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An agency of Industry Canada

CA 2155091 C 2003/03/25

(11)(21) 2 155 091

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(22) Date de dépôt/Filing Date: 1995/07/31

(41) Mise à la disp. pub./Open to Public Insp.: 1996/02/02

(45) Date de délivrance/Issue Date: 2003/03/25

(30) Priorités/Priorities: 1994/08/01 (06-179935) JP; 1994/10/28 (06-264719) JP; 1995/06/07 (07-140175) JP

(51) Cl.Int.^{6}/Int.Cl.^{6} B23K 35/26, H01L 23/488

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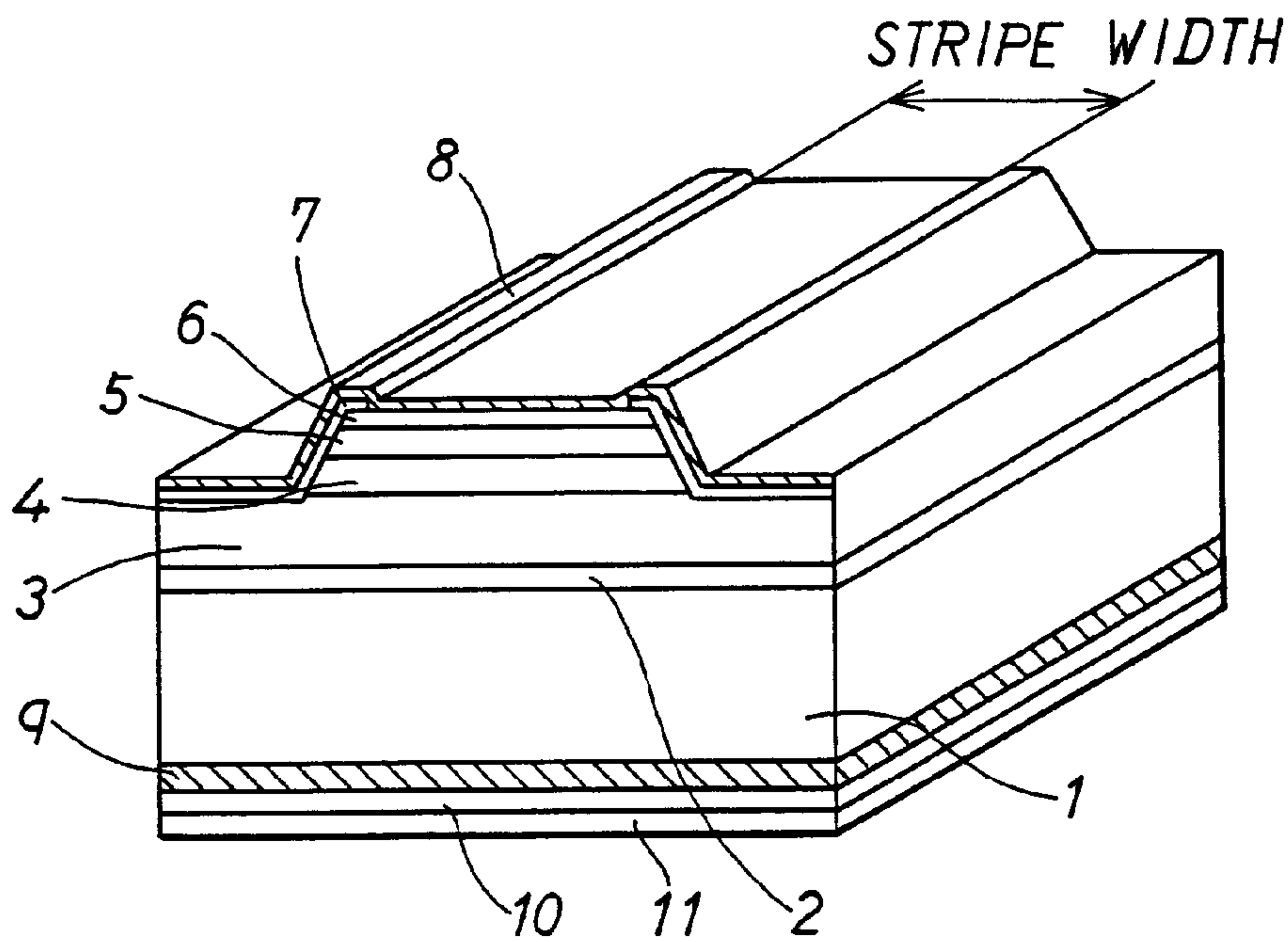
(54) Titre : MATERIAU LIANT ET METHODE DE LIAISONNEMENT POUR SEMICONDUCTEUR
(54) Title: BONDING MATERIAL AND BONDING METHOD FOR ELECTRIC ELEMENT



(57) Abrégé/Abstract:
A material and method for bonding a semiconductor device to a pedestal, which can obtain satisfactory bonding strength and stable electric contact, are disclosed. On an n-type electrode constituting an ohmic electrode for a semiconductor laser device are formed a Ni layer and an Au-Sn solder layer. Then, the solder layer is melted and bonded to a heat sink provided with Au-plating. The film thickness of the Ni layer is set to approximately 500Å or more. When the solder layer is melted, Ni in the Ni layer diffuses into the solder layer and Sn in the solder layer diffuses into the Ni layer. By this mutual diffusion, bonding strength and wettability between the semiconductor device and pedestal are improved. In addition, by setting the composition ratio of the Ni layer to the Au-Sn solder layer to between about l.3wt% and about 10wt%, the melting point of the mixed alloy is lower, and bonding can be carried out at lower temperatures. Concurrently, a higher bonding strength can be obtained.

ABSTRACT OF THE DISCLOSURE

A material and method for bonding a semiconductor device to a pedestal, which can obtain satisfactory bonding strength and stable electric contact, are disclosed. On an n-type electrode constituting an ohmic electrode for a semiconductor laser device are formed a Ni layer and an Au-Sn solder layer. Then, the solder layer is melted and bonded to a heat sink provided with Au-plating. The film thickness of the Ni layer is set to approximately 500Å or more. When the solder layer is melted, Ni in the Ni layer diffuses into the solder layer and Sn in the solder layer diffuses into the Ni layer. By this mutual diffusion, bonding strength and wettability between the semiconductor device and pedestal are improved. In addition, by setting the composition ratio of the Ni layer to the Au-Sn solder layer to between about 1.3wt% and about 10wt%, the melting point of the mixed alloy is lower, and bonding can be carried out at lower temperatures. Concurrently, a higher bonding strength can be obtained.

BONDING MATERIAL AND BONDING METHOD FOR ELECTRIC ELEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a bonding material and a bonding method for soldering electrical elements (devices), such as semiconductor laser devices, to a pedestal.

2. Related Arts:

In soldering semiconductor devices, such as semiconductor laser devices, to a pedestal plated with Au, such as heat sink, stem and circuit board, formed pellets of a eutectic solder, such as Au-Sn and Pb-Sn, have conventionally been used. For reasons related to method of manufacture and handling convenience, the formed pellets, should have dimensions in the order of hundreds of μm x hundreds of μm and the film thickness formed from the pellets should be at least tens of μm.

To satisfy these requirements, the volume of the solder layer may be excessively large. Consequently, when soldering a semiconductor device to a pedestal, the position of the semiconductor device may change during soldering or protuberances may be formed at the edges of the semiconductor device. When a semiconductor laser device is to be bonded, the protuberant solder layer may disturb or obscure the laser light.

A technique developed to solve this problem is disclosed in the European Patent Publication No. 0119691A2.

This technique does not use any formed pellet but provides on the semiconductor laser device a barrier layer consisting of Pd or Pt, a comparatively thick Au electrode and a Sn layer formed by means of evaporation to thereby form an eutectic layer of Sn and Au in preparation for mounting. Another technique similar to this is disclosed in the United States Patent No. 5,197,654.

However, even if the solder layer is made thinner, if wettability between the solder layer and the mounting surface is poor, incomplete electrical contact may result due to a small volume of solder. As a result, sufficiently high bonding strength and sufficiently low resistance can not simultaneously be obtained.

SUMMARY OF THE INVENTION

In view of the above problem, one object of the present invention is to bond a semiconductor device to a pedestal in such a way that a sufficient bonding strength and a stable electric connection can be obtained.

The inventors of the present invention exploited the fact that Sn and Ni are highly compatible with each other and can form an intermetallic compound.

As an ohmic electrode for a GaAs substrate, a stack of Ni and Au on an alloy of Au and Ge (hereinafter this type structure will be expressed as Au-Ge/Ni/Au) is known. In this structure, it is said that when the film thickness of Ni is increased, contact resistance increases, and therefore, Ni is used with a thickness of approximately 200Å. In this case, Ni is used as a barrier electrode for preventing the diffusion of the surface Au. For this reason, the inventors of the present invention considered using this metal system and tried to deposit, by means of evaporation, a solder containing Sn thereon, and to solder the same to a pedestal such as a heat sink.

However, there is the problem that Au on Ni diffuses into the solder layer and the bonding strength and wettability of the solder are detrimentally affected.

To counter this problem, the inventors tried soldering without providing the Au layer and found that the wettability is improved and stable soldering with a high bonding strength is achieved. This results from the fact that Ni diffuses into the solder layer and Sn in the solder layer diffuses into the Ni, i.e., mutual diffusion occurs, and as a result, the bonding strength and wettability of the solder are improved.

Furthermore, in bonding the semiconductor laser device, it is preferable to select a bonding material which can lower the bonding temperature, thereby minimizing heat damage to the semiconductor laser device. The inventors of the present invention studied this problem from various aspects and discovered, as described later, that if the Au-Sn solder is used, Ni diffuses into the Au-Sn layer to form an Au-Sn-Ni alloy and thereby lowers the bonding temperature.

The present invention is based on the above described trials and discoveries. Specifically, the present invention provides:

a bonding material, for bonding an electrode of an electrical element to a pedestal, consisting essentially of an Au-Sn-Ni alloy with Au as a main component, wherein Ni is contained in an amount of at least 1.3wt% preferably under 10wt%.

In the above bonding material, the Au-Sn-Ni alloy can be provided on a bonding part by forming a stacked structure of an Au-Sn alloy layer containing Au as a main component and an Ni layer on the bonding part and heating the same.

Furthermore, the present invention also provides a method of mounting an electrical element to a pedestal, comprising the steps of: 1) forming an electrode layer on the electrical element; 2) forming an Ni layer on the electrode layer; 3) forming a solder layer containing Sn directly on the Ni layer; and 4) heating the electrical element so as to cause the solder layer and the Ni layer to mutually diffuse as well as to cause ohmic contact of the electrode layer with the electrical element, thereby forming an Sn-Ni alloy containing Ni in an amount of at least 1.3wt% and less than 10wt% and bonding the electrical element to the pedestal.

According to the present invention, the bonding material is composed of an Au-Sn-Ni alloy containing Au as the main component and containing Ni in an amount of at least 1.3wt%, and preferably under 10wt%. Bonding with a high strength can be made at a low temperature and at the same time the increase in contact resistance can be minimized.

Furthermore, according to the bonding method of the present invention, the Ni layer and the solder layer containing Sn are formed on the electrode of the electrical element, and the solder layer is melted to be bonded to the pedestal.

Here, mutual diffusion, i.e., Ni in the Ni layer diffuses into the solder layer and Sn in the solder layer diffuses into the Ni layer, occurs during the melting of the solder layer. By this mutual diffusion, the Au-Sn-Ni alloy can obtained, and the bonding strength and wettability of the solder can be improved without using any formed pellet of eutectic solder.

In accordance with the present invention there is further provided a method of bonding an electrical element to a pedestal, comprising the steps of: 1) forming successively on a mounting surface of an electric element an Ni layer and a solder layer composed of an Au-Sn alloy with Au as a main component; and 2) bonding the electrical element to the pedestal by forming an Au-Sn-Ni alloy containing Ni in an amount of 1.3wt% to 10wt% based on the weight of the alloy heating and melting the solder layer to mutually diffuse Ni and Sn.

In accordance with the present invention there is further provided a semiconductor laser device which comprises a plurality of units stacked one upon another, each unit comprising: an n-type GaAs or InP substrate layer, a p-type electrode layer over a front surface of the substrate layer, an n-type electrode layer over a back surface of the substrate layer, and a bonding material on either the n-type electrode layer or the p-type electrode layer, the bonding material being composed of an Ni layer having a thickness of at least 500Å on the n- or p-type electrode layer and an Au-Sn solder layer on the Ni layer and the bonding material being formed by heating the solder layer to diffuse Ni into the Au-Sn solder layer and Sn into the Ni layer so as to cause an ormic contact of the n- or P-type electrode layer with the substrate layer, wherein the bonding material of an outermost unit is bonded to a pedestal plated with Au.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and characteristics of the present invention will be appreciated from a study of the following detailed description, the appended claims, and drawings, all of which form a part of this application. In the drawings:

FIG. 1 is a perspective view illustrating a semiconductor laser device of an embodiment where the present invention is applied to the semiconductor laser device;

FIG. 2 is a perspective view illustrating the state when the semiconductor laser device has been die-bonded to a heat sink;

FIG. 3 is a schematic view illustrating the construction when an n-GaAs substrate with an n-type electrode, Ni layer and solder layer formed on the back side thereof is bonded to a pedestal such as a heat sink;

FIG. 4 is a characteristic diagram indicating the relationship between the thickness of the Ni layer and the bonding strength measured by a vibration test;

FIG. 5 is a graph indicating the relationship between the thickness and the bonding strength of the solder layer;

FIG. 6 is a graph indicating the variation in the melting point when the composition ratio of Ni thermally diffused into an Au80wt%-Sn20wt% layer was varied;

FIG. 7 is a graph indicating the relationship between the composition ratio of Ni in the Au80wt%-Sn20wt% layer and the bonding strength;

FIGS. 8A, 8B and 8C are views showing the construction where a driving IC for a display device has been mounted on a glass substrate; and

FIG. 9 is a view showing the construction where a semiconductor laser device has been mounted on a Si substrate provided with a SiN_X optical guide.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

Description will now be given to preferred embodiments of the present invention applied to a semiconductor laser device.

A semiconductor laser device is a structure in which each working region is provided in a crystal formed by means of epitaxial growth on a GaAs or InP substrate. Generally, an n-type substrate is used in this application. As a material system, a GaAs-AlGaAs system, an InGaAsP-InP system, or an InGaP-InGaAlP system, or the like can be used, for example. As an epitaxial growth method, liquid phase epitaxy, molecular beam epitaxy (MBE), or metal organic chemical vapor deposition

(MOCVD), can be used, for example. As an active layer, a double hetero structure, or a quantum well structure, are examples.

FIG. 1 is a perspective view of a semiconductor laser device before being bonded to a pedestal, to which this embodiment is applied.

On an n-GaAs substrate 1 are stacked an n-GaAs buffer layer 2, an n-AlGaAs clad layer 3, an active layer 4 having an AlGaAs/GaAs multiquantum well structure, a p-AlGaAs clad layer 5 and a p-GaAs layer 6 in this order. The active layer 4 through the p-GaAs layer 6 are formed to be of mesa shape. On the top of the n-AlGaAs clad layer 3 and the mesa part is formed an insulating film 7 of SiO_2 or the like with a window part therein. On the insulating film 7 is formed a p-type electrode (upper electrode) 8.

The p-type electrode 8 is made of a film formed by making a film to a specified thickness by electron beam evaporation, sputtering or the like. For the p-type electrode 8, Au-Zn/Au, Cr/Au, Mo/Au, Ti/Pt/Au, etc. can be used. Other materials can also be used as long as ohmic contact is attained.

On the back of the n-GaAs substrate 1 is formed an n-type electrode (lower electrode) 9 of Au-Ge. On the surface of the n-type electrode 9 is formed a bonding material comprising an Ni layer 10 and a solder layer 11.

The semiconductor laser device so constructed is bonded to a heat sink, another semiconductor substrate, a circuit board, etc. The method of mounting will now be described.

A plurality of the semiconductor laser devices illustrated in FIG. 1 are stacked and placed on a heat sink 21 as shown in FIG. 2. The stacked laser structure is indicated by numeral 22 in FIG. 2. In this case, the bonding material of the upper semiconductor laser device is positioned on the p-type electrode of the lower semiconductor laser device.

The heat sink 21 is made of Cu, Fe or the like, and the surface thereof is provided with a highly conductive metal, such as Ni and Au, formed by means of plating, evaporation, sputtering or the like. A plurality of semiconductor laser devices are positioned on top of each other and stacked on the heat sink 21. At this time, vacuum tweezers are used for carrying chips, and it is preferable to use the vacuum tweezers which also function as a pressurizing part to apply pressure to the chips when the devices are heated by a heater because the use of such vacuum tweezers makes it easier to obtain the required positional accuracy.

The semiconductor laser devices stacked on the heat sink 21 are pressurized while being held steady, and then heated to melt the respective solder layer 11 for bonding. After the temperature has reached the level that can melt the solder layers 11, the semiconductor laser devices are left at this temperature for a period of from seconds to minutes and then cooled. It is possible to heat all the semiconductor laser device while the heat sink and the semiconductor laser chips are fixed steady. For example, heat can be applied in a thermostatic bath, or heat can be applied from the back side of the heat sink by a heater or the like. The latter method is preferable for ease of operation.

After the above die bonding, the upper electrode and a driving circuit wiring are bonded to each other with a wire 23 made of Au, Pt or the like to attain electric contact to the semiconductor laser. Then, the whole unit is sealed in a can, if necessary, to complete the semiconductor laser.

Now, description will be given to the forming of the above n-type electrode 9, Ni layer 10 and solder layer 11 and the bonding thereof to the heat sink 21. The composition of this portion is illustrated in FIG. 3.

On the back surface of the n-GaAs substrate 1 is formed an Au-Ge layer as the n-type electrode 9. Instead of Au-Ge, other materials can be used for the n-type electrode 9 as long as an ohmic electrode can be formed, such as Au-Zn/Au, Cr/Au, Ti/Pt/Au, Au-Ge/Ni/Au, Au-Sn/Au, and an alloy layer thereof. Such materials are formed on the back surface of the n-GaAs substrate 1 to a specified thickness by means of electron beam evaporation (vacuum deposition), resistance heating evaporation, sputtering or the like.

Next, the Ni layer 10 is formed on the n-type electrode 9 in the same way. Then, as the solder layer 11, an alloy containing Sn, such as Au-Sn and Pb-Sn, is formed on the Ni layer 10. The method of forming the solder layer 11 will be described later.

The electrode 9, Ni layer 10, and solder layer 11 containing Sn formed as described above, are laid on the heat sink 21 provided with plating 21a of Ni, Au or the like as illustrated in FIG. 3. The whole is then pressurized and heated to mutually melt the solder layer 11 and the Ni layer 10, and then cooled, so that the semiconductor laser device is mounted on the heat sink 21. As a result of this heat treatment, the electrode 9 is sintered and ohmic contact with the substrate 1 is attained.

It is also acceptable that the formed electrode 9, Ni layer 10, and solder layer 11 containing Sn are heated to approximately 360°C to attain the ohmic contact of the electrode 9 and concurrently form a eutectic layer of the Ni layer 10 and the solder layer 11 containing Sn. Then, the substrate 1 with the eutectic layer is laid on the heat sink 21 provided with the plating 21a of Ni, Au or the like, pressurized and heated to melt the eutectic layer, and then cooled, so that the semiconductor laser device is mounted on the heat sink 21.

As preferred soldering materials, Au-Sn, Au-Si, In, In-Pb, Pb-Sn, Au-Pb, Au-Ge, may be used. Among these materials, good wettability of the solder and high bonding strength can be attained by stacking the Ni layer and the solder layer containing Sn, such as Au-Sn and Pb-Sn. This effect is particularly pronounced when Au-Sn is used as the solder layer.

The Ni layer 10 has dual roles. It acts as 1) a barrier electrode preventing mutual diffusion of the soldering material and the electrode, and 2) it improves the wettability of the solder by diffusing into the solder layer 11. In particular, when Au is used on the top layer of the electrode 9, the stability of contact is degraded as Au is active and diffuses at a low temperature into the solder layer for soldering. Therefore, a barrier electrode is necessary. When the electrode is made of Au or an alloy containing Au, the barrier electrode is particularly effective.

The film thickness of Ni as a barrier electrode should be at least 200Å. If the Ni layer is thinner than 200Å, the Ni layer will lose the role of barrier metal.

FIG. 4 illustrates the dependence of the strength of the bonding layer on the thickness of the Ni layer in a case where a film of Au-Ge as electrode was formed to a thickness of 1,000Å on an n-GaAs substrate of 0.5mm x 0.5mm in size. Ni/Au-Sn (Au and Sn are eutectic) were stacked on the electrode and subjected to a vibration test. The vibration test was conducted under Condition D of JIS C7022A-10 within a frequency range of 10Hz to 2,000Hz with an acceleration of 20G in 3 directions for 48 minutes. The thickness of the Au-Sn solder layer 11 was fixed to 1.5μm.

As the film thickness of the Ni layer 10 increases the bonding strength increases, and no difference is seen in the bonding strength when the thickness of Ni is 1,000Å or more. When the film thickness is 1,000Å or more, the substrate breaks during the test, and the actual bonding strength is greater than the value indicated by the figure. When the film thickness is 200Å, the layer peels and sufficient bonding strength is not obtained. A bonding strength of 500 gf or more ensures sufficient bonding to pass various reliability tests. Therefore the Ni layer must be 500Å or thicker.

Formation of the solder layer 11 will now be described.

To form the solder layer 11, stacking of the materials of the alloy, such as Au-Sn was attempted. With this arrangement, the composition ratio can be readily devised and the materials to be evaporated can be easily controlled. However, if the film thickness of the layers varies, composition variation will occur. Generally, eutectic compositions are used for the solder. This means that if variations of composition occurs, the melting point rises. If the melting point changes in this way, the mounting conditions must be changed accordingly. If the conditions are not changed, the solder may not melt, or it may melt incompletely. As a result, a constant bonding strength can not be obtained after mounting.

To solve the problem, a study was made to form a film of the alloy, such as Au-Sn, Pb-Sn, In, In-Pb, Au-Si and Au-Pb, as the solder layer 11 by vapor growth, that is, to form the solder layer 11 by means of physical vapor growth using the above alloy as an evaporation source.

The physical vapor growth referred to herein, which is called "physical vapor deposition (PVD)," is a method which does not use any chemical reaction but uses only physical changes, such as evaporation, sputtering and ion-plating, for forming thin films. Physical vapor deposition may be described as a phenomenon wherein the material to be deposited on a substrate reaches the substrate in the state of vapor or cluster and condenses or adsorbes to form a thin film. Methods using chemical reactions include "chemical vapor deposition (CVD)." In this method, the source material is reacted in the vapor phase using energy, such as heat, plasma or light, to form a thin film through chemical reaction. CVD is different in principle from PVD.

By forming the solder layer 11 by PVD, even if the film thickness varied from layer to layer, almost no change was seen in the melting point, and the problem of variation of composition was essentially solved.

Film-forming methods such as vapor phase growth, electron beam evaporation, resistance heating evaporation, sputtering, can be used. Among these, with electron beam evaporation and resistance heating evaporation, the composition ratio in the deposited product varies slightly from the composition ratio in the source material due to differences in the vapor pressure of the components of the alloy. For this reason, it is preferable to use a sputtering method for film formation. When electron beam evaporation or resistance heating evaporation is used, if almost all the source material is completely evaporated, there is essentially no change in the composition ratio between the source material and the deposited film. In addition, even if all the material is not evaporated, as the composition ratio depends on the vapor pressure, the composition ratio of the deposited film does not vary from batch to batch.

A conventional technique using formed pellets as a soldering material suffers the drawback that protuberances caused by excessive solder may cover the light emitting layer and disturb or obscure the light output. However, by forming a thin film for the solder layer 11 by means of vapor growth, there is no excessive overflow of the solder, and a solder layer having a highly reproducible composition ratio can be obtained, whereby a stable bonding with a high bonding strength can be achieved.

The film thickness of the above solder layer 11 will now be discussed.

By using vapor growth for forming a thin film for a solder layer, excessive overflow of solder can be prevented. When a plurality of semiconductor laser devices are stacked as described above, there is the possibility that if the solder layer is comparatively thick, the solder overflow may cover the light emitting layer. The same problem can occur when the electrode on the side near the light emitting layer is soldered as in the second example described herein later). On the other hand if the solder layer is thin, there is the problem that bonding strength is low.

FIG. 5 illustrates the relationship between the thickness of the solder layer and bonding strength when a semiconductor laser device of 0.5mm x 0.5mm in size is mounted on a copper heat sink plated with Au.

The bonding strength increases as the film thickness of the solder layer increases, until no difference is seen in the bonding strength when the film thickness is 1μm or more. As the substrate breaks when the film thickness is 1μm or more, the actual strength is greater than that indicated by the figure. It has been found that a bonding strength of 500 gf or more is sufficient and can pass various reliability tests. Therefore, there are few problems if the solder layer has a thickness of 3,000Å or more.

The thickness of the solder layer is related to the surface roughness (Ra) of the bonding surface, which was 1,000Å in this measurement. Generally, the solder layer should be thicker than the surface roughness. It is found from the results of this test that the solder layer should be approximately three times as thick as the surface roughness. In mounting, a stem with a bonding surface having a surface roughness (Ra) of 500Å to 2,500Å was used. Since stems having a surface roughness of 1,000Å are usually used, the thickness of the solder layer should be at least 3,000Å, and preferably be 5,000Å or more.

The bonding strength increases as the film thickness of the solder layer increases. However, when the solder layer becomes thicker, there is a problem of the overflow of the soldering material. Particularly, when a plurality of semiconductor laser devices are stacked, the overflow of the soldering material often covers the light emitting layer. Furthermore, to form a thicker solder layer, longer time and more material to be evaporated are required. There is little overflow of the soldering material when the solder layer is under 1μm. However, when the thickness thereof is over 1μm, the soldering material overflows from the rear surface of the chip. When the solder layer has a thickness of over 3μm, the soldering material sticks to the light emitting surface side, and when the solder layer has a thickness of over 4μm, the soldering material partly covers the light emitting layer. From these results, it is advisable that the film thickness of the solder layer be under 3μm.

Therefore, by setting the film thickness of the solder layer 11 to 0.3μm (3,000Å) to 3μm, bonding with a high bonding strength can be obtained. In addition, when a plurality of semiconductor laser devices are stacked, the soldering material of the stack part does not cover the light emitting layer, whereby both a stable light output and a high bonding strength can be obtained.

Examples of the fabrication of a semiconductor device using the above solder layer 11 will now be described.

(First Example)

A semiconductor laser device of a GaAs/AlGaAs system was made on a n-GaAs substrate, and the side of the n-type electrode thereof was soldered to a copper heat sink plated with Au. At this time, three semiconductor laser devices were stacked up. As an n-type electrode, a layer composed of 88wt% of Au and 12wt% of Ge was formed to a thickness of 1,000Å. On this n-type electrode were provided an Ni layer of 1,000Å and Au-Sn solder layer of 1μm. The film of Au-Ge/Ni was formed by means of electron beam evaporation, and the solder layer was formed by means of sputtering. The size of the semiconductor laser device was 500μm x 600μm x 110μm. Three semiconductor devices were stacked up on the copper heat sink plated with Au and mounted thereon at a temperature of 340°C and a pressure of 60g. The devices mounted had no overflow of soldering material and no obscuring of the light emitting layer by the soldering material. When a stress test was conducted on this example at a variable frequency of 10Hz to 2,000Hz and $20G/sec^2$ for 48 minutes in three directions, no changes were noted. The bonding strength of the device was measured on a sheer tester, and found to be over 1kgf.

(Second Example)

A semiconductor laser device of an InGaP-InGaAlP system was made on an n-GaAs substrate. The side of a p-type electrode was soldered to a copper heat sink plated with Au. As the p-type electrode, films of Ti of 1,000Å thick, Pt of 2,000Å thick and Au of 3,000Å thick were formed respectively, and on these films were provided Ni layer of 800Å thick and Au-Sn solder layer of 0.8μm thick. The films were formed by means of electron beam evaporation. The size of the semiconductor laser device was 600μm x 700μm x 110μm. The p-type electrode was soldered. However, the soldering material did not cover the active layer, and therefore, good light emission could be obtained. In addition, a bonding strength of at least 1kgf was obtained, and a stable contact was achieved.

(Third Example)

A GaAs electric field effect transistor was made on a semi-insulating GaAs substrate and soldered to a printed circuit board plated with Au. On the back surface of the semi-insulating GaAs substrate were provided a Ni layer of 1,000Å thick and Au-Sn solder layer of 2μm thick. The films were formed by means of sputtering. The size of the device was 500μm x 600μm x 180μm. The device was mounted at a temperature of 360°C and a pressure of 100g. The bonding strength of the device was measured on a shear tester, and found to be at least 1kgf.

When the above semiconductor laser device is bonded to a heat sink, it is effective to set the temperature, pressure, pressurizing time, etc. for bonding to larger values, to improve the wettability or the bonding strength. However, because As in the GaAs used in the semiconductor laser device has a low sublimating temperature, high bonding temperatures can cause thermal damage to the device. In addition, high pressures and a long pressurizing time can also cause mechanical damage to the light emitting layer.

Therefore, in bonding semiconductor laser devices, a bonding material which lowers the bonding temperature and alleviates thermal damage to the semiconductor laser device should be selected.

The inventors of the present invention made studies on the above problem from various aspects and found that a melting point lower than that of a pellet composed of 80wt% of Au and 20wt% of Sn could be obtained when a Au-Sn system solder was used as the solder layer 11 and a stacked structure of Ni/(Au80wt%-Sn20wt%) was employed. The reason for this is that Ni diffuses into the Au-Sn layer and forms an Au-Sn-Ni alloy.

Based on the above, the film thickness of Ni was varied to change the concentration of Ni thermally diffusing into the Au80wt%-Sn20wt% layer and a phase diagram was drawn. The results are illustrated in FIG. 6.

In FIG. 6, letters L and S denote the liquid phase and the solid phase, respectively, and α and β denote the solid solution of Au-Sn-Ni, respectively. Therefore, letters $(L+\alpha)$ and $(L+\beta)$ indicate the mixed state of the liquid phase and solid phase, respectively. The upper abscissa axis represents the film thickness of the Ni layer when the thickness of the Au80wt%-Sn20wt% layer is set to 1.5μm in the Ni/(Au80wt%-Sn20wt%) multilayer structure.

In this phase diagram, the melting point of the (Au80wt%-Sn20wt%)-Ni alloy becomes lower than that of Au80wt%-Sn20wt% pellet as the amount of Ni increases. When the composition ratio (i.e., content) of Ni (the weight ratio of Ni to the total weight of the bonding material) is 1.3wt%, the melting point is lowered by approximately 10°C.

When the amount of Ni is increased to approximately 3wt%, the lowest melting point is obtained. This is called the eutectic point. The melting point is lowered by 25°C or more down from that of the Au80wt%-Sn20wt% pellet. Therefore, the bonding temperature can be decreased by 25°C or more from that of conventional bonding which must be performed at the melting point of Au80wt%-Sn20wt%. This means that thermal damage to the device being soldered can be reduced.

The above effect and the effect described later are obtained by the diffusion of Ni into the Au-Sn layer to form an Au-Sn-Ni alloy. The effect can be obtained not only by the stacked structure of Ni/(Au80wt%-Sn20wt%) and but also by a layer of (Au80wt%-Sn20wt%)-Ni alloy.

FIG. 7 illustrates the relationship between the composition ratio of Ni in an Au80wt%-Sn20wt% layer and the bonding strength thereof. From this figure, it can be seen that at low Ni ratios the bonding strength increases essentially linearly as the composition ratio of Ni increases but plateaus when the composition ratio is 2.5wt% or more. In this experiment, bonding strength was measured for composition ratios up to 9.5wt% and sufficient bonding strength was confirmed.

In the bonding strength test, in a structure with a Ni content of 0.7wt%, peeling occurs at the bonding surface between the solder layer and the heat sink, but with a Ni content of 1.3wt% or more, there was no peeling on the bonding surface. However, the bonded device part fractured. It has been shown that a bonding strength of 500gf or more permits devices to withstand various reliability tests. It can be seen from FIG. 7 that a Ni content of 1.3wt% or more results in a bonding strength greater than 500gf.

In FIG. 7, when the Ni contents were 1.3wt% and 1.7wt%, a pressure of 50g was applied during bonding. When the content was 2.5wt% or more, no pressure was applied, but the bonding was performed with the weight of the device alone. Apparently, when the Ni content is 2.5wt% or more, a sufficient bonding strength can be obtained with the weight of the device alone.

From these results, it can be seen that by the addition of Ni to the Au80wt%-Sn20wt% layer, the melting point of the solder can be lowered and the bonding strength can be improved. At Ni contents of 1wt% to 10wt% the melting point lowers by 10°C or more. However taking also wettability and bonding strength into consideration, it is preferable that the Ni content is 1.3wt% or more. Furthermore, it is particularly preferable that the Ni content is around 3wt%, say, 2wt% to 5wt%, in a ternary alloy because a ternary eutectic alloy is formed with the lowest melting point and the composition remains constant for a long time within this composition ratio range, after the solder solidifies.

If the Ni content is increased by thickening the Ni layer on the Au-Ge layer and the Ni content exceeds 10wt%, an intermetallic compound between Sn and Ni is produced. Such intermetallic compounds are insulators, with the result that the resistance of the bonded part increases. Therefore, taking into consideration the increase in the resistance of the bonded portion, it is preferable that the Ni composition ratio is less than 10wt%.

As described above, in bonding a semiconductor laser device to a pedestal, etc., by using a soldering material containing a constant amount of Ni in Au-Sn eutectic solder, and by using a pedestal having on the surface an Au layer, bonding with a good wettability and high bonding strength can reproducibly be obtained. As mentioned previously, the composition ratios of the various components are varied by adjusting the relative thickness of the layers.

In the above Ni/(Au80%-Sn20wt%) stacked structure, it is preferable that the thickness of the Ni layer is 500Å or more as described above and the film thickness of the Au-Sn alloy solder layer is within a range of 0.3μm to 3μm. Furthermore, as can been seen from FIG. 6, it is preferable that the thickness of the Ni layer is around 90nm, i.e., 70nm to 120nm, to make the Ni content around 3wt% which obtains a three component eutectic point in the case when the Au-Sn eutectic alloy layer is 1.5μm thick. In this case, in order to minimize the increase in the resistance of the bonded portion, it is preferable that the thickness of the Ni layer is under 300nm.

Examples of fabrication using the above bonding material will be now described.

(Fourth Example)

A semiconductor laser device of a GaAs/AlGaAs system was made on an n-GaAs substrate, and the n-type electrode thereof was soldered to a copper heat sink plated with Au. As the n-type electrode, an Au88wt%-Ge12wt% layer of 0.1μm was formed, and on the n-type electrode were provided Ni of 0.1μm and Au-Sn solder of 1.5μm. At this time, the (Au-Ge)/Ni layers were formed by means of electron beam evaporation, and the solder layer was formed by means of sputtering. The size of the semiconductor laser device was set to 500μm x 600μm x 110μm. The device was laid on the copper heat sink plated with Au and mounted thereon at a temperature of 340°C without applying any pressure. When the device was subjected to a vibration test conducted at a variable frequency of 10Hz to 2,000Hz and 20G for 48 minutes in three directions, no change in condition was noted. The bonding strength of the device was measured on a tester and found to be approximately 1kg. The composition ratio of the bonding material for this measurement was Au77.3wt%-Sn19.3wt%-Ni3.4wt%.

(Fifth Example)

A semiconductor laser device of an InGaP-InGaAlP system was made on an n-GaAs substrate, and the p-type electrode thereof was soldered to a copper heat sink plated with Au. As the p-type electrode, layers of Ti of 0.1μm, Pt of 0.2μm and Au of 0.3μm were formed, and on the p-type electrode were provided a Ni layer of 0.1μm and Au-Sn solder of 1.0μm. The films were formed by means of electron beam evaporation. The size of the semiconductor laser device was set to 600μm x 700μm x 110μm. The p-type electrode was soldered at a temperature of 340°C and a pressure of 30g. In the resulting product, the soldering material did not cover the active layer, and therefore, good light emission was obtained. Moreover, a bonding strength of 1kgf or more was obtained, indicating a stable contact was achieved. The composition ratio of the bonding material for this measurement was Au76wt%-Sn19wt%-Ni5wt%.

(Sixth Example)

To the top surface of the p-type electrode of a semiconductor laser device was soldered the n-type electrode side of the upper semiconductor laser device to yield a stacked structure. As the p-type electrode, layers of Cr of 0.04μm, Pt of 0.1μm and Au of 0.5μm were formed. As the n-type electrode, an Au88wt%-Ge12wt% layer of 0.1μm was formed, and on the n-type electrode were provided Ni layer of 0.1μm and Au-Sn solder layer of 1.5μm. At this time, the (Au-Ge)/Ni layers were formed by means of electron beam evaporation, and the solder layer was formed by means of sputtering. The size of the semiconductor laser device was set to 600μm x 700μm x 110μm. The n-type electrode was soldered to the p-type electrode at a temperature of 340°C and a pressure of 30g. The bonding strength between the devices was measured on a shear tester and found to be over 500kgf. At this time, the soldering material did not cover the active layer, and good light emission could be obtained. In addition, by stacking the semiconductor laser devices, the light output was increased. The composition ratio of the soldering material for bonding for this measurement was Au77.3wt%-Sn19.3%-Ni3.4wt%.

In the above embodiments, heat sinks plated with Au, Ni, etc., were used as pedestals. However, the semiconductor laser device may also be soldered to a pedestal made of Fe, Cu or the like.

In the above, the description is in reference to semiconductor laser devices. It is understood that the present invention may also be applied to other types of semiconductor devices. In particular, the present invention may be applied to those devices using Schottky electrodes, as well as to those using ohmic electrodes. Among the materials which can be used for the Schottky electrode are Al, Pt, Au, Ta, Cr, W, Mo, Ti, Cu, Ag and Al-Si.

The present invention may also be applied to electrical elements, such as chip resistors and chip capacitors, as well as other semiconductor devices.

Another example of application of the above Au-Sn-Ni bonding material will now be described.

(Seventh Example)

When a driving IC 30 for a liquid crystal display device, an electroluminescence (hereinafter referred to as EL) display device, etc. is mounted on a glass substrate 31 and connected to conductors (electrodes) 32, the arrangements illustrated in FIGS. 8A, 8B and 8C can be used. FIG. 8A illustrates an application using a mount pad 33 and wires 34, FIG. 8B illustrates an application using bumps 36, and FIG. 8C illustrates an application using beam leads 37. The Au-Sn-Ni bonding material of the invention is used as a bonding material for bonding the mount pad 33 to a mount part 35 in FIG. 8A, as the bump 36 in FIG. 8B, and as the beam lead 37 in FIG. 8C.

An example of mounting the driving IC 30 on an EL display panel by using the structure illustrated in FIG. 8A will now be described.

To make the EL display panel, a film of ITO (indium tin oxide), which is not shown, was formed to a thickness of 0.1μm as the transparent electrode on the glass substrate 31 and processed to have a striped configuration. In a region where an EL device (not shown) is disposed, the EL device was formed on the glass substrate 31 as follows: a CaS:Eu layer was formed to a thickness of 1μm as a luminescent layer by means of electron beam evaporation; a SiO_2 layer of 0.3μm in thickness was formed as an insulating layer by means of RF plasma enhanced CVD; and an Al layer was formed to a thickness of 0.15μm and patterned to the specified pattern as a back electrode 32. Then, in a region where the driving IC 30 is located on the glass substrate 31, a Ni film was formed to a thickness of 0.1μm, and then an Au layer was formed to a thickness of 0.5μm, and these films were patterned to the specified patterns to thereby provide the mount pad 35 and the wire-bonding pad of the electrode 32. The films for the mount pad 35 and the wire-bonding pad were formed by means of sputtering. Then, another glass substrate was located over the EL device forming region of the substrate 31 to interpose the EL device therebetween and bonded with epoxy resin, and silicon oil was sealed therein to form a protecting layer for the EL device, so that the fabrication of the EL display panel was completed.

Next, a Ni layer was formed to a thickness of 0.2μm on the back surface of the driving IC 30 to bond the driving IC 30 to the glass substrate 31, and then an Au80wt%-Sn20wt% layer was formed to a thickness of 2μm thereon. Both the layers were formed by means of sputtering. The driving IC 30 was bonded to the mount pad 35 at a temperature of 350°C and a pressure of 80g. On the other hand, the pad for leading the EL panel wiring 32 was connected to the pad for leading the driving IC 30 with Au wires 34. In this way, the driving IC 30 was mounted on the glass substrate 31 with a constant bonding strength. The composition ratio of the bonding material 33 at the mounting was Au76wt%-Sn19wt%-Ni5wt%.

(Eighth Example)

FIG. 9 illustrates the application where semiconductor laser device 40 of a GaAs/AlGaAs system was bonded to a Si substrate 42 provided with a SiN_X optical guide by using bumps 44. For the bumps 44, an Au78wt%-Sn19.5wt%-Ni2.5wt% bonding material was used, and the semiconductor laser device 40 was mounted on the Si substrate 42 by using four bumps each diameter of which is Φ 40μm. The bumps 44 were formed on the Au pad 43 on the Si substrate 42. For the back surface electrode 41 of the semiconductor laser device 40, Au-Ge/Ni/Au layers were used with a thickness of 0.1μm, 0.02μm and 0.4μm, respectively. The semiconductor laser device 40 was laid on the bumps 44, and the entire substrate 42 was loaded within a thermostatic bath to cause the bumps 44 to melt, thereby soldering the device 40 to substrate 42. In this way, the semiconductor laser device 40 was mounted on the Si substrate 42.

While the present invention has been demonstrated and described with reference to the foregoing preferred embodiments, it will be apparent to those skilled in the art that changes in form and detail may be made therein without departing from the scope of the invention.

27957-14

CLAIMS:

1. A bonding material for bonding an electrode of an electrical element to a pedestal, consisting essentially of an Au-Sn-Ni alloy, containing Au as a main component, wherein Ni is contained in an amount of at least 1.3wt% and less than 10wt% in the alloy.

2. A bonding material according to claim 1, wherein Ni is contained in an amount of 2.5wt% or more and under 10wt%.

3. A bonding material according to claim 1, wherein the amount of Ni is 2wt% to 5wt%.

4. A bonding material according to any one of claims 1 through 3, wherein the Au-Sn-Ni alloy is produced by heating a stacked structure composed of an Au-Sn alloy layer containing Au as a main component, and an Ni layer.

5. A bonding material according to claim 4, wherein the Ni layer has a thickness of at least 500Å.

6. A bonding material according to claim 4 or 5, wherein the Au-Sn alloy layer is a film formed by means of physical vapor growth.

7. A bonding material according to claim 5 or 6, wherein the Au-Sn alloy layer has a thickness of 0.3μm to 3μm.

8. A bonding material according to any one of claims 1 through 7, wherein the pedestal is composed of a material selected from the group consisting of Au, Ni, Fe, and Cu, on a surface of which the electrical element is to be bonded.

9. A bonding material according to any one of claims 1 through 8, wherein the electrical element to be bonded is a semiconductor laser device.

10. A method of mounting an electrical element to a pedestal, comprising the steps of:

1) forming an electrode layer on the electrical element;

2) forming an Ni layer on the electrode layer;

3) forming a solder layer containing Sn directly on the Ni layer; and

4) heating the electrical element so as to cause the solder layer and the Ni layer to mutually diffuse as well as to cause ohmic contact of the electrode layer with the electrical element, thereby forming an Sn-Ni alloy containing Ni in an amount of at least 1.3wt% and less than 10wt% and bonding the electrical element to the pedestal.

11. A method according to claim 10, wherein the Ni layer formed in step 2) has a thickness of at least 500Å.

12. A method according to claim 10 or 11, wherein the solder layer formed in step 3) is an Au-Sn alloy layer and the Sn-Ni alloy formed in step 4) is an Au-Sn-Ni alloy.

13. A method according to claim 12, wherein the Au-Sn alloy layer is formed by means of physical vapor growth.

14. A method according to claim 13, wherein the Au-Sn alloy layer is a eutectic Au-Sn alloy layer.

15. A method according to any one of claims 12 through 14, wherein the Au-Sn alloy layer has a thickness of 0.3μm to 3μm.

16. A method according to claim 14, wherein the Ni layer formed in step 2) has a thickness of 70nm to 120nm, and the

eutectic Au-Sn alloy layer has a thickness of approximately 1.5μm.

17. A method according to any one of claims 10 through 16, wherein the step of forming the electrode layer includes a step of forming an Au containing film on the electrical element.

18. A method of bonding an electrical element to a pedestal, comprising the steps of:

1) forming successively on a mounting surface of an electric element an Ni layer and a solder layer composed of an Au-Sn alloy with Au as a main component; and

2) bonding the electrical element to the pedestal by forming an Au-Sn-Ni alloy containing Ni in an amount of 1.3wt% to 10wt% based on the weight of the alloy heating and melting the solder layer to mutually diffuse Ni and Sn.

19. A method according to claim 18, wherein step 2) includes:

i) heating the solder layer to form an alloy layer containing Ni and Sn;

ii) placing the electrical element on the pedestal, interposing the alloy layer therebetween;

iii) heating the electrical element at a temperature higher than a melting point of the alloy layer; and

iv) cooling the electrical element to bond the electrical element to the pedestal.

20. A method according to claim 18 or 19, wherein the Ni layer formed has a film thickness of 500Å or more.

21. A method according to any one of claims 18 through 20, wherein the solder layer is formed by means of physical vapor growth using an alloy as an evaporation source.

22. A method according to any one of claims 18 through 21, wherein the solder layer formed has a film thickness of 0.3μm to 3μm.

23. A method according to any one of claims 18 through 22, wherein a surface of the pedestal to which the electrical element is bonded is composed of a material selected from the group consisting of Au, Ni, Fe and Cu.

24. A method according to any one of claims 18 through 23, wherein the electrical element is a semiconductor laser device.

25. A semiconductor laser device which comprises a plurality of units stacked one upon another, each unit comprising:

an n-type GaAs or InP substrate layer,

a p-type electrode layer over a front surface of the substrate layer,

an n-type electrode layer over a back surface of the substrate layer, and

a bonding material on either the n-type electrode layer or the p-type electrode layer, the bonding material being composed of an Ni layer having a thickness of at least 500Å on the n- or p-type electrode layer and an Au-Sn solder layer on the Ni layer and the bonding material being formed by heating the solder layer to diffuse Ni into the Au-Sn solder layer and Sn into the Ni layer so as to cause an ohmic contact of the nor p-type electrode layer with the substrate layer, wherein the bonding material of an outermost unit is bonded to a pedestal plated with Au, and wherein the bonding material contains Au as a main component and contains Ni in an amount of 1.3wt% or more and under 10wt%.

26. A semiconductor laser device according to claim 25, wherein the n-type electrode layer is formed of Au-Ge, Au-Zn/Au, Cr/Au, Ti/Pt/Au, Au-Ge/Ni/Au or Au-Sn/Au.

27. A semiconductor laser device according to claim 25 or 26, wherein the Au-Sn solder layer is formed by means of vapor growth and has a thickness of at least 3,000Å but not exceeding 3μm.

28. A semiconductor laser device according to any one of claims 25 to 27, wherein the bonding material is on the n-type electrode layer which is directly on the substrate layer.

29. A semiconductor laser device according to claim 28 wherein each unit further comprises, between the substrate layer and the p-type electrode layer:

an n-GaAs buffer layer on the substrate layer;

an n-AlGaAs clad layer on the GaAs buffer layer;

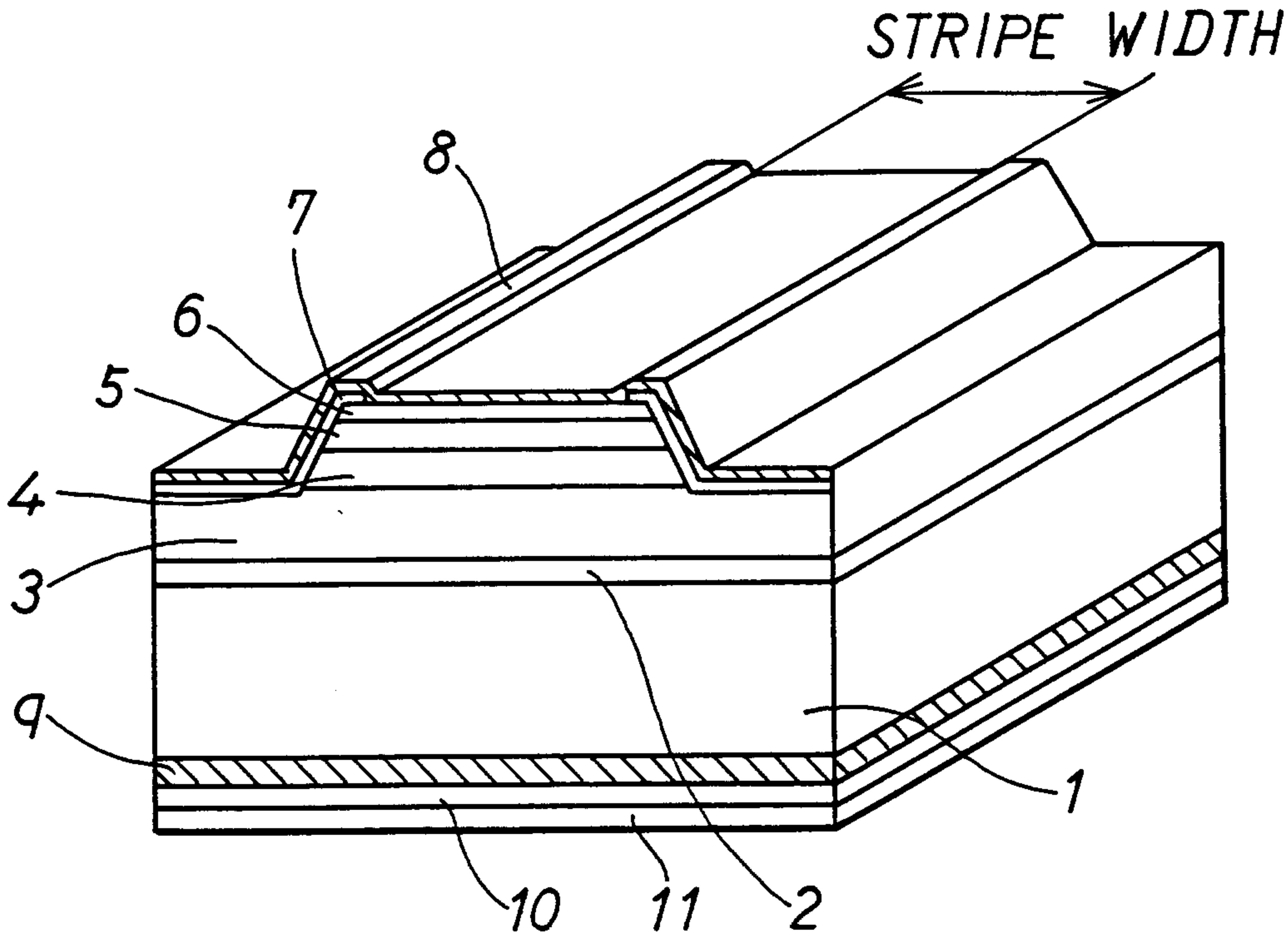
an active layer on the n-AlGaAs clad layer;

a p-A1GaAs clad layer on the active layer;

a p-GaAs layer on the p-AlGaAs clad layer; and an insulating film with a window part therein on the p-GaAs layer.

30. A semiconductor laser device according to any one of claims 25 to 27, wherein the bonding material is on the p-type electrode layer.

F/G.1



F/G.7

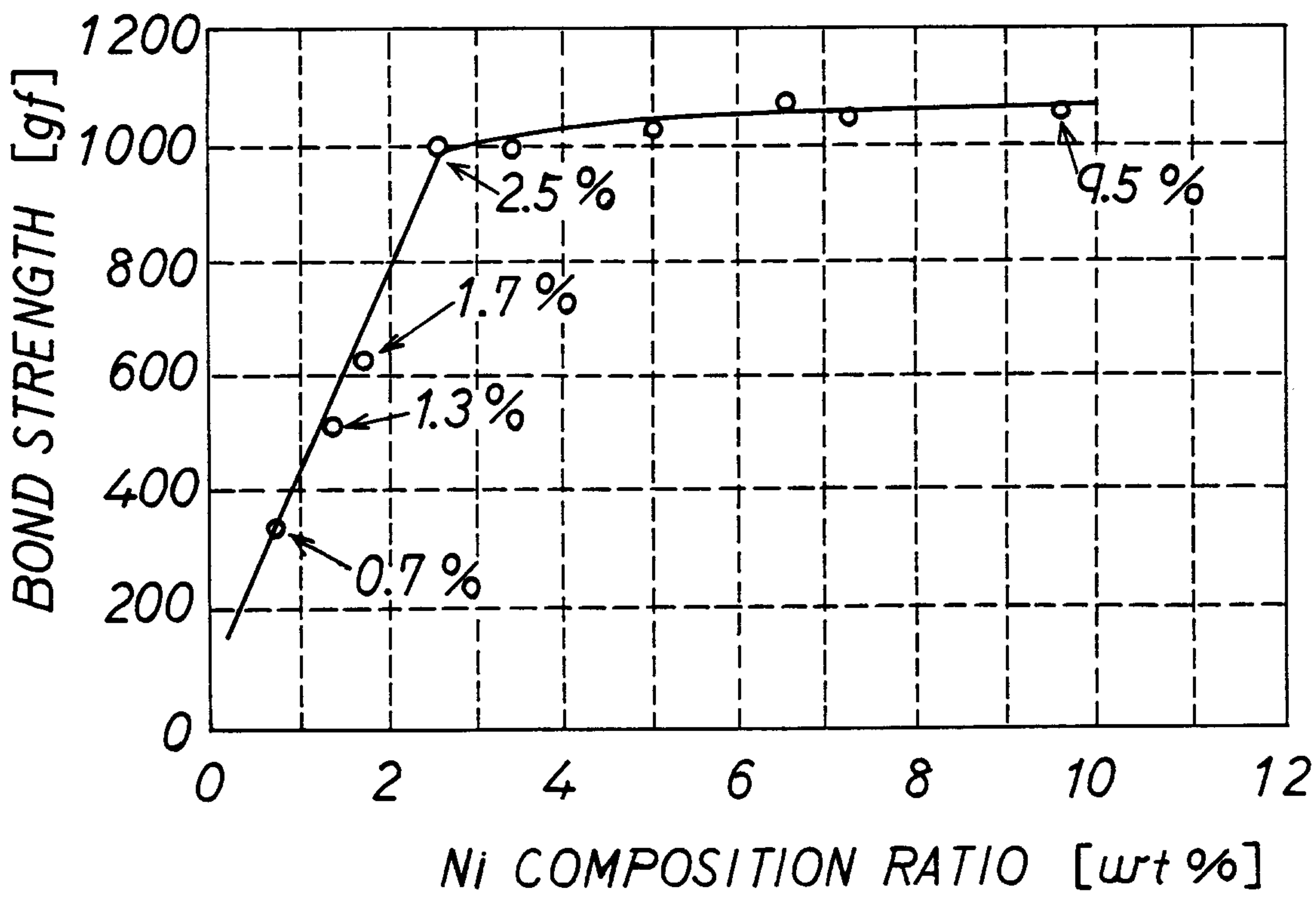


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FIG. 2

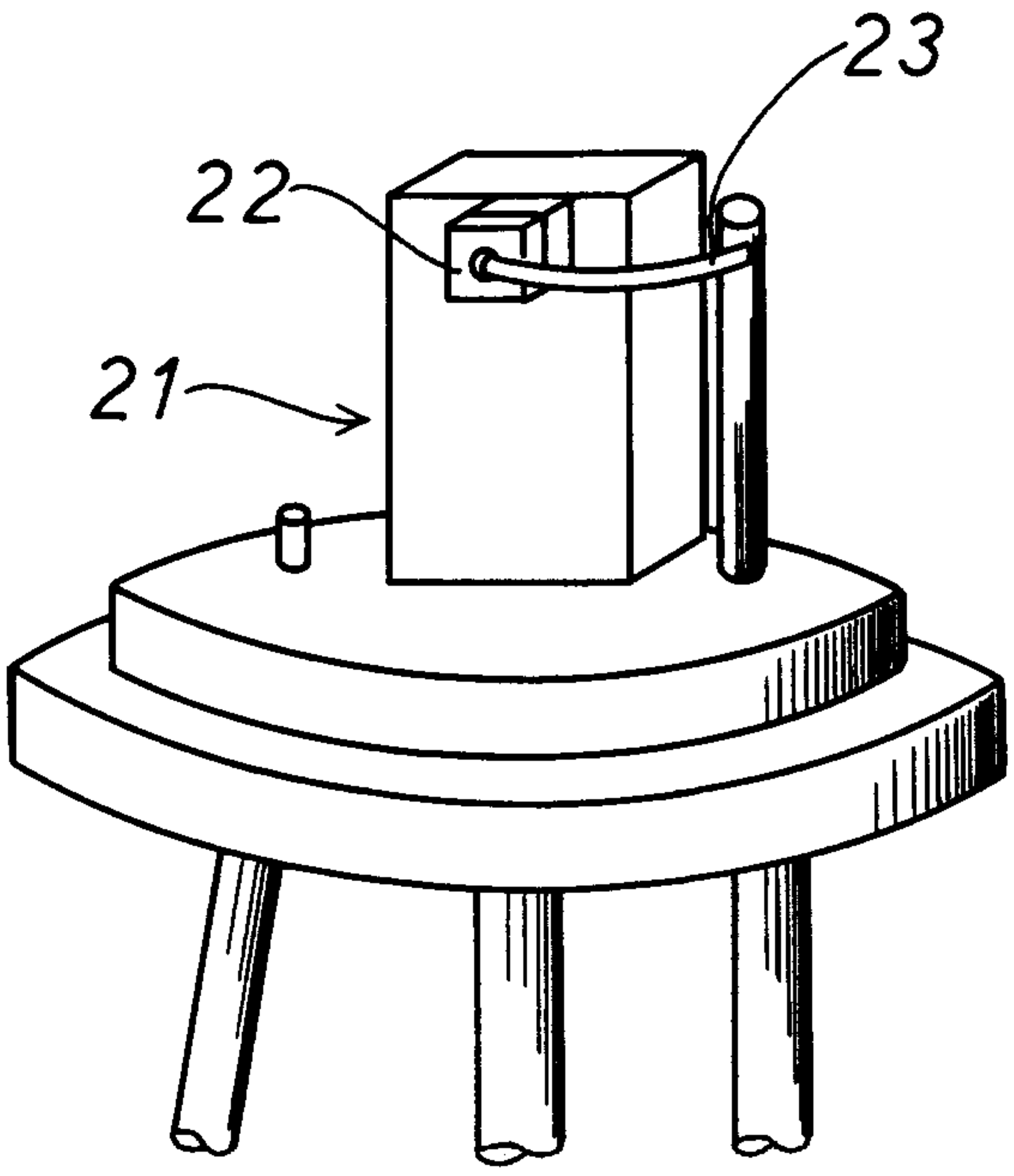

FIG. 3

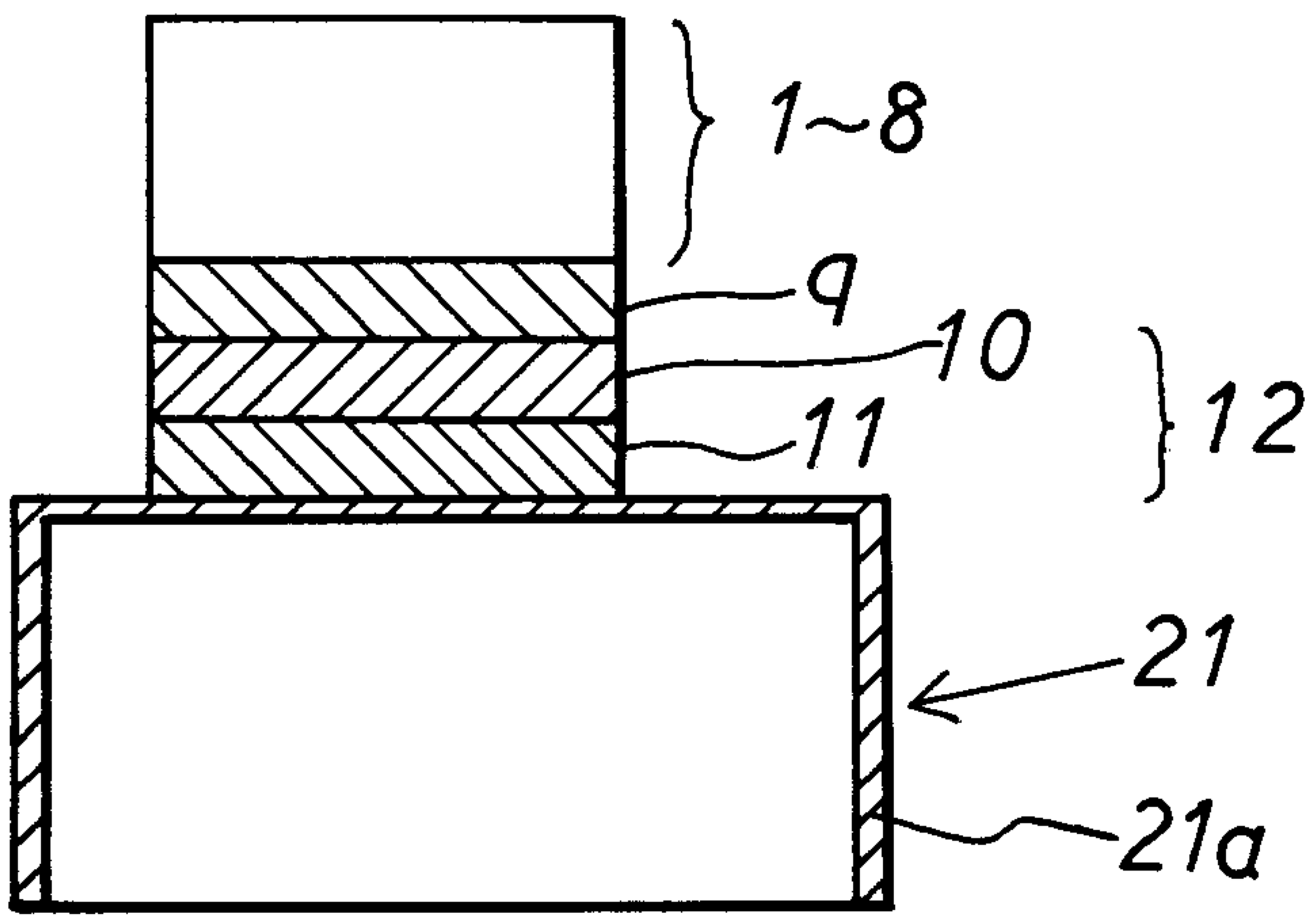

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FIG. 4

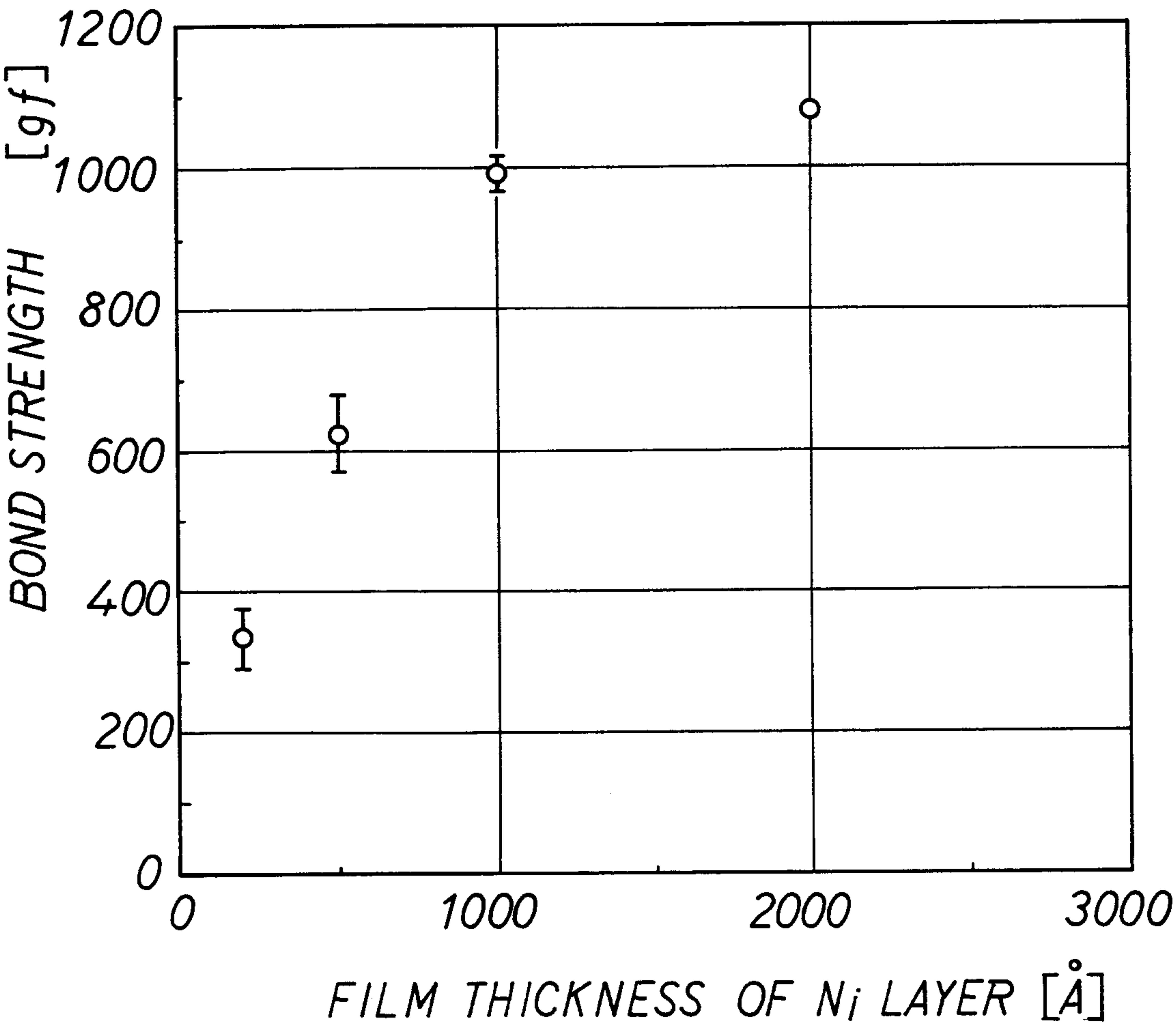

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FIG.5

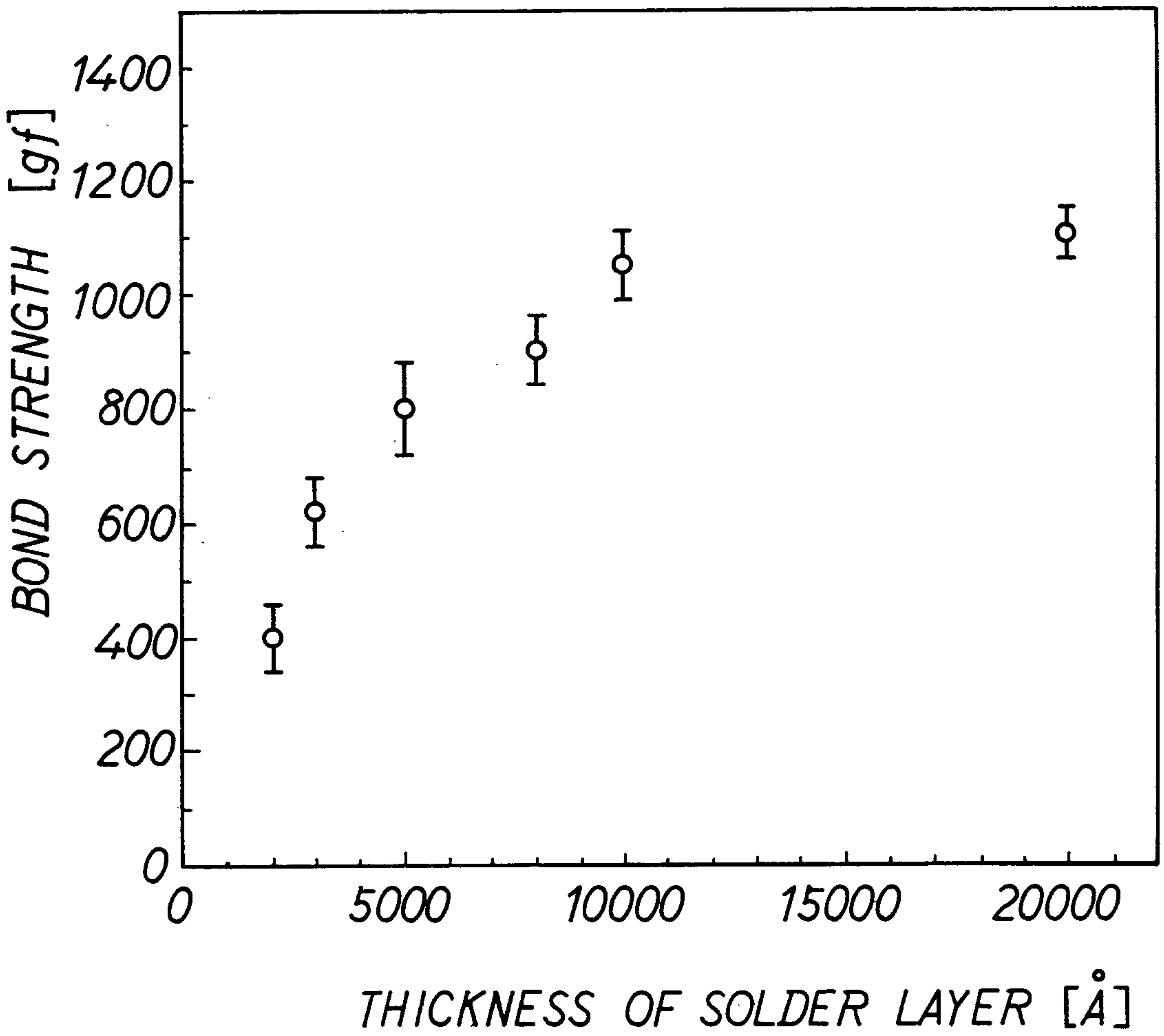

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FIG. 6

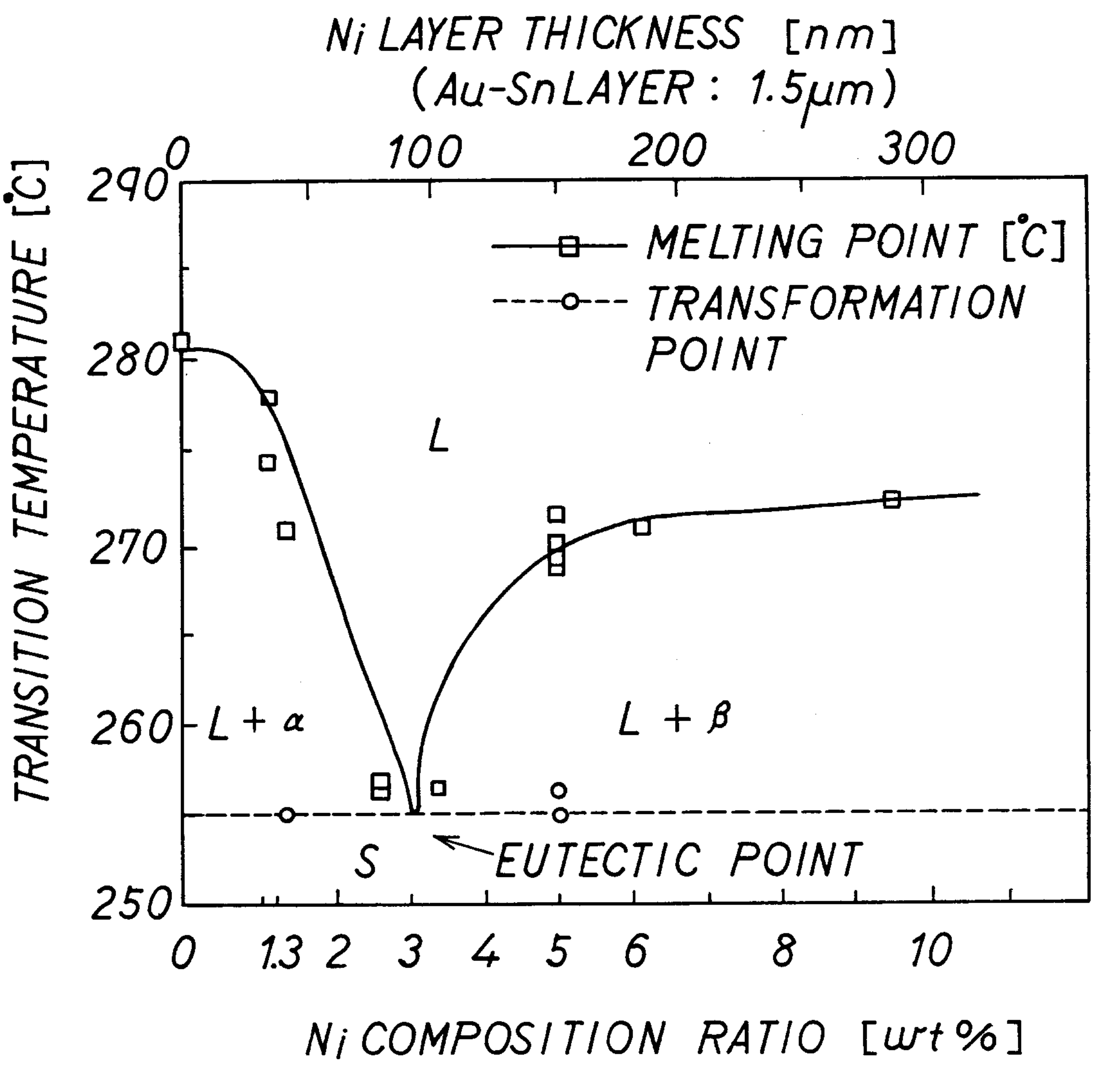

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FIG. 8A

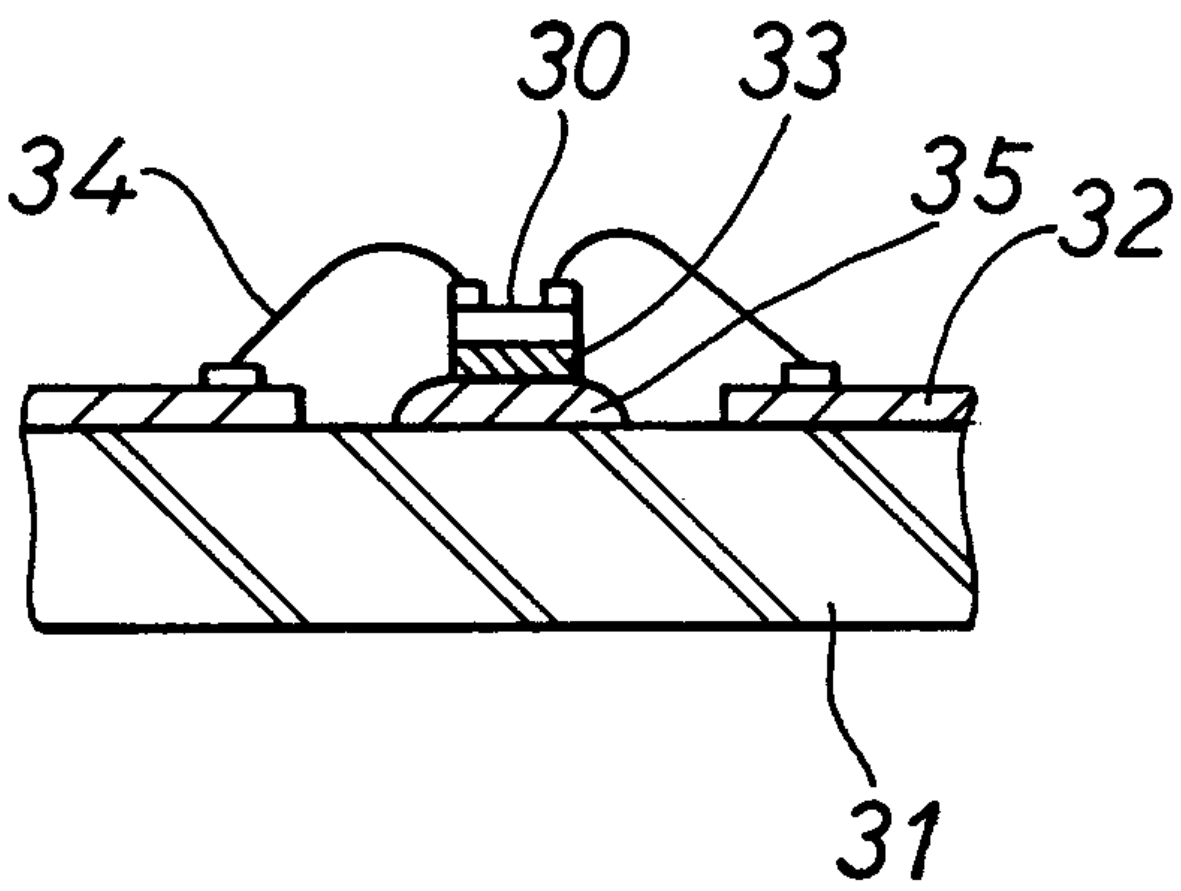


FIG. 8B

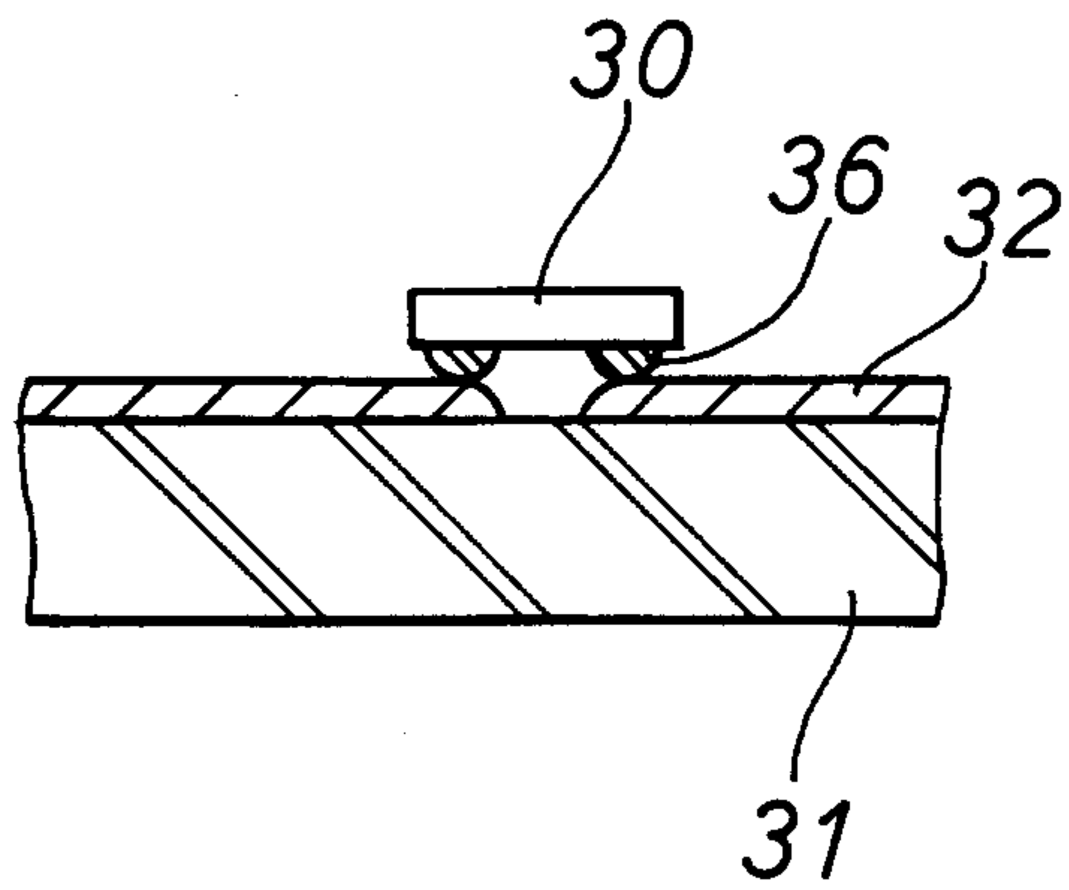


FIG. 8C

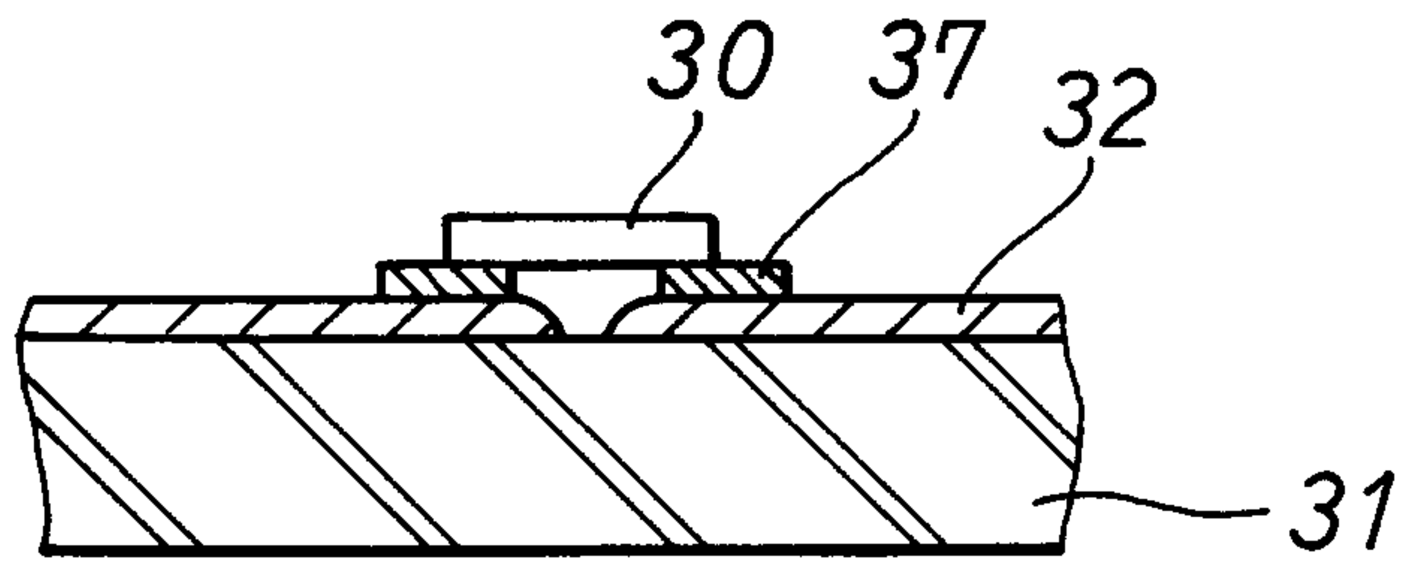
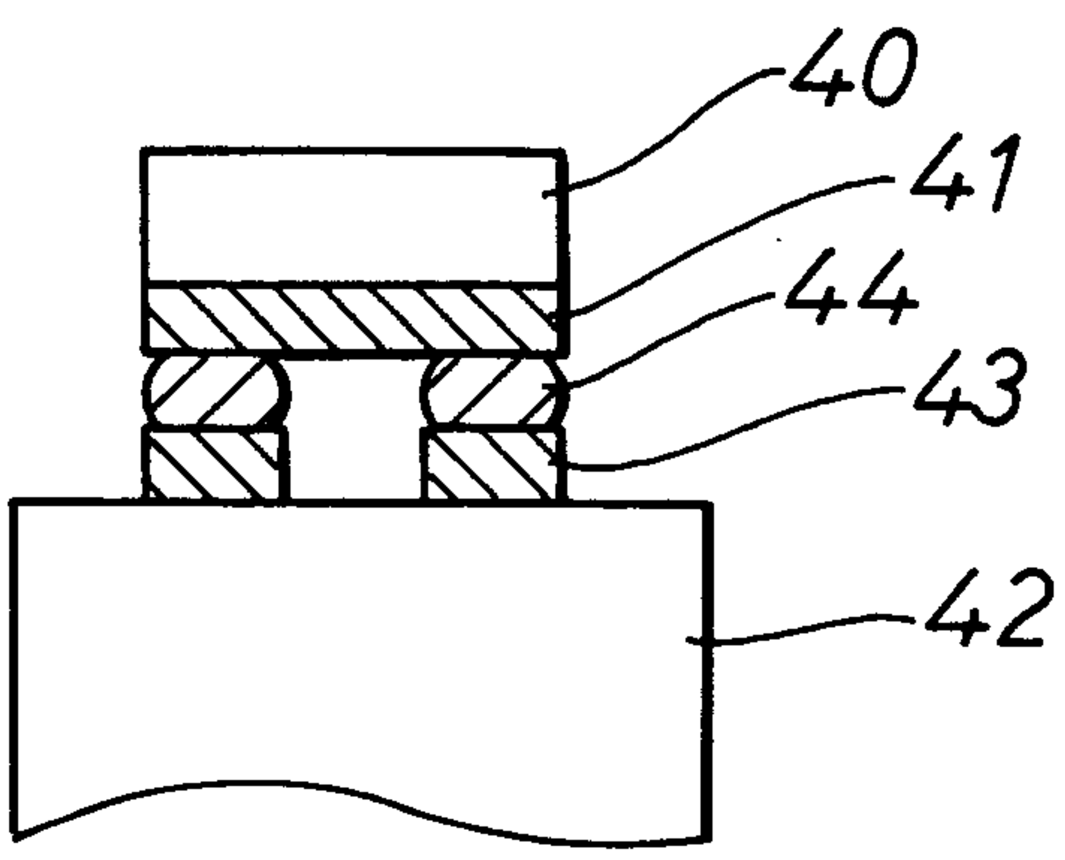
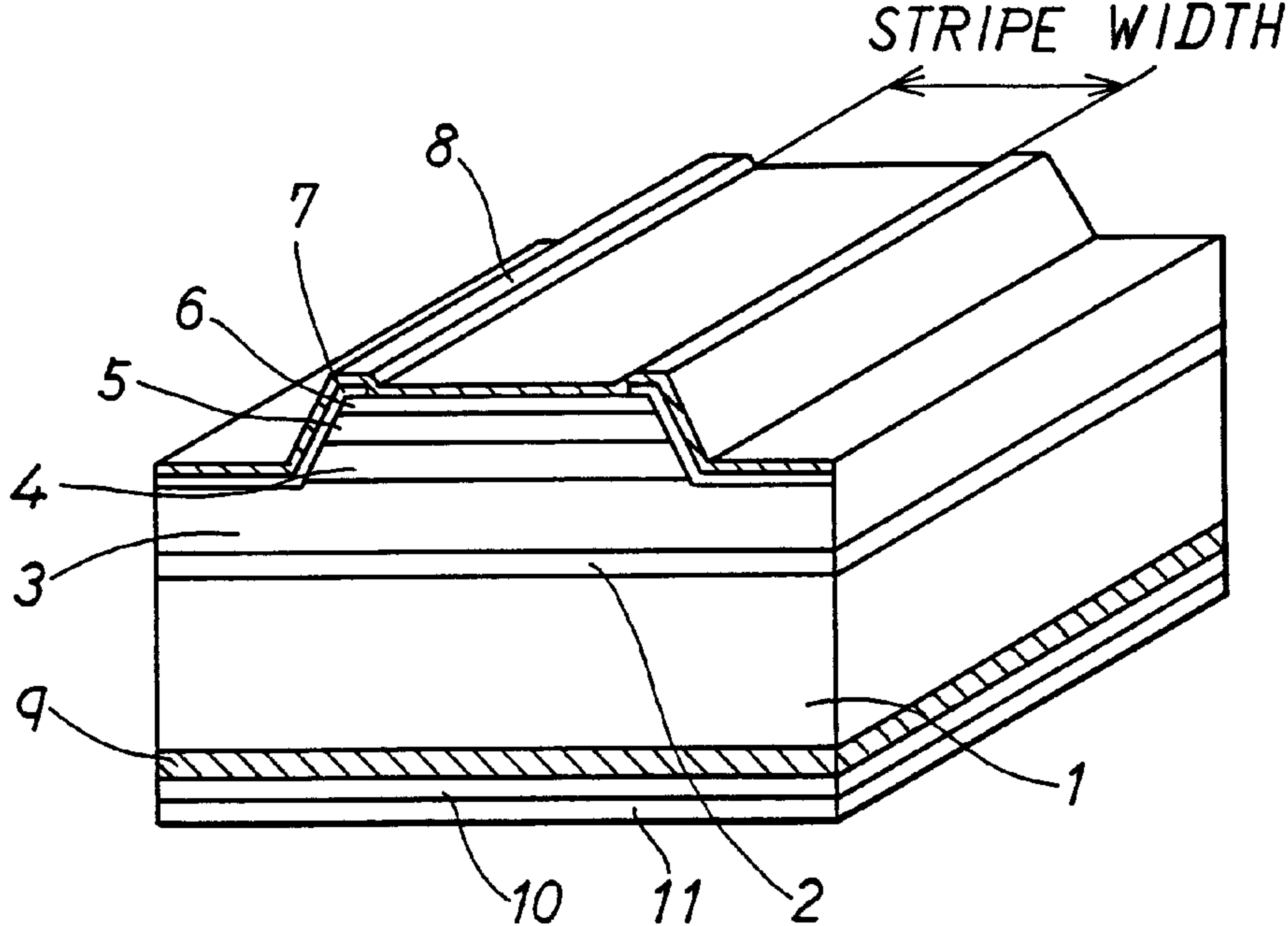


FIG. 9




STRIPE WIDTH
8
7
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2
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