter as claimed in any one of claims 1 to 7, the columnar crystalline grains constituting the columnar polycrystalline

film have a shorter grain diameter of at least 100nm or more. Therefore, the grain boundaries at the tip portion of the emitter which cause variations in etching are decreased, thereby enabling etching of the columnar polycrystalline film into a uniform shape. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 9 of the present invention, in the emitter as claimed in claim 9, an angle formed between the columnar crystalline grain and the substrate is 83° or more. Therefore, the grain boundaries at the tip portion of the emitter which cause variations in etching are decreased, thereby enabling etching of the columnar polycrystalline film into a more uniform shape. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 10 of the present invention, in the emitter as claimed in claim 2, the second insulator includes at least oxygen or nitrogen. Therefore, the diffusion of impurities from the glass to the columnar polycrystalline film is suppressed, thereby providing the columnar polycrystalline film of excellent crystallinity. Further, the uniformity of the

emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 11 of the present invention, in the emitter as claimed in claim 1 or claim 2, the patterned first insulator is circular. Thereby, the emitter with a sharp tip portion can be realized easily by etching the columnar polycrystalline film.

According to claim 12 of the present invention, in the emitter as claimed in claim 1 or claim 2, the patterned first insulating film is polygonal. Thereby, in addition to the effect of claim 11 of the present invention, the exposure accuracy of photolithography can be enhanced as well as the cost of the exposure mask can be lowered.

An emitter manufacturing method as claimed in claim 13 of the present invention includes a step of forming a columnar polycrystalline film by depositing columnar crystalline grains on a substrate along a same crystal axis, a step of forming a patterned first insulator on the columnar polycrystalline film, and a step of etching the columnar polycrystalline film employing the patterned first insulator. Thereby, even when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good

reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

An emitter manufacturing method as claimed in claim 14 of the present invention includes a step of forming a second insulator on a substrate, a step of forming a second insulator on a substrate, a step of forming a columnar polycrystalline film by depositing columnar crystalline grains on the second insulator along a same crystal axis, a step of forming a patterned first insulator on the columnar polycrystalline film, and a step of etching the columnar polycrystalline film employing the patterned first insulator. Thereby, even when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 15 of the present invention, in the emitter manufacturing method as claimed in claim 13 or claim 14, the columnar crystalline grains constituting the columnar polycrystalline film have crystal axes and crystal faces, which are uniform in a fixed direction with respect to the substrate. Thereby, even when a large number of emitters are formed, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission

characteristics due to variations in the emitter shape can be suppressed.

According to claim 16 of the present invention, in the emitter manufacturing method as claimed in any one of claims 13 to 15, the columnar polycrystalline film includes at least silicon. Thereby, the columnar polycrystalline film can be realized by a low-temperature process at 500°C or below. Therefore, the columnar polycrystalline film can be etched into a uniform shape on a large-area substrate, thereby obtaining the uniformity of the emitter shape with good reproducibility as well as suppressing variations in the electron emission characteristics due to variations in the emitter shape even when a large number of emitters are formed.

According to claim 17 of the present invention, in the emitter manufacturing method as claimed in any one of claims 13 to 16, the orientation surface of the columnar polycrystalline film is {100}. Thereby, the crystal axis and the crystal face are easy to be aligned, thereby enabling uniform shape etching. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 18 of the present invention, in the emitter manufacturing method as claimed in any one of claims 13 to 16, the orientation surface of the columnar polycrystalline film is {100}. Thereby, the crystal axis and the crystal face are easy to be aligned, thereby enabling uniform shape etching. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed. Further, the barrier by the grain boundary can be suppressed as well as the trap level formed at the interface of the insulator is lowered. Therefore, the mobility of the running electron is increased, thereby realizing efficient emitters.

According to claim 19 of the present invention, in the emitter manufacturing method as claimed in any one of claims 13 to 18, etching is performed to the columnar polycrystalline film such that the curvature radius of a tip portion of the emitter becomes 50nm or less. Thereby, the concentration of the electric field on the tip portion of the emitter is increased, thereby enabling emission of electrons at low voltages.

According to claim 20 of the present invention, in the emitter manufacturing method as claimed in any one of claims 13 to 19, the columnar crystalline grains in the columnar polycrystalline film have a shorter grain diameter of at least

100nm or more. Thereby, the grain boundaries at the tip portion of the emitter which cause variations in etching are reduced, thereby enabling etching of the columnar polycrystalline film into a uniform shape. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 21 of the present invention, in the emitter manufacturing method as claimed in claim 20, the angle formed between the columnar crystalline grain and the substrate is 83° or more. Thereby, the grain boundaries at the tip portion of the emitter which cause variations in etching are decreased, thereby enabling etching of the columnar polycrystalline film into a more uniform shape. Therefore, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 22 of the present invention, in the emitter manufacturing method as claimed in claim 14, the second insulator includes at least oxygen or nitrogen. Thereby, the diffusion of impurities from the glass to the columnar polycrystalline film is suppressed, thereby providing

the columnar polycrystalline film of excellent crystallinity. Further, the uniformity of the emitter shape can be obtained with good reproducibility as well as variations in the electron emission characteristics due to variations in the emitter shape can be suppressed.

According to claim 23 of the present invention, in the emitter manufacturing method as claimed in claim 13 or claim 14, the patterned first insulator is circular. Thereby, the emitter with a sharp tip portion can be realized easily by etching the columnar polycrystalline film.

According to claim 24 of the present invention, in the emitter manufacturing method as claimed in claim 13 or claim 14, the patterned first insulator is polygonal. Thereby, in addition to the effect of claim 11 of the present invention, the exposure accuracy of photolithography can be enhanced as well as the cost of the exposure mask can be lowered.

A cold-electron emitting element manufacturing method as defined in claim 25 of the present invention includes a step of manufacturing an emitter by the emitter manufacturing method as defined in claim 13 or claim 14, a step of forming a third insulator and an extraction gate electrode with leaving the patterned first insulator on the columnar polycrystalline film, and a

step of forming an opening by removing only the upper part of the first insulating film patterned on the columnar polycrystalline film. Therefore, the extraction gate electrode can be formed easily without employing a photolithography process, resulting in a reduced cost for manufacturing a cold-electron emitting element.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross sectional view of a columnar polycrystalline substrate according to a first embodiment of the present invention.

Figure 2 is a sectional view showing processes of a method for manufacturing a cold-electron emitting element employing the columnar polycrystalline substrate shown in figure 1.

Figure 3 is a diagram showing a Raman spectrum of the columnar polycrystalline substrate according to the first embodiment of the present invention.

Figure 4 is a cross sectional view of a columnar polycrystalline substrate in which an underlying layer is provided according to a second embodiment of the present invention.

Figure 5 is a cross sectional view of a columnar polycrystalline substrate in which a crystal orientation and a crystal face are uniform in a fixed direction according to a third and a fifth embodiments of the present invention.

Figure 6 is a cross sectional view of the cold-electron emitting element according to a fourth embodiment of the present invention.

Figure 7 is a diagram for explaining the electron emission amount from the cold-electron emitting element depending on the difference in film structure according to a sixth embodiment of the present invention.

Figure 8 is a diagram showing a XRD spectrum of the columnar polycrystalline silicon of {110} plane.

Figure 9 is a diagram for explaining the relationship between the intensity of the electric field applied to a tip portion of the emitter and the curvature radius of the tip portion of the emitter.

Figure 10 is a sectional view of a polycrystalline film in the prior art.

Figure 11 is a sectional view of an emitter which employs the polycrystalline film in the prior art.

BEST MODE TO EXECUTE THE INVENTION

(Embodiment 1)

Hereinafter, a first embodiment of the present invention will be described with reference to figures 1 and 2.

Figure 1 is a cross sectional view of a columnar polycrystalline substrate according to the first embodiment of the present invention. Figure 2 is a sectional view showing

processes of a manufacturing method of an emitter and a cold-electron emitting element according to the first embodiment of the present invention.

In figure 1, numeral 1 denotes a substrate such as a glass, and numeral 2 denotes a columnar polycrystalline film. Further, numeral 3 denotes a grain boundary showing a boundary between crystalline grains, and numeral 4 denotes a columnar crystalline grain.

Hereinafter, the formation of the columnar polycrystalline film 2 will be described. By a plasma enhanced chemical vapor deposition (PCVD) method which employs, as material gas, silane gas of 0.1-3% diluted by hydrogen gas, the columnar polycrystalline film 2 as a columnar polycrystalline silicon film with a grain diameter of about 100-140nm in which crystal orientation and crystal face are uniform is formed on the substrate 1 such as a glass shown in figure 1 under the condition of substrate temperature of 200-350°C, film formation pressure of 0.1-5Pa, and RF power of 300W-1kW. The film formed under this condition becomes the columnar polycrystalline film 2 which has mainly {110} plane.

Further, when the film is formed on the substrate 1 such as a glass shown in figure 1 by, for example, the same PCVD method employing mixed gas of silane gas and silicon tetrafluoride gas as the material gas under the condition of substrate temperature of 250-450°C, film formation pressure of

100-170Pa, and RF power of 50-500W, the columnar polycrystalline film 2 with a grain diameter of about 250nm which has mainly {100} plane is obtained.

The so-formed columnar polycrystalline film 2 having either {110} or {100} plane can realize the cold-electron emitting element with emitters of uniform shape as the effect of the present invention.

While the columnar polycrystalline film 2 includes amorphous layer, it is desirable that the crystallinity rate, i.e., the rate of polycrystalline and amorphous included in unit area, is 80% or more in order to form emitters of uniform shape.

The crystallinity is represented by $I(520)/(I(520)+I(480))$, as a relation between the intensity $I(520)$, which is measured by Raman spectrometry to be the intensity of Raman shift amount of the crystalline phase as about 520cm^{-1} , and the intensity $I(480)$, which is measured by Raman spectrometry to be the intensity of Raman shift amount of the amorphous phase as about 480 cm^{-1} (see Fig.3).

Further, in this embodiment a typical deposition condition is specified. Under a deposition condition having particular ranges of gas flow rate, gas mixture ratio, substrate temperature, film formation pressure, RF power and the like, the columnar polycrystalline film 2 can be obtained by employing mixed gas including silicon gas, and the grain

diameter or the size can be varied in dependence on this deposition condition.

For example, figure 8 shows an X-ray diffraction (XRD) spectrum of a typical columnar polycrystalline silicon film formed under the condition of substrate temperature of 300°C, film formation pressure of 2Pa, and RF Power of 300W by the plasma-activated chemical vapor deposition (PCVD) method employing mixed gas of silane and hydrogen. The film formed on the condition as described above has a strong peak at about 47.4° of 2θ and is oriented to (220) face.

Further, the columnar polycrystalline film 2 oriented to {110} face is obtained when the film is formed under the condition of substrate temperature of 300°C, film formation pressure of 100Pa, and RF Power of 300W by the PCVD method employing mixed gas of silane gas and silicon tetrafluoride gas, and the peak of (400) face appears at about 63.2° of 2θ in the XRD spectrum (not shown).

Then, a manufacturing method of an emitter and a cold-electron emitting element manufactured by employing the above-mentioned columnar polycrystalline film 2 will be described with reference to figure 2.

After the columnar polycrystalline film 2 is formed on the substrate 1 (Fig. 2(a)) as described above, first insulator 5 of SiO₂ or the like is patterned on the columnar polycrystalline film such that each dot takes the circular or

polygonal form, by using the PCVD method, sputtering method, deposition method, or the like, as shown in figure 2(b). This patterning is performed by, for example, depositing the insulator to a thickness of around 200nm, and applying a processing to the insulator to form dot patterns of circular or polygonal form with a diameter of around 1 μ m by photolithography process.

After the formation of the first insulator 5 in circular or polygonal form, the columnar polycrystalline film 2 is processed by performing reactive ion etching (RIE), thereby to obtain emitter 6 as shown in figure 2(c). As the etching gas, halogen gas such as SF₆ is used.

Subsequently, a gate insulating layer 7 comprising such as SiO₂ and a drawing gate electrode 8 comprising such as Nb are formed by the deposition method or the like as shown in figure 2(d). By controlling the film thickness of the gate insulating layer 7, the distance between the tip portion of the emitter 6 and the drawing gate electrode 8 can be varied easily, and the electric field can be concentrated on the tip portion of the emitter 6 effectively, whereby the cold-electron emitting element of favorable electron emission efficiency can be obtained.

Finally, as shown in figure 2(e), upper parts of the first insulating film 5 which was processed into the circular or polygonal dot pattern are removed by a lift-off method, thereby

forming openings. Further, while in this first embodiment the gate insulating layer 7 and the extraction gate electrode 8 are removed to form the openings by the lift-off method, it is also possible to form the same by an etching-back method.

As described above, according to this first embodiment, the emitter 6 is manufactured by providing the columnar polycrystalline film 2 and performing the etching thereto, whereby the crystal orientations and the crystal faces of respective columnar crystalline grains are made uniform. Therefore, at all portions except for on the grain boundary 3, the isotropic or anisotropic etching rate while performing the wet or reactive ion etching is equalized. Thereby, the emitter 6 can be manufactured with good reproducibility and, the uniformity for a large number of emitters 6 formed over a wide range can be obtained.

In addition, the columnar polycrystalline film 2 at least includes silicon and, specifically, it comprises a polycrystalline silicon film or a polycrystalline silicon germanium. By employing these materials including silicon, the columnar polycrystalline film can be formed on a large-area substrate by a process at a low temperature of 500°C or below. Therefore, the columnar polycrystalline film can be etched into a uniform shape on a large-area substrate, thereby obtaining the uniformity of the emitter shape with good reproducibility as well as suppressing variations in the electron emission

characteristic due to variations in the emitter shape, even when a large number of emitters are formed on a large-area substrate.

(Embodiment 2)

Hereinafter, a second embodiment of the present invention will be described with reference to figure 4.

Figure 4 is a sectional view of a columnar polycrystalline substrate according to the second embodiment of the present invention. A cold-electron emitting element according to this second embodiment differs from the above-mentioned cold-electron emitting element according to the first embodiment, where the columnar polycrystalline film 2 is formed without coating the substrate with an insulator, only in that the emitter and the cold-electron emitting element are manufactured by forming the columnar polycrystalline film 2 which comprises columnar crystalline grains being deposited along the same crystal axis after the insulator is formed on the substrate. Thus, the same elements as those shown in the first embodiment are denoted by the same reference numerals and their descriptions will be omitted.

In figure 4 a second insulator 9 is formed on the glass substrate 1. As this processing for forming the second insulator 9 on the glass substrate 1, a silicon dioxide film SiO_2 of about 300-1000nm is formed under the condition of substrate temperature of 200-300°C, film formation pressure of

0.1-10Pa, and RF power of 300-500W by the PCVD method employing mixed gas of, for example, silane gas and N_2O gas, or TEOS and oxygen as material gas. The process after the formation of the second insulating film 9 is the same as that shown in the first embodiment and the description will be omitted.

As described above, by forming the second insulating film 9 on the substrate 1, diffusion of impurities included in the substrate 1 such as boron or sodium can be suppressed, thereby enhancing the crystallinity of the columnar polycrystalline film 2.

In addition, the second insulating film 9 may be the one that includes at least oxygen or nitrogen. In other words, such as a silicon nitride film SiN_x , a suboxide nitride film, or a composite film of these can also be employed other than the silicon dioxide film SiO_2 , and the same effect can be obtained.

(Embodiment 3)

Hereinafter, a third embodiment of the present invention will be described with reference to figure 5.

Figure 5 is a sectional view of a columnar polycrystalline substrate in which the crystal orientation and the crystal face are uniform in a fixed direction. The same elements as those shown in the first embodiment are denoted by the same reference numerals and their descriptions will be omitted.

In figure 5, the columnar polycrystalline grain 4 is

arranged such that the crystal axis and the crystal face are uniform in a fixed direction with respect to the substrate. Numeral 10 denotes the crystal orientation indicating the direction of each crystalline grain, and the crystal face is oriented by {110} or {100} vertically to the crystal axis 10.

When the crystallinity rate is preferably 80% or more, this arrangement of the columnar polycrystalline grain in the columnar polycrystalline film can be obtained even when the amorphous phase is included in the columnar polycrystalline film 2. The process after forming the columnar polycrystalline substrate comprising the columnar polycrystalline grain 4 of uniform shape is the same as that shown in the first embodiment and the description will be omitted.

As described above, according to this third embodiment the columnar polycrystalline grain 4 in the columnar polycrystalline film 2 has the crystal axis and the crystal face uniform in a fixed direction with respect to the substrate 1, whereby the etching rate of the isotropic or anisotropic etching can be made equal not only in the same crystalline grains but also in all the crystalline grain areas other than the grain boundary. Therefore, the emitters are manufactured with good reproducibility and the uniformity of the shape can be obtained in numerous emitters formed over a wide range.

(Embodiment 4)

Hereinafter, a fourth embodiment of the present invention

will be described with reference to figure 6.

Figure 6 is a sectional view of an emitter part of a cold-electron emitting element manufactured by employing the columnar polycrystalline film 2 according to the fourth embodiment of the present invention. In figure 6, numeral 11 denotes a shorter grain diameter of the columnar crystalline grain, numeral 6 denotes an emitter, and numeral 12 denotes a tip portion of the emitter. In figure 6, the same elements as those shown in the first embodiment are denoted by the same reference numerals and their descriptions will be omitted.

Generally, when the curvature radius of the tip portion of the emitter 12 is 50nm or more, concentration of the electric field on the tip portion of the emitter 12 by the drawing gate electrode 8 (see Fig.2(e)) is not performed effectively, and therefore, it is required to apply high voltage of 50V or more to the drawing gate electrode 8 in order to obtain the electric field intensity of 10^6V/mm which is required for electron emission of silicon. Since it is preferable for a driving circuit that the gate voltage is 50V or less, the curvature radius of the tip portion of the emitter 12 is preferably 50nm or less.

In addition, 10^6V/mm or more of electric field intensity is generally required for cold-electron emission of silicon, and provided that the distance between the emitter and the drawing gate electrode which applies voltage V (V) to the

emitter positively is d , and the curvature radius of the tip portion of the emitter is r , the electric field intensity F at the tip portion of the emitter is represented by the following equation (1).

$$F = 2V/r \ln(2d/r) \quad (\text{V/mm}) \quad \dots (1)$$

The relation of the electric field intensity F to the curvature radius r of the tip portion of the emitter in case where $d = 0.5 \times 10^{-6}(\text{m})$, $V = 60, 80$, and $100 (\text{V})$, in the equation (1) will be described in figure 9. In the figure, the conditions of $V > 80\text{V}$ and $r < 50\text{nm}$ must be satisfied in order to obtain 10^6V/mm or more for F . Accordingly, the larger r is, the higher voltage is required, in order to apply an electric field of 10^6V/mm or more to the tip portion of the emitter and conversely, the smaller r is, only a lower voltage is required. When a high voltage is required, the driving circuit for controlling the emitter becomes complicated, and moreover, there occurs a problem of a breakdown voltage of the insulating layer underlying the drawing gate electrode, resulting in an expensive cold-electron emitting element device. Accordingly, by setting the curvature radius as 50nm or less, an inexpensive low-voltage driving circuit can be provided.

By the usual reactive etching method employing halogen gas or wet etching method including hydrofluoric acid, it is very difficult to sharpen the curvature radius of the tip portion of the emitter 12 extremely to be less than 50nm , for example,

around a few nanometers or less, and usually the curvature radius becomes around 50nm. Thus, by making the shorter grain diameter 11 of the columnar crystalline grain be 100nm or more, the cold-electron emitting element having emitters of uniform shape can be realized.

Further, when the shorter grain diameter 11 of the columnar crystalline grain is smaller than 100nm in case where the curvature radius of the tip portion of the emitter 12 is formed as small as around 50nm, the probability (possibility) that the grain boundary is located at the tip portion of the emitter is high, resulting in that the tip portion of the emitter 12 which has the curvature radius of around 50nm is not formed with good reproducibility because of the grain boundary.

In addition, the grain boundary 3 has many defects, which results in that the electron emission amount is decreased when the defects are located on the tip portion of the emitter 12. For the reasons described above, the shorter grain diameter 11 of the columnar crystalline grain is preferably 100nm or more.

As described above, according to the fourth embodiment, since the shorter grain diameter 11 of the columnar crystalline grain is at least 100nm or more, grain boundary having different etching rate does not exist at the tip portion of the emitter 12, whereby the tip portion of the emitter 12 can be formed with good reproducibility.

(Embodiment 5)

Hereinafter, a fifth embodiment of the present invention will be described with reference to figures 5 and 2(e). The same elements as those shown in the third embodiment are denoted by the same reference numerals and their descriptions will be omitted.

In figure 5, numeral 10 denotes crystal axis indicating the direction of each crystalline grain. Each crystalline grain 4 is formed at an angle of 83° or more against the substrate 1. This is because the thickness of the columnar polycrystalline film 2 with a grain diameter of at least $0.1\mu\text{m}$ needs to be at least around $0.8\mu\text{m}$ in order to form the emitters, and $\tan^{-1} (0.8/0.1) \approx 83^\circ$ is required so as not to make grain boundary with different etching rate exist in the area of the tip portion of the emitter while forming the emitters. In addition, as shown in figure 2(e), when the electron is drawn by concentrating the electric field on the tip portion of the emitter 12, because the electron flows in an approximately vertical direction to the substrate 1, the electron has to flow to the tip portion of the emitter crossing the grain boundary if the crystalline grain is formed at an angle of 83° or less against the substrate 1. On the other hand, when the angle is 83° or more, the electron can flow to the tip portion of the emitter in the same crystalline grain without crossing the grain boundary including many defects, thereby the emission current is not decreased.

As described above, according to the fifth embodiment, since each crystalline grain 4 is formed at an angle of 83° or more against the substrate 1, grain boundary with different etching rate does not exist at the tip portion of the emitter, whereby the tip portion of the emitter 12 can be formed with good reproducibility. Moreover, the cold-electron emitting element of excellent electron emission characteristic can be obtained.

(Embodiment 6)

Hereinafter, a sixth embodiment of the present invention will be described with reference to figures 1 and 7. The description of the respective components in figure 1 will be omitted as they were described in the first embodiment.

The crystal face of the columnar crystalline grain 4 is $\{110\}$ or $\{100\}$ orientation surface. By making the orientation surface of the columnar polycrystalline film 2 $\{110\}$, the crystal orientation and the crystal face are easy to be aligned, thereby enabling uniform shape etching, and realizing the cold-electron emitting element with the emitters of excellent uniformity.

Further, by making the orientation surface $\{110\}$ or $\{100\}$ orientated, an energy barrier against electron movement by the grain boundary while the electrons in the columnar polycrystalline film 2 run through the semiconductor layer can be lowered, and the mobility of the electron is increased,

thereby realizing an increase in the electron emission amount as well as a quicker response.

Further, when the orientation surface is {100}, in comparison with the case of {110} face orientated, the barrier by the grain boundary is lowered, thereby to ease the electron flow, and trap of carrier on the boundary face between the gate insulating layer and the semiconductor crystal face is decreased with relative to {110} face orientated, thereby to further ease the electron flow on the interface between the semiconductor and the insulating layer. Therefore, the mobility of the electron is further increased, thereby realizing an increase in the electron emission amount and a quicker response.

Figure 7 shows the result of the measurement for the electron emission from the emitter of a thousand of chips due to the difference in the crystal structure, that is carried out in the present invention. The voltage applied to the drawing gate electrode is made equal. In figure 7, in case where the emitters are formed by the columnar polycrystalline film 2 of {110} face orientated, the electron emission amount is twice or more as that in case where the emitters are formed by the amorphous silicon film. The electron emission amount has a relation with the light emission luminance from a phosphor and the light emission luminance is in proportion to the electron emission amount. Accordingly, only a lower extraction gate

voltage is required in order to obtain the same electron emission amount (light emission luminance) in case where the emitters are formed by the columnar polycrystalline film 2 of {100} plane than in case where the emitters are formed by the amorphous silicon film, thereby resulting in a lowered voltage.

Further, in comparison with the columnar polycrystalline film of {110} plane, that of {100} face orientated realizes an increase in the current amount from the cold-electron emitting element, thereby resulting in a lowered voltage.

As described above, according to the sixth embodiment, when the crystal face of the columnar crystalline grain is {110} or {100} plane, there is provided an increase in the electron emission amount, thereby resulting in an cold-electron emitting element that is driven by a low voltage.

APPLICABILITY IN INDUSTRY

According to an emitter and an emitter manufacturing method of the present invention, by performing etching to the columnar polycrystalline film which is obtained by depositing the columnar crystalline grains on the substrate along the same crystal axis, the emitters having regular shapes in their tip portions can be formed with good reproducibility, whereby the uniformity of the emitter shape is obtained even when a large number of emitters are formed on a large-area substrate. Thereby, variations in the electron emission characteristics of

cold-electron emitting element due to variations in the emitter shape can be suppressed, and therefore, the emitters can be used as an electron source of diverse electron beam utilization devices such as a flat-type image display device, various sensors, a high-frequency oscillator, ultra-fast devices, an electron microscope, an electron beam exposure apparatus, or the like.

CLAIMS

1. An emitter formed by forming a columnar polycrystalline film which comprises columnar crystalline grains being deposited on a substrate along a same crystal axis, and thereafter patterning a first insulator on the columnar polycrystalline film, and

performing etching to the columnar polycrystalline film employing the patterned first insulator.

2. An emitter which is formed by forming a second insulator on a substrate and forming a columnar polycrystalline film by depositing columnar crystalline grains on the second insulator along a same crystal axis, and thereafter forming a patterned first insulator on the columnar polycrystalline film, and

performing etching to the columnar polycrystalline film employing the patterned first insulator.

3. The emitter as claimed in claim 1 or claim 2, the columnar crystalline grains constituting the columnar polycrystalline film have crystal axes and crystal faces uniform in a fixed direction with respect to the substrate.

4. The emitter as claimed in any one of claims 1 to 3, wherein

the columnar polycrystalline film includes at least silicon.

5. The emitter as claimed in any one of claims 1 to 4, wherein

an orientation surface of the columnar polycrystalline film is {110}.

6. The emitter as claimed in any one of claims 1 to 4, wherein

an orientation surface of the columnar polycrystalline film is {100}.

7. The emitter as claimed in any one of claims 1 to 6, wherein

the curvature radius of a tip portion of the emitter formed by performing etching to the columnar polycrystalline film is 50nm or less.

8. The emitter as claimed in any one of claims 1 to 7, wherein

the columnar crystalline grains constituting the columnar polycrystalline film have a shorter grain diameter of at least 100nm or less.

9. The emitter as claimed in claim 8, wherein

an angle formed between the columnar crystalline grain and the substrate is 83° or more.

10. The emitter as claimed in claim 2, wherein
the second insulator includes at least oxygen or nitrogen.
11. the emitter as claimed in claim 1 or claim 2, wherein
the patterned first insulator is circular.
12. The emitter as claimed in claim 1 or claim 2, wherein
the patterned first insulator is polygonal.
13. An emitter manufacturing method comprising:
a step of forming a columnar polycrystalline film by
depositing columnar crystalline grains on a substrate along a
same crystal axis;
a step of forming a patterned first insulator on the
columnar polycrystalline film; and
a step of etching the columnar polycrystalline film
employing the patterned first insulator.
14. An emitter manufacturing method comprising:
a step of forming a second insulator on a substrate;

a step of forming a columnar polycrystalline film by depositing columnar crystalline grains on the second insulator along a same crystal axis;

a step of forming a patterned first insulator on the columnar polycrystalline film; and

a step of etching the columnar polycrystalline film employing the patterned first insulator.

15. The emitter manufacturing method as claimed in any one of claims 12 to 14, wherein

the columnar crystalline grains constituting the columnar polycrystalline film have crystal orientations and crystal faces which are uniform in a fixed direction with respect to the substrate.

16. The emitter manufacturing method as claimed in any one of claims 12 to 15, wherein

the columnar polycrystalline film includes at least silicon.

17. The emitter manufacturing method as claimed in any one of claims 12 to 16, wherein

the orientation surface of the columnar polycrystalline film is {110}.

18. The emitter manufacturing method as claimed in any one of claims 12 to 16, wherein

the orientation surface of the columnar polycrystalline film is {100}.

19. The emitter manufacturing method as claimed in any one of claims 12 to 18, wherein

the etching is performed to the columnar polycrystalline film such that the curvature radius of a tip portion of the emitter becomes 50nm or less.

20. The emitter manufacturing method as claimed in any one of claims 12 to 19, wherein

the columnar crystalline grains in the columnar polycrystalline film have a shorter grain diameter of at least 100nm or more.

21. The emitter manufacturing method as claimed in claim 20, wherein

the angle formed between the columnar crystalline grain and the substrate is 83° or more.

22. The emitter manufacturing method as claimed in claim 14, wherein

the second insulator includes at least oxygen or nitrogen.

23. The emitter manufacturing method as claimed in claim 13 or claim 14, wherein
the patterned first insulator is circular.

24. The emitter manufacturing method as claimed in claim 13 or claim 14, wherein
the patterned first insulator is polygonal.

25. A cold-electron emitting element manufacturing method,
comprising:

a step of manufacturing an emitter by the emitter manufacturing method as claimed in claim 13 or claim 14;

a step of forming a third insulator and drawing gate electrode with leaving the first patterned insulator on the columnar polycrystalline film; and

a step of forming an opening by removing only the upper part of the first insulator patterned on the columnar polycrystalline film.