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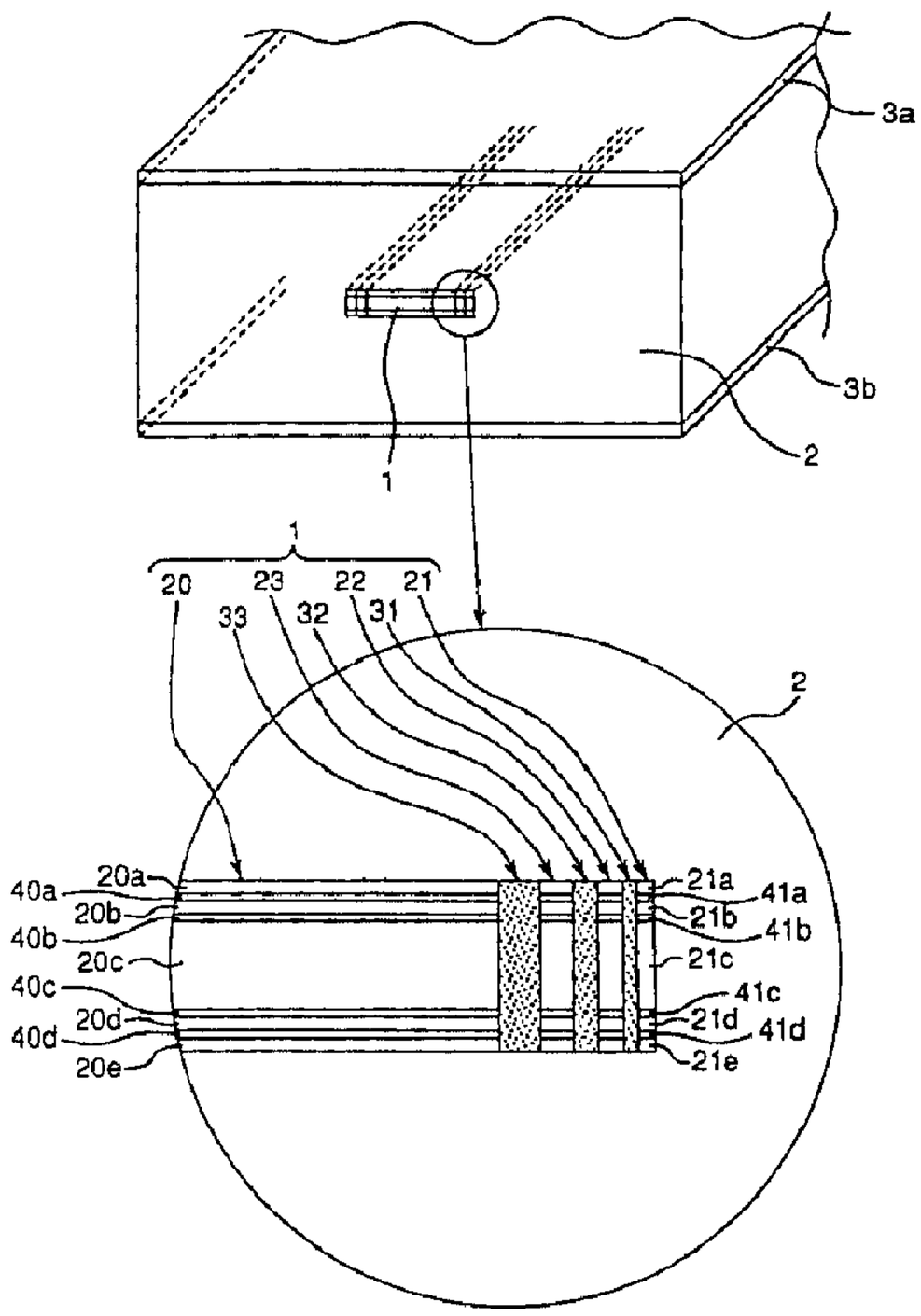


(57) Abrégé/Abstract:
A high frequency filter includes a high frequency resonator that has a high frequency low loss electrode. The high frequency low loss electrode has a main conductor and at least one sub-conductor formed along a side of the main conductor. The width of at least one of the sub-conductors has a multi-layer structure in which thin-film conductors and thin-film dielectrics are alternately laminated.

ABSTRACT OF THE DESCRIPTION

A high frequency filter includes a high frequency resonator that has a high frequency low loss electrode. The high frequency low loss electrode has a main conductor and at least one sub-conductor formed along a side of the main conductor. The width of at least one of the sub-conductors has a multi-layer structure in which thin-film conductors and thin-film dielectrics are alternately laminated.

HIGH FREQUENCY LOW LOSS ELECTRODE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a high frequency low loss electrode for use in transmission lines and resonators operative in a microwave band and a millimeter wave band which are used mainly in radio communication, a transmission line, a high frequency resonator, a high frequency filter, an antenna common device, and a communication equipment each including the high frequency low loss electrode.

2. Description of the Related Art

In microwave IC's and monolithic microwave IC's operated at a high frequency, used generally are strip-type transmission lines and microstrip-type transmission lines which can be easily produced and of which the size and weight can be reduced. As a resonator for such uses, one in which the above-described line is set at a length equal to a quarter-wavelength or a half-wavelength, or a circular resonator containing a circular conductor are employed. The transmission loss of these lines and the unloaded Q of the resonators are determined mainly by the conductor loss. Accordingly, the performance of the microwave IC's and the monolithic microwave IC's depends on how much the conductor loss can be reduced.

These lines and resonators are formed with conductors with

a high conductivity such as copper, gold, or the like. However, the conductivities of metals are inherent to the materials. There is a limitation in a method of selecting a metal with a high conductivity, and forming the metal into an electrode to reduce the loss. Accordingly, great attention has been given to the fact that at the high frequency of a microwave or a millimeter wave, a current is concentrated onto the surface of an electrode, caused by the skin effect, and most of the loss occurs in the vicinity of the surface (end portion) of the conductor. It has been investigated to reduce the conductor loss from the standpoint of the structure of the electrode. For example, in Japanese Unexamined Patent Publication 8-321706, disclosed is the structure in which plural linear conductors with a constant width are arranged in parallel to the propagation direction at constant intervals to reduce the conductor loss. Moreover, in Japanese Unexamined Patent Publication 10-13112, disclosed is the structure in which the end portion of an electrode are divided into plural parts, so that a current concentrated at the end portion is dispersed to reduce the conductor loss.

However, the method by which the whole of an electrode is divided through plural conductors having an equal width as disclosed in Japanese Unexamined Patent Publication 8-321706 has the problem that the effective cross-sectional area of the electrode is decreased, so that the conductor loss cannot be

effectively reduced.

Moreover, as regards the method in which the end of the electrode is divided into plural sub-conductors having substantially the same width as disclosed in Japanese Unexamined Patent Publication 10-13112, it is effective to some degree in relaxing the current concentration and reducing the conductor loss. However, it can not be recognized that the effect is satisfactory.

SUMMARY OF THE INVENTION

In accordance with an aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wave length multiplied by an integer, the high frequency

transmission line having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wave length multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors formed along a side of the main conductor, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a smaller

width, at least one of said sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with yet another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wavelength multiplied by an integer, the transmission line having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors formed along a side of the main conductor, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a smaller width, and at least one of said sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with yet another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wavelength multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors formed along a side of the main conductor, said sub-conductors being formed so that a sub-conductor thereof

positioned nearer to the outside has a smaller width, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wavelength multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors

excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

In accordance with another aspect of the present invention, there is provided a high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wavelength multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a triplet type strip line including a high low loss electrode according to an embodiment of the present invention;

FIG. 2 is a graph showing the attenuation of a current density inside a conductor;

FIG. 3 illustrates the phase change of a current density inside of a conductor;

FIG. 4 illustrates the phase change of a current density when conductors and dielectrics are alternately arranged;

FIG. 5A is a perspective view of a triplet type strip line model for analysis of a multi-line structure electrode according to the present invention;

FIG. 5B is an enlarged cross-sectional view of the strip conductor in the model of FIG. 5A;

FIG. 5C is a sill enlarged cross-sectional view of the strip conductor;

FIG. 6 is a two-dimensional equivalent circuit diagram of the multi-layer multi-line model of FIG. 5C;

FIGS. 7A and 7B are one-dimensional equivalent circuit diagrams, each circuit diagram being in one direction of the multi-layer multi-line model of FIG. 5C;

FIG. 8 is a perspective view of a triplet type strip line model used in the simulation of the multi-line structure electrode according to the present invention;

FIG. 9A is a view of a conventional electrode not having a multi-line structure used in the simulation;

FIG. 9B illustrates the simulation results of the electric field distribution;

FIG. 9C illustrates the simulation results of the phase distribution;

FIG. 10 illustrates an electrode having a multi-line structure according to the present invention used in the simulation;

FIG. 11A illustrates the simulation results of an electric field distribution in the electrode of FIG. 10;

FIG. 11B illustrates the simulation results of a phase distribution in the electrode of Fig. 10;

FIG. 12 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 1;

FIG. 13 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 2;

FIG. 14 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 3;

FIG. 15 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 4;

FIG. 16 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 5;

FIG. 17 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 6;

FIG. 18 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 7;

FIG. 19 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 8;

FIG. 20 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 9;

FIG. 21 is a cross-sectional view showing the

configuration of a high frequency low loss electrode of the modification example 10;

FIG. 22 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 11;

FIG. 23 is a cross-sectional view showing the configuration of a high frequency low loss electrode of the modification example 12;

FIG. 24 is a cross-sectional view showing the configuration of the high frequency low loss electrode of the modification example 13 of the present invention;

FIG. 25 is a cross-sectional view showing the configuration of the high frequency low loss electrode of the modification example 14 of the present invention;

FIG. 26 A is a perspective view showing the configuration of a circular strip resonator which is an application example 1 of a high frequency low loss electrode according to the present invention;

FIG. 26B is a perspective view showing the configuration of a circular resonator wich is an application example 2 of a high frequency low loss electrode according to the present invention;

FIG. 26C is a perspective view showing the configuration of a microstrip line which is an application example 3 of a high frequency low loss electrode according to the present invention;

FIG. 26D is a perspective view showing the configuration of a coplanar line which is an application example 4 of a high frequency low loss electrode according to the present invention;

FIG. 27A is a perspective view showing the configuration of a coplanar strip line which is an application example 7 of a high frequency low loss electrode according to the present invention;

FIG. 27B is a perspective view showing the configuration of a parallel slot line which is an application example 6 of a high frequency low loss electrode according to the present invention;

FIG. 27C is a perspective view showing the configuration of a slot line which is an application example 7 of a high frequency low loss electrode according to the present invention;

FIG. 27D is a perspective view showing the configuration of a high impedance microstrip line which is an application example 8 of a high frequency low loss electrode according to the present invention;

FIG. 28A is is a perspective view showing the configuration of a slot line which is an application example 7 of a high frequency low loss electrode according to the present invention;

FIGS. 28B and 28C are perspective views each showing the configuration of a half-wave type microstrip line resonator which is an application example 10 of a high frequency low loss

electrode according to the present invention;

FIG. 28D is a perspective view showing the configuration of a quarter-wave type microstrip line resonator which is an application example 11 of a high frequency low loss electrode according to the present invention;

FIGS. 29A and 29B are plan views showing the configuration of a half-wave microstrip line filter which is an application example 12 of a high frequency low loss electrode according to the present invention;

FIG. 29C is a plan view showing the configuration of a circular strip filter which is an application example 13 of a high frequency low loss electrode according to the present invention;

FIG. 30 is a block diagram showing the configuration of a duplexer 700 as an application example 14; and

FIG. 31 illustrates the configuration of an application example including the duplexer 700 of FIG. 30.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, a high frequency low loss electrode according to an embodiment of the present invention will be described. FIG. 1 shows a triplet type strip line including the high frequency low loss electrode 1 of the embodiment. The strip line has the configuration in which the high frequency low loss electrode 1 having a predetermined width is formed in the center

of a dielectric 2 with a rectangular cross-section, and ground electrodes 3a and 3b are formed in parallel to the high frequency low loss electrode 1. In the high frequency low loss electrode 1 of this embodiment, as shown in the enlarged view of FIG. 1, the end portion is divided into sub-conductors 21, 22, and 23, so that an electric field concentrated in the end portion is dispersed, and the conductor loss at a high frequency is reduced. In this embodiment, the sub-conductors 21, 22, and 23 are formed to have a lamination structure in which thin-film conductors and thin-film dielectrics are laminated alternately, and thereby, the conductor loss in the sub-conductors 21, 22, nd 23 is reduced, that is, the conductor loss in the end portion of the high frequency low loss electrode is reduced.

In particular, in the high frequency low loss electrode 1 of this embodiment, the sub-conductor 23 is formed to be adjacent to the main conductor 20 through a sub-dielectric 33. The sub-dielectric 32, the sub-conductor 22, the sub-dielectric 31, and the sub-conductor 21 are formed sequentially toward the outside in that order. The sub-conductors 23, 22, and 21 are formed so that the width of a sub-conductor thereof positioned nearer to the outside (more distant from the main conductor) is smaller to reduce the conductor loss of all the sub-conductors, the sub-conductors 21, 22, and 23 are formed to have a width of up to $\pi/2$ times the skin depth δ at an applied frequency, and the respective widths of the sub-dielectrics 33, 32, and 31 are

set so that currents substantially in phase flow through the respective sub-conductors 21, 22, and 23. Accordingly, the concentration of an electric field in the end portion of the electrode, caused when no sub-conductors are provided, can be effectively dispersed in the respective sub-conductors 21, 22, and 23.

Further, the sub-conductor 21 has a multi-layer structure in which a thin-film conductor 21a, a thin-film dielectric 41a, a thin-film conductor 21b, a thin-film dielectric 41b, a thin-film conductor 21c, a thin-film dielectric 41c, a thin-film conductor 21d, a thin-film dielectric 41d, and a thin-film conductor 21e are laminated.

In the sub-conductor 21, the thin-film conductors 21a, 21b, 21c, 21d, and 21e are formed so that a thin-film conductor thereof lying at a further inside position is thicker, in order that the conductor loss of the sub-conductor is reduced. The film-thicknesses of the thin-film dielectrics 41a, 41b, 41c, and 41d are set so that currents substantially in phase flow through the thin-film conductors 21a, 21b, 21c, 21d, and 21e, correspondingly. In this embodiment, the sub-conductors 22 and 23 are formed in the same manner as the sub-conductor 21.

The film-thicknesses of the thin-film conductors 21a, 21b, 21c, 21d, and 21e which are preferable for reduction of the conductor loss of the sub-conductors, and the film-thicknesses of the thin-film dielectrics 41a, 41b, 41c, and 41d which are

preferable to be made to flow currents substantially in phase through the thin-film conductors 21a, 21b, 21c, 21d, and 21e will be described later.

Hereinafter, as regarding the high frequency low loss electrode 1 of this embodiment, a method of setting the line-widths of the sub-conductors and the widths of the sub-dielectrics will be described.

1. Currents and Phases in Respective Sub-conductors

(Current Densities and Phases in Conductor Insides)

In general, the current density function J(z) inside a conductor is expressed by the following mathematical formula 1, caused by the skin effect which occurs at a high frequency. In the mathematical formula 1, z represents a distance in the depth direction from the surface taken as the reference (0), and δ represents the skin depth at an angular frequency ω (= $2\pi f$) which is expressed by the mathematical formula 2. Further, σ represents a conductivity, and μ_0 a permeability in vacuum. Accordingly, inside of the conductor, the current density is decreased at a position deeper from the surface as shown in FIG. 2.

[mathematical formula 1]

$$J(z)=J_0 e^{-(1+j)z/\delta} \quad (A/m^2)$$

[mathematical formula 2]

$$\delta = \sqrt{2/\omega\mu_0\sigma}$$

Accordingly, the absolute value of the amplitude of the

current density is expressed by the following mathematical formula 3, and is attenuated to 1/e at $z = \delta$. The phase of the amplitude of the current density is expressed by the mathematical formula 4. As z is increased (namely, at a position deeper from the surface), the phase is increased on the minus side, and at $z = \delta$ (surface skin depth), the phase is decreased by 1 rad (about 60°) as compared with that at the surface.

[mathematical formula 3]

$$abs(J(z)) = |J_0| e^{-z/\delta}$$

[mathematical formula 4]

$$arg(J(z)) = -z/\delta$$

Accordingly, a power loss P_{loss} is expressed by the following mathematical formula 5 using resistivity $\rho = 1/\sigma$. The overall power loss P^{o}_{loss} of a conductor which is sufficiently thick is expressed by the formula 6. At $z = \delta$, $(1-e^{-2})$ of the overall power loss P^{o}_{loss}, namely, 86.5 % is lost.

[mathematical formula 5]

$$P_{loss} = \int_0^z \rho |J(z)|^2 dz \quad (\rho = 1/\sigma : \text{resistivity})$$

$$= \rho |J_0|^2 \delta / 2(1 - e^{-2z/\delta})$$

[mathematical formula 6]

$$P^{0}_{loss} = \rho |J_0|^2 \delta / 2$$

Further, by using the current density function J (z), the surface current K is given by the following mathematical formula 7. The surface current K is a physical quantity which is

coincident with the tangential component of a magnetic field (hereinafter, referred to as a surface magnetic field) at the surface of a conductor. The surface current K is in phase with the surface magnetic field, and has the same dimension as the surface magnetic field, namely, the dimension of A/m.

[mathematical formula 7]

$$K = \int_0^\infty J(z)dz = \delta J / (1 + j)$$

As seen in the mathematical relation formula 7, the phase of the current density J_0 at the surface is 45°, if observed at the time when the phase of the surface current K (namely, the surface magnetic field) is 0°, Accordingly, the phase of the current density function J(z) inside the conductor can be illustrated by a model as shown in FIG. 3. Further, when the phase of the current density J_0 is 45°, the surface current K is given by the following formula 8.

[mathematical formula 8]

$$K = |K| = \delta|J_0| / \sqrt{2}$$

Assuming that the phase of the current density amplitude is not changed with the depth (behaviors like direct current), the surface current is expressed by following formula 9.

[mathematical formula 9]

$$K' = \int_0^\infty |J_0| e^{-2/\delta} dz$$

$$= \delta|J_0|$$

As understood by the comparison of the formulae 8 and 9, the surface current K at a high frequency is decreased to be $1/\sqrt{2}$ = 70.7% as compared with the surface current K' of the direct current. It is speculated that this is because an ineffective current flows. In fact, it can be recognized that the overall power loss calculated based on the formula 9 can be expressed by the formula 5.

On the other hand, if the current density expressed by the formula 9 is multiplied by $1/\sqrt{2}$ so that the surface currents are equal to each other, the overall power loss, on the condition that the equal surface currents are realized, will be $(1/\sqrt{2})^2$ = 1/2 = 50 %.

Accordingly, under the ideal limit condition that the phases of the current densities are made equal to 0°, and the phases suffer no changes inside the conductor, the power loss can be reduced to 50%. Practically, since the phase of the current density is decreased inside the conductor, it is difficult to realize the above-described ideal state.

(Current and Phase in Each Sub-conductor)

However, in the multi-line structure in which sub-conductors and sub-dielectrics are alternately arranged, the periodic structure in which the phase is changed periodically in the range of $\pm\theta$ as shown in FIG. 4 can be realized by utilization of the phenomena that the phase of a current density inside a dielectric increases. That is, characteristically, in the high

frequency low loss electrode 1 of this embodiment, realized is the structure in which the phases of the current densities inside the sub-conductors are changed periodically in a relative small range with respect to the center of 0, by setting θ at a small value in the above-described periodic structure, and thereby, an ineffective current is reduced.

Accordingly, the following two points as requirements to be preferred and satisfied for the high frequency low loss electrode 1 of this embodiment can be derived from the above-described discussion.

(1) The line-width of each sub-conductor is set so that the change width (2θ) of the current density phase is small. As seen in the above description, as the line-width of the sub-conductor is narrower, the change width of the phase can be more reduced to reach the above-described ideal state. Practically, in consideration of the manufacturing cost, the phase is set preferably at $\theta \leq 90°$, and more preferably at $\theta \leq 45°$.

The setting at $\theta \leq 90°$ can be achieved by setting the line width of each sub-conductor at $\pi\delta/2$ or lower. Further, the setting at $\theta \leq 45°$ can be made by setting the line-width of each sub-conductor at $\pi\delta/4$ or lower.

(2) The widths of the sub-dielectrics are set so that the changed current density phases in the respective sub-conductors lying on the current-approaching side are cancelled out.

2. Processing of Multi-Line Structure by Equivalent

Circuit

Hereinafter, the multi-line structure of the high frequency low loss electrode 1 of the present invention will be described in reference to a simplified modeled structure.

FIG. 5A shows a triplet type strip line model which can be analyzed relatively easily, and will be used in the following description. The model has the configuration in which a strip conductor 101 with a rectangular cross-section is provided in a dielectric 102. The strip conductor 101 is configured so that the cross-section is symmetric with respect to right and left and upper and lower sides as shown in FIG. 5B. Further, as shown in FIG. 5C, the strip conductor 101 has the multi-line structure in an end portion thereof, and is composed of multi-layers in the thickness direction. More particularly, the strip conductor 101 is composed of many sub-conductors, and has the matrix structure in which the sub-conductors (1, 1), (2, 1), (3, 1) ... are arranged in the thickness direction, and the sub-conductors (1, 1), (1, 2), (1, 3) ... are arranged in the width direction.

The two-dimensional equivalent circuit as shown by the multi-layer multi-line model in FIG. 5C can be expressed as in FIG. 6. In FIG. 6, Fcx represents the cascade connection matrix of the conductors in the width direction thereof, and Fcy the cascade connection matrix of the conductors in the thickness direction thereof. The codes (1, 1), (1, 2) ... , which

correspond to the respective sub-lines, are appended to Fcx and Fcy.

Ft represents the cascade connection matrix of the dielectric layers in the respective lines. The dielectric layers are numbered sequentially from the uppermost layer. Fs represents the cascade connection matrix of the adjacent conductor lines in the width direction, and numbered sequentially from the outside. The respective cascade connection matrixes Fcx, Fcy, Ft, and Fs are expressed by the following formulae 10 through 13. In the formulae 10 through 13, L and g represent the width and the thickness of each sub-conductor, and S the width of the sub-dielectric between adjacent sub-conductors. Accordingly, the cascade connection matrixes Fcx, Fcy, Ft, and Fs correspond to the widths and the thicknesses of the respective sub-conductors, and the widths of the respective sub-dielectrics. In this case, Zs represents the surface (characteristic) impedance of each conductor, and expressed by $Zs = (1 + j)\sqrt{\{(\omega\mu_0)/(2\sigma)\}}$.

[mathematical formula 10]

$$F_{cx} = \begin{pmatrix} \cosh\left(\frac{1+j}{\delta}\cdot\frac{L}{2}\right) & Zs\sinh\left(\frac{1+j}{\delta}\cdot\frac{L}{2}\right) \\ \frac{1}{Zs}\sinh\left(\frac{1+j}{\delta}\cdot\frac{L}{2}\right) & \cosh\left(\frac{1+j}{\delta}\cdot\frac{L}{2}\right) \end{pmatrix}$$

[mathematical formula 11]

$$F_{cy} = \begin{pmatrix} \cosh\left(\frac{1+j}{\delta}\cdot\frac{g}{2}\right) & Zs\sinh\left(\frac{1+j}{\delta}\cdot\frac{g}{2}\right) \\ \frac{1}{Zs}\sinh\left(\frac{1+j}{\delta}\cdot\frac{g}{2}\right) & \cosh\left(\frac{1+j}{\delta}\cdot\frac{g}{2}\right) \end{pmatrix}$$

[mathematical formula 12]

$$F_t = \begin{pmatrix} 1 & j\omega\mu_0 t\left(1-\frac{\varepsilon_m}{\varepsilon_t}\right) \\ 0 & 1 \end{pmatrix}$$

[mathematical formula 13]

$$F_s = \begin{pmatrix} 1 & j\omega\mu_0 S\left(1-\frac{\varepsilon_m}{\varepsilon_s}\right) \\ 0 & 1 \end{pmatrix}$$

Accordingly, theoretically, the line width L and the thickness g of the respective sub-conductors, and the width S and the thickness t of the respective sub-dielectrics may be set so that the real part (resistance component) of the surface impedance of the respective sub-conductors is minimum, by operating the connection matrixes based on the two-dimensional equivalent circuit of FIG. 6.

However, it is difficult to determine analytically the line width L and the thickness g of the respective sub-conductors, and the width S and the thickness t of the respective sub-dielectrics based on the two-dimensional equivalent circuit of FIG. 6 and in the above-described conditions.

Accordingly, by the inventors, by using the equivalent circuit of FIG. 7 which is the one-dimensional model in the width

direction of the equivalent circuit of FIG. 6, the recurrence formula expressed by the formula 14 is obtained on the condition that the real part (resistance component) of the surface impedance of the respective sub-conductors is minimum. The line width L of the respective sub-conductors and the width S of the respective sub-dielectrics are set based on the parameter b satisfying the recurrence formula and the formulae 15 and 16. The equivalent circuit of FIG. 7 is the one-dimensional model in which the equivalent circuit of FIG. 6 is taken as a single layer, and the thickness direction of the single layer is not considered.

[mathematical formula 14]

$$b_{k+1} = \tanh^{-1} (\tan b_k)$$

[mathematical formula 15]

$$L_{k+1} = L_k \ (b_{k+1} \ / \ b_k)$$

[mathematical formula 16]

$$S_{k+1} = S_k \ (b_{k+1} \ / \ b_k)$$

As described above, the line-width L of the respective sub-conductors and the width S of the respective sub-dielectrics were set, and the conductor loss at a high frequency was evaluated by a finite element method. It has been identified that the loss can be reduced as compared with the case where the line-width L of the respective sub-conductors and the width S of the respective sub-dielectrics are set at equal values, respectively. When the line-width L of the respective sub-conductors and the

width S of the respective sub-dielectrics are set, it is necessary to give the initial values of b_1, L_1, and S_1 previously. In this invention, it is preferable that the initial values are set so that the electric current phases of the respective current densities are in the range of ± 90° or ± 45°. As a result of the analysis using the one-dimensional model of FIG. 7A, a satisfactory relationship is derived between L1 and S1 to which initial values are to be given, in order to minimize the surface resistance. The initial values are given to L1 and S1 so as to satisfy the relationship, so that currents substantially in phase flow through the respective sub-conductors. That is, by the examination from the circuit theoretical standpoint, it is concluded that the preferable condition which the widths of the respective dielectrics are to satisfy is "the widths of the sub-dielectrics are set so that the changed current density phases in the sub-conductors on the current-approaching side are cancelled out". Thus, the same results as the conditions described in (2) of Paragraph Number (0039) can be obtained.

Further, by the inventors, the line-width L of the respective sub-conductors and the width S of the respective sub-dielectrics are set by using the following mathematical formulae 17 and 18 which are decreasing functions analogous to the recurrence formula of the mathematical formula 14, instead of the formula 14. The conductor loss at a high frequency was evaluated by the finite element method. As a result, it has been

identified that in the above-described manner, the loss can be reduced as compared with the case where the line-widths of the sub-conductors and also, the widths S of the sub-dielectrics are set at the same values, correspondingly.

[mathematical formula 17]

$$b_{k+1} = \tanh^{-1} b_k$$

[mathematical formula 18]

$$b_{k+1} = \tan b_k$$

The results obtained by use of the respective formulae 14, 17, and 18 become different when the initial values are given differently. Thus, it can be decided with much difficulty which formula is most appropriate.

That is, the recurrence formula of the formula 14 is determined by use of the one-dimensional model, and does not necessarily give an optimum result when it is applied to the two dimensional model. Practically, inside the sub-conductors, the width direction and the thickness direction are influenced with each other, so that the propagation vector includes angular information. However, the angular information is not considered by the equivalent circuit of FIG. 6. Accordingly, the formulae 14, 17, and 18 have no essential physical meanings, and play a role like a trial function in the two-dimensional model. Thus, after the effectiveness of the results obtained by use of these trial functions are confirmed by use of the finite element method, the final line-widths are set.

However, from the above-described circuit theoretical discussion, it is evident that the overall conductor loss at a high frequency can be reduced by setting the width of a sub-line positioned nearer to the outside at a smaller value. Also, from the same discussion as described above, it is obvious that when the single layer, multi-line structure is employed, the overall conductor loss can be reduced by setting the thickness of a sub-line positioned nearer to the outside at a smaller value.

Hereinafter, the thicknesses of the thin-film conductors of each sub-conductor and the thicknesses of the thin-film dielectrics will be described. In the sub-conductor having a multi-layer structure, currents can be effectively dispersed in the respective thin-film conductors by setting the film-thicknesses of the respective thin-film dielectrics so that currents substantially in phase flow through the respective thin-film conductors. Consequently, the skin effect of the sub-conductor at a high frequency can be inhibited. In this case, in order that a high frequency current flows through each thin-film conductor, it is more preferable that the thickness of each thin-film conductor is not more than the skin depth δ in consideration of the skin effect. This is because substantially no currents flow in the part of the electrode deeper than the skin depth δ, even if the thin-films are thicker than the skin depth δ.

Moreover, as a result of the examination of the equivalent

circuit of FIG. 7B which is a one-dimensional model in the thickness direction of the equivalent circuit of FIG. 6, it is more preferable that the thicknesses of each thin-film conductor and each thin-film dielectric are set as follows. That is, by use of the equivalent circuit of FIG. 7B and the conditions that the real part (resistance component) of the surface impedance of the sub-conductor is minimum, the recurrence formula represented by the formula 19 is obtained. Based on a parameter b satisfying the recurrence formula, and the formulae 20 and 21, the thickness g of each sub-conductor and the thickness X of each thin-film dielectric are set. In this case, the equivalent circuit of FIG. 7B is a one-dimensional model obtained from the viewpoint of one sub-conductor in the equivalent circuit of FIG. 6, under no consideration of the equivalent circuit of FIG. 6 in the width direction.

[mathematical formula 19]

$$a_{k+1} = \tanh^{-1}(\tan a_k)$$

[mathematical formula 20]

$$g_{k+1} = g_k \ (a_{k+1} \ / \ a_k)$$

[mathematical formula 21]

$$X_{k+1} = X_k \ (a_{k+1} \ / \ a_k)$$

The thickness g of each sub-conductor and the thickness X of each thin-film dielectric were set as described above, and the conductor loss at a high frequency was evaluated by a finite element method. It has been identified that the loss can be

further reduced as compared with the case where the thickness g of each sub-conductor and the thickness X of each thin-film dielectric are separately set to be the same, correspondingly. It is necessary to give initial values to a_1, g_1, and X_1 when the thickness g of each sub-conductor and the thickness X of each thin-film dielectric are set.

As a result of the analysis using the one-dimensional model of FIG. 7B, it is preferable that to make minimum the surface resistance of a sub-conductor, a satisfactory relationship is derived between g_1 and X_1 to which the initial values are given, and g_1 and X_1 are given so as to satisfy the relationship. The more preferable conditions which the thickness of each thin-film conductor is to satisfy are that "the thin-film conductors of a sub-conductor are formed so that a thin-film conductor thereof lying at a further inside position is thicker".

Further, by the inventors, the thicknesses g of the thin-film conductors and the thicknesses X of the thin-film dielectrics are set by using the following formulae 22 and 23 which are decreasing functions analogous to the recurrence formula of the formula 19, instead of the formula 19. The conductor loss at a high frequency was evaluated by the finite element method. As a result, it has been identified that in the above-described manner, the loss can be reduced as compared with the case where the thicknesses g of the thin-film conductors and the thicknesses X of the thin-film dielectrics are set to be equal,

correspondingly.

[mathematical formula 22]

$$a_{k+1} = \tanh^{-1} a_k$$

[mathematical formula 23]

$$a_{k+1} = \tan a_k$$

The results obtained by use of the formulae 19, 22, and 23 are different with initial values given differently. Accordingly, it can be decided with much difficulty which formula is most appropriate.

That is, the recurrence formula of the mathematical formula 19 is determined by use of the one-dimensional model, and does not necessarily give an optimum result when the two-dimensional model is used. Further, practically, inside of each sub-conductor, mutual action occurs in the width and thickness directions, so that the propagation vector includes angular information. However, the equivalent circuit of FIG. 6 is given not considering the information. Accordingly, in the two-dimensional model, the formulae 19, 22, and 23 have no essential physical meanings, and play a role like a trial function. Thus, the effectiveness of the results obtained by use of these trial functions are confirmed by the finite element method or the like, and the final thicknesses of the thin-film conductors and the thicknesses of the thin-film dielectrics are set.

As seen in the above description, from the circuit theoretical discussion, it is understood that in a sub-conductor

having a multi-layer structure, the whole conductor loss at a high frequency in the sub-conductor can be further reduced by setting so that a thin-film conductor thereof lying at a further inside position has a larger thickness, as compared with the case where the thicknesses of the thin-film conductors are set at the same value.

The widths of the sub-conductors and those of the sub-dielectrics are set based on the above-described principle. The results simulated by the finite element method will be described below.

Each simulation described below was carried out by use of a model provided by filling a dielectric 201 with a relative dielectric constant of $\varepsilon r = 45.6$ into the complete conductor cavity 202 as shown in FIG. 8, and disposing an electrode 10 (200) in the center of the dielectric 201. The electrode 10 is an electrode according to the present invention having a multi-line structure, while an electrode 200 is conventional one, not having the multi-line structure.

FIG. 9 shows the electric field distribution and the phase of the electrode 200 as a conventional example not having the multi-line structure. The simulation was carried out by use of the model of which the cross-section is one fourth of that of the electrode 200 as shown in FIG. 9A. The overall width W of the electrode 200 was 400 μm, and the thickness T of the electrode 200 was 11.842 μm. As a result of the simulation, it is

understood that the electric field is concentrated onto the end of the electrode as shown in FIG. 9B, and the phase of the electric field is more decreased at a further inside position of the electrode 200. The results of the simulation at 2 GHz are as follows.

(1) attenuation constant α: 0.79179 Np/m,

(2) phase constant β: 283.727 rad/m,

(3) conductor Qc (= $\beta/2\alpha$) ; 179.129

On the other hand, the simulation results at 2 GHz of the high frequency low loss electrode according to the present invention, having a multi-line multi-layer structure as shown in FIG. 10 are as follows.

(1) attenuation constant α: 0.46884 Np/m,

(2) phase constant β: 283.123 rad/m,

(3) conductor Qc (= $\beta/2\alpha$) ; 301.940

In this case, the conductor line widths L1, L2, L3, and L4 of the sub-conductors 51, 52, 53, and 54 were set at 1.000 μm, 1.166 μm, 1.466 μm, and 2.405 μm, respectively.

The dielectric line widths S1, S2, S3, and S4 of the dielectrics 61, 62, 63, and 64 were set at 0.3 μm, 0.35 μm, 0.44 μm, and 0.721 μm, respectively.

The thicknesses G1, G2, G3, G4, and G5 of the thin-film conductors were set at 0.6 μm, 0.676 μm, 0.793 μm, 1.010 μm, and 1.816 μm, respectively.

The thicknesses X1, X2, X3, and X4 of the thin-film

dielectrics were set at 0.2 μm, 0.225 μm, 0.264 μm, and 0.337 μm.

In this case, as shown in FIG. 10, the above G5 represents half of the thickness of the thin-film conductor positioned at the center of the sub-conductors. The overall thickness of the sub-conductors was taken as 11.842 μm.

In the above simulation, the conductivity σ of the conductor was 52.9 MS/m, and the dielectric constants of the dielectric lines and the thin-film dielectrics were 10.0, respectively, and were used in the calculation.

Further, it is seen that the electrode according to the present invention having a multi-line multi-layer structure, the electric field is dispersed and distributed in the respective ends of the thin-film conductors as shown in FIG. 11A. Further, as shown in FIG. 11C, the phases of the electric fields are distributed in the respective thin-film conductors so that the electric fields are substantially in phase in the respective thin-film conductors.

From the above-described discussion, the requirements which the high1 frequency low loss electrode 1 of this embodiment is to satisfy are as follows.

Requirements for Low Loss at High Frequency

(i) The line-width of each sub-conductor is set so that the change-width (2θ) of the current density phase is small. Concretely, preferably, the phase angle is set at $\theta \leq 90°$, and

more preferably, at $\theta \leq 45°$.

(ii) The sub-conductors are formed so that the width of a sub-conductor thereof positioned nearer to the outside is smaller.

(iii) The sub-conductors are formed so that the thickness of a sub-conductor thereof positioned nearer to the outside is smaller.

(iv) The widths of the sub-dielectrics are set so that the changed current density phases in the sub-conductors lying on the current-approaching side is cancelled out, respectively. That is, the widths of the sub-dielectrics are set so that the currents flowing in the respective sub-conductors are substantially in phase.

(v) The film thicknesses of the respective dielectric thin films are set so that currents substantially in phase flow through the respective thin-film conductors.

(vi) The thicknesses of the respective thin-film conductors are set at a value which is up to the skin depth δ.

(vii) The thicknesses of the respective thin-film conductors are set so that a thin-film conductor thereof lying at a further inside position is thicker.

As seen in the above description, in the high frequency low loss electrode 1 of the present invention, the sub-conductors 21, 22, and 23, and also, the sub-dielectrics 31, 32, and 33 are so formed that a sub-conductor thereof and a sub-dielectric

thereof lying at a position more distant from the main conductor 20 have a smaller width, correspondingly. The respective sub-conductors 21, 22, and 23 are formed to have a width which is up to $\pi/2$ times the skin depth δ at an applied frequency. Moreover, the widths of the respective sub-dielectrics 31, 32, and 33 are set so that the currents flowing in the respective sub-conductors 21, 22, and 23 are substantially in phase. Accordingly, currents in the dispersion state can be flown through the respective sub-conductors 21, 22, and 23, the conductor loss in the end portions can be reduced. In the high frequency low loss electrode of this embodiment, each sub-conductor has the multi-layer structure in which the thin-film conductors and the thin-film dielectrics are laminated alternately, the film thicknesses of the respective thin-film dielectrics are set so that currents substantially in phase flow through the respective thin-film conductors, the film-thicknesses of the respective thin-film conductors are smaller than the skin depth δ and are set so that the thickness of a thin-film conductor thereof lying at a further inside position is larger. Consequently, currents can be dispersed in the portions of the respective thin-film conductors which are shallower as compared with the skin depth, and the conductor loss of all the sub-conductors can be further reduced. Thus, the conductor loss in the end portions can be much reduced. In the high frequency low loss electrode of this embodiment, the

conductor loss at a high frequency can be remarkably reduced as compared with the conventional electrode.

In the above embodiment, as a preferred form of the present invention, the high frequency low loss electrode 1 satisfying the requirements (i), (ii), (iv), (v), (vi), and (vii) for reduction of the loss under the above-described high frequency condition is described. According to the present invention, a variety of modifications satisfying at least one of the above-described seven requirements is possible. In the modification examples described below, the conductor loss in the end portions at a high frequency can be reduced as the conventional example.

Modification Example 1

In a high frequency low loss electrode as a modification example 1, sub-conductors 201, 202, 203, and 204, and sub-dielectrics 301, 302, 303, and 304 are alternately disposed in the electrode end portion, as shown in FIG. 12. In the modification example 1, the the sub-conductors 201, 202, 203, and 204 are formed so that the width of a sub-conductor thereof positioned nearer to the outside is smaller. The sub-conductor 201 is formed to have a line width of up to $\pi\delta/2$, preferably, that of up to $\pi\delta/4$. The sub-dielectrics 301, 302, 303, and 304 are formed so that the width of a sub-dielectric thereof positioned nearer to the outside is smaller. Each sub-conductor comprises thin-film conductors and thin-film dielectrics

laminated alternately. For example, the sub-conductor 201 comprises a thin-film conductor 201a, a thin-film dielectric 251a, a thin-film conductor 201b, a thin-film dielectric 251b, a thin-film conductor 201c, a thin-film dielectric 251c, a thin-film conductor 201d, a thin-film dielectric 251d, and a thin-film conductor 201e are laminated. The sub-conductors 202, 203, and 204 are formed in the same manner as described above. In this modification exampel, the respective thin-film conductors are formed to have the same thickness, and the respective thin-film dielectrics are set at the same thickness. Further, in this modification example 1, a main conductor 19 is formed as a single layer. In the high frequency low loss electrode of the modification example 1 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 2

In a high frequency low loss electrode a modification example 2, sub-conductors 205, 206, 207, and 208, and sub-dielectrics 305, 306, 307, and 308 are alternately disposed in the electrode end portion, as shown in FIG. 13. In this modification example 2, the sub-conductors 205, 206, 207, and 208 are formed to have a line width of up to $\pi\delta/2$, preferably, that of up to $\pi\delta/4$. Further, the sub-dielectrics 305, 306, 307, and 308 are formed to have the same width. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics

laminated alternately. For example, the sub-conductor 205 comprises a thin-film conductor 205a, a thin-film dielectric 251a, a thin-film conductor 205b, a thin-film dielectric 251b, a thin-film conductor 205c, a thin-film dielectric 251c, a thin-film conductor 205d, a thin-film dielectric 251d, and a thin-film conductor 205e laminated alternately. The sub-conductors 202, 203, and 204 are formed in the same manner as described above. In the modification example 2, dielectrics 2a and 2b surrounding the high frequency low loss electrode have dielectric constants different from each other. The thin-film conductors lying on the dielectric 2a side and the thin-film conductors on the dielectric 2b side are set to have the thicknesses which correspond to the dielectric constants of the dielectrics 2a and 2b, respectively. In other words, the respective thin-film conductors are formed to have the same effective thickness. In the high frequency low loss electrode of the modification example 2 formed as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode, as well as that in the modification example 1.

Modification Example 3

In a high frequency low loss electrode as a modification example 3, sub-conductors 209, 210, 211, and 212, and sub-dielectrics 309, 310, 311, and 312 are alternately disposed in the electrode end portion, as shown in FIG. 14. In this

modification example 3, the sub-conductors 209, 210, 211, and 212 are set to have substantially the same width. Further, in the modification example 3, the sub-conductors 209, 210, 211, and 212 are formed to have, preferably, a line width of up to $\pi\delta/2$, more preferably, that of up to $\pi\delta/4$. Further, the sub-dielectrics 309, 310, 311, and 312 are formed to have the same width. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 209 comprises a thin-film conductor 209a, a thin-film dielectric 259a, a thin-film conductor 209b, a thin-film dielectric 259b, a thin-film conductor 209c, a thin-film dielectric 259c, a thin-film conductor 209d, a thin-film dielectric 259d, and a thin-film conductor 209e laminated together. The sub-conductors 202, 203, and 204 are formed in the same manner as described above. In the modification example 3, in each sub-conductor, the thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker. For example, in the sub-conductor 209, the thin-film conductor 209c is formed to be thickest, and the thin-film conductors 209b and 209d, and the thin-film conductors 209a and 209e are formed to be thinner in that order, correspondingly. In the high frequency low loss electrode of the modification example 3 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 4

In a high frequency low loss electrode as a modification example 4, sub-conductors 213, 214, 215, and 216, and sub-dielectrics 313, 314, 315, and 316 are alternately disposed in the electrode end portion, as shown in FIG. 15. In this case, each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 213 is formed of a thin-film conductor 213a, a thin-film dielectric 263a, a thin-film conductor 213b, a thin-film dielectric 263b, a thin-film conductor 213c, a thin-film dielectric 263c, a thin-film conductor 213d, a thin-film dielectric 263d, and a thin-film conductor 263e laminated together. The sub-conductors 214, 215, and 216 are formed in the same manner as described above. In the modification example 4, in each sub-conductor, the thin-film condujctors are formed so that the width of a thin-film conductor thereof lying at a further inside position is larger. For example, in the sub-conductor 213, the thin-film conductor 213c is formed to have a largest width. The thin-film conductors 213b and 213d, and the thin-film conductors 213a and 213e are formed to have a smaller width, in that order. In the high frequency low loss electrode of the modification example 4 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 5

In the high frequency low loss electrode of the modification example 5, sub-conductors 217, 218, 219, and 220, and sub-dielectrics 317, 318, 319, and 320 are alternately disposed in the electrode end portion, as shown in FIG. 16. In the modification example 5, the sub-conductors 217, 218, 219, and 220 have the same width, and are set so that a sub-conductor thereof positioned nearer to the outside is thinner. In the modification example 5, the line widths of the sub-conductors are preferably up to $\pi\delta/2$, more preferably, up to $\pi\delta/4$. The sub-dielectrics 317, 318, 319, and 320 are formed to have the same width. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 217 comprises a thin-film conductor 217a, a thin-film dielectric 267a, a thin-film conductor 217b, a thin-film dielectric 267b, a thin-film conductor 217c, a thin-film dielectric 267c, a thin-film conductor 217d, a thin-film dielectric267d, and a thin-film conductor 217e laminated together. In this modification example 5, the sub-conductors 218, 219, and 220 each are formed of the layers of which the number is equal to that of the sub-conductor 217. However, in a sub-conductor thereof positioned nearer to the main conductor, thicker thin-film conductors and thicker thin-film dielectrics are laminated. In the high frequency low loss electrode of the modification example

5 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 6

In a high frequency low loss electrode as a modification example 6, sub-conductors 221, 222, 223, and 224, and sub-dielectrics 321, 322, 323, and 324 are alternately disposed in the electrode end portion, as shown in FIG. 17. In the modification example 6, the sub-conductors 221, 222, 223, and 224 have the same width, and are set so that for a sub-conductor thereof positioned nearer to the outside, the lamination number is smaller, so that the sub-conductor is thinner. In the modification example 6, the line-width of each sub-conductor is preferably up to $\pi\delta/2$, more preferably up to $\pi\delta/4$. Further, the sub-dielectrics 321, 322, 323, and 324 are formed to have the same width. In the high frequency low loss electrode of the modification example 6 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 7

In a high frequency low loss electrode as a modification example 7, sub-conductors 225, 226, 227, and 228, and sub-dielectrics 325, 326, 327, and 328 are alternately disposed in the electrode end portion, as shown in FIG. 18. In the modification example 7, the sub-conductors 225, 226, 227, and

228 are formed so that the width of a sub-conductor thereof positioned nearer to the outside is smaller. The sub-dielectrics 325, 326, 327, and 328 are formed so that the width of a sub-conductor thereof positioned nearer to the outside is smaller. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 225 comprises a thin-film conductor 225a, a thin-film dielectric 275a, a thin-film conductor 225b, a thin-film dielectric 275b, a thin-film conductor 225c, a thin-film dielectric 275c, a thin-film conductor 225d, a thin-film dielectric 275d, and a thin-film conductor 225e laminated together. The above thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker.

In the high frequency low loss electrode of the modification example 7 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode example.

Modification Example 8

The high frequency low loss electrode of the modification example 8 comprises sub-conductors 229, 230, 231, and 232, and sub-dielectrics 329, 330, 331, and 332 which are alternately disposed in the electrode end portion, as shown in FIG. 19. In the modification example 8, sub-conductors 229, 230, 231, and 232 are formed so that the width of a sub-conductor thereof

positioned nearer to the outside is smaller. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 229 comprises a thin-film conductor 229a, a thin-film dielectric 279a, a thin-film conductor 229b, a thin-film dielectric 279b, a thin-film conductor 229c, a thin-film dielectric 279c, a thin-film conductor 229d, a thin-film dielectric 279d, and a thin-film conductor 229e laminated together. The above thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker and wider. Further, in the modification example 8, for each sub-conductor, the thin-film conductors and the thin-film dielectrics are formed so that a thin-film conductor thereof and a thin-film dielectric thereof positioned nearer to the main conductor 19 are wider, respectively. In the high frequency low loss electrode of the modification example 8 configured as described above, the conductor loss at a high frequency in the end portion thereof can be reduced as compared with the conventional electrode.

Modification Example 9

The high frequency low loss electrode of the modification example 9 comprises sub-conductors 233, 234, 235, and 236, and sub-dielectrics 333, 334, 335, and 336 which are alternately disposed in the electrode end portion, as shown in FIG. 20. In the modification example 9, sub-conductors 233, 234, 235, and

236 are formed so that a sub-conductor thereof positioned nearer to the outside is narrower in width and thinner. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 233 comprises a thin-film conductor 233a, a thin-film dielectric 283a, a thin-film conductor 233b, a thin-film dielectric 283b, a thin-film conductor 233c, a thin-film dielectric 283c, a thin-film conductor 233d, a thin-film dielectric 283d, and a thin-film conductor 233e laminated together. The above thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker and wider. Further, in the modification example 9, in each sub-conductor, the thin-film conductors and the thin-film dielectrics are formed so that a thin-film conductor thereof and a thin-film dielectric thereof positioned nearer to the main conductor 19 are wider, respectively. In the high frequency low loss electrode of the modification example 9 configured as described above, the conductor loss at a high frequency in the end portion thereof can be reduced as compared with a conventional electrode.

Modification Example 10

The high frequency low loss electrode of the modification example 10 comprises sub-conductors 237, 238, 239, and 240, and sub-dielectrics 337, 338, 339, and 340 are alternately disposed in the electrode end portion, as shown in FIG. 21. In the

modification example 10, the sub-conductors 237, 238, 239, and 240 are formed so that for a sub-conductor thereof positioned nearer to the outside, the lamination number is smaller. The sub-conductor 237 positioned nearest to the outside is formed of a single layer. Further, with respect to the sub-conductors having a lamination structure, the thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker and wider. In the high frequency low loss electrode of the modification example 10 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

Modification Example 11

The high frequency low loss electrode of the modification example 11 comprises sub-conductors 241, 242, 243, and 244, and sub-dielectrics 341, 342, 343, and 344 which are alternately disposed in the electrode end portion, as shown in FIG. 22. In the modification example 11, the sub-conductors 241, 242, 243, and 244 are formed so that a sub-conductor thereof positioned nearer to the outside has a smaller width. The sub-dielectrics 341, 342, 343, and 344 are formed so that a sub-dielectric thereof positioned nearer to the outside has a smaller width. Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, the sub-conductor 241 comprises a thin-film conductor 241a, a

thin-film dielectric 291a, a thin-film conductor 241b, a thin-film dielectric 291b, a thin-film conductor 241c, a thin-film dielectric 291c, a thin-film conductor 241d, a thin-film dielectric 291d, and a thin-film conductor 241e laminated together. The above thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker. Especially, in the modification example 11, the respective dielectric constants of the sub-dielectrics 341 through 344 are lower than that of the dielectric 2 surrounding the sub-dielectrics 341 through 344.

In the high frequency low loss electrode of the modification example 7 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode, as an example.

Modification Example 12

As shown in FIG. 23, the high frequency low loss electrode of the modification example 12 is configured in the same manner as that of the modification example 11 except that a main conductor 20 having a multi-layer structure in which the thin-film conductors and the thin-film dielectrics are alternately laminated is used, instead of the main conductor 19 in the form of a single layer in the modification example 11 of FIG. 22. That is, characteristically, the main conductor 20 comprises a thin-film conductor 20a, a thin-film dielectric 40b,

a thin-film conductor 20b, a thin-film dielectric 40b, a thin-film conductor 20c, a thin-film dielectric 40c, a thin-film conductor 20d, a thin-film dielectric 40d, and a thin-film conductor 20e laminated together, and in the main conductor 20, the thin-film conductors are formed so that a thin-film conductor lying at a further inside position is thicker.

In the high frequency low loss electrode of the modification example 12 configured as described above, the conductor loss of the main conductor can be reduced, and thereby, the loss can be more decreased as compared with the modificaion example 11.

Modification Example 13

Characteristically, the high frequency low loss electrode of the modification example 13, as shown in FIG. 24, is the same as the modification example 12 shown in FIG. 23 except that in the main conductor 20, as shown in FIG. 24, the respective thin-film conductors have the same thickness, and the thin-film dielectrics are the same thickness.

With this configuration, the high frequency low loss electrode of the modification example 13 is effective in reducing the conductor loss of the main conductor. The low loss can be realized as well as the modification example 12.

Modification Example 14

The high frequency low loss electrode of the modification example 14 comprises sub-conductors 121, 122, 123, and 124, and

sub-dielectrics 172, 173, 174, and 175 which are alternately disposed in the electrode end portion and formed on a dielectric substrate 2c, as shown in FIG. 25. In the modification example 14, the sub-conductors 121, 122, 123, and 124 have the same width, and moreover, the sub-dielectrics 172, 173, 174, and 175 have the same width.

Each sub-conductor comprises the thin-film conductors and the thin-film dielectrics laminated alternately. For example, each of the sub-conductors 121 through 124 comprises a thin-film conductor 121a, a thin-film dielectric 171a, a thin-film conductor 121b, a thin-film dielectric 171b, a thin-film conductor 121c, a thin-film dielectric 171c, and a thin-film conductor 121d laminated together. The thin-film conductors are formed so that a thin-film conductor thereof positioned nearer to the surface (more distant from the substrate 2c) is thicker.

In the high frequency low loss electrode of the modification example 14 configured as described above, the conductor loss at a high frequency in the end portion can be reduced as compared with the conventional electrode.

As described above, the high frequency low loss electrode of the present invention having different configurations can be realized. The above embodiments and the modification examples are described in the case of three or four sub-conductors, as an example. Needless to say, the present invention is not

limited to the three or four sub-conductors. For the configuration, fifty through one hundred or more sub-conductors may be used. The loss can be reduced more effectively by increasing the number of the sub-conductors and shortening the widths of the sub-conductors.

Further, according to the present invention, a superconductor may be used for a main conductor. If the superconductor is used for the main conductor, a current in the end portion of the main conductor can be decreased, and thereby, a relatively high current can be flown.

Moreover, according to the present invention, the conductivities of the sub-conductors may be set at different values. The dielectric constants of the sub-dielectrics may be set at different values.

The high frequency low loss electrode of the present invention can be applied for various devices by utilizing the low loss characteristics. Hereinafter, an application example of the present invention will be described.

Application Example 1

FIG. 26A is a perspective view showing the configuration of a circular strip resonator of the application example 1. The circular strip resonator comprises a rectangular dielectric substrate 401, a ground conductor 551 formed on the lower surface of the dielectric substrate 401, and a circular conductor 501 formed on the upper surface of the substrate 401. In this

circular strip resonator, the circular conductor 501 is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor at the periphery, and thereby, the conductor loss in the end portion can be reduced as compared with a conventional circular conductor having no sub-conductors. Consequently, in the circular strip resonator of the application example 1 of FIG. 26A, the unloaded Q can be increased as compared with the conventional circular strip resonator.

Application Example 2

FIG. 26B is a perspective view showing the configuration of a circular resonator of the application example 2. The circular resonator comprises a rectangular dielectric substrate 402, a ground conductor 552 formed on the lower surface of the circular dielectric substrate 402, and a circular conductor 502 formed on the upper surface of the circular substrate 402. In this circular strip resonator, the circular conductor 502 is made of the high frequency low loss electrode of the present invention which has at least one sub-conductors at the periphery. The conductor loss in the end portion can be reduced as compared with a conventional circular conductor having no sub-conductors. Consequently, in the circular resonator of the application example 2 of FIG. 26B, the unloaded Q can be increased as compared with the conventional circular resonator. In the circular resonator of this application example 2, the ground conductor 552 may be made of the high frequency low loss electrode of the

present invention. With this configuration, the unloaded Q can be further enhanced.

Application Example 3

FIG. 26C is a perspective view showing the configuration of a microstrip line of the application example 3. The microstrip line comprises a dielectric substrate 403, a ground conductor 553 formed on the lower surface of the dielectric substrate 403, and a strip conductor 503 formed on the upper surface of the substrate 403. In this microstrip line, the strip conductor 503 is made of the high frequency low loss electrode of the present invention having at least one sub-conductor in each of the end portions (indicated by the circles in FIG. 26C) on the opposite sides of the strip conductor 503, and the conductor loss in the end portions can be reduced as compared with a conventional strip conductor having no sub-conductors. Consequently, in the microstrip line of the application example 3 of FIG. 26C, the transmission loss can be reduced as compared with a conventional microstrip line.

Application Example 4

FIG. 26D is a perspective view showing the configuration of a coplanar line of the application example 4. The coplanar line comprises a dielectric substrate 403, ground conductors 554a and 554b provided at a predetermined interval on the upper surface of the dielectric substrate 403, and a strip conductor 504 formed between the ground conductors 554a and 554b. In the

coplanar line, the strip conductor 504 is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor in each of the end portions (indicated by the circles in FIG. 26D) on the opposite sides of the strip conductor 504, and moreover, each of the ground conductors 554a and 554b is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor on the inside end portion thereof (indicated by the circles in FIG. 26D). With this configuration of the coplanar line of the application example 4 of FIG. 26D, the transmission loss can be reduced as compared with a conventional coplanar line.

Application Example 5

FIG. 27A is a perspective view showing the configuration of a coplanar strip line of the application example 5. The coplanar strip line comprises a dielectric substrate 403, a strip conductor 505 and a ground conductor 555 provided at a predetermined interval, in parallel on the upper surface of the dielectric substrate 403. In the coplanar strip line, the strip conductor 505 is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor in each of the end portions (indicated by the circles in FIG. 27A) on the opposite sides thereof, and the ground conductor 555 is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor on the inside end-portion thereof (indicated by the circle in FIG. 27A),

opposed to the strip conductor 505. With this configuration, the transmission loss of the coplanar strip line of the application example 5 shown in FIG. 27A can be reduced as compared with a conventional coplanar strip line.

Application Example 6

FIG. 27B is a perspective view showing the configuration of a parallel slot line of the application example 6. The parallel slot line comprises the dielectric substrate 403, a conductor 506a and a conductor 506b formed at a predetermined interval on the upper surface of the dielectric substrate 403, and conductors 506c and 506d formed at a predetermined interval on the lower surface of the dielectric substrate 403. In the parallel slot line, the conductors 506a and 506b are made of the high frequency low loss electrode having at least one sub-conductor in the respective inside end portions (indicated by the circle in FIG. 27B) opposed to each other, respectively. The conductor 506c and the conductor 506d are made of the high frequency low loss electrode having at least one sub-conductor in the end portions (indicated by the circle in FIG. 27B) opposed to each other, respectively. With this configuration, in the parallel slot line of the application example 6 of FIG. 27B, the transmission loss can be reduced as compared with a conventional parallel slot line.

Application Example 7

FIG. 27C is a perspective view showing the configuration

of a slot line of the application example 7. The slot line comprises the dielectric substrate 403, conductors 507a and 507b formed at a predetermined interval on the upper surface of the dielectric substrate 403. In the slot line, the conductors 507a and 507b are made of the high frequency low loss electrode which have at least one sub-conductor in the inside end portions (indicated by the circles in FIG. 27C) opposed to each other, respectively. With this configuration, in the slot line of the application example 7 of FIG. 27C, the transmission loss can be reduced as compared with a conventional slot line.

Application Example 8

FIG. 27D is a perspective view showing the configuration of a high impedance microstrip line of the application example 8. The high impedance microstrip line comprises the dielectric substrate 403, a strip conductor 508 formed on the upper surface of the dielectric substrate 403, and ground conductors 558a and 558b formed at a predetermined interval on the lower surface of the dielectric substrate 403. In the high impedance microstrip line, the strip conductor 508 is made of the high frequency low loss electrode which has at least one sub-conductor in each of the end portions (indicated by the circles in FIG. 27D) on the opposite sides thereof. The ground conductors 558a and 558b have at least one sub-conductor in the respective inside end portions (indicated by the circles in FIG. 27D) thereof opposed to each other. With this configuration, in the high impedance microsrip

line of the application example 8 of FIG. 27D, the transmission loss can be reduced as compared with a conventional high impedance microstrip line.

Application Example 9

FIG. 28A is a perspective view showing the configuration of a parallel microstrip line of the application example 9. The parallel microstrip line comprises a dielectric substrate 403a having a ground conductor 559a formed on one side thereof and a strip conductor 509a formed on the other side thereof, and a dielectric substrate 403b having a ground conductor 559b formed on one side thereof, and a strip conductor 509b formed on the other side, in which the dielectric substrates 403a and 403b are arranged in parallel so that the strip conductors 509a and 509b are opposed to each other. In this parallel microstrip line, each of the strip conductors 509a and 509b is made of the high frequency low loss electrode of the present invention which has at least one sub-conductor in each of the opposite end portions (indicated by the circles in FIG. 28A) thereof. Consequently, in the parallel microstrip line of the application example 9 of FIG. 28A, the transmission loss can be reduced as compared with a conventional parallel microstrip line.

Application Example 10

FIG. 28B is a perspective view showing the configuration of a half-wave type microstrip line resonator of the application example 10. The half-wave type microstrip line resonator

comprises the dielectric substrate 403, a ground conductor 560 formed on the lower surface of the dielectric substrate 403, and a strip conductor 510 formed on the upper surface of the dielectric substrate 403. In this half-wave type microstrip line resonator, the strip conductor 510 is made of the high frequency low loss electrode of the present invention, and comprises a main conductor 510a, and three sub-conductors 510b formed along each of the end-portions on the opposite sides of the main conductor 510a. The conductor loss in the end portions can be reduced as compared with a conventional strip conductor having no sub-conductors. Consequently, the unloaded Q of the half-wave microstrip line resonator of the application example 10 of FIG. 28B can be enhanced as compared with that of a conventional half-wave microstrip line resonator.

As regards the strip conductor 510 in the above-described half-wave type microstrip line resonator, the main conductor 510a and the sub-conductors 510b, as shown in FIG. 28C, may be connected to each other through conductors 511 provided on the opposite ends of them.

Application Example 11

FIG. 28D is a perspective view showing the configuration of a quarter-wave type microstrip line resonator of the application example 11. The quarter-wave type microstrip line resonator comprises the dielectric substrate 403, a ground conductor 562 formed on the lower surface of the dielectric

substrate 403, and a strip conductor 512 formed on the upper surface of the dielectric substrate 403. In this quarter-wave type microstrip line resonator, the strip conductor 512 is made of the high frequency low loss electrode of the present invention, and comprises a main conductor 512a, and three sub-conductors 512b formed along each of the end portions of the main conductor 512a on the opposite sides thereof. The main conductor 512a and the sub-conductors 512b are connected to a ground conductor 562, in one side of the dielectric substrate 403. The main conductor 512a and the sub-conductors 512b are connected to the ground conductor 562 in an side-face of the dielectric substrate 403. The unloaded Q of the quarter-wave type microstrip line resonator of the application example 11 of FIG. 28D configured as described above can be enhanced as compared with that of a conventional quarter-wave microstrip line resonator.

Application Example 12

FIG. 29A is a plan view showing the configuration of a half-wave microstrip line filter. The half-wave type microstrip line filter has the configuration in which three half-wave type microstrip line resonators 651 formed in the same manner as that of the application example 10 are arranged between a microstrip line 601 for inputting and a microstrip line 602 for outputting, which are formed in the same manner as that of the application example 8, respectively. In the half-wave type microstrip line filter formed as described above, the

transmission loss of the microstrip line 601 for inputting and the microstrip line 602 for outputting can be reduced. In addition, the unloaded Q of the half-wave type microstrip line resonator 651 can be enhanced. Accordingly, the insertion loss can be reduced, and moreover, the out-of-band attenuation can be increased, as compared with a conventional half-wave type microstrip line filter.

Further, in the half-wave type microstrip line filter of the application example 12, as shown in FIG. 29B, the half-wave type microstrip line resonators 651 may be arranged so that they are opposed to each other in their end-faces.

The number of the half-wave microstrip line resonators 651 is not limited to three or four.

Application Example 13

FIG. 29C is a plan view showing the configuration of a circular strip filter of the application example 13. The circular strip filter has the configuration in which three circular strip resonators 660 formed in the same manner as the application example 1 are arranged between the microstrip line 601 for inputting and the microstrip line 602 for outputting, formed in the same manner as the application example 8. In the circular strip filter formed as described above, the transmission loss of the microstrip line 601 for inputting and the microstrip line 602 for outputting can be reduced, and moreover, the unloaded Q of the circular strip resonator 660 can

be enhanced. Accordingly, the insertion loss can be reduced, and the out-of-band attenuation can be increased.

Further, in the circular strip filter of the application example 13, the number of the circular strip resonator 660 is not limited to three.

Application Example 14

FIG. 30 is a block diagram showing the configuration of a duplexer 700 of the application example 14. The duplexer 700 comprises an antenna terminal T1, a receiving terminal T2, a transmitting terminal T3, a receiving filter 701 provided between the antenna terminal T1 and the receiving terminal T2, and a transmitting filter 702 provided between the antenna terminal T1 and the transmitting terminal T3. In the duplexer 700 of the application example 14, the receiving filter 701 and the transmitting filter 702 are formed with the filter of the application example 12 or 13, respectively.

The duplexer 700 configured as described above has excellent separation characteristics for receiving - transmitting signals.

Further, in the duplexer 700, as shown in FIG. 28, an antenna is connected to the antenna terminal T1, a receiving circuit 801 to the receiving terminal T2, and a transmitting circuit 802 to the transmitting terminal T3, and is used as a portable terminal of a mobile communication system, as an example.

As seen in the above description, the first high frequency low loss electrode of the present invention comprises a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately. Accordingly, an electric filed concentrated onto the end portion of the electrode can be dispersed into the respective sub-conductors, and the conductor loss of a sub-conductor having a multi-layer structure can be reduced. Thus, the conductor loss at a high frequency can be decreased.

Preferably, in the first high frequency low loss electrode of the present invention, the sub-conductor positioned nearest to the outside of the sub-conductors is set at a width smaller than $(\pi/2)$ times the skin depth δ, more preferably at a width smaller than $(\pi/3)$ times the skin depth δ at an applied frequency. Accordingly, an ineffective current in the sub-conductor positioned nearest to the outside can be reduced, and thereby, the conductor loss at a high frequency can be effectively reduced.

When the first high frequency low loss electrode of the present invention includes plural sub-conductors, ineffective currents in the respective sub-conductors can be reduced, and moreover, the conductor loss at a high frequency can be decreased by setting the widths of the respective sub-conductors at a value smaller than $(\pi/2)$ times the skin depth δ at an applied frequency.

Furthermore, when the first high frequency low loss electrode of the present invention includes plural sub-conductors, the conductor loss can be reduced more effectively by setting the thickness of a sub-conductor positioned nearer to the outside of the plural sub-conductors at a smaller value.

Preferably, in the first high frequency low loss electrode of the present invention, the interval between the main conductor and the sub-conductor adjacent to the main conductor, and the intervals between adjacent sub-conductors are set so that an interval thereof positioned nearer to the outside is shorter correspondingly to the widths of the adjacent sub-conductors, in order that currents substantially in phase can flow through the respective sub-conductors. Thereby, the currents flowing through the respective sub-conductors can be effectively dispersed, and moreover, the conductor loss at a high frequency can be reduced.

Moreover, when the first high frequency low loss electrode of the present invention includes sub-dielectrics, the dielectric constants of the sub-dielectrics may be set so that the dielectric constant of a sub-dielectric thereof positioned nearer to the outside is lower, correspondingly to the widths of the adjacent sub-conductors, in order to flow currents in substantially in phase through the respective sub-conductors. Thus, the conductor loss at a high frequency can be reduced.

Preferably, in the sub-conductors having a multi-layer

structure of the first high frequency low loss electrode of the present invention, the thin-film conductors may be formed so that a thin-film conductor thereof lying at a further inside position is thicker. Accordingly, the conductor loss of the sub-conductor having a multi-layer structure can be reduced, and the conductor loss at a high frequency can be decreased.

The second high frequency low loss electrode of the present invention comprises a main conductor, and plural sub-conductors formed along a side of the main conductor. The sub-conductors are formed so that the width of a sub-conductor thereof positioned nearer to the outside thereof is smaller, and at least one of the sub-conductors has a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately. Accordingly, currents can be dispersed and flown through the plural sub-conductors. and the resistance of the sub-conductors having a multi-layer structure can be reduced, and thereby, the conductor loss at a high frequency can be decreased.

Preferably, in the second high frequency low loss electrode of the present invention, the width of at least one of the above sub-conductors is set preferably at a value ($\pi/2$) times the skin depth δ, and more preferably at a value of ($\pi/3$) times the skin depth δ, at an applied frequency. Thus, an ineffective current in the sub-conductors can be reduced, currents can be effectively dispersed in the sub-conductors, and

the conductor loss at a high frequency can be decreased.

In the second high frequency low loss electrode of the present invention, currents substantially in phase can be efficiently dispersed in the respective sub-conductors, and the conductor loss at a high frequency can be reduced preferably by setting the intervals, and the widths and dielectric constants of the sub-dielectrics.

In the second high frequency low loss electrode of the present invention, the resistance losses of the sub-conductors at a high frequency can be decreased, and the conductor loss can be reduced at a high frequency preferably by forming the thin-film conductors of a sub-conductor having a multi-layer structure so that a thin-film conductor thereof lying at a further inside position is thicker.

The third high frequency low loss electrode of the present invention comprises a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding the sub-conductor positioned nearest to the outside of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately, the sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has the less number of the laminated thin-film conductors. Accordingly, currents can be effectively dispersed, the resistances of the respective sub-conductors can be decreased, and the conductor

loss at a high frequency can be reduced.

The first high frequency resonator of the present invention includes any one of the above-described first through third high frequency low loss electrodes. Accordingly, the unloaded Q can be enhanced as compared with a conventional example.

The high frequency transmission line of the present invention includes any one of the first through third high frequency low loss electrodes of the present invention. Accordingly, the transmission loss can be reduced.

The high frequency filter of the present invention includes any one of the first through third high frequency resonators. Accordingly, the out-of-pass band attenuation can be increased.

Further, the antenna common device of the present invention includes the high frequency filter. Accordingly, the isolation between transmission and reception can be enhanced.

What is claimed is:

1. A high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

2. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wave length multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

3. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wave length multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor, and at least one sub-conductor formed along a side of the

main conductor, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

4. The high frequency filter according to any one of claims 1-3, wherein the sub-conductor positioned nearest to the outside of the sub-conductors has a width smaller than $(\pi/2)$ times the skin depth δ at an applied frequency.

5. The high frequency filter according to any one of claims 1-3, wherein the sub-conductor positioned nearest to the outside of the sub-conductors has a width smaller than $(\pi/3)$ times the skin depth δ at an applied frequency.

6. The high frequency filter according to any one of claims 1-5, wherein the high frequency low loss electrode includes plural sub-conductors, and each of the plural sub-conductors has a width smaller than $(\pi/2)$ times the skin depth δ at an applied frequency.

7. The high frequency filter according to any one of claims 1-6, wherein the plural sub-conductors are formed so that a sub-conductor thereof positioned nearer to the outside is thinner.

8. The high frequency filter according to any one of claims 1-7, wherein sub-dielectrics are provided between the main conductor and the sub-conductor adjacent to the main conductor and between adjacent sub-conductors, respectively.

9. The high frequency filter according to any one of claims 1-8, wherein the interval between the main conductor and the sub-conductor adjacent to the main conductor and the intervals between adjacent sub-conductors are formed so that an interval thereof positioned nearer to the outside is shorter.

10. The high frequency filter according to claim 8, wherein the plural sub-dielectrics are formed so that a sub-dielectric thereof positioned nearer to the outside has a lower dielectric constant.

11. The high frequency filter according to any one of claims 1-10, wherein the thin-film conductors in each of the sub-conductors having a multi-layer structure are formed so that a thin-film conductor thereof lying at a further inside position is thicker.

12. A high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors

formed along a side of the main conductor, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a smaller width, at least one of said sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

13. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wavelength multiplied by an integer, the transmission line having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors formed along a side of the main conductor, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a smaller width, and at least one of said sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

14. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wavelength multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor, and plural sub-conductors formed along a side of the main conductor, said sub-conductors being formed so that a sub-

conductor thereof positioned nearer to the outside has a smaller width, at least one of the sub-conductors having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately.

15. The high frequency filter according to any one of claims 12-14, wherein at least one of said sub-conductors has a width smaller than $(\pi/2)$ times the skin depth δ at an applied frequency.

16. The high frequency filter according to any one of claims 12-14, wherein at least one of said sub-conductors has a width smaller than $(\pi/3)$ times the skin depth δ at an applied frequency.

17. The high frequency filter according to any one of claims 1-7, wherein sub-dielectrics are provided between the main conductor and the sub-conductor adjacent to the main conductor and between adjacent sub-conductors, respectively.

18. The high frequency filter according to any one of claims 12-16, wherein the interval between the main conductor and the sub-conductor adjacent to the main conductor and the intervals between adjacent sub-conductors are set so that an interval thereof positioned nearer to the outside is shorter.

19. The high frequency filter according to claim 17, wherein the sub-dielectrics are set so that sub-dielectric positioned nearer to the outside of said plural sub-dielectrics has a lower dielectric constant.

20. The high frequency filter according to any one of claims 12-19, wherein in the sub-conductor having a multi-layer structure, the thin-film conductors are formed so that a thin-film conductor thereof lying at a further inside position is thicker.

21. A high frequency filter including a high frequency resonator having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

22. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a quarter-wavelength multiplied by an

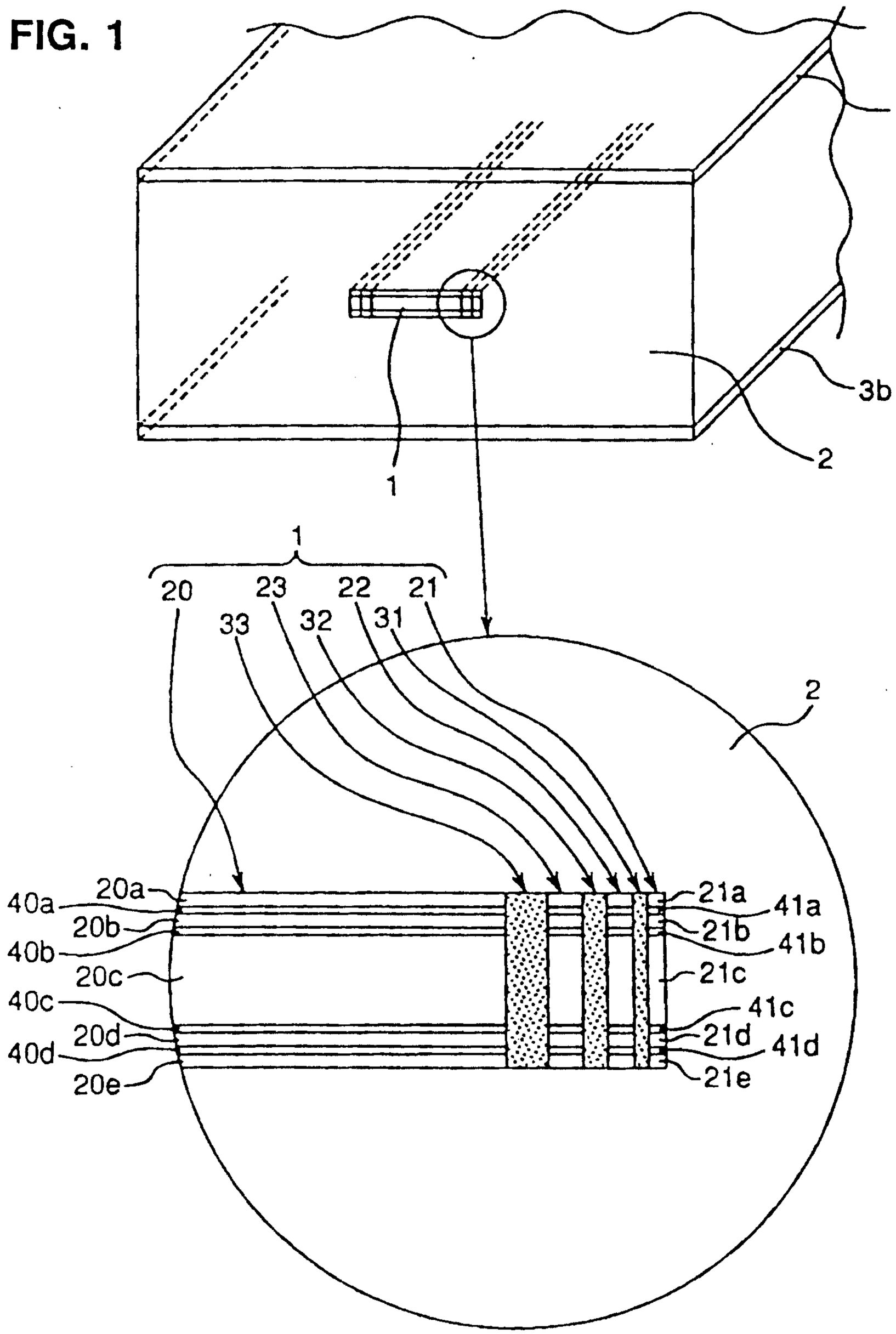
integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-film dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

23. A high frequency filter including a high frequency resonator having a high frequency transmission line of which a length is set at a half-wavelength multiplied by an integer, the high frequency transmission line having a high frequency low loss electrode comprising a main conductor and plural sub-conductors formed along a side of the main conductor, the sub-conductors excluding at least the sub-conductor positioned nearest to the outside having a multi-layer structure in which thin-film conductors and thin-dielectrics are laminated alternately, said sub-conductors being formed so that a sub-conductor thereof positioned nearer to the outside has a fewer number of laminated thin-film conductors.

24. A high frequency filter according to any one of claims 1-23, wherein the main conductor is a thin-film multi-layer electrode comprising thin-film conductors and thin-film dielectrics laminated alternately.

25. The high frequency filter according to any one of claims 1-24, wherein at least one of the main conductor and the sub-conductors is made of a super conductor.

FIG. 1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41d
21e

FIG. 2

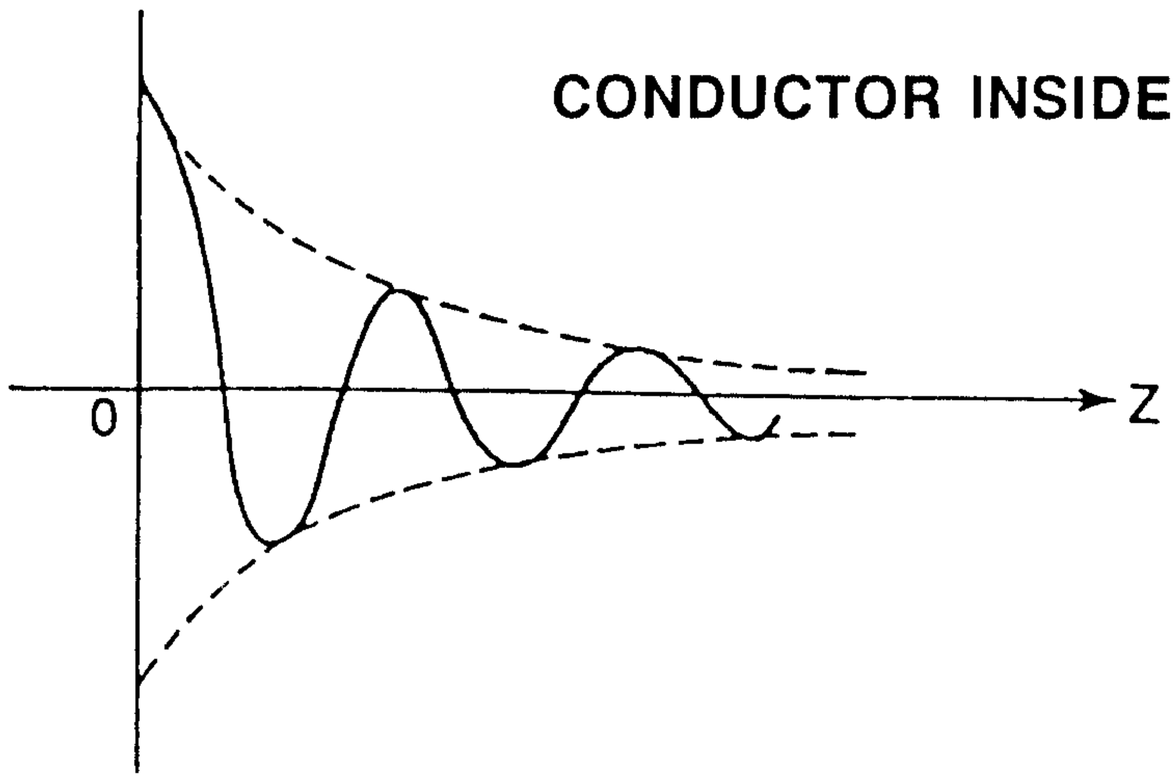


FIG. 3

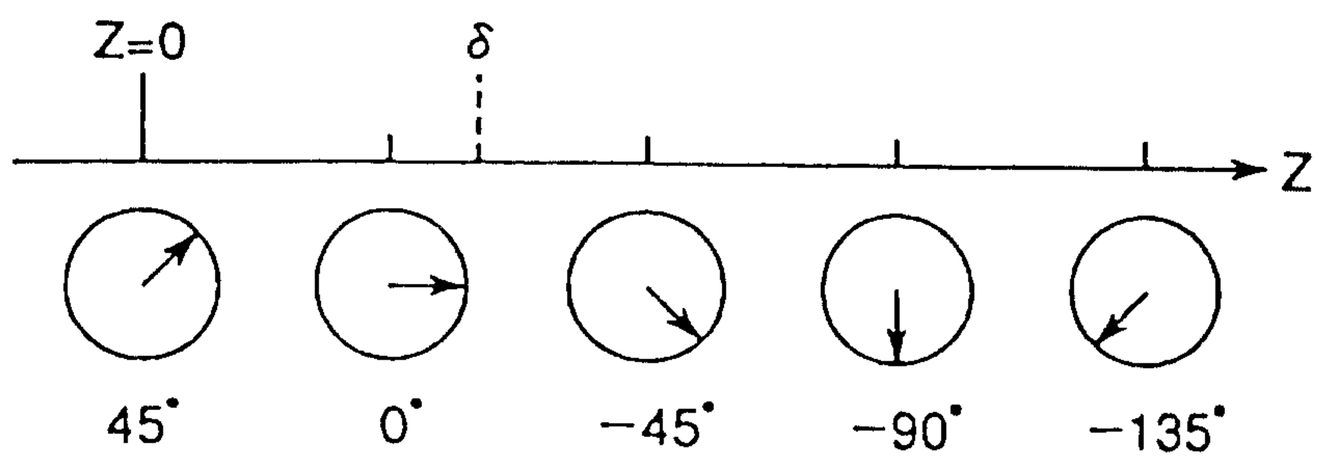


FIG. 4

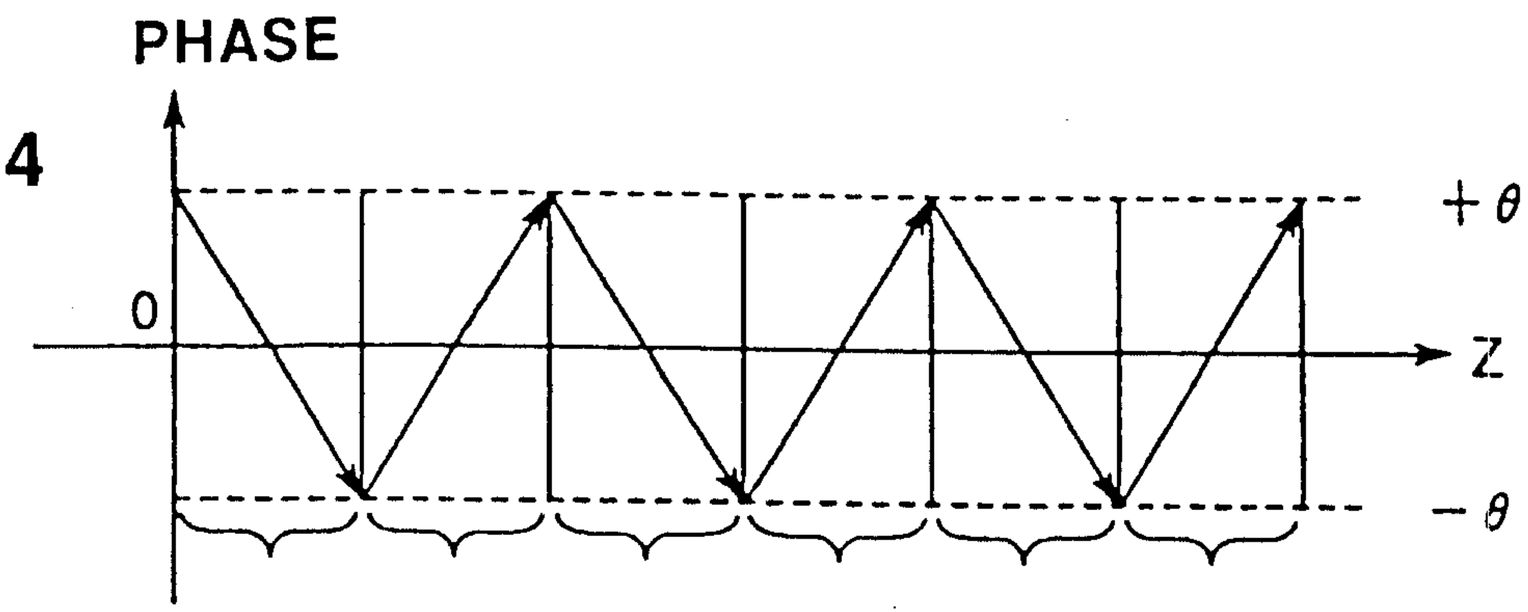


FIG. 5A

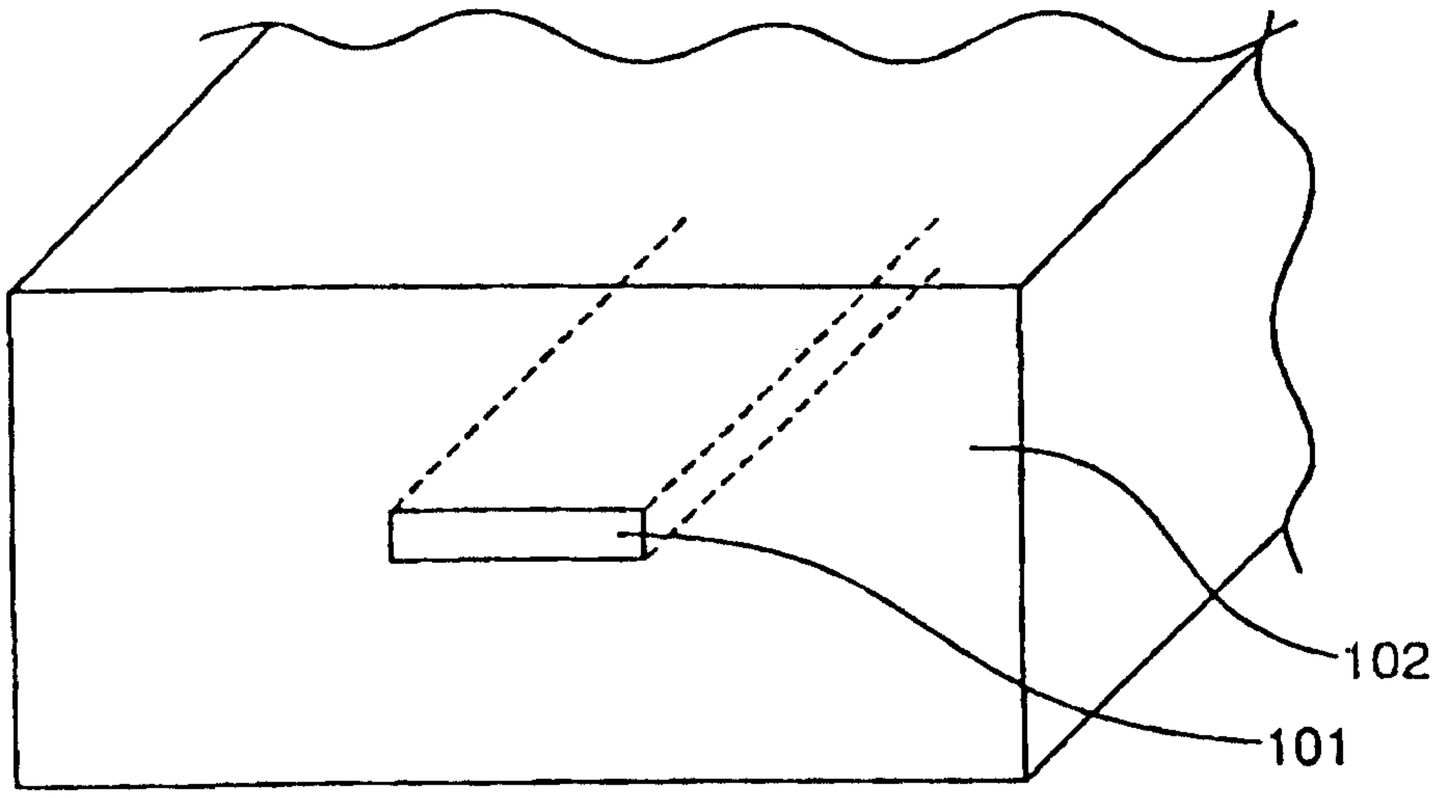


FIG. 5B

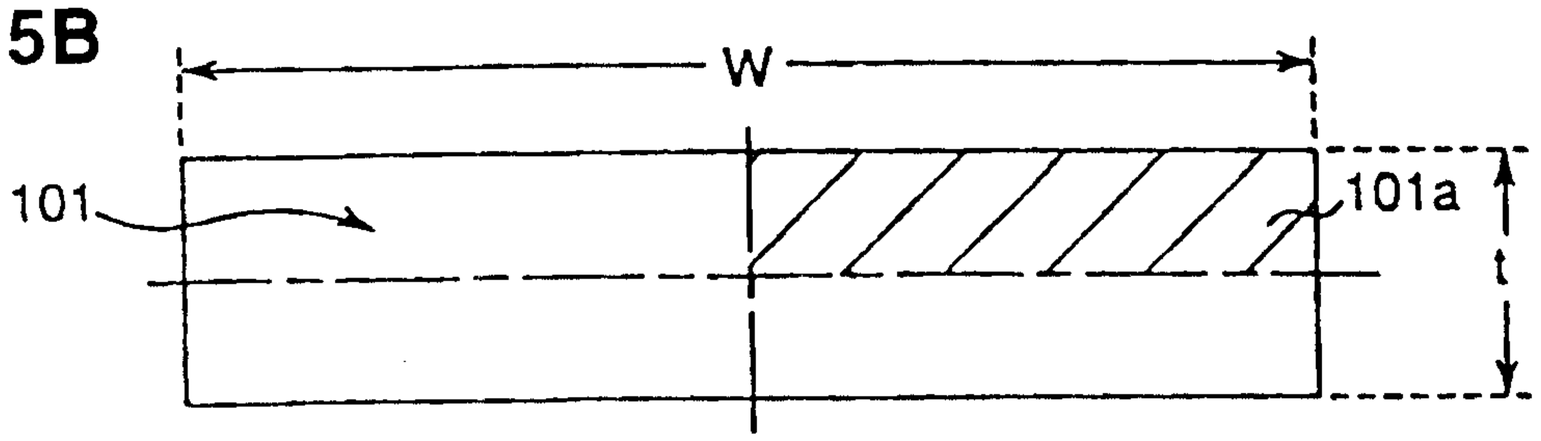
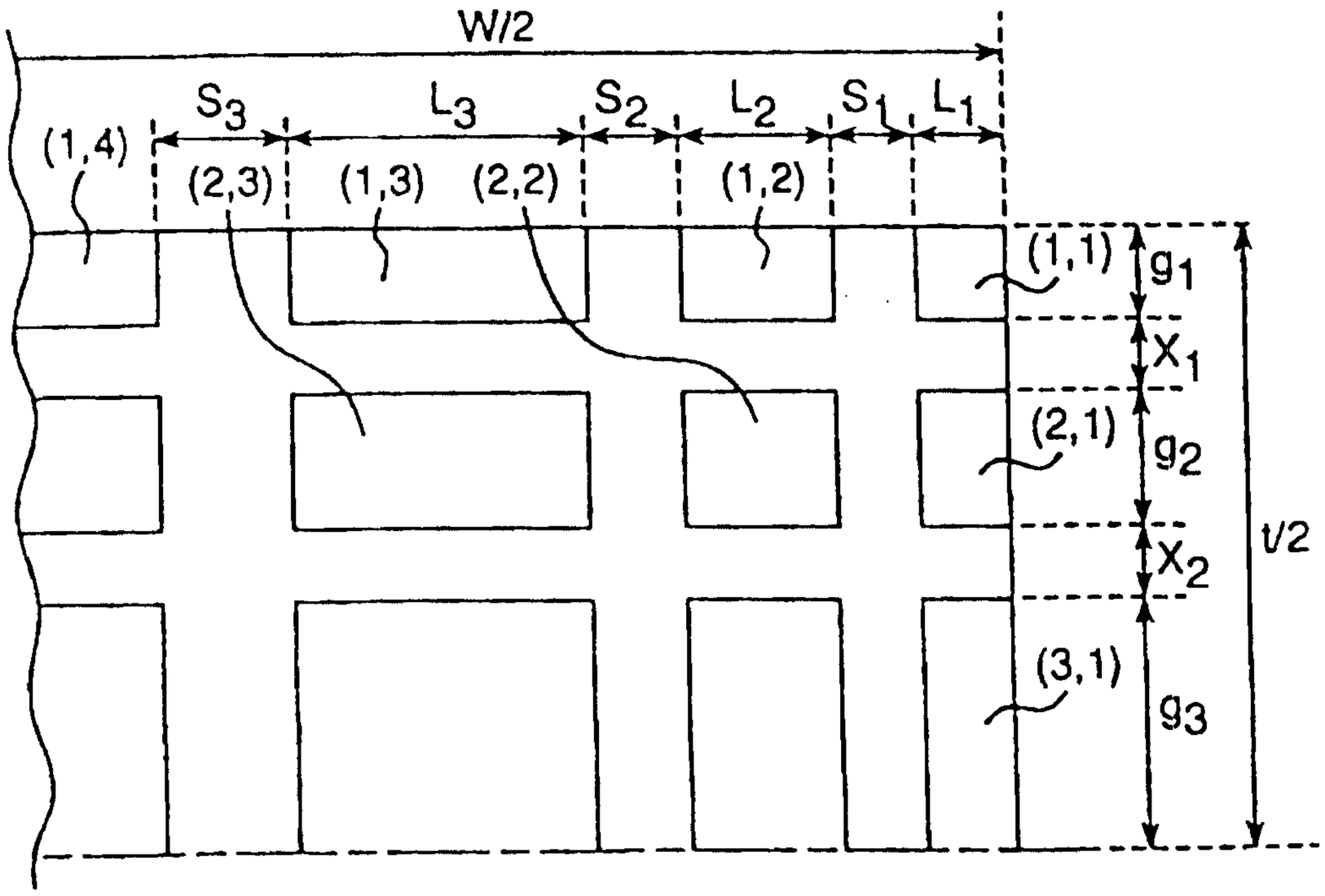
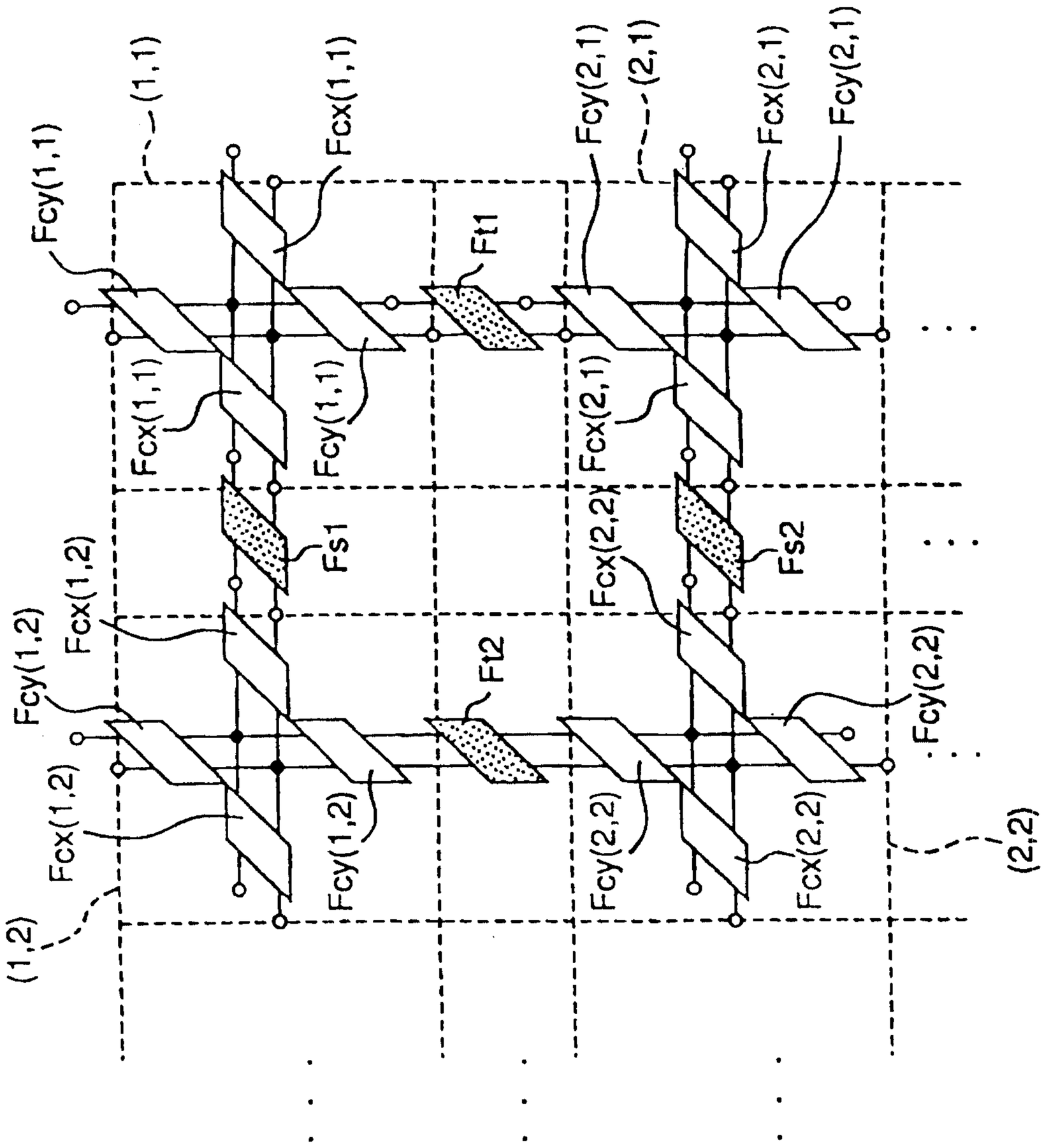


FIG. 5C

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(2,1)
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Fcy(2,1)
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Fcy(1,1)
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Fcx(2,2)
Fs1
Fs2
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Ft2
Fcy(2,2)
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Fcx(2,2)
(1,2)
(2,2)

FIG. 6

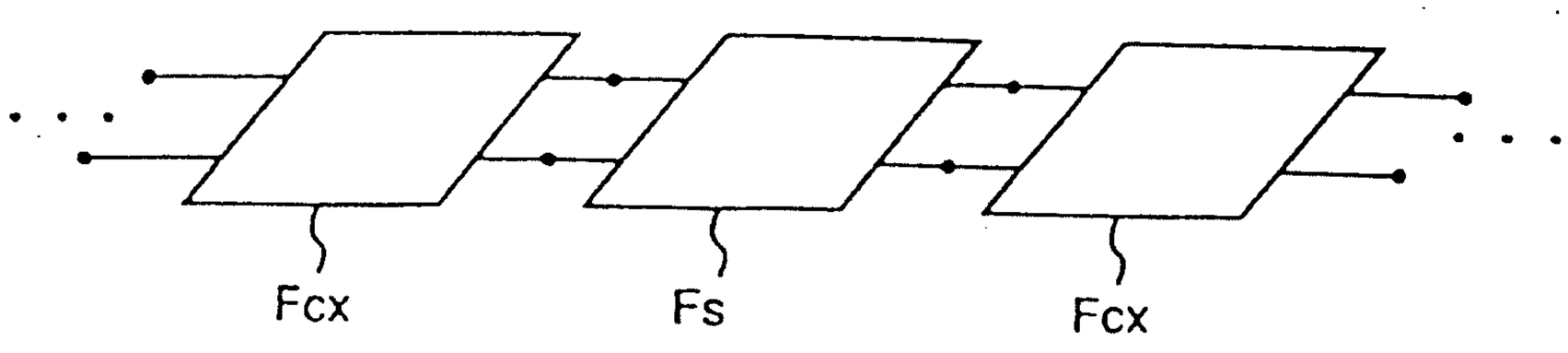


FIG. 7A

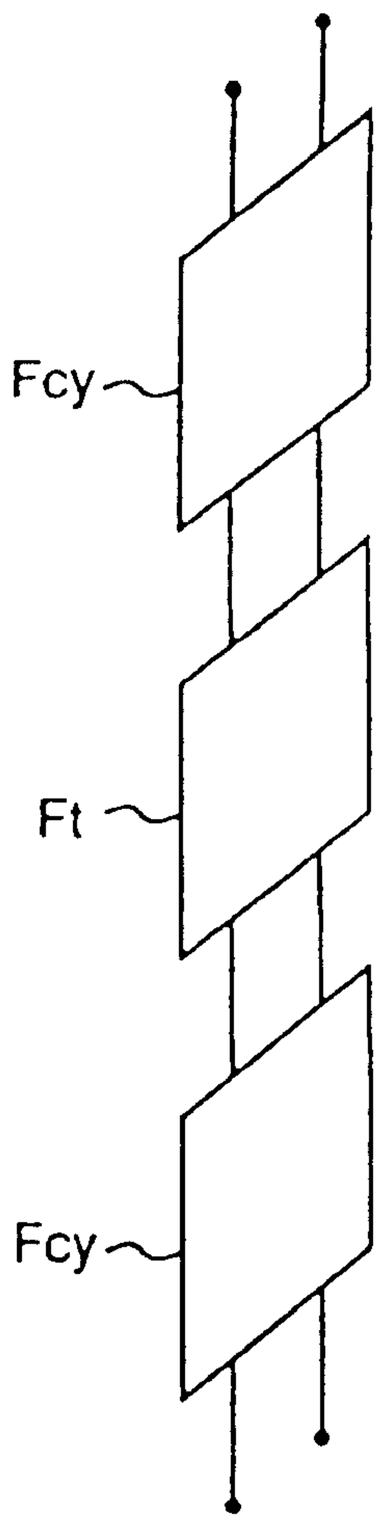


FIG. 7B

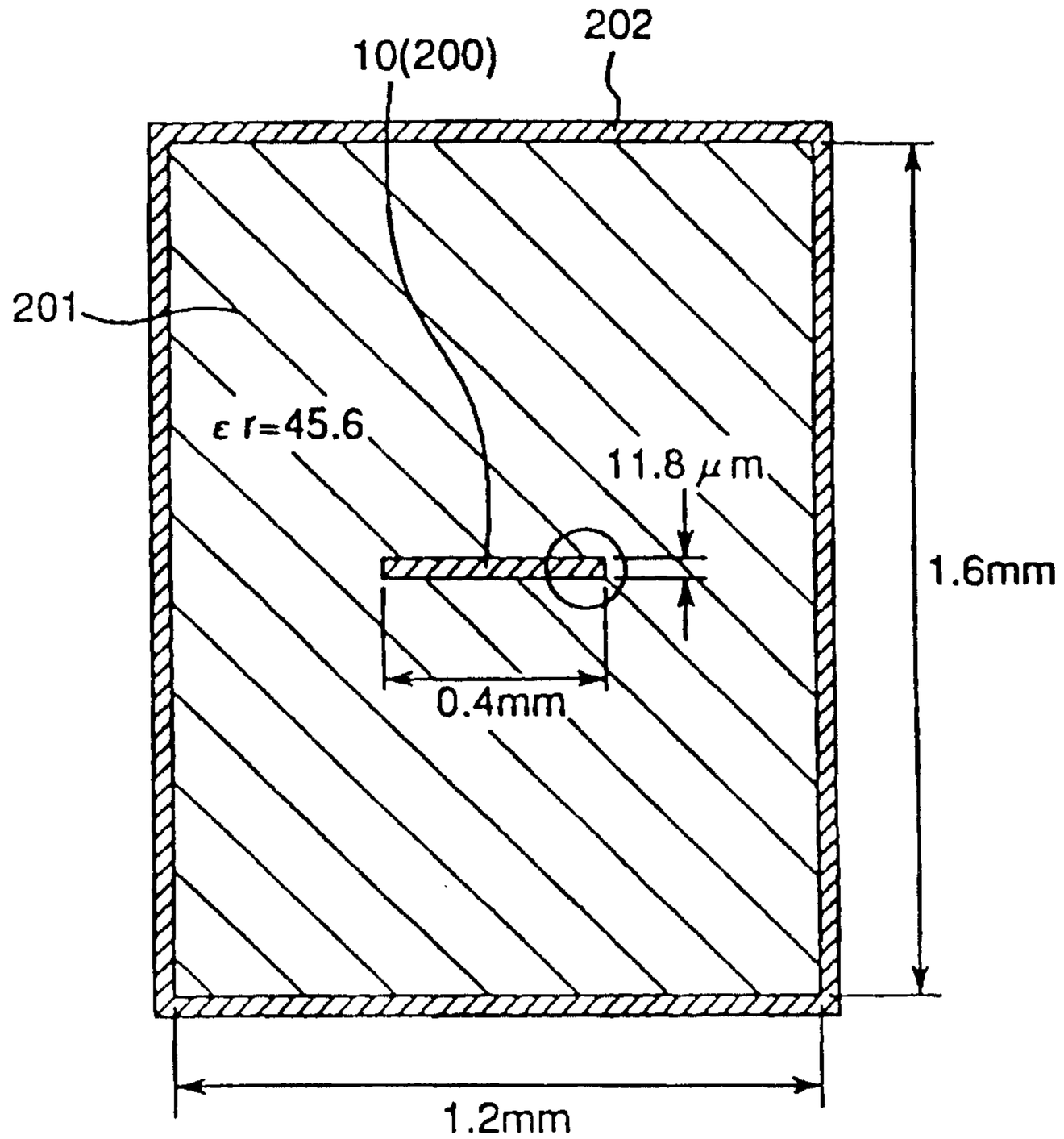


FIG. 8

PRIOR ART

FIG. 9A

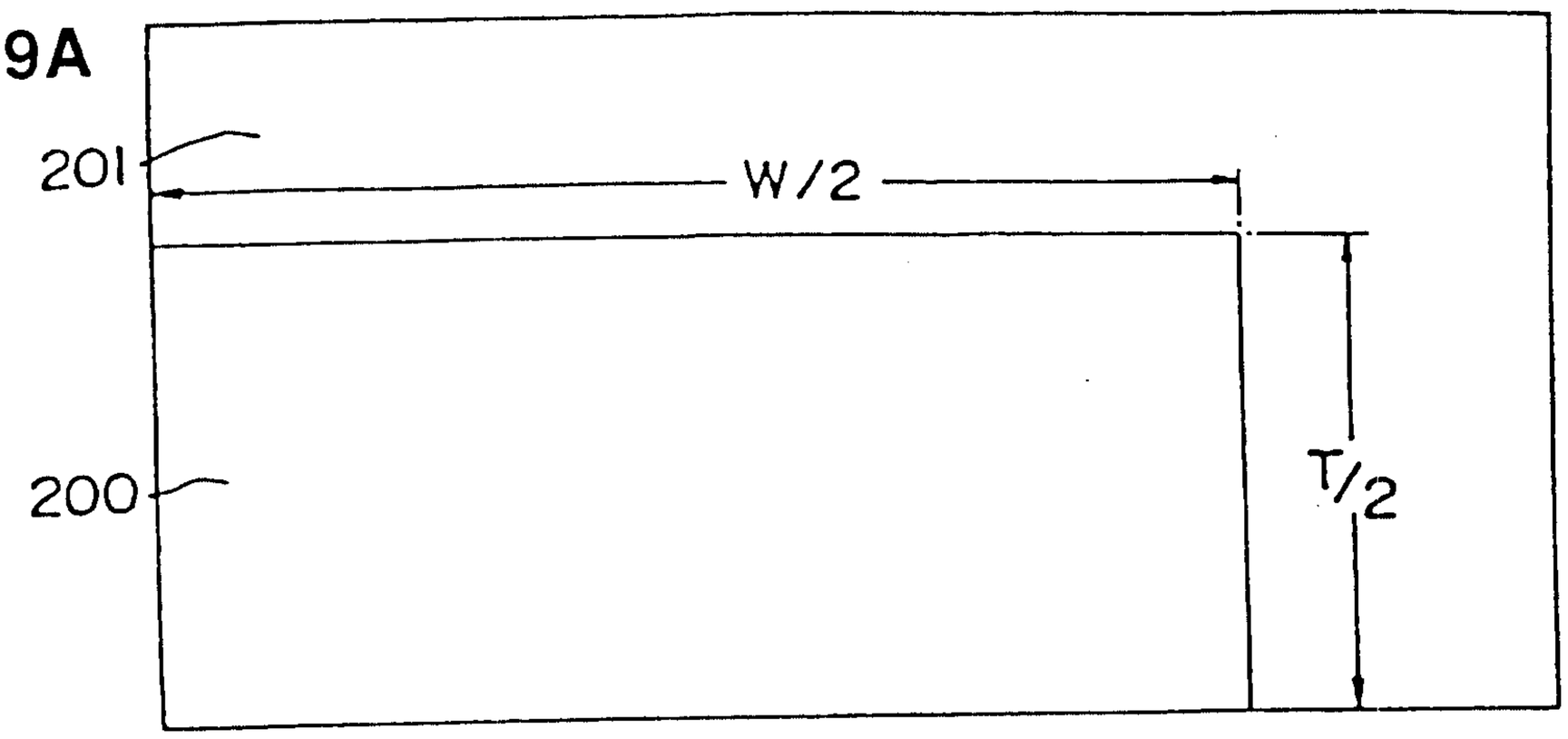
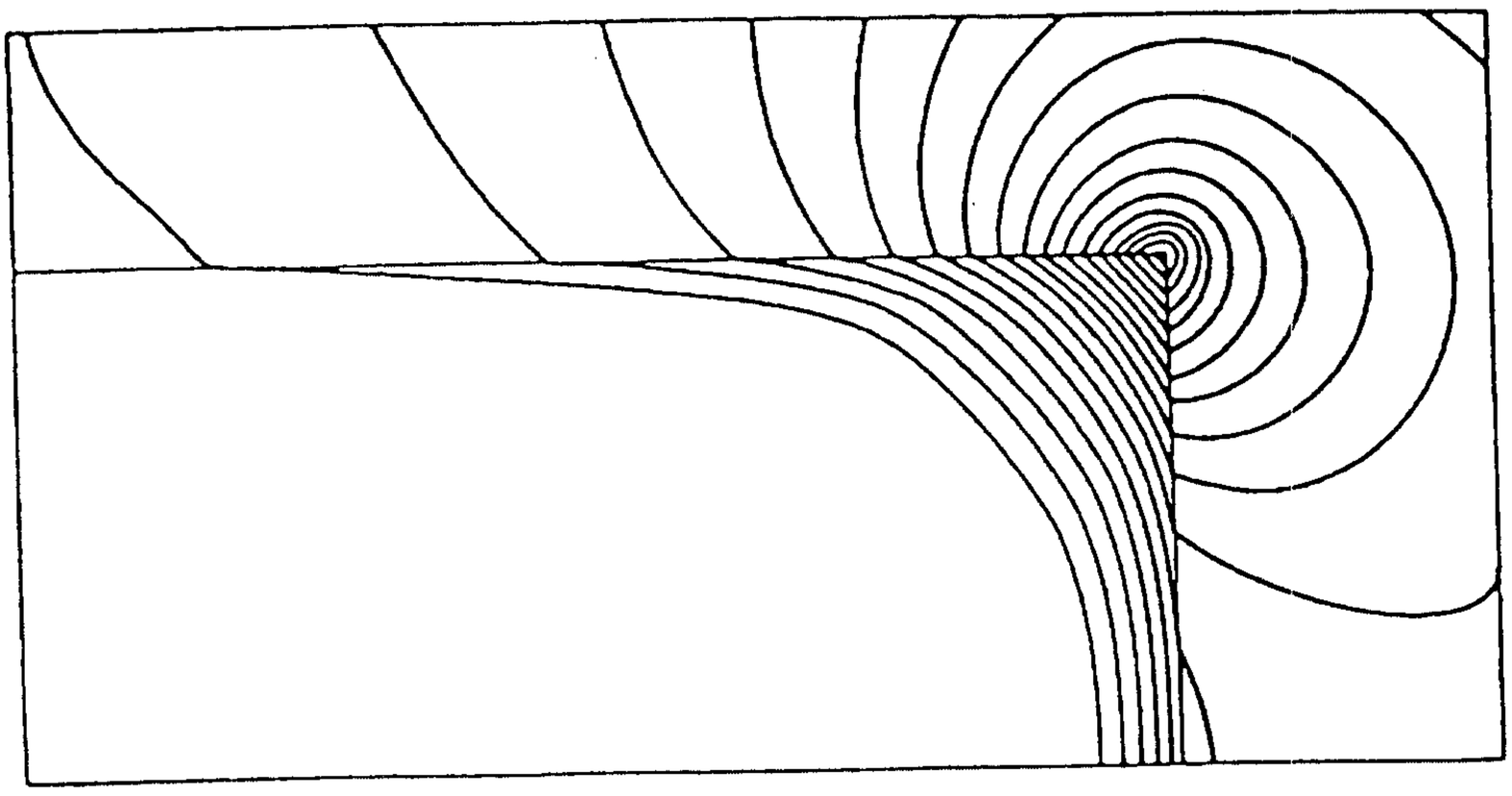
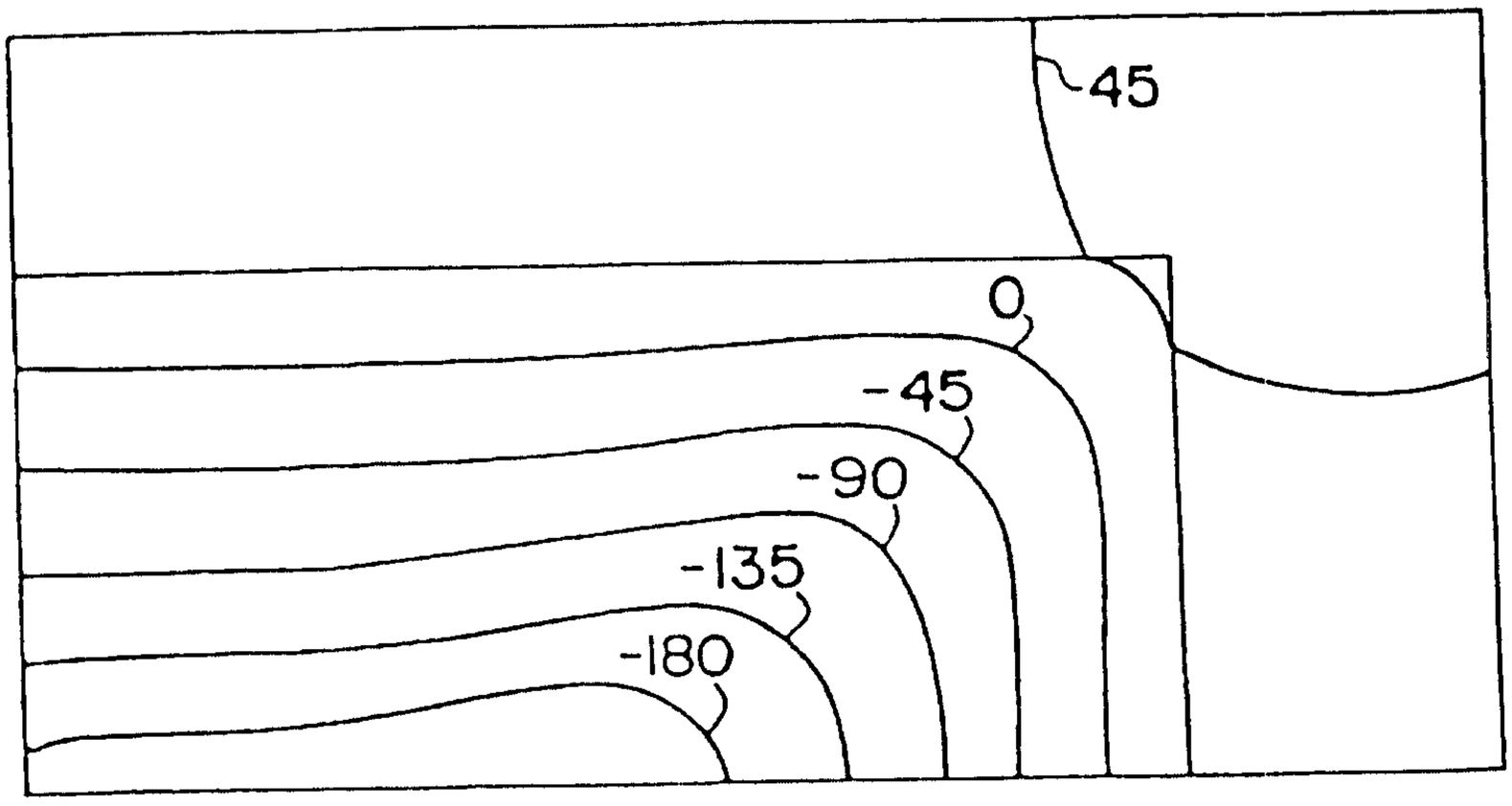


FIG. 9B



PRIOR ART

FIG. 9C



PRIOR ART

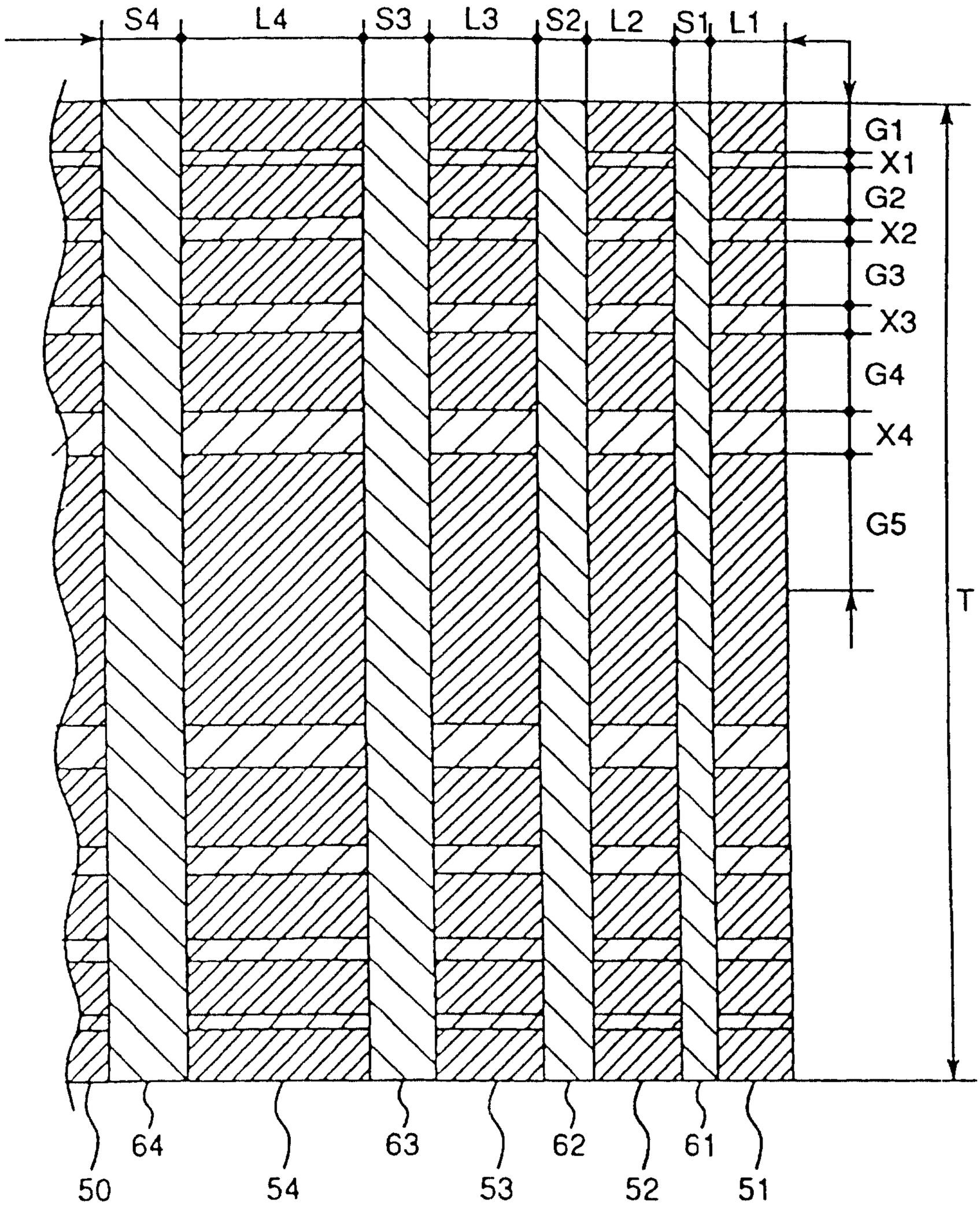

S4
L4
S3
L3
S2
L2
S1
L1
G1
X1
G2
X2
G3
X3
G4
X4
G5
T
64
63
62
61
50
54
53
52
51

FIG. 10

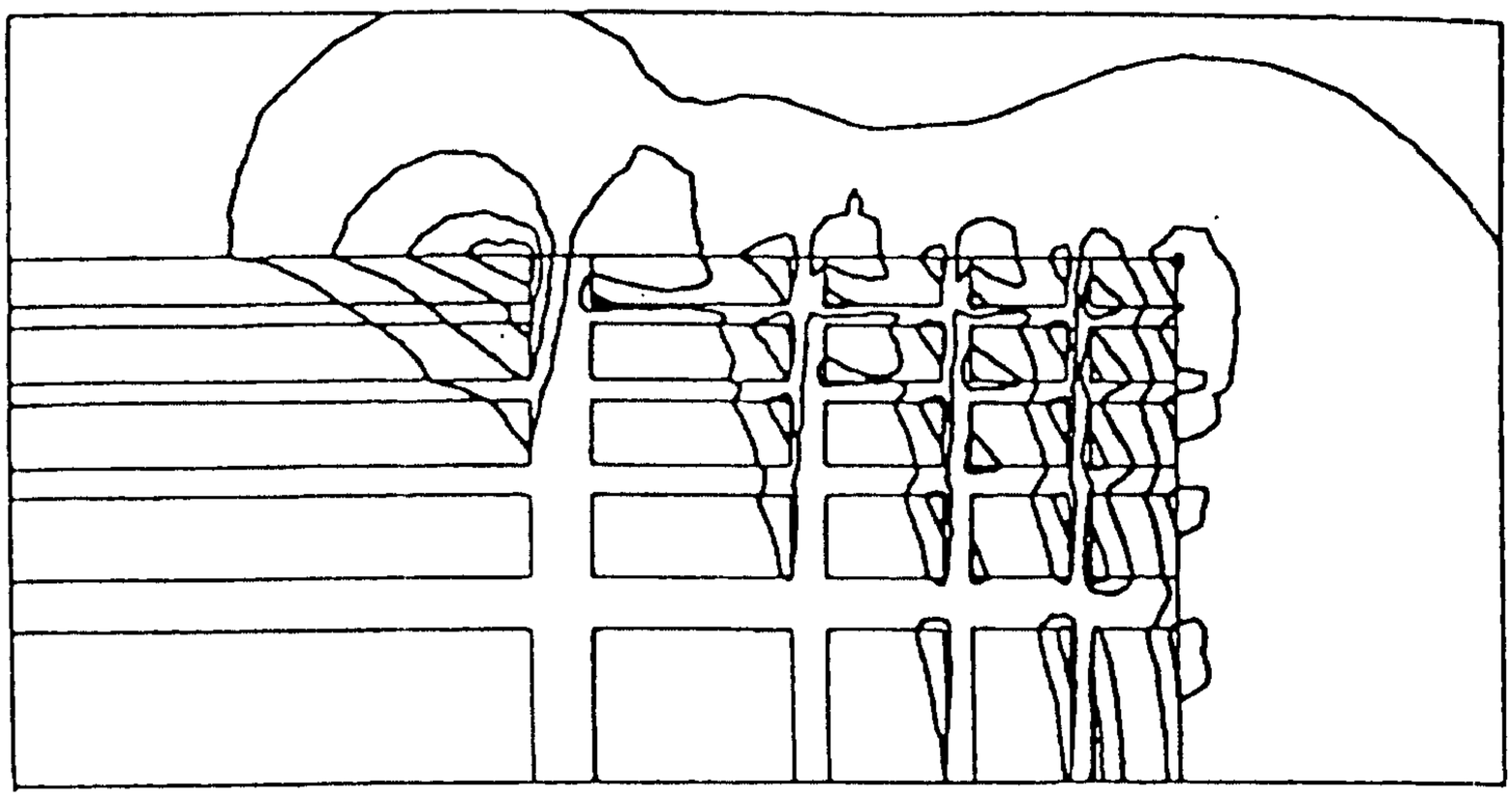


FIG. 11A

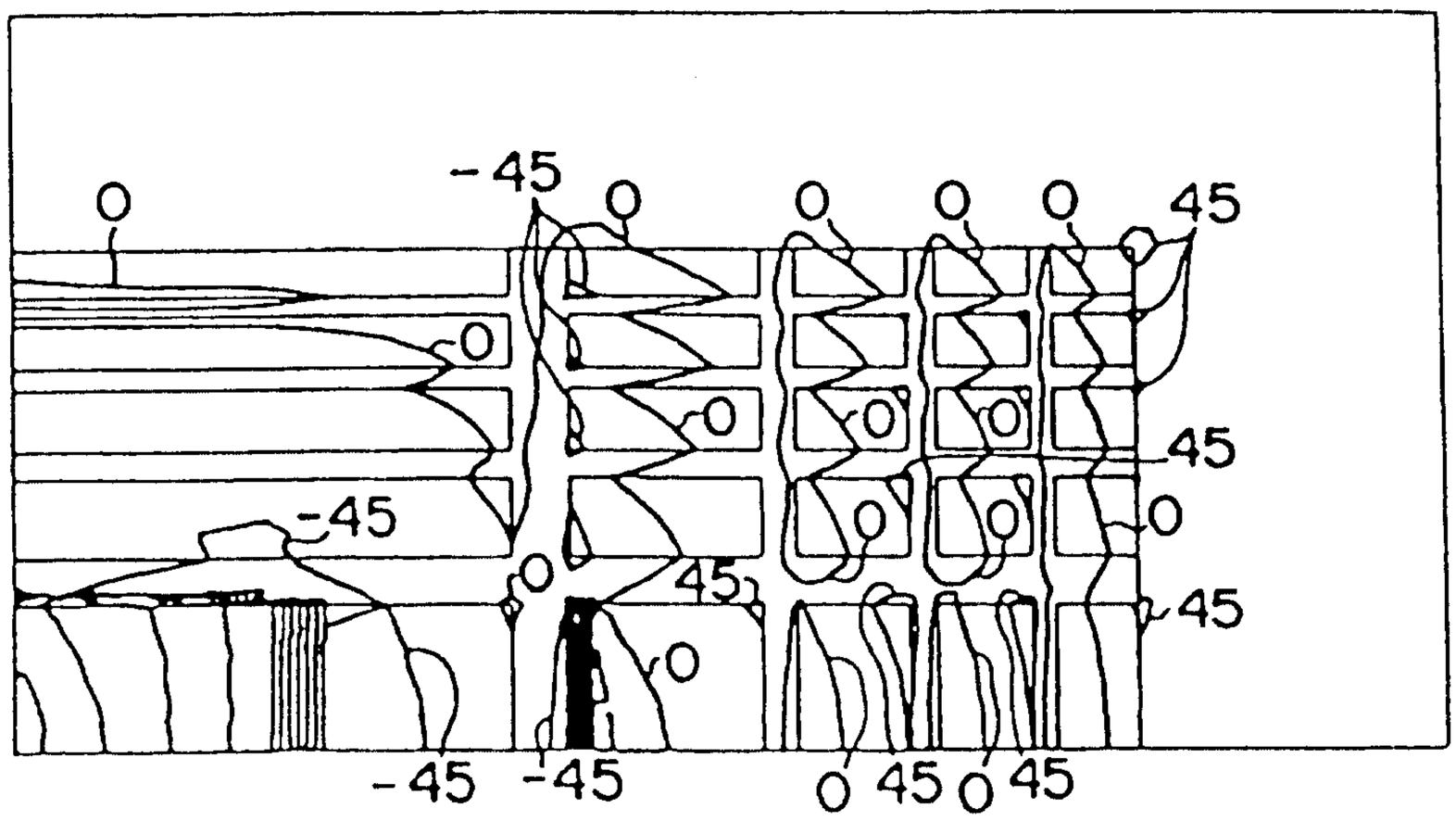


FIG. 11B

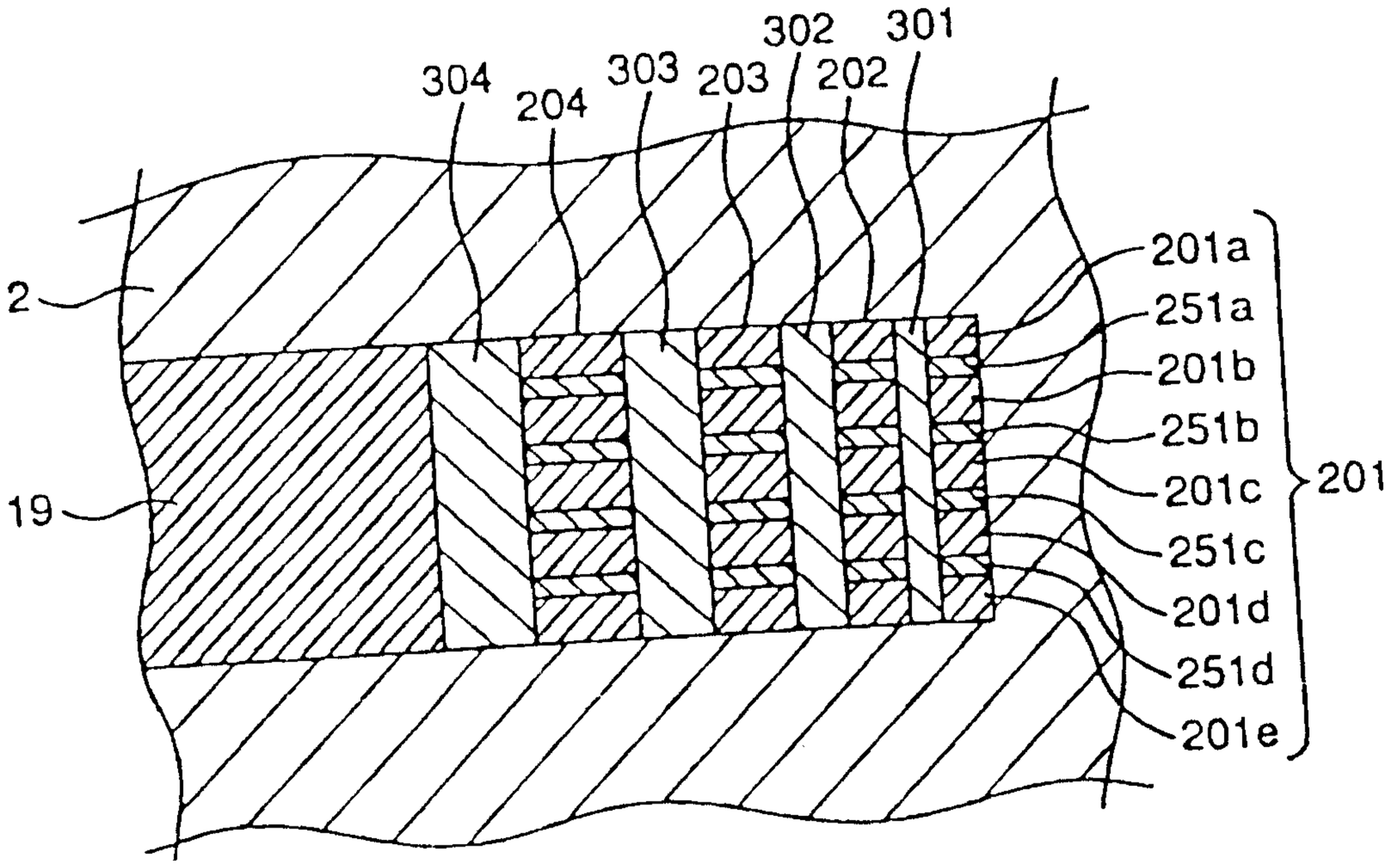

304
204
303
203
302
202
301
2
19
201a
251a
201b
251b
201c
251c
201d
251d
201e
201

FIG. 12

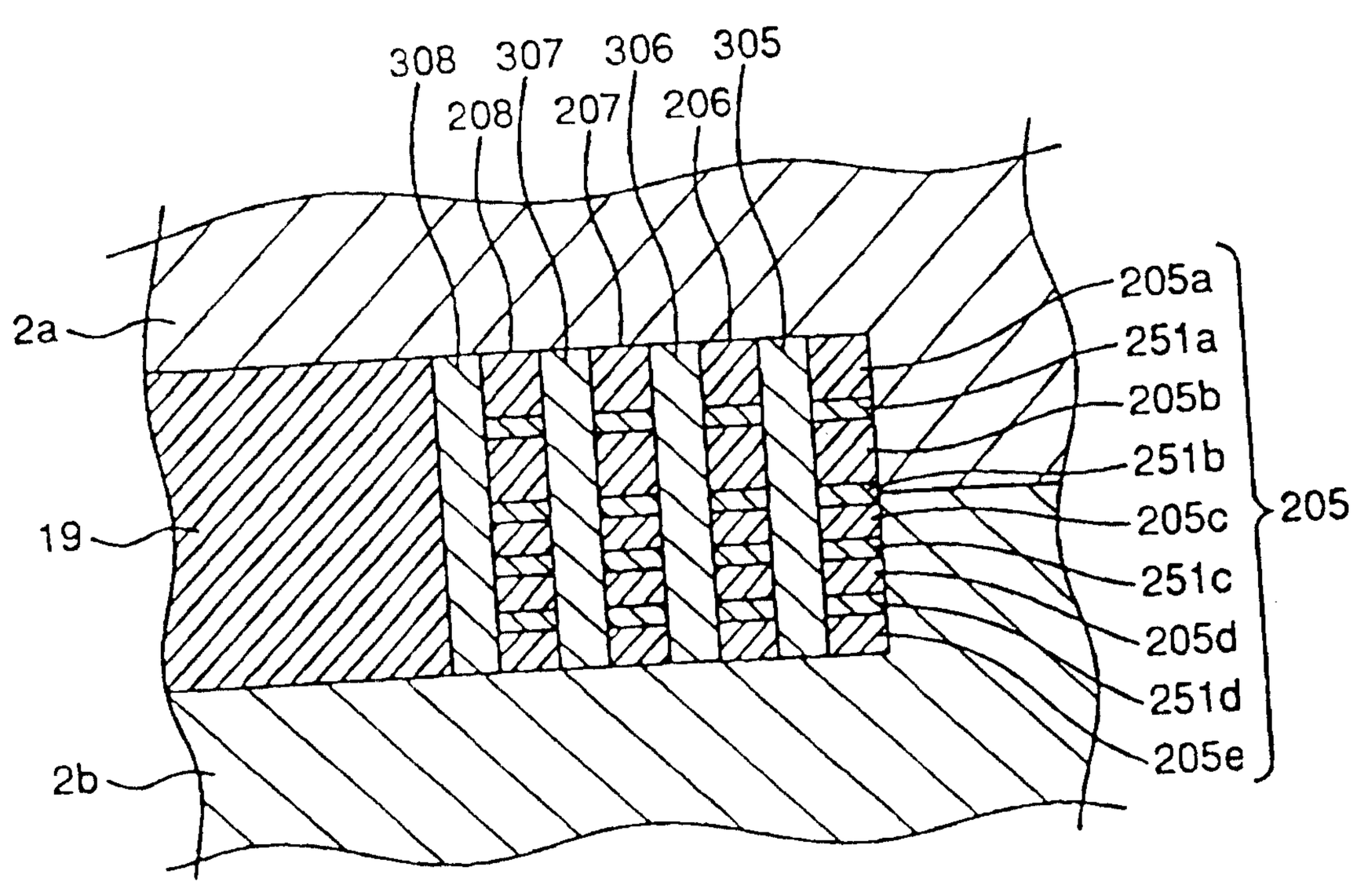

308
208
307
207
306
206
305
2a
19
2b
205a
251a
205b
251b
205c
251c
205d
251d
205e
205

FIG. 13

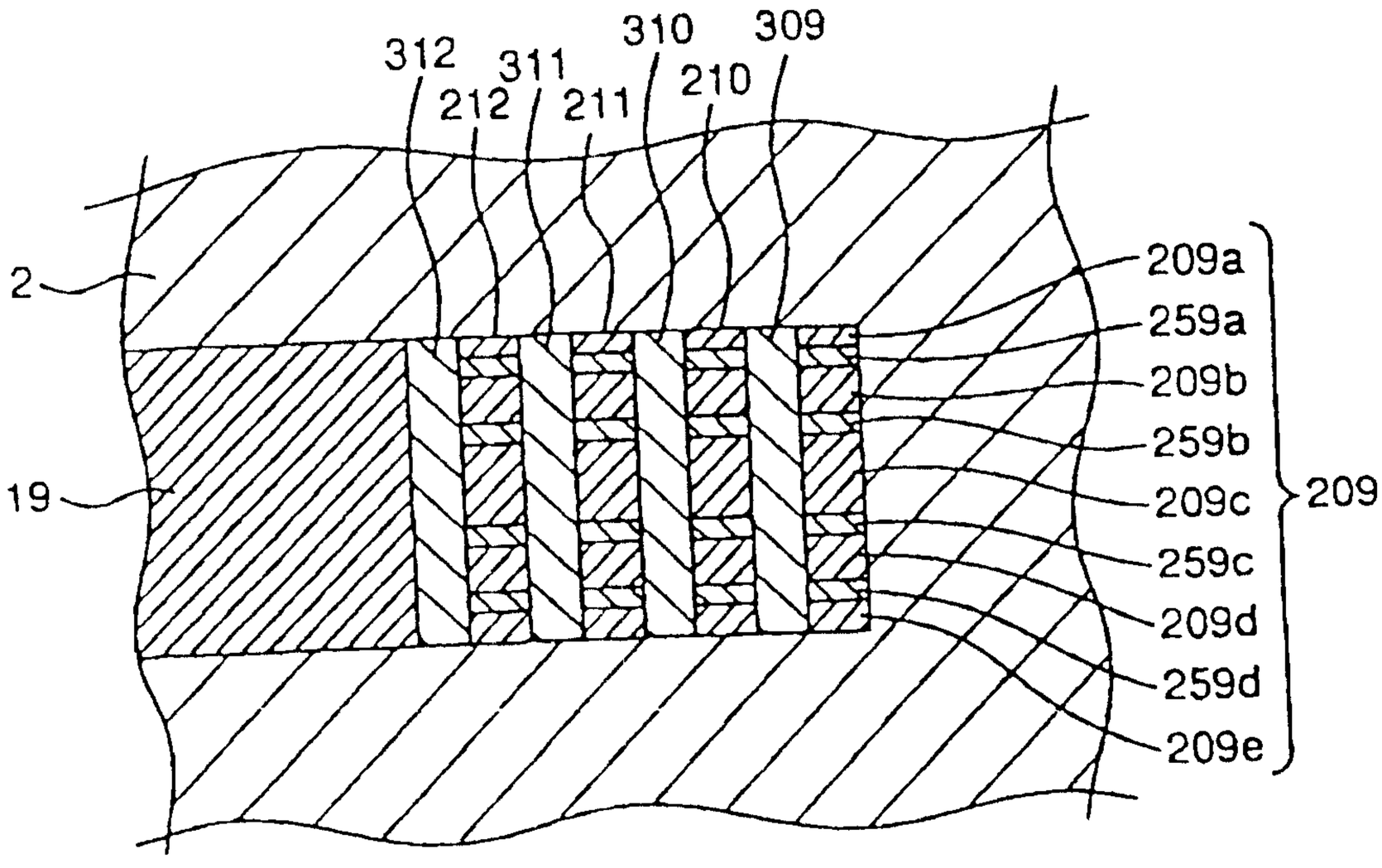

312
311
310
309
212
211
210
2
19
209a
259a
209b
259b
209c
209
259c
209d
259d
209e

FIG. 14

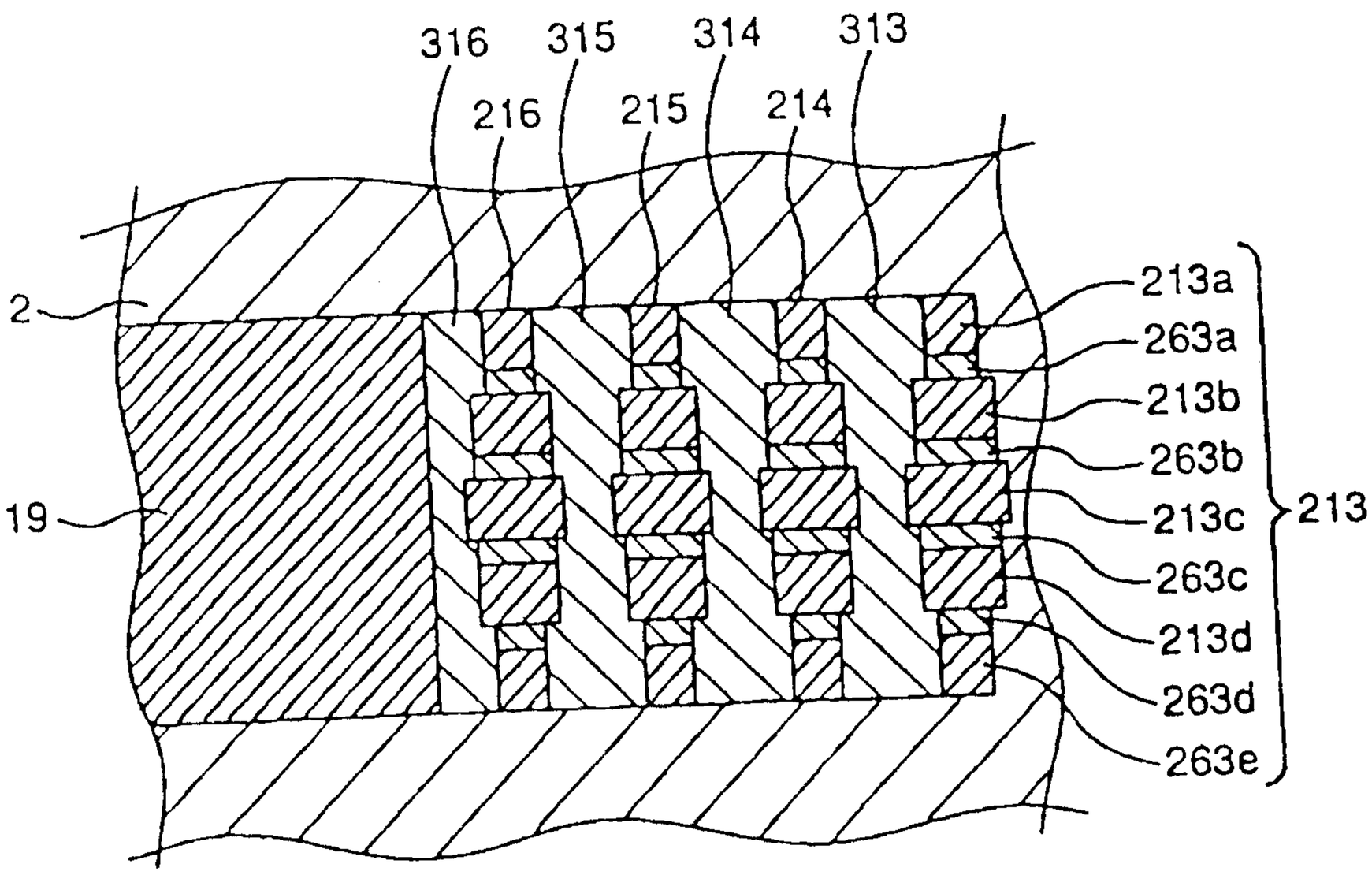

316
315
314
313
216
215
214
2
19
213a
263a
213b
263b
213c
213
263c
213d
263d
263e

FIG. 15

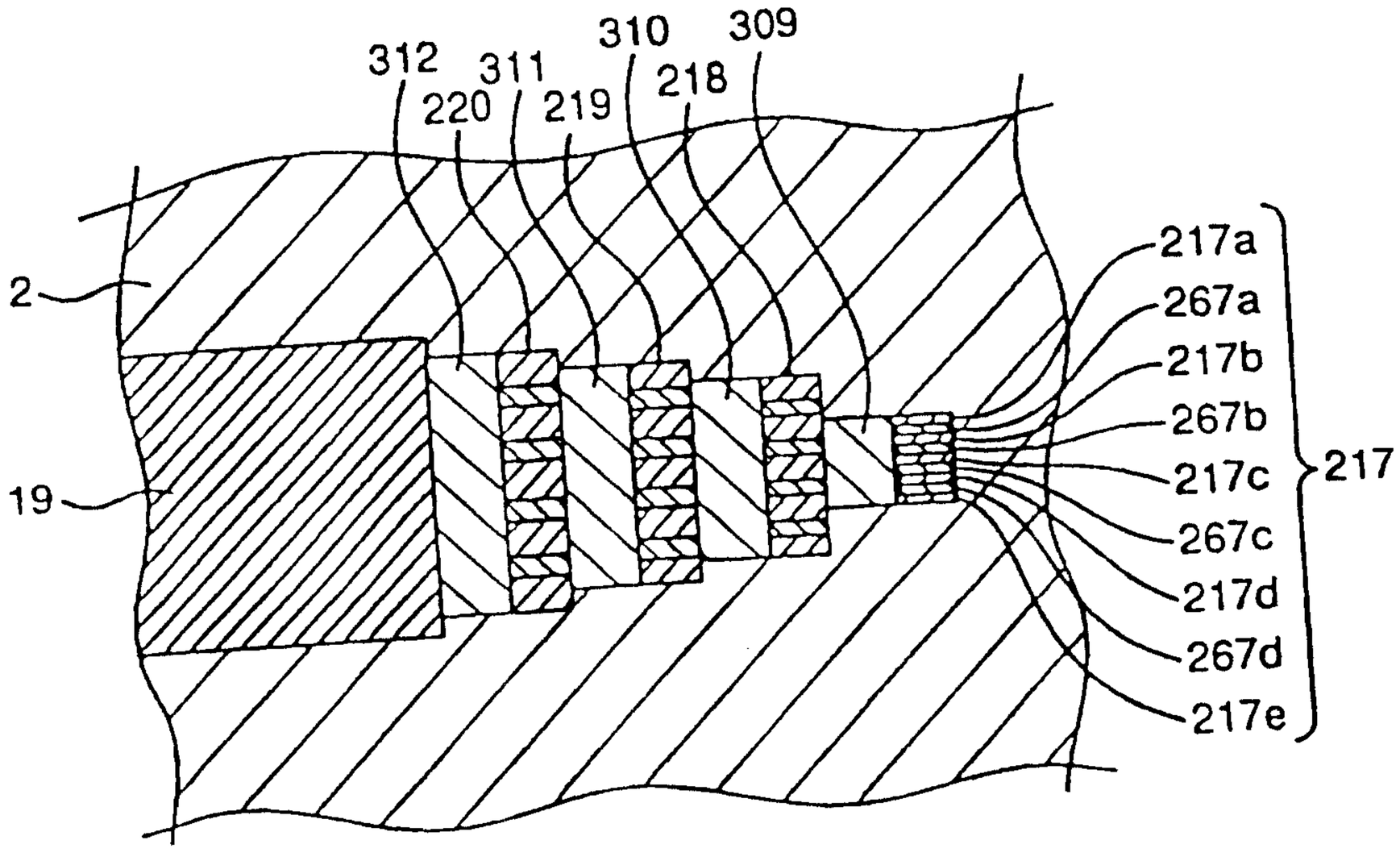

312
311
310
309
220
219
218
2
19
217a
267a
217b
267b
217c
267c
217d
267d
217e
217

FIG. 16

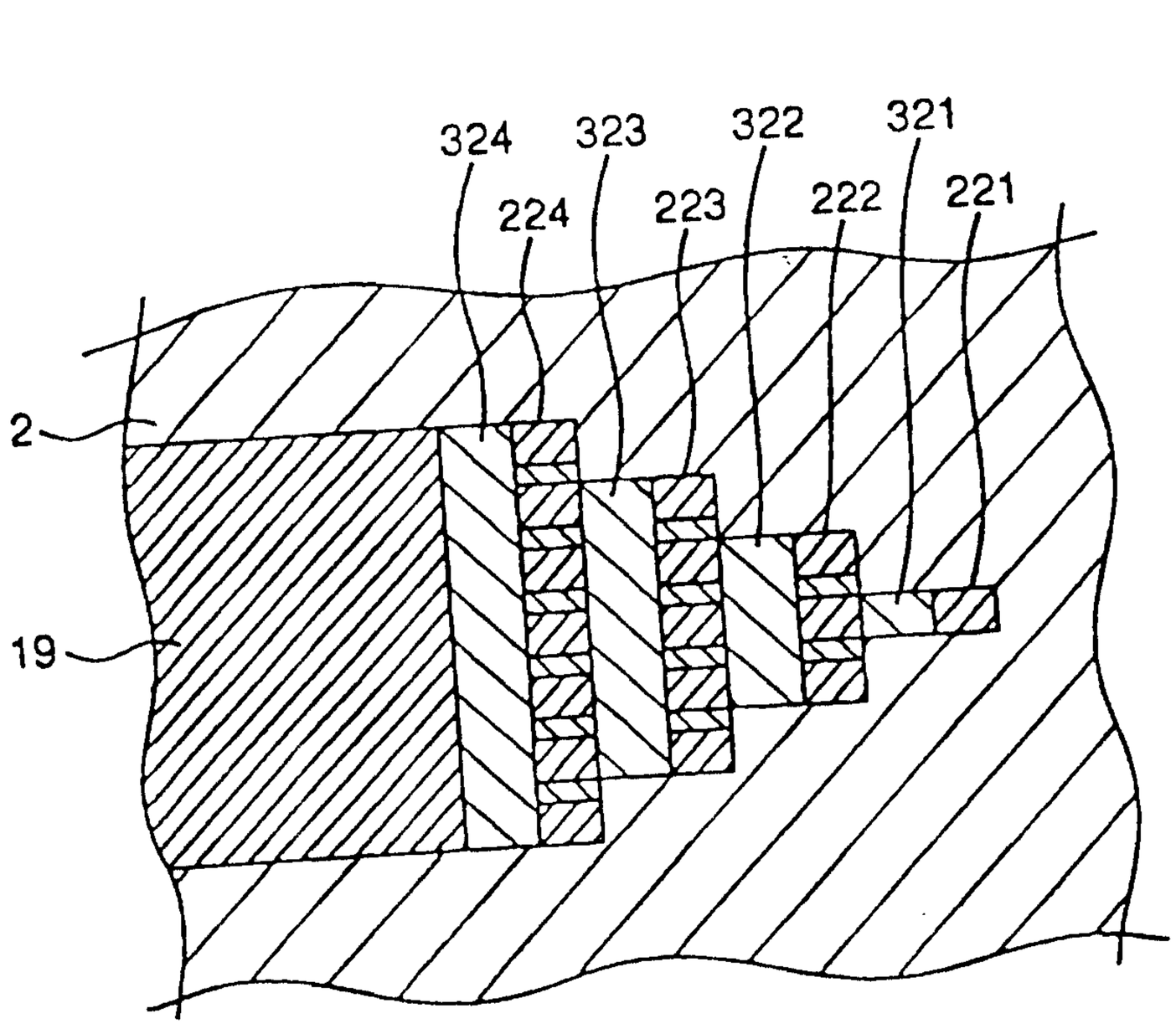

324
323
322
321
224
223
222
221
2
19

FIG. 17

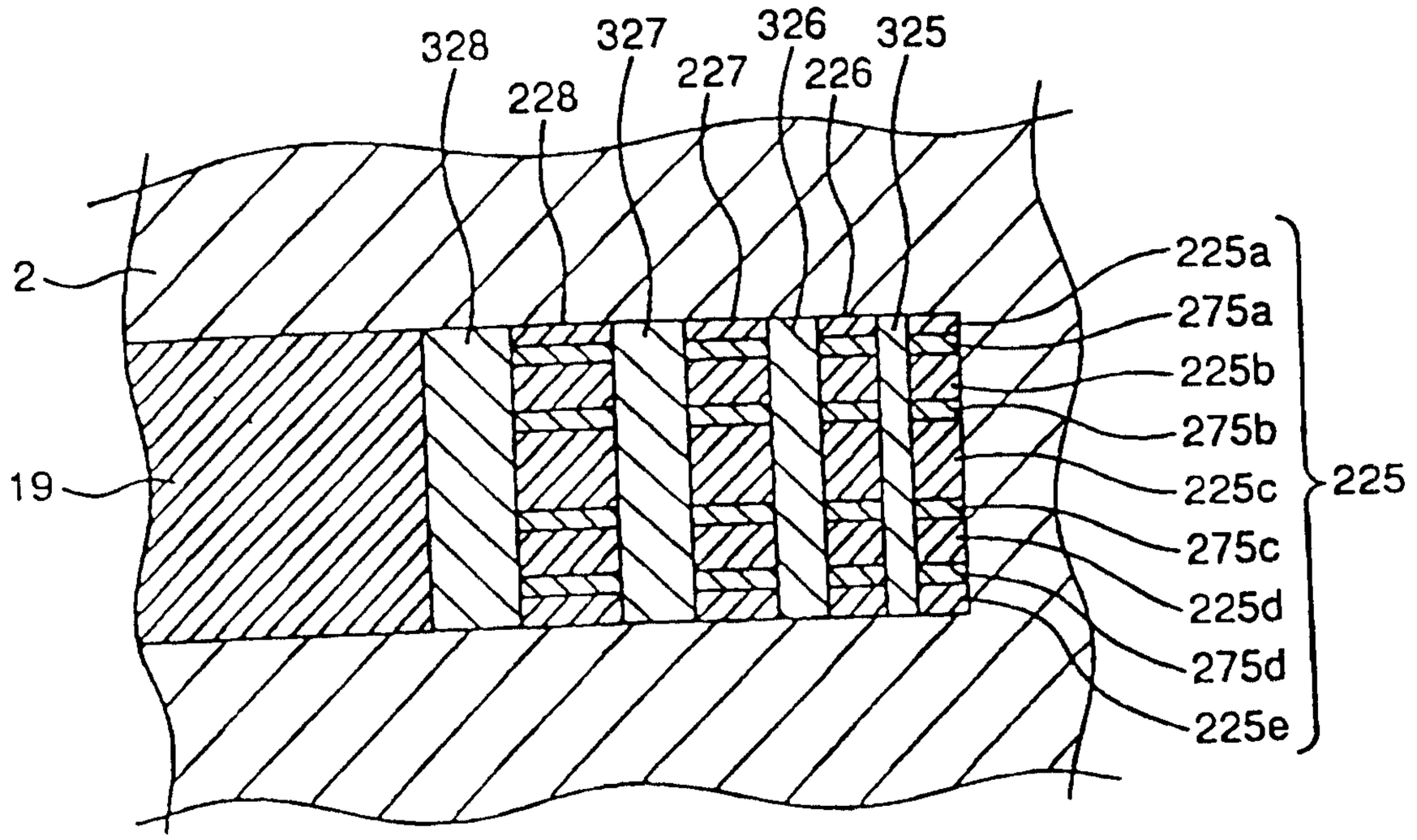

328
228
327
227
326
226
325
2
19
225a
275a
225b
275b
225c
275c
225d
275d
225e
225

FIG. 18

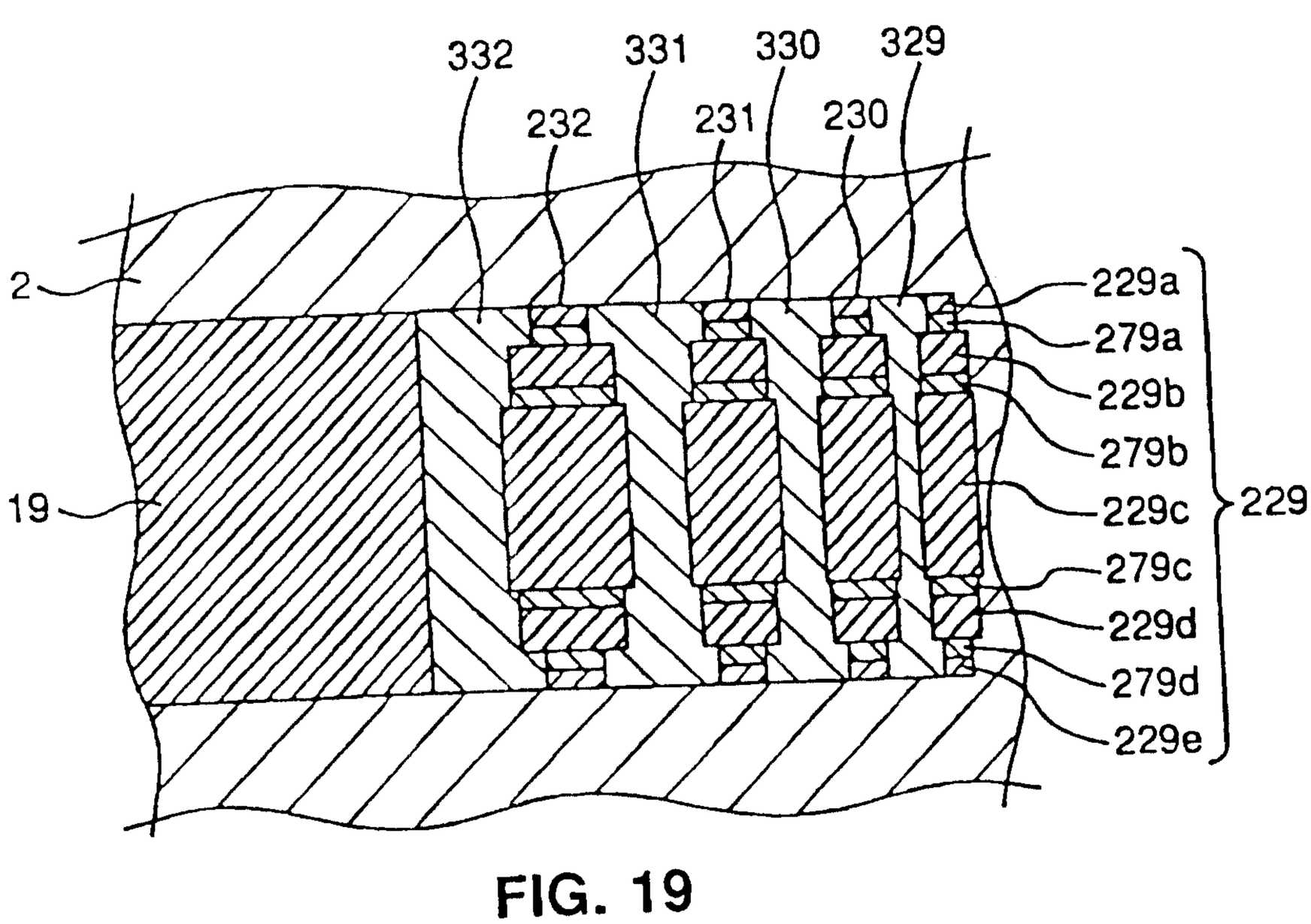

332
232
331
231
330
230
329
2
19
229a
279a
229b
279b
229c
279c
229d
279d
229e
229

FIG. 19

FIG. 20

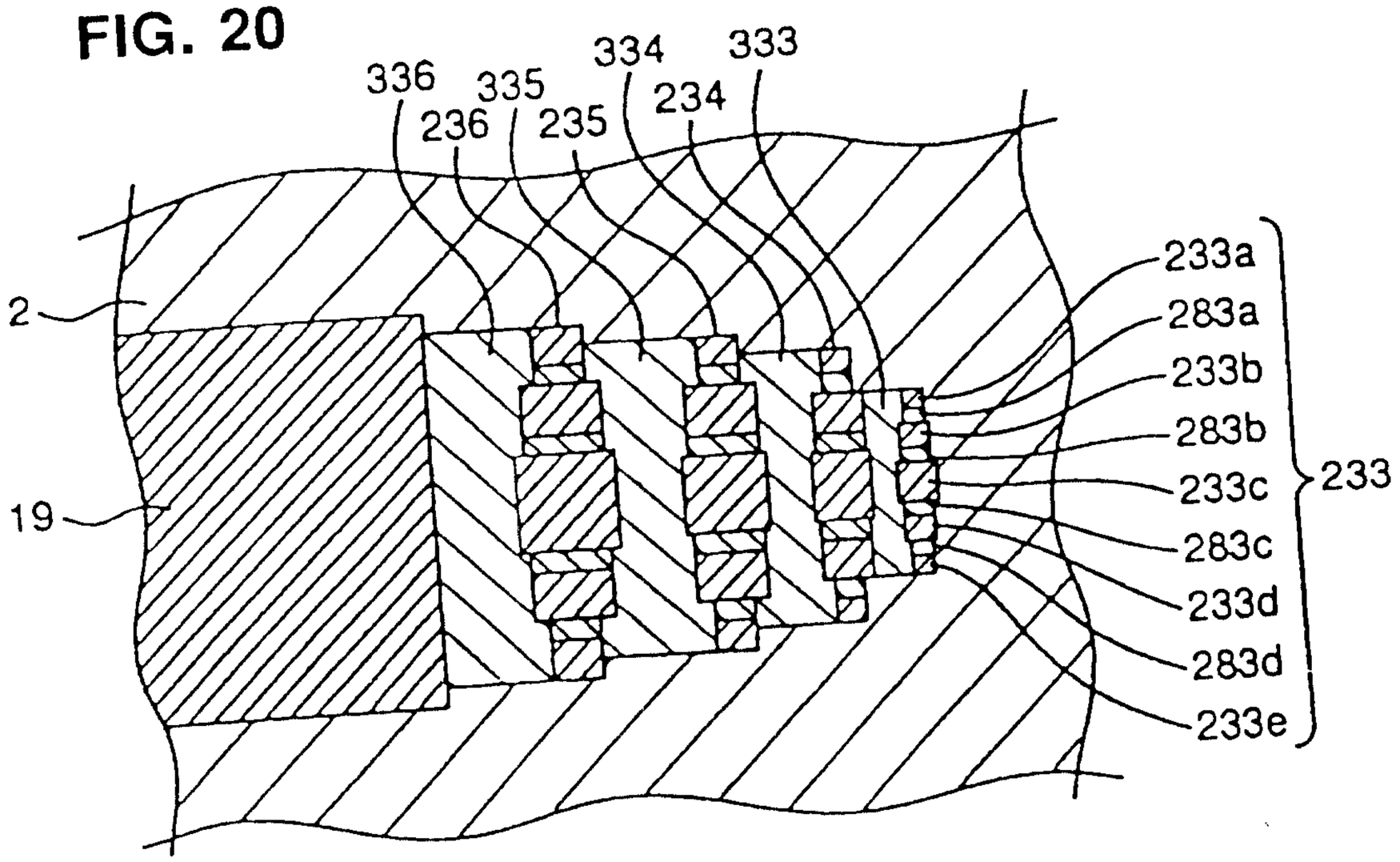
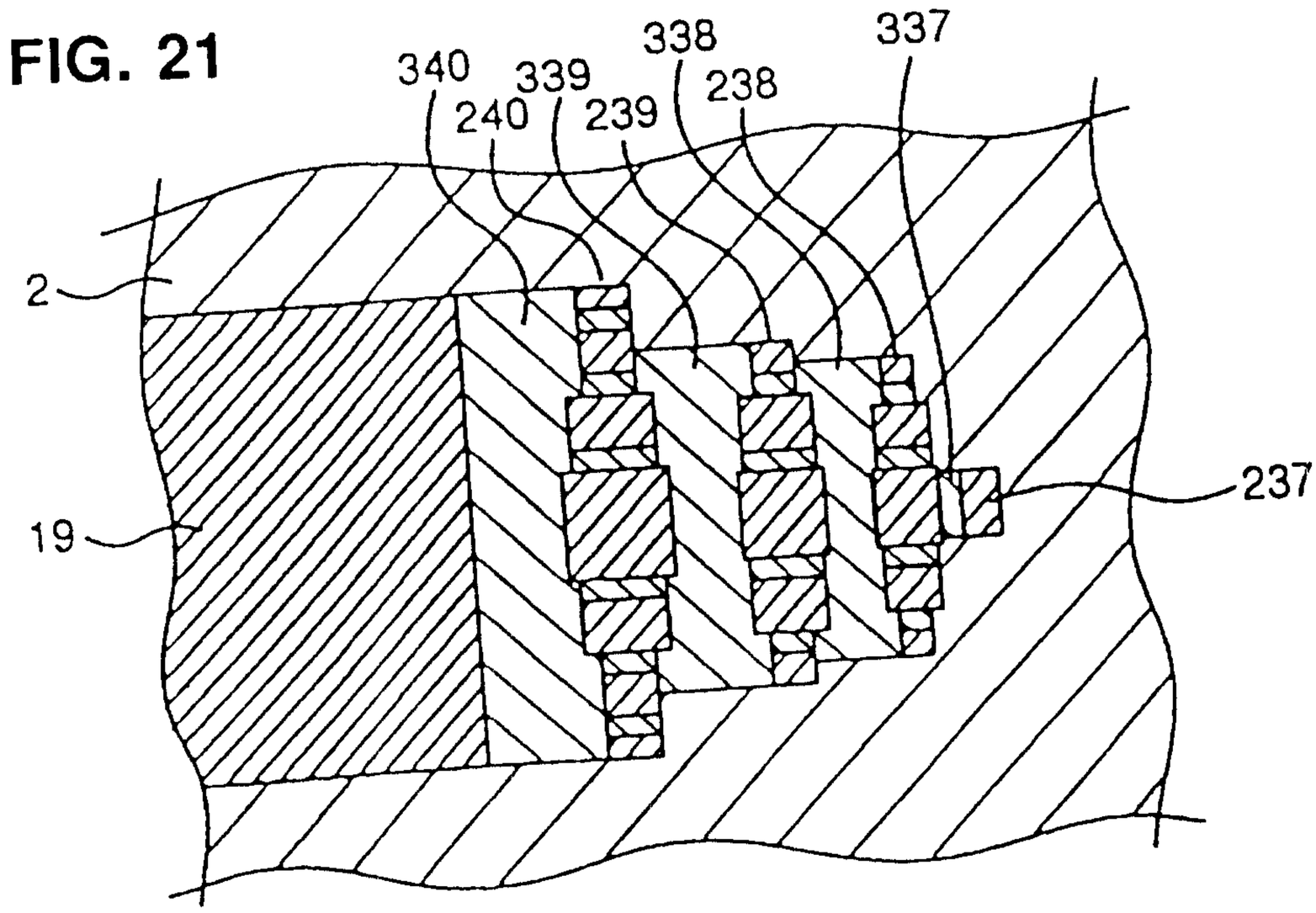
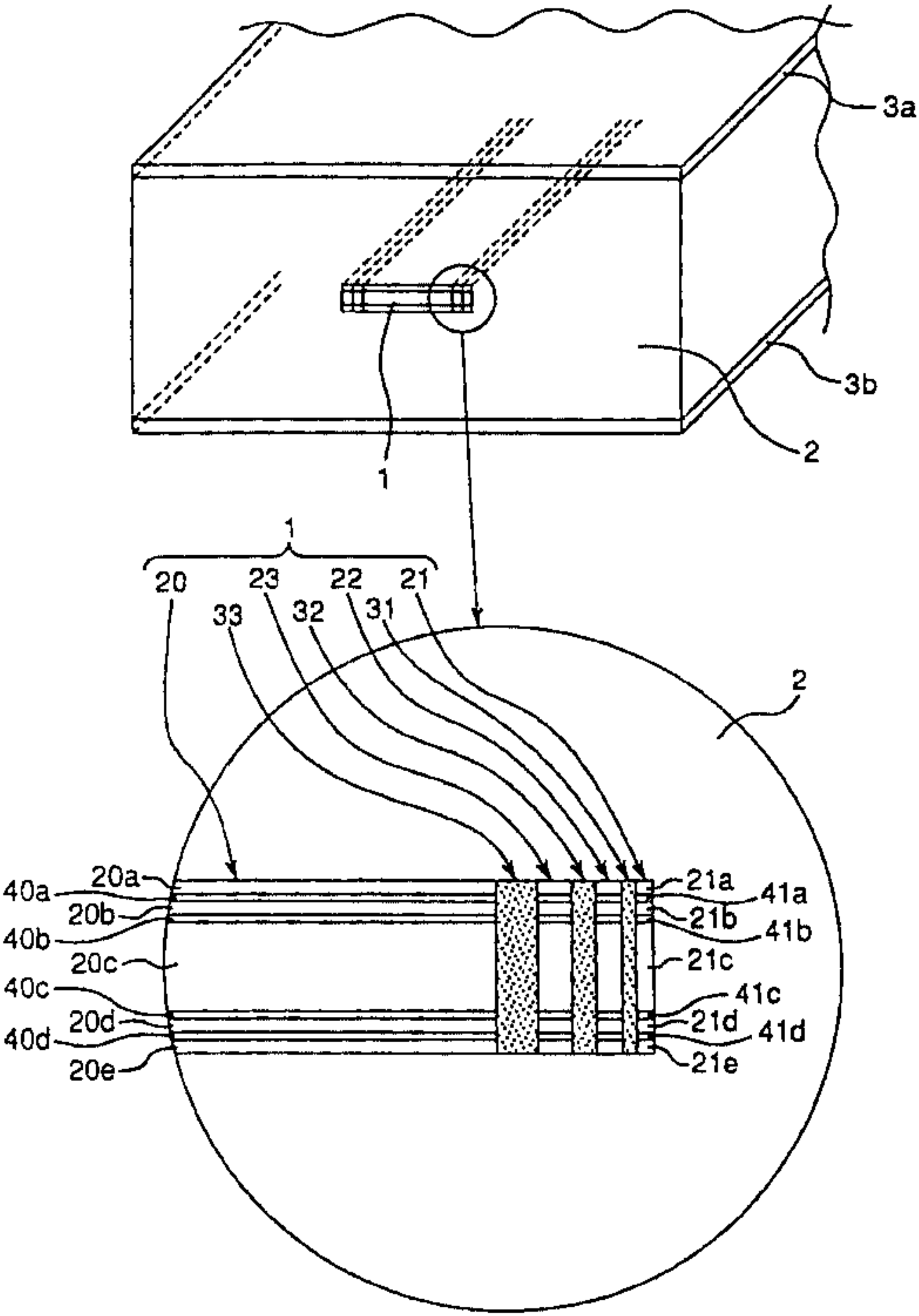

336
335
334
333
236
235
234
2
19
233a
283a
233b
283b
233c
283c
233d
283d
233e
233

FIG. 21


340
339
338
337
240
239
238
2
19
237


3a
3b
2
1
1
20
23
22
21
33
32
31
2
20a
40a
20b
40b
20c
40c
20d
40d
20e
21a
41a
21b
41b
21c
41c
21d
41d
21e