



(19)

Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 702 388 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
20.03.1996 Bulletin 1996/12

(51) Int. Cl.⁶: **H01J 23/24**

(21) Application number: **95112960.0**

(22) Date of filing: **17.08.1995**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **17.08.1994 JP 192962/94**
29.05.1995 JP 129977/94

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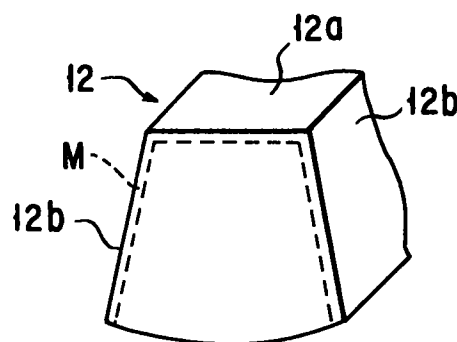
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(54) **Slow-wave circuit assembly for traveling-wave tube and method of manufacturing a slow-wave circuit assembly**

(57) In a slow-wave circuit assembly for a traveling-wave tube according to this invention, an element different from the base material of dielectric support rods (12) for supporting a slow-wave line is implanted into the base material surface of each support rod (12) to a predetermined depth at a predetermined concentration, and the electrical resistance of the surface is lower than the electrical resistance of the base material itself. In addition, the slow-wave circuit assembly for the traveling-wave tube is manufactured such that the element is ion-implanted into the surface of the dielectric support rod (12) to a predetermined depth at a predetermined dose, and then the dielectric support rod (12) is subjected to annealing in a non-oxidizing atmosphere. Therefore, in the slow-wave circuit assembly for the traveling-wave tube, the dielectric support rod (12) is suppressed from being charged in a long-time operation. The manufacturing method is good in reproducibility and assembling properties.



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Description

The present invention relates to a slow-wave circuit assembly of a traveling-wave tube known as an electron tube for amplifying a microwave and, more particularly, to a dielectric support rod for supporting a slow-wave line of a slow-wave circuit assembly and a method of manufacturing the dielectric support rod.

A traveling-wave tube, as is well known, is an electron tube using an interaction between a focused electron beam and, for example, a microwave propagating through a spiral slow-wave line. More specifically, when the microwave is propagating through the spiral slow-wave line, the microwave interacts with the electron beam adjacent to the spiral slow-wave line to partially transmit the energy of the electron beam to the microwave, thereby amplifying the microwave. For this reason, the microwave applied to the input terminal of the spiral slow-wave line adjacent to a cathode is amplified and appears at the output terminal of the spiral slow-wave line. The microwave is extracted to an external circuit as an amplified microwave output. The electron beam interacting with the microwave is caught by a collector electrode and converted into heat.

The elongated spiral slow-wave line is generally inserted in an elongated pipe-like metal vacuum vessel and electrically connected to a conductor, e.g., the central conductor of a coaxial line, having both the ends which respectively receive and output a microwave. In addition, the spiral slow-wave line is stably supported by, e.g., three dielectric support rods and arranged on the central axis of the vacuum vessel. Therefore, these dielectric support rods are in contact with the inner surface of the vacuum vessel and the outer surface of the spiral slow-wave line at once.

As the material of the dielectric support rods, for the sake of electrical characteristics, mechanical characteristics, thermal characteristics, and the like, beryllium oxide, aluminum oxide, silica or the like is used. Of these materials, although beryllium oxide is poisonous and mechanically brittle, beryllium oxide having good electrical insulation properties, a small dielectric loss, high heat withstanding characteristic, and good heat conduction characteristics is popularly used.

In recent years, boron nitride is being practically used as a dielectric support rod. For example, pyrolytic boron nitride (to be referred to as PBN hereinafter) is used. PBN is mechanically more flexible than beryllium oxide, and has a small dielectric constant and good assembling properties. However, since PBN has a small secondary electron emission coefficient which is 1 or less, the surface of the PBN support rod is easily charged when electrons passing through the PBN support rod partially collide with PBN.

An electron beam emitted from the cathode of the traveling-wave tube passes through a hollow space of the spiral slow-wave line by the focusing effect of a magnet arranged outside the traveling-wave tube to reach a collector electrode. However, since the electron beam

has a velocity distribution and travels with limited spread, a small number of electrons inevitably collide with the spiral slow-wave line and the dielectric support rods. The collision of electrons and the emission of secondary electrons positively or negatively charge the surface of each dielectric support rod. If the charge amount is considerably large, the traveling-wave tube cannot be normally operated. More specifically, when the surface of the dielectric support rod is locally charged, the traveling path of electron beam is varied by an electrostatic focusing effect or an electrostatic deflection effect, and electrons colliding with the spiral slow-wave line or the dielectric support rod increase in number. As a result, the interaction between the microwave and the electron beam is insufficient, and the microwave is not sufficiently amplified. Collision of electrons with the spiral slow-wave line and the dielectric support rod causes increases in charge amount and a current flowing in the spiral slow-wave line. As a result, a temperature in the traveling-wave tube increases, and the traveling-wave tube may be broken.

As a method of reducing an amount of charge on the surface of the dielectric support rod, a method of forming a coating consisting of magnesium oxide or titanium oxide on the surface of the support rod is known. This art is disclosed in, e.g., U.S.P. Nos. 5,038,076 and 5,071,055, German Pat. Appln. KOKAI Publication No. 3,235,753, and Jpn. Pat. Appln. KOKAI Publication No. 5-89788.

The oxide coating for suppressing the surface of the dielectric support rod from being charged is effective in a traveling-wave tube in which a microwave output power is relatively low. However, when the coating is applied to a high-power traveling-wave tube in which a temperature easily becomes high and the energy of collision of electrons with the dielectric support rod is large, the coating cannot have high reliability.

When an oxide coating is formed on the surface of the dielectric support rod, changes in oxide coating, e.g., changes in physical and chemical states such as a change in reduction and thickness of the oxide coating or formation of cracks, easily occur due to a high-temperature operation for a long time and an abrupt change in temperature. Therefore, the charge prevention effect may be changed or degraded. In addition, the oxide coating may be peeled from the surface of dielectric support rod, and the oxide coating cannot be controlled at high accuracy or stabilized when the oxide coating is formed.

It is an object of the present invention to provide a slow-wave circuit assembly for a traveling-wave tube, which suppresses charging on the surface of a dielectric support rod even in a long-time operation and is good in reproducibility and assembling properties, and a method of manufacturing the slow-wave circuit assembly.

According to the present invention, there is provided a slow-wave circuit assembly for a traveling-wave tube in which an element different from a base material of dielectric support rods for supporting a slow-wave line is implanted into base material surfaces of the support rods

to a predetermined depth at a predetermined concentration to decrease a surface electrical resistance to a value smaller than an electrical resistance of the base material.

According to the present invention, there is provided a method of manufacturing a slow-wave circuit assembly, comprising the steps of ion-implanting an element different from a base material of dielectric support rods from base material surfaces of the dielectric support rods into the base material to a predetermined depth at a predetermined concentration, and performing annealing for the dielectric support rods in a non-oxidizing atmosphere.

According to the present invention, the element ion-implanted into the base material of the dielectric support rods to a predetermined depth at a predetermined concentration sets the surface electrical resistance of each dielectric support rod to be lower than the electrical resistance of the base material of the support rod itself, thereby preventing the surface of the support rod in operation from being charged. A stable bond between the base element of the dielectric support rod and the ion-implanted element can be obtained, a change in surface resistance is small, and a stable operation of the traveling-wave tube can be kept. The slow-wave circuit assembly can be manufactured at high accuracy with good reproducibility.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1A is a schematic sectional side view showing a spiral slow-wave circuit assembly for a traveling-wave tube according to an embodiment of the present invention, and FIG. 1B is a schematic sectional side view showing a dielectric support rod of the spiral slow-wave circuit assembly;

FIG. 2 is a graph showing a concentration distribution of an ion-implanted element which is implanted into the surface of the dielectric support rod in FIG. 1 in the direction of depth of the dielectric support rod; and

FIG. 3A is a schematic longitudinal sectional view showing a high-frequency attenuation portion formed in a part of a BN dielectric support rod according to another embodiment of the present invention, and

FIG. 3B is a graph showing a surface resistance distribution of the high-frequency attenuation portion.

A slow-wave circuit assembly for a traveling-wave tube according to an embodiment of the present invention will be described with reference to the accompanying drawings. Note that the same reference numerals throughout the drawings denote the same parts.

FIG. 1A is a schematic sectional side view showing the spiral slow-wave circuit assembly for the traveling-wave tube, and FIG. 1B is a view illustrating the cross section of a dielectric support rod of the spiral slow-wave circuit assembly. In an elongated pipe-like stainless vac-

uum vessel 11 in which a vacuum state is set, three dielectric support rods 12 are arranged around the center of the stainless vacuum vessel 11 at an angular interval of 120°, and a slow-wave line 13 obtained by spirally winding, e.g., a molybdenum tape, is supported and fixed inside the dielectric support rods 12. The contact portions of the vacuum vessel, the dielectric support rods, and the slow-wave line are in tight mechanical contact with each other or are brazed to each other to form a heat-conductive path. In an operation of the traveling-wave tube, an electron beam e travels in the central space of the spiral slow-wave line 13 to interact with an electromagnetic wave, i.e., a microwave, thereby amplifying the microwave.

In each dielectric support rod 12 for supporting the slow-wave line, an element different from the base material of the dielectric support rod 12 is implanted into the base material surface to a predetermined depth at a predetermined concentration. An area in which the element is implanted is represented by reference symbol M in FIG. 1B. This area extends from a surface 12a which is in contact with the slow-wave line of the dielectric support rod 12 and both side surfaces 12b to a predetermined depth.

As a material of the dielectric support rod 12, various dielectrics: ceramics such as a boron nitride (BN) such as the above PBN, beryllia (BeO), alumina (Al_2O_3), aluminum nitride (AlN), and silicon nitride (Si_3N_4); quartz (SiO_2); and other heat-resistant glass materials, each of which is known as a dielectric for supporting the slow-wave line of a traveling-wave tube can be used. In addition, an element ion-implanted to decrease a surface electric resistance is an element different from the element constituting the base material of the dielectric support rod. As the element, an element except for hydrogen and inert gases such as argon is used.

The first embodiment will be described below in accordance with a preferable manufacturing method. As the base material of the dielectric support rod 12, PBN is prepared by the same pyrolytic method as described above. This PBN, as described above, has a hexagonal system, and is layered boron nitride having strong anisotropy as mechanical, thermal, and electrical characteristics. The PBN has a high electrical resistance and a small dielectric loss as characteristic features. The PBN has good heat conductivity and is so mechanically flexible that it is not easily bent.

The dielectric support rod 12 using the PBN as a base material is processed into an elongated rod having the cross section shown in FIG. 1A, one side having a width of about 1 mm, and a length of about 150 mm.

As an element serving as an ion implantation species, magnesium (Mg) which is a Group II element in the periodic table, and Mg ions are implanted into the base material surface of the dielectric support rod 12 to a predetermined depth. An ion implantation apparatus is constituted by an ion source, a mass separator, a subsequent acceleration tube, a beam scanner, and an implantation chamber. Mg is evaporated in the ion cham-

ber of the ion source, and the Mg vapor collides with electrons to be ionized. The resultant ions are extracted from the ion chamber to form an ion beam by a focusing effect. Thereafter, the ion beam is guided to the mass separator, and only Mg ions are extracted from the mass separator. The Mg ions are implanted in the PBN base material at an ion acceleration voltage of, e.g., 180 kV, and a dose of 2.0×10^{14} (atoms/cm²).

In the Mg concentration distribution of an Mg-ion-implanted region M in the PBN base material surface formed as described above, as indicated by a dotted line A in FIG. 2, the concentration is maximum in an area having a depth of 1 μ m or less in the PBN base material surface, and the concentration gradually decreases as the depth increases.

The PBN support rod 12 in which Mg ions were implanted was subjected to annealing in a vacuum state at a temperature of about 900°C for an hour. It was confirmed that this annealing activated the Mg ions implanted in the PBN base material surface portion, the electrical resistance of the PBN base material surface decreases to a value of 10^9 (Ω -cm²) by about 100 times, compared with the electrical resistance obtained before the annealing. This is because the crystallinity of the PBN base material is recovered by the annealing, and Mg is partially substituted for boron (B) to exhibit hole conduction. It was confirmed that the surface resistance rarely changed by a high-temperature operation in a vacuum state for a long time. The maximum Mg concentration in the annealed PBN base material surface is lower than the original value indicated by the dotted line A, and the concentrations of the surface increase by about 10 times, as indicated by a solid line B in FIG. 2. In addition, it was confirmed that the Mg ions were diffused in a deeper area and widely distributed. For this reason, it is proved that the surface electrical resistance of the PBN support rod having a surface in which Mg ions are implanted is decreased by annealing. In addition, a change in surface resistance in a high-temperature operation for a long time can be prevented by the annealing, and a stable operation can be assured. In this manner, a slow-wave circuit support rod having the ion-implanted area M of a predetermined element extending in the dielectric base material surface to a predetermined depth can be obtained.

The dielectric support rod manufactured as described above was set in an electron microscope, electrons were kept irradiated on the dielectric support rod under conditions of acceleration voltages of 10 kV, 15 kV, and 20 kV for five minutes, the presence/absence of electrons charged on the surface of the dielectric support rod was quantitatively examined. As a result, under any conditions, it was rarely detected that the dielectric support rod according to the present invention was charged.

According to the manufacturing method of the present invention, an ion species to be implanted can be freely selected, and the ions can be implanted while counting the ions. For this reason, the number of ions

can be set at high accuracy, and the electrical resistance of the surface can be accurately controlled. In addition, since the ions are implanted into the dielectric support rod, the thermal, chemical, and mechanical resistances of the support rod of the present invention are good more than those of a conventional support rod having a surface on which a coating is plated or deposited. Since the present invention has an arrangement in which no resistive coating layer adheres to the surface of the dielectric support rod, the size of the dielectric support rod does not change, design and assembling can be performed at high accuracy.

In the above embodiment, although Mg which is a Group II element is ion-implanted in the PBN base material, the element to be implanted is not limited to Mg. At least one selected from other Group II elements (Be, Ca, Sr, Ba, Zn, Cd, Hg) may be ion-implanted at a proper dose in the BN base material serving as the dielectric support rod. At least one selected from Group IV elements (Ti, Zr, Hf, C, Si, Ge, Sn, Pb) or Group VI elements (Cr, Mo, W, O, S, Se, Po) may be implanted at a proper dose.

As the next example, an example wherein Si as a Group IV element is ion-implanted in a dielectric support rod consisting of PBN will be described below. A silicon fluoride (SiF₄) gas is used as an ion species. The gas is ionized by discharging, and an Si element is implanted in a PBN base material.

A sample obtained by implanting Si ions in the surface of the PBN base material at a dose of 1×10^{14} (atoms/cm²) and a sample obtained by implanting Si ions at a dose of 2×10^{14} (atom/cm²), and a sample obtained by implanting Si ions at a dose of 5×10^{14} (atoms/cm²) were subjected to annealing in a vacuum state at about 900°C for about an hour. The surface potentials of these samples obtained as described above were measured with an electron microscope. As a result, when the beam acceleration voltage of the electron microscope was set to be 10 kV, the surface potentials of the samples became 6.6 kV, 8.0 kV, and 9.7 kV, respectively. It was confirmed that an amount of charge is in inverse proportion to the number of implanted Si ions. Note that, in this measuring method, the charge amount becomes zero when the surface potential is equal to the acceleration voltage, i.e., 10 kV.

When Si is used as an ion species, a saturation vapor pressure is relatively low. For this reason, an Si element is rarely evaporated from the surface of the PBN support rod during the manufacture of a traveling-wave tube and an operation of the completed traveling-wave tube, and the traveling-wave tube can keep stable performance for a long period of time.

As an element to be ion-implanted, an element which causes the surface of the support rod after the annealing to have electrical conductivity at a predetermined high resistance can be arbitrarily selected in accordance with the relationship between the base material of the dielectric support rod and the element. A metal element which easily obtains physical and chem-

ical stability is preferably used. In addition, when the base material of the dielectric support rod is a Group III-IV compound such as boron nitride (BN), at least one element selected from Group II, IV, or VI elements is preferably used as an ion species to be implanted. As described above, the dielectric support rod in which ions are implanted is subjected to annealing in a non-oxidizing atmosphere, and an element constituting the base material is partially substituted for the implanted element to electrically, stably activate the implanted element. The electrical resistance of the surface of the BN support rod is preferably decreased and stabilized.

Note that the number of ions to be implanted preferably falls within the range of 1.0×10^{12} (atoms/cm²) to 1.0×10^{16} (atoms/cm²). In addition, annealing performed after ion implantation may be performed in not only a vacuum state, but also a nitrogen atmosphere, inert gas (argon or the like) atmosphere, or another non-oxidizing atmosphere. The temperature of the annealing is preferably set to be relatively high because the high temperature can stabilize a reaction within a short time. However, in practice, the temperature is preferably set to be a temperature falling within the range of 600°C to 1,200°C. When the annealing is performed at a temperature higher than the above temperature, the implanted element is abruptly evaporated and eliminated, and a required concentration cannot be obtained.

In an embodiment shown in FIG. 3A, a high-frequency attenuator, provided in a part of the BN dielectric support rod, for attenuating a high-frequency wave is also formed by ion implantation. More specifically, the concentration of a metal element implanted in the surface of the dielectric support rod 12 is set to be highest in a maximum attenuation area ATT in which a high-frequency wave propagating through a slow-wave line 13 is maximally attenuated, and the concentration gradually decreases at both the sides of the maximum attenuation area ATT, thereby obtaining a concentration distribution for a charge prevention effect as described above. Therefore, the surface resistance of the dielectric support rod has a distribution, as indicated by a lower curve R in FIG. 3B, such that the surface resistance is set to be a value at which a high-frequency wave is sufficiently absorbed in the maximum attenuation area ATT, and gradually increases in both the sides of the maximum attenuation area ATT.

According to this embodiment, the surface resistance of a high-frequency attenuation portion can be considerably accurately distributed by controlling the number of ions to be implanted. In addition, unlike a deposited coating or a coated film of a high-frequency attenuation material which is generally known, peeling or a change in property rarely occurs. The electrical discontinuity of the boundary between the high-frequency attenuation portion and other areas can be prevented. Since the high-frequency attenuation portion can also be formed in the step of implanting ions for preventing charging, the manufacturing process can be simplified.

A slow-wave line to which the present invention can be applied is not limited to a spiral slow-wave line. A slow-wave line such as a double-ladder slow-wave line or a ring-and-bar-shaped slow-wave line which is supported by dielectric support rods can be used.

As has been described above, according to the present invention, the surface of a dielectric support rod consisting of boron nitride can be prevented from being charged, and the dielectric support rod can be manufactured with good reproducibility and high accuracy. Peeling and a change in property rarely occurs, and a stable operation of a traveling-wave tube for a long period of time can be assured.

Claims

1. A slow-wave circuit assembly for a traveling-wave tube, comprising:
 - a slow-wave line (13), in which an electron beam (e) travels, for propagating a high-frequency wave;
 - a vacuum vessel (11) in which said slow-wave line (13) is arranged; and
 - dielectric support rods (12), arranged in said vacuum vessel (11), for supporting said slow-wave line (13) in said vacuum vessel (11),
 characterized in that said dielectric support rods (12) consist of a dielectric base material, an element different from the base material is implanted into a surface of each of said dielectric support rods (12) to a predetermined depth at a predetermined concentration, and an electrical resistance of the surface of said dielectric support rod (12) is lower than an electrical resistance of the base material itself.
2. An assembly according to claim 1, characterized in that the base material of said dielectric support rods (12) is boron nitride.
3. An assembly according to claim 2, characterized in that the element to be implanted is at least one element selected from the group consisting of Groups II, IV, and VI elements in the periodic table.
4. An assembly according to claim 1, characterized in that a high-frequency attenuation portion for attenuating a high-frequency wave is formed in a part of each of said dielectric support rods (12), and the element is implanted in said high-frequency attenuation portion of said dielectric support rod (12).
5. A method of manufacturing a slow-wave circuit assembly for a traveling-wave tube in which a slow-wave line (13) is supported by dielectric support rods (12), characterized by comprising the steps of:
 - ion-implanting, in a dielectric base material of said dielectric support rods (12), an element different from the base material to a predetermined depth

at a predetermined dose; and
performing annealing for said dielectric support rods (12) in a non-oxidizing atmosphere.

6. A method according to claim 5, characterized in that boron nitride is used as the base material of said dielectric support rods. 5
7. A method according to claim 6, characterized in that an ion species to be implanted includes at least one element selected from the group consisting of Groups II, IV, and VI elements in the periodic table. 10
8. A method according to claim 5, characterized in that the ions are implanted at a dose falling within the range of 1.0×10^{12} (atoms/cm²) to 1.0×10^{16} (atoms/cm²). 15
9. A method according to claim 5, characterized in that a temperature at which the annealing is performed falls within the range of 600°C to 1,200°C. 20

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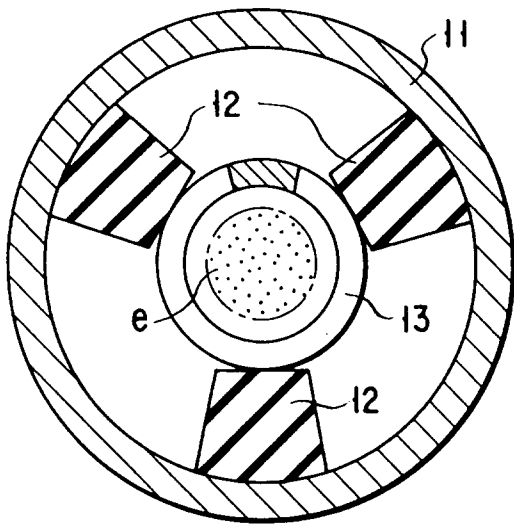


FIG. 1A

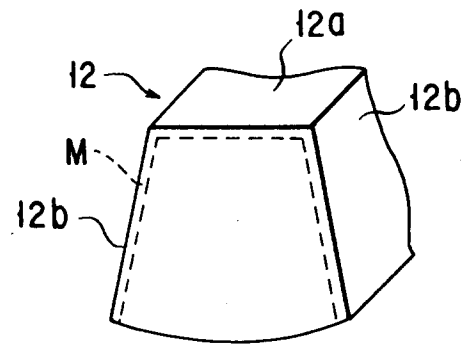


FIG. 1B

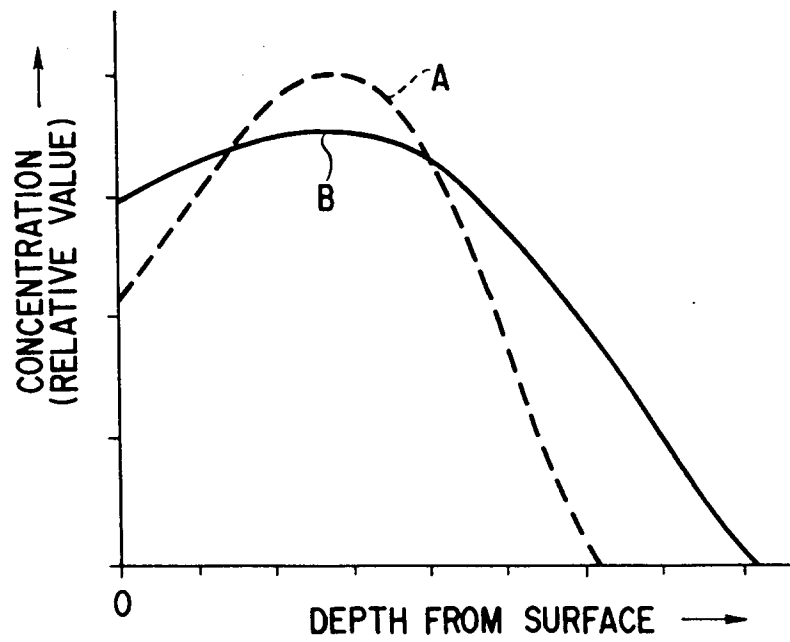


FIG. 2

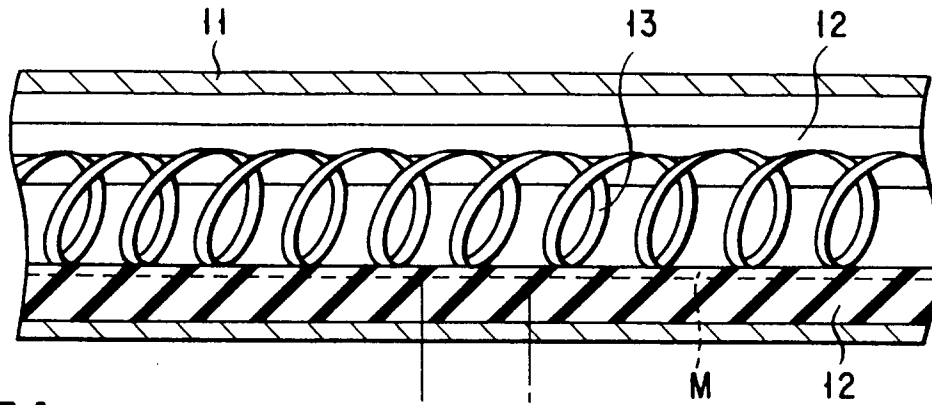


FIG. 3A

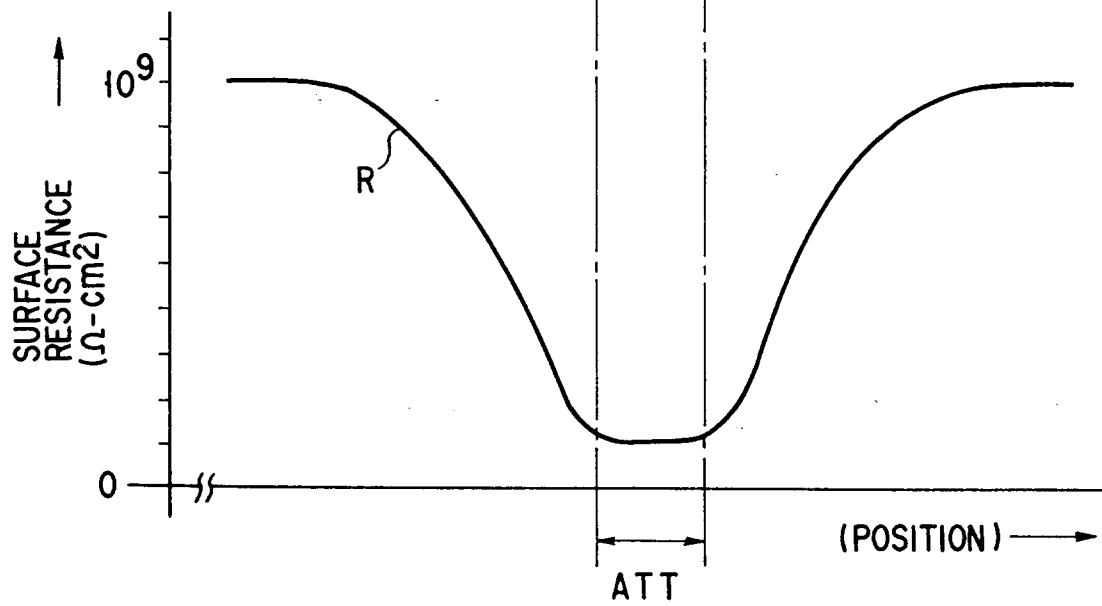


FIG. 3B



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 95 11 2960

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 015 no. 209 (E-1072) ,28 May 1991 & JP-A-03 059929 (TOSHIBA CORP) 14 March 1991,	1,3,4	H01J23/24
Y		1,2	
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A		3,6,7	
	* abstract *		
	* page 3, line 23 - line 24 *		
	* page 3, last paragraph *		
	* page 4, last paragraph *		
	* page 5, line 4 - line 21 *		
	* page 5, line 29 - page 6, line 32 *		

D,A	DE-A-32 35 753 (SIEMENS AG) 29 March 1984	1,3,7	
	* abstract; claim 2 *		
	* page 2, line 14 - line 30 *		

The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		23 November 1995	Martín Vicente, M
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