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(54) **SLOW-WAVE STRUCTURE, TRAVELING WAVE TUBE, AND NETWORK DEVICE**

(57) A slow-wave structure, a traveling-wave tube, and a network device are provided, relating to the field of vacuum electronics. The slow-wave structure includes a housing, a slow-wave transmission line, an input coupler, and an output coupler. The housing includes a first housing cover and a second housing cover that are connected in a stacked manner along a first direction, forming a stacked structure. The slow-wave transmission line is located in a first plane perpendicular to the first direction,

both the input coupler and the output coupler are electrically connected to the slow-wave transmission line, and at least one of the input coupler and the output coupler is not coplanar with the first plane, ensuring good consistency with the stacking direction. This helps simplify the production and assembly of the input coupler and/or the output coupler, improve their integration, and implement miniaturization of the slow-wave structure.

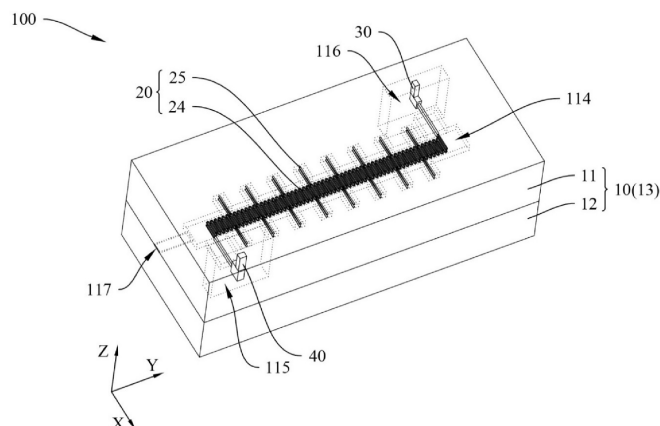


FIG. 1

Description

[0001] This application claims priority to Chinese Patent Application No. 202311615520.9, filed with the China National Intellectual Property Administration on November 29, 2023 and entitled "SLOW-WAVE STRUCTURE, TRAVELING-WAVE TUBE, AND NETWORK DEVICE", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This application relates to the field of vacuum electronic device technologies, and in particular, to a slow-wave structure, a traveling-wave tube, and a network device.

BACKGROUND

[0003] A millimeter-wave power amplifier includes a traveling-wave tube and a solid-state power amplifier. The applicable power of a solid-state power amplifier is relatively low, significantly limiting the coverage distance of a base station using a solid-state power amplifier. Consequently, a large number of base stations must be deployed to meet coverage requirements, thereby increasing deployment costs. In contrast, a traveling-wave tube offers higher applicable power, and the use of a traveling-wave tube amplifier can enhance the equivalent isotropic radiated power of a base station, thereby reducing the number of base stations and saving deployment costs.

[0004] Traveling-wave tubes are classified by their slow-wave structure types into traveling-wave tubes of the all-metal waveguide slow-wave structure type and traveling-wave tubes of the dielectric-supported slow-wave structure type. A traveling-wave tube of the all-metal waveguide slow-wave structure type has metal walls that employ a specially designed structure to fold the transmission path of electromagnetic waves, thereby reducing the propagation phase velocity of the electromagnetic waves and enabling energy conversion between the electromagnetic waves and electrons. However, a traveling-wave tube of the all-metal waveguide slow-wave structure type operates in a transverse electric/transverse magnetic (TE/TM) mode, and it interacts with an electron beam by using the total field of harmonics, resulting in poor amplification effect.

[0005] A traveling-wave tube of the dielectric-supported slow-wave structure type has a metal slow-wave line, dielectric-supported rods, and a metal envelope. The metal slow-wave line is used to transmit electromagnetic waves, the dielectric-supported rods provide structural support for the metal slow-wave line, and the metal envelope functions as a waveguide that encloses the dielectric-supported rods and the metal slow-wave line. Since the materials of the dielectric-supported rods and the metal envelope typically differ, the traveling-wave

tube of the dielectric-supported slow-wave structure type has a dual-conductor structure, enabling the waveguide to operation in transverse electromagnetic (TEM/quasi-TEM) mode. Compared with the transverse electric/transverse magnetic mode, the transverse electromagnetic mode has a stronger electric field and wider bandwidth, allowing the traveling-wave tube of the dielectric-supported slow-wave structure type to achieve better amplification performance while maintaining a compact size. However, the input coupler and the output coupler of the traveling-wave tube of the dielectric-supported slow-wave structure type has a low level of integration with the waveguide. Furthermore, the assembly consistency between the input coupler and the output coupler and waveguide is relatively poor during the assembly process, hindering further miniaturization and integration of the traveling-wave tube of the dielectric-supported slow-wave structure type.

SUMMARY

[0006] This application provides a slow-wave structure, a traveling-wave tube, and a network device. At least one of the input coupler and the output coupler is disposed perpendicular to or parallel to a plane that is perpendicular to the stacking direction. This helps simplify the production and assembly of the input coupler and/or the output coupler, improve their integration, and implement miniaturization of the slow-wave structure.

[0007] According to a first aspect, this application provides a slow-wave structure, including: a housing, including a first housing cover and a second housing cover that are connected in a stacked manner along a first direction; a slow-wave transmission line, extending along a first plane perpendicular to the first direction, where the slow-wave transmission line is fixed in a first waveguide formed by the first housing cover and the second housing cover; and an input coupler and an output coupler, both electrically connected to the slow-wave transmission line, where at least one of the input coupler and the output coupler is not coplanar with the first plane.

[0008] The slow-wave structure provided in this application includes the housing, the slow-wave transmission line, the input coupler, and the output coupler. The housing includes the first housing cover and the second housing cover that are connected in the stacked manner along the first direction, so that the slow-wave structure is a stacked structure. In a manufacturing process of the slow-wave structure, layer structures in the slow-wave structure can be separately processed. This helps implement planar batch manufacturing, shorten processing time, and improve production and processing efficiency of the slow-wave structure. At least one of the input coupler and the output coupler is not coplanar with the first plane, ensuring good consistency with the stacking direction. In other words, at least one of the input coupler and the output coupler has good consistency with an assembly manner of the slow-wave structure. This helps

simplify the production and assembly of the input coupler and/or the output coupler, improve their integration, and implement miniaturization of the slow-wave structure.

[0009] In a possible implementation, the input coupler includes a plurality of first metal portions sequentially connected, the output coupler includes a plurality of second metal portions sequentially connected, two adjacent first metal portions or two adjacent second metal portions form a stepped structure, and at least one of an arrangement direction of the plurality of first metal portions and an arrangement direction of the plurality of second metal portions is angled relative to the first plane. At least one of the arrangement direction of the plurality of first metal portions and the arrangement direction of the plurality of second metal portions has the included angle with the first plane, so that two adjacent first metal portions or two adjacent second metal portions are sequentially connected in the stacking direction. This helps simplify the production and assembly of the input coupler and/or the output coupler, improve the integration of the input coupler and the output coupler, and implement the miniaturization of the slow-wave structure.

[0010] In a possible implementation, the input coupler further includes an input coaxial cable and a second waveguide, the input coaxial cable is electrically connected to the slow-wave transmission line and the plurality of first metal portions, the plurality of first metal portions and at least part of the input coaxial cable are located in the second waveguide, and the second waveguide is configured to couple an electromagnetic wave. The input coupler further includes the input coaxial cable and the second waveguide, and the input coaxial cable is configured to convert a waveguide mode of the electromagnetic wave from a TEM mode into a quasi-TEM mode, so that a mode of the electromagnetic wave at the slow-wave transmission line is the quasi-TEM mode. This helps improve an amplification effect of the slow-wave structure on the electromagnetic wave.

[0011] In a possible implementation, the slow-wave structure includes at least one attenuator, where the attenuator is electrically connected to the output coupler or the input coupler, and the attenuator is configured to absorb an electromagnetic wave. The attenuator is electrically connected to the output coupler or the input coupler. This helps avoid that the electromagnetic wave is reflected to the slow-wave transmission line, improve transmission stability of the electromagnetic wave at the slow-wave transmission line, and ensure the amplification effect of the slow-wave structure on the electromagnetic wave.

[0012] In a possible implementation, the slow-wave transmission line includes at least two transmission line segments, two adjacent transmission line segments are disposed at a spacing, the slow-wave structure includes at least two attenuators, each transmission line segment is electrically connected to at least one attenuator, the slow-wave structure further includes at least two couplers at spacings, and the coupler at the spacing is electrically

connected to the transmission line and the attenuator. The slow-wave transmission line includes at least two transmission line segments, and a single transmission line segment is electrically connected to at least one attenuator, so that the attenuator is disposed at each transmission line segment to absorb a redundant electromagnetic wave. This avoids that the electromagnetic wave is reflected at each transmission line segment, and helps improve transmission stability of the electromagnetic wave at each transmission line segment.

[0013] In a possible implementation, neither the input coupler nor the output coupler is coplanar with the first plane, and each coupler at the spacing is coplanar with the first plane. Neither the input coupler nor the output coupler is coplanar with the first plane, and each coupler at the spacing is coplanar with the first plane. This helps simplify a manner of disposing the input coupler and the output coupler, improve the integration of the input coupler and the output coupler, reduce space occupied by the attenuator and the coupler at the spacing, and implement the miniaturization of the slow-wave structure.

[0014] In a possible implementation, the at least two transmission line segments are different in at least one of periodicity quantity and periodicity length. The at least two transmission line segments are different in at least one of periodicity quantity and periodicity length, so that a reduction rate of a phase velocity of the electromagnetic wave at each transmission line segment varies. This helps improve the amplification effect of the slow-wave structure on the electromagnetic wave.

[0015] In a possible implementation, the attenuator is in a wedge shape. A cross-sectional area of the attenuator on a side close to the coupler at the spacing is larger than a cross-sectional area of the attenuator on a side away from the coupler at the spacing, and the cross section is perpendicular to a direction from the coupler at the spacing to the attenuator. The attenuator is in the wedge shape. This helps reduce reflection of the electromagnetic wave in the attenuator, so that the attenuator can absorb an electromagnetic wave with a larger frequency range and larger power.

[0016] In a possible implementation, the attenuator, the input coupler, and the output coupler are all integrated with the first housing cover. The attenuator, the input coupler, and the output coupler are all integrated with the first housing cover. This helps implement assembly of the input coupler and the output coupler in the stacking direction and provide accommodation space for the attenuator, improves the integration of the attenuator, the input coupler, and the output coupler, and helps implement the miniaturization of the slow-wave structure.

[0017] In a possible implementation, the first housing cover has a first input hole and a first output hole, the input coupler is fixed to an inner wall of the first input hole, and the output coupler is fixed to an inner wall of the first output hole. The input coupler and the output coupler are respectively fixed to the inner wall of the first input hole and the inner wall of the first output hole, so that at least

part of the input coupler and at least part of the output coupler are accommodated in a housing layer of the first housing. This improves the integration of the input coupler and the output coupler with the first housing, and helps implement the miniaturization of the slow-wave structure.

[0018] In a possible implementation, the slow-wave structure further includes a first energy transmission window and a second energy transmission window, where the first energy transmission window seals the first input hole, the second energy transmission window seals the first output hole, the first energy transmission window is electrically connected to the input coupler and an input waveguide interface, and the second energy transmission window is electrically connected to the output coupler and an output waveguide interface. The slow-wave structure further includes the first energy transmission window and the second energy transmission window, so that the first energy transmission window and the second energy transmission window respectively implement sealing of the first waveguide at the first input hole and the first output hole, to ensure sealing performance of the first waveguide.

[0019] In a possible implementation, an inner wall of at least one of the first input hole and the first output hole has a flange, and the flange supports and is connected to at least one of the first energy transmission window and the second energy transmission window. The inner wall of at least one of the first input hole and the first output hole has the flange. This helps improve stability of a position of the first energy transmission window and/or the second energy transmission window in the slow-wave structure.

[0020] In a possible implementation, the second housing cover has a second input hole and a second output hole, the first input hole and the second input hole communicate with each other along the first direction, and the first output hole and the second output hole communicate with each other along the first direction. The slow-wave structure further includes a first reflecting member and a second reflecting member, the first reflecting member seals the second input hole, and the second reflecting member seals the second output hole. The second housing cover has the second input hole and the second output hole, the first reflecting member seals the second input hole, and the second reflecting member seals the second output hole. This helps ensure that the first waveguide is in a sealed state. The first reflecting member and the second reflecting member are disposed, so that phase cancellation occurs between an electromagnetic wave after reflection and an original electromagnetic wave, to improve stability of the electromagnetic wave in a transmission process.

[0021] In a possible implementation, one of the first housing cover and the second housing cover includes a circuit layer, and the circuit layer is connected to the other one of the first housing cover and the second housing cover in a stacked manner along the first direction. One of the first housing cover and the second housing cover

includes the circuit layer, and the circuit layer is connected to the other one of the first housing cover and the second housing cover in the stacked manner along the first direction, so that the slow-wave transmission line can be integrated with another structure in the slow-wave structure in the stacking direction. This improves integration of the slow-wave transmission line with the housing, and helps implement the miniaturization of the slow-wave structure.

[0022] In a possible implementation, the slow-wave transmission line is parallel to the first plane, there are at least two slow-wave transmission lines, and the at least two slow-wave transmission lines are disposed at a spacing in a stacked manner along the first direction. There are at least two slow-wave transmission lines. This helps generate electric fields in a same direction and improve the amplification effect of the slow-wave structure on the electromagnetic wave.

[0023] In a possible implementation, the input coupler and the output coupler are located on a same side of the slow-wave transmission line along the first direction. The input coupler and the output coupler are located on the same side of the slow-wave transmission line along the first direction, so that space occupied by the slow-wave transmission line, the input coupler, and the output coupler along the first direction is reduced. This helps implement the miniaturization of the slow-wave structure.

[0024] According to a second aspect, this application further provides a traveling-wave tube, including an electron gun, a collector, a focusing system, an input apparatus, an output apparatus, and the slow-wave structure according to any one of the implementations of the first aspect. Both the electron gun and the collector are fixed to a housing of the slow-wave structure, the electron gun is configured to emit electrons into a first waveguide of the slow-wave structure, the collector is configured to collect the electrons in the first waveguide, the focusing system is configured to cause the electrons to pass through the slow-wave structure, the input apparatus is electrically connected to an input coupler of the slow-wave structure, the input apparatus is configured to send an electromagnetic wave to the input coupler, the output apparatus is electrically connected to an output coupler of the slow-wave structure, and the output coupler is configured to send an amplified electromagnetic wave to the output apparatus. Beneficial effects of this embodiment are similar to those corresponding to the foregoing embodiment, and details are not described in this embodiment again.

[0025] According to a third aspect, this application further provides a network device, including an antenna and the traveling-wave tube according to the second aspect. The antenna is electrically connected to the traveling-wave tube, and the antenna is configured to send an electromagnetic wave amplified by the traveling-wave tube. Beneficial effects of this embodiment are similar to those corresponding to the foregoing embodiment, and details are not described in this embodiment

again.

BRIEF DESCRIPTION OF DRAWINGS

[0026]

FIG. 1 is a schematic perspective view of a structure of a slow-wave structure according to an implementation of this application;

FIG. 2 is an exploded view of a slow-wave structure according to the implementation shown in FIG. 1;

FIG. 3 is a diagram of a structure of a first housing cover in the implementation shown in FIG. 1;

FIG. 4 is a diagram of a structure of a slow-wave structure in which neither an input coupler nor an output coupler is coplanar with a first plane and no housing is disposed according to an implementation of this application;

FIG. 5 is a diagram of a structure of a slow-wave structure in which only an input coupler is not coplanar with a first plane and no housing is disposed according to an implementation of this application;

FIG. 6 is a diagram of a structure of a slow-wave structure in which only an output coupler is not coplanar with a first plane and no housing is disposed according to an implementation of this application;

FIG. 7 is a diagram of a structure of a slow-wave structure that has a single transmission line segment and a single attenuator and in which no housing is disposed according to an implementation of this application;

FIG. 8 is a diagram of a structure of a slow-wave structure that has two transmission line segments and two attenuators and in which no housing is disposed according to an implementation of this application;

FIG. 9 is a diagram of a structure of a slow-wave structure that has three transmission line segments and four attenuators and in which no housing is disposed according to an implementation of this application;

FIG. 10 is a diagram of a structure of a slow-wave structure that has an energy transmission window and a reflecting member according to an implementation of this application;

FIG. 11 is an exploded view of a slow-wave structure according to the implementation shown in FIG. 10;

FIG. 12 is a schematic perspective view of a structure of an inner wall of a first input hole and a first energy transmission window according to an implementation of this application;

FIG. 13 is an exploded view of an inner wall of a first input hole and a first energy transmission window according to the implementation shown in FIG. 12;

FIG. 14 is a diagram of a system of a traveling-wave tube according to an implementation of this application; and

FIG. 15 is a diagram of a system of a network device

according to an implementation of this application.

DESCRIPTION OF EMBODIMENTS

[0027] The following describes embodiments of this application with reference to the accompanying drawings in embodiments of this application.

[0028] For ease of understanding, the following first explains and describes English abbreviations and related technical terms in embodiments of this application.

[0029] It should be noted that the described embodiments are merely part of rather than all of embodiments of this application. All other embodiments obtained by a person of ordinary skill in the art based on embodiments of this application without creative efforts shall fall within the protection scope of this application.

[0030] The terms used in embodiments of this application are merely for the purpose of describing specific embodiments, and are not intended to limit this application. The terms "a", "said" and "the" of singular forms used in embodiments and the appended claims of this application are also intended to include plural forms, unless otherwise specified in the context clearly.

[0031] It should be understood that the term "and/or" in this specification is merely a same field for describing associated objects and represents that three relationships may exist. For example, A and/or B may represent the following three cases: Only A exists, both A and B exist, and only B exists. In addition, the character "/" in this specification generally indicates an "or" relationship between the associated objects.

[0032] Depending on the context, for example, the term "if" as used herein may be explained as "when", "while", "in response to determining", or "in response to detecting". Similarly, depending on the context, the phrase "if determining" or "if detecting (a stated condition or event)" may be explained as "when determining", "in response to determining", "when detecting (the stated condition or event)", or "in response to detecting (the stated condition or event)".

[0033] It should be understood that, the terms "first", "second", and the like used in this application are merely used for distinguishing and description, but cannot be understood as an indication or implication of relative importance or an indication or implication of a sequence.

[0034] In the descriptions of this application, orientation or position relationships indicated by the terms "center", "upper", "lower", "front", "rear", "left", "right", "vertical", "horizontal", "top", "bottom", "inner", "outer", and the like are based on orientation or position relationships shown in the accompanying drawings, and are used only for ease and brevity of description of this application, rather than indicating or implying that a specified apparatus or component needs to have a specific orientation, and be constructed and operated in the specific orientation. Therefore, this cannot be understood as a limitation on this application.

[0035] In the descriptions of this application, it should

be noted that due to a manufacturing error or an assembly error, there is some angle deviation in a design that should be vertical or parallel, for example, a deviation within 15 degrees, which is also considered as vertical or parallel in this implementation.

[0036] In this application, "in a range of..." includes end values at both ends of the range by default except that it is separately indicated that an end value is not included. For example, a range of 1 to 5 includes the two values 1 and 5.

[0037] In the descriptions of this application, it should be noted that, unless otherwise expressly specified and limited, the terms such as "mount", "interconnect", and "connect" should be understood in a broad sense, for example, may be a fixed connection, a detachable connection, an abutting connection, or an integral connection. A person of ordinary skill in the art may understand specific meanings of the foregoing terms in this application according to specific situations.

[0038] It should be understood that, in this application, "electrically connected" may be understood as physical contact and electrical conduction between components, or may be understood as a form in which different components in a line structure are connected through physical lines that can transmit a signal, such as a printed circuit board (printed circuit board, PCB) copper foil or a conductor wire. Both "connect" and "interconnect" may indicate a mechanical connection relationship or a physical connection relationship. For example, that A is connected to B or A and B are interconnected may indicate that there is a fastening component (for example, a screw, a bolt, or a rivet) between A and B, or A and B are in contact with each other and it is difficult to separate A from B.

[0039] In this application, an electrical length may be expressed by multiplying a physical length (namely, a mechanical length or a geometric length) by a ratio of transmission time of an electrical or electromagnetic signal in a medium to time required by the signal to travel, in free space, for a distance that is the same as the physical length of the medium. The electrical length may satisfy the following formula:

$$\bar{L} = L \times a/b$$

[0040] L is the physical length, a is the transmission time of the electrical or electromagnetic signal in the medium, and b is the transmission time in the free space.

[0041] Alternatively, an electrical length may be a ratio of a physical length (namely, a mechanical length or a geometric length) to a wavelength of a transmitted electromagnetic wave. The electrical length may satisfy the following formula:

$$\bar{L} = L/\lambda$$

[0042] L is the physical length, and λ is the wavelength of the electromagnetic wave.

[0043] Coupling is a phenomenon that two or more circuit elements or electrical networks closely cooperate with and affect each other in input and output, and energy is transmitted from one side to another side through interaction.

[0044] A millimeter-wave transmitter has advantages of a wide frequency band and high linearity, can meet requirements for ultra-large capacity transmission of a communication system, and brings great advantages to a millimeter-wave communication system. A millimeter-wave power amplifier is a core component of the millimeter-wave transmitter, and performance of the millimeter-wave power amplifier directly determines costs, a size, and transmission performance of the millimeter-wave transmitter. The millimeter-wave power amplifier includes a solid-state power amplifier and a traveling-wave tube. The applicable power of a solid-state power amplifier is relatively low, causing the millimeter-wave transmitter using the solid-state power amplifier to have low output power, and significantly limiting the coverage distance of a base station. Consequently, and a larger number of base stations must be deployed to meet coverage requirements, thereby increasing deployment costs.

[0045] The traveling-wave tube is a microwave electron tube that implements an electromagnetic wave amplification function through synchronization between a speed of an electron beam and a phase velocity of an electromagnetic wave. In the traveling-wave tube, the electron beam interacts with a traveling electromagnetic wave in a slow-wave circuit, and the electron beam continuously transfers kinetic energy to the electromagnetic wave, so that the electromagnetic wave is amplified. Because the electron beam interacts with a slow-wave structure instead of a resonant cavity, the traveling-wave tube has a wide operating frequency band, high efficiency, and large output power.

[0046] The slow-wave structure is an apparatus for implementing enhancement of interaction between electrons and an electromagnetic field in the traveling-wave tube, so that energy of an electronic flow is more effectively converted into high-frequency energy of the electromagnetic wave. A propagation speed of the electromagnetic wave in vacuum is the speed of light, and a movement speed of the electron beam in vacuum is far less than the speed of light. Therefore, to cause the electromagnetic wave to interact with the electron beam, a specific high-frequency structure needs to be used to reduce a movement velocity of the electromagnetic wave on an equiphase surface. In other words, the phase velocity of the electromagnetic wave needs to be reduced, so that the movement speed of the electrons is close to the phase velocity of the electromagnetic wave, to meet a synchronization condition.

[0047] The slow-wave structure includes a slow-wave structure of an all-metal waveguide type and a slow-wave structure of a dielectric-supported type. A material of the slow-wave structure of the all-metal waveguide type is all-metal, which is more conducive to processing and man-

ufacturing. The slow-wave structure includes a hollow metal waveguide tube. The hollow metal waveguide tube is configured to deform or fold a transmission path of an electromagnetic wave, to reduce a propagation phase velocity of the electromagnetic wave and implement energy conversion between the electromagnetic wave and electrons. The slow-wave structure of the all-metal waveguide type operates in a transverse electric wave/transverse magnetic (TE/TM) mode. In an electromagnetic wave transmission process, a transmission speed of the electromagnetic wave in the TE/TM mode is high. Therefore, more transmission paths of the electromagnetic wave need to be folded, to reduce the phase velocity of the electromagnetic wave to a required range. Consequently, a length of the hollow metal waveguide tube in a transmission direction of the electromagnetic wave is increased. Consequently, a structure size of the slow-wave structure of the all-metal waveguide type is increased, and a miniaturization requirement cannot be met. In addition, because a waveguide of this type needs to operate on a spatial harmonic wave to implement a slow-wave effect, an electric field of the electromagnetic wave transmitted through the hollow metal waveguide tube is small in the transmission direction. Consequently, the slow-wave structure of the all-metal waveguide type has a poor amplification effect on the electromagnetic wave.

[0048] The slow-wave structure of the dielectric-supported type includes a metal slow-wave line, dielectric-supported rods, and a metal envelope that are sequentially sleeved. The metal slow-wave line is used to transmit electromagnetic waves, and a structure of the metal slow-wave line is a bending structure, so that a path of the electromagnetic wave is folded when the electromagnetic wave is transmitted at the metal slow-wave line, to reduce a propagation phase velocity of the electromagnetic wave and implement energy conversion between the electromagnetic wave and electrons. The metal envelope functions as a waveguide that encloses the dielectric-supported rods and the metal slow-wave line. Materials of the dielectric-supported rods and the metal envelope are different. The material of the dielectric-supported rods is usually ceramic. The slow-wave structure of the dielectric-supported type has a dual-conductor structure, so that the slow-wave structure of the dielectric-supported type operates in a transverse electromagnetic (TEM/quasi-TEM) mode. Compared with the TE/TM mode, the TEM/quasi-TEM mode has a wider bandwidth, and easier reduction of the phase velocity of the electromagnetic wave to the required range in a small size. In addition, because this type of slow-wave structure operates on a first spatial harmonic wave in the TEM mode, an electric field of the electromagnetic wave transmitted through the metal slow-wave line is large in a transmission direction, so that the slow-wave structure of the dielectric-supported type has a good amplification effect on the electromagnetic wave.

[0049] The slow-wave structure of the dielectric-sup-

ported type is more conducive to miniaturization of the traveling-wave tube. However, currently, integration of an input coupler and an output coupler of the slow-wave structure of the dielectric-supported type with a waveguide is low, and the input coupler and the output coupler have poor consistency with a waveguide assembly manner in an assembly process. This causes assembly of a traveling-wave tube of the dielectric-supported type to be complex and an error to be easily generated, and is also not conducive to further miniaturization of the traveling-wave tube of the dielectric-supported type.

[0050] This application provides a slow-wave structure 100. FIG. 1 is a schematic perspective view of a structure of a slow-wave structure 100 according to an implementation of this application, and FIG. 2 is an exploded view of a slow-wave structure 100 according to the implementation shown in FIG. 1. The slow-wave structure 100 includes a housing 10 and a slow-wave transmission line 20. The housing 10 includes a first housing cover 11 and a second housing cover 12 that are connected in a stacked manner along a first direction (a Z direction in FIG. 1). The first housing cover 11 and the second housing cover 12 enclose to form a first waveguide 13, and the slow-wave transmission line 20 is fixed in the first waveguide 13.

[0051] The first waveguide 13 allows electrons to pass through. The first waveguide 13 may extend along a straight line in a second direction (a Y direction in FIG. 1), which may be perpendicular to the first direction. The cross-sectional area of the first waveguide 13 perpendicular to the second direction may remain unchanged along the second direction, to ensure consistency of the channel area of the first waveguide 13 along the extension direction, prevent the electrons from being blocked by an inner wall while traveling through the first waveguide 13, and improve space utilization of the first waveguide 13. The cross-sectional shape of the first waveguide 13 includes but is not limited to a circle or a rectangle, and may be set based on an actual requirement.

[0052] The slow-wave transmission line 20 is for transmission of an electromagnetic wave, the slow-wave transmission line 20 is fixed in the first waveguide 13, and the electromagnetic wave transmitted through the slow-wave transmission line 20 interacts with the electrons in the first waveguide 13 to amplify the electromagnetic wave.

[0053] The slow-wave transmission line 20 has a folded structure that folds the propagation path of the electromagnetic wave when the electromagnetic wave is transmitted at a metal slow-wave line, to reduce the propagation phase velocity of the electromagnetic wave. The entire slow-wave transmission line 20 may extend along a straight line along the second direction, and an extension direction of the slow-wave transmission line 20 is the same as the extension direction of the first waveguide 13, so that the overall transmission direction of the electromagnetic wave at the slow-wave transmission line 20 is the same as a transmission direction of the electrons

in the first waveguide 13.

[0054] FIG. 4 is a diagram of a structure of a slow-wave structure 100 in which neither an input coupler 30 nor an output coupler 40 is coplanar with a first plane 26, and the housing 10 is not disposed according to an implementation of this application. The slow-wave transmission line 20 may extend along the first plane 26, the first plane 26 is one of planes perpendicular to the first direction, the entire slow-wave transmission line 20 extends along the second direction on the first plane 26, and a central axis of the slow-wave transmission line 20 is located on the first plane 26, so that the slow-wave transmission line 20 is symmetrically disposed relative to the first plane 26.

[0055] In an embodiment, the slow-wave transmission line 20 may extend in a spiral manner along the second direction. In a spiral extension process of the slow-wave transmission line 20, the radius of a single spiral may remain unchanged, to ensure consistency of folding degrees of the path at all positions when the electromagnetic wave is transmitted through the metal slow-wave line.

[0056] In an embodiment, the slow-wave transmission line 20 may alternatively curve and extend along the second direction on the first plane 26. The slow-wave transmission line 20 includes a plurality of curved lines that are connected in a head-to-tail manner. The plurality of curved lines may have a same shape and a same size, and the shape of the plurality of curved lines includes but is not limited to a U shape, a V shape, or an S shape.

[0057] The slow-wave structure 100 further includes the input coupler 30 and the output coupler 40. Both the input coupler 30 and the output coupler 40 are electrically connected to the slow-wave transmission line 20. The input coupler 30 is configured to input the electromagnetic wave to the slow-wave transmission line 20. In a process of transmitting the electromagnetic wave by the slow-wave transmission line 20, the electrons in the first waveguide 13 interact with an electromagnetic wave field of the electromagnetic wave, and the electrons continuously transfer kinetic energy to the electromagnetic wave field, so that the electromagnetic wave is amplified. The slow-wave transmission line 20 transmits an amplified electromagnetic wave to the output coupler 40, and the output coupler 40 outputs the amplified electromagnetic wave from the slow-wave structure 100.

[0058] At least one of the input coupler 30 and the output coupler 40 is not coplanar with the first plane 26. In an embodiment, refer to FIG. 4. Neither the input coupler 30 nor the output coupler 40 may be coplanar with the first plane 26. In an embodiment, FIG. 5 is a diagram of a structure of a slow-wave structure 100 in which only an input coupler 30 is not coplanar with a first plane 26 and no housing 10 is disposed according to an implementation of this application. The input coupler 30 may not be coplanar with the first plane 26, and the output coupler 40 may be coplanar with the first plane 26. In an embodiment, FIG. 6 is a diagram of a structure of a slow-wave structure 100 in which only an output coupler 40 is

not coplanar with a first plane 26 and no housing 10 is disposed according to an implementation of this application. The input coupler 30 may be coplanar with the first plane 26, and the output coupler 40 may not be coplanar with the first plane 26.

[0059] That at least one of the input coupler 30 and the output coupler 40 is not coplanar with the first plane 26 means that at least one of the input coupler 30 and the output coupler 40 is not parallel to the first plane 26, and at least one of the input coupler 30 and the output coupler 40 is not located on the first plane 26. Both the input coupler 30 and the output coupler 40 may be angled relative to the first plane 26; the input coupler 30 is angled relative to the first plane 26, and the output coupler 40 is parallel to the first plane 26; or the input coupler 30 is parallel to the first plane 26, and the output coupler 40 is angled relative to the first plane 26.

[0060] For example, both the input coupler 30 and the output coupler 40 are perpendicular to the first plane 26; the input coupler 30 is perpendicular to the first plane 26, and the output coupler 40 is parallel to the first plane 26; or the input coupler 30 is parallel to the first plane 26, and the output coupler 40 is perpendicular to the first plane 26.

[0061] The housing 10 includes the first housing cover 11 and the second housing cover 12 that are connected in the stacked manner along the first direction. The slow-wave structure 100 may be a stacked structure. In a manufacturing process of the slow-wave structure 100, layer structures in the slow-wave structure 100 can be separately processed, so that the layer structures in the slow-wave structure 100 can be simultaneously processed. This helps implement planar batch manufacturing, shorten processing time, and improve production and processing efficiency of the slow-wave structure 100. In addition, the processed layer structures can be sequentially assembled in a stacking direction. An assembly manner in the stacking direction has a small error and is more applicable to industrial production and manufacturing. This helps simplify a processing and assembly process of the slow-wave structure 100, improve production precision and a yield rate of the slow-wave structure 100, and improve an amplification effect of the slow-wave structure 100 on the electromagnetic wave and stability of amplification.

[0062] At least one of the input coupler 30 and the output coupler 40 is not coplanar with the first plane 26, and at least one of the input coupler 30 and the output coupler 40 has the included angle with the first plane 26 in a disposing process, so that a disposing direction of at least one of the input coupler 30 and the output coupler 40 has good consistency with the stacking direction. When the input coupler 30 or the output coupler 40 is processed, at least one of the input coupler 30 and the output coupler 40 can be integrated with another structure in the slow-wave structure 100 in the stacking direction, to improve integration of at least one of the input coupler 30 and the output coupler 40, and help implement min-

iaturation of the slow-wave structure 100. In addition, this further helps match the stacking connection manner of the first housing cover 11 and the second housing cover 12, implement assembly of the input coupler 30 or the output coupler 40 in the stacking direction, and simplify a manner of disposing the input coupler 30 and/or the output coupler 40, so that the assembly of the input coupler 30 or the output coupler 40 is more convenient for industrial production.

[0063] The slow-wave structure 100 provided in this application includes the housing 10, the slow-wave transmission line 20, the input coupler 30, and the output coupler 40. Both the input coupler 30 and the output coupler 40 are electrically connected to the slow-wave transmission line 20. The housing 10 encloses the first waveguide 13. The slow-wave transmission line 20 is fixed in the first waveguide 13, so that the electromagnetic wave can be transmitted through the slow-wave transmission line 20, and the electrons in the first waveguide 13 can act on the electromagnetic wave transmitted through the slow-wave transmission line 20, to implement amplification of the electromagnetic wave. The slow-wave structure 100 uses a TEM/quasi-TEM mode. This helps ensure that the electromagnetic wave has a good amplification effect.

[0064] The housing 10 includes the first housing cover 11 and the second housing cover 12 that are connected in the stacked manner along the first direction, so that the slow-wave structure 100 is the stacked structure. In the manufacturing process of the slow-wave structure 100, the layer structures in the slow-wave structure 100 can be separately processed. This helps implement the planar batch manufacturing, shorten the processing time, and improve the production and processing efficiency of the slow-wave structure 100. In addition, at least one of the input coupler 30 and the output coupler 40 is not coplanar with the first plane 26, so that at least one of the input coupler 30 and the output coupler 40 has good consistency with the stacking direction. In other words, at least one of the input coupler 30 and the output coupler 40 has good consistency with an assembly manner of the slow-wave structure 100. This helps simplify production and assembly of the input coupler 30 and/or the output coupler 40, improve integration of the input coupler 30 and the output coupler 40, and implement the miniaturization of the slow-wave structure 100.

[0065] In a possible implementation, refer to FIG. 4. The input coupler 30 includes a first mode converter 31, and the output coupler 40 includes a second mode converter 41. The first mode converter 31 is configured to convert a waveguide mode of the electromagnetic wave from a TE mode to the TEM mode, and the second mode converter 41 is configured to convert the mode of the electromagnetic wave from the TEM mode to the TE mode, so that a mode of the electromagnetic wave is the TE mode when the electromagnetic wave is output.

[0066] The first mode converter 31 has a plurality of first metal portions 311, the plurality of first metal portions

311 are sequentially connected, and two adjacent first metal portions 311 form a stepped structure. Similarly, the second mode converter 41 has a plurality of second metal portions 411, the plurality of second metal portions 411 are sequentially connected, and two adjacent second metal portions 411 form a stepped structure. At least one of the first mode converter 31 and the second mode converter 41 is not coplanar with the first plane 26. In other words, at least one of an arrangement direction of the plurality of first metal portions 311 and an arrangement direction of the plurality of second metal portions 411 is angled relative to the first plane 26.

[0067] Refer to FIG. 4. When neither the first mode converter 31 nor the second mode converter 41 is coplanar with the first plane 26, both the arrangement direction of the plurality of first metal portions 311 and the arrangement direction of the plurality of second metal portions 411 are angled relative to the first plane 26. Refer to FIG. 5. When the first mode converter 31 is not coplanar with the first plane 26, and the second mode converter 41 is coplanar with the first plane 26, the arrangement direction of the plurality of first metal portions 311 is angled relative to the first plane 26, and the arrangement direction of the plurality of second metal portions 411 is parallel to the first plane 26. Refer to FIG. 6. When the first mode converter 31 is coplanar with the first plane 26, and the second mode converter 41 is not coplanar with the first plane 26, the arrangement direction of the plurality of first metal portions 311 is parallel to the first plane 26, and the arrangement direction of the plurality of second metal portions 411 is angled relative to the first plane 26.

[0068] For example, both the arrangement direction of the plurality of first metal portions 311 and the arrangement direction of the plurality of second metal portions 411 are perpendicular to the first plane 26; the arrangement direction of the plurality of first metal portions 311 is perpendicular to the first plane 26, and the arrangement direction of the plurality of second metal portions 411 is parallel to the first plane 26; or the arrangement direction of the plurality of first metal portions 311 is parallel to the first plane 26, and the arrangement direction of the plurality of second metal portions 411 is perpendicular to the first plane 26.

[0069] When the input coupler 30 and the output coupler 40 are processed, one of the first mode converter 31 and the second mode converter 41 that is not coplanar with the first plane 26 can implement integration with another structure in the slow-wave structure 100 in the stacking direction. To be specific, at least one of the plurality of first metal portions 311 and the plurality of second metal portions 411 is sequentially disposed in the stacking direction, and two adjacent first metal portions 311 or two adjacent second metal portions 411 are sequentially connected in the stacking direction. This helps simplify the production and the assembly of the input coupler 30 and/or the output coupler 40, improve the integration of the input coupler 30 and the output coupler 40, and implement the miniaturization of the slow-wave

structure 100. Two adjacent first metal portions 311 or two adjacent second metal portions 411 may be sequentially welded along the stacking direction, so that the plurality of first metal portions 311 form the integrated first mode converter 31 or the plurality of second metal portions 411 form the integrated second mode converter 41.

[0070] For example, refer to FIG. 4. Both the first mode converter 31 and the second mode converter 41 are perpendicular to the first plane 26, and both the arrangement direction of the plurality of first metal portions 311 and the arrangement direction of the plurality of second metal portions 411 are perpendicular to the first plane 26. When the input coupler 30 and the output coupler 40 are processed, the plurality of first metal portions 311 and the plurality of second metal portions 411 are sequentially connected in the stacking direction, and volumes of the plurality of first metal portions 311 and volumes of the plurality of second metal portions 411 in the stacking direction decrease sequentially, so that two adjacent first metal portions 311 or two adjacent second metal portions 411 form the stepped structure in the stacking direction.

[0071] For example, refer to FIG. 5. The first mode converter 31 is perpendicular to the first plane 26, the second mode converter 41 is parallel to the first plane 26, the arrangement direction of the plurality of first metal portions 311 is perpendicular to the first plane 26, and the arrangement direction of the plurality of second metal portions 411 is parallel to the first plane 26. When the input coupler 30 is processed, the plurality of first metal portions 311 are sequentially connected in the stacking direction, so that the production and the assembly of the input coupler 30 are more convenient, and the integration of the input coupler 30 is improved.

[0072] In an implementation, refer to FIG. 2, FIG. 3, and FIG. 4. FIG. 3 is a diagram of a structure of a first housing cover in the implementation shown in FIG. 1. The input coupler 30 further includes an input coaxial cable 32 and a second waveguide 33. The input coaxial cable 32 is electrically connected to the slow-wave transmission line 20 and the first mode converter 31. The input coaxial cable 32 is configured to convert the waveguide mode of the electromagnetic wave from the TEM mode to the quasi-TEM mode, so that a mode of the electromagnetic wave at the slow-wave transmission line 20 is the quasi-TEM mode. Two ends of the input coaxial cable 32 may be respectively electrically connected to the slow-wave transmission line 20 and the first mode converter 31. The input coaxial cable 32 is electrically connected to the plurality of first metal portions 311. The input coaxial cable 32 may be directly connected to a single first metal portion 311 that is located at an end and that is in the plurality of first metal portions 311. In other words, the input coaxial cable 32 may be in contact with the single first metal portion 311 that is located at the end and that is in the plurality of first metal portions 311. The plurality of first metal portions 311 and at least part of the input coaxial cable 32 are located in the second waveguide 33, and the second waveguide 33 is configured to couple

the electromagnetic wave, so that the electromagnetic wave is transmitted from the input coupler 30 to the slow-wave transmission line 20.

[0073] Similarly, the output coupler 40 includes an output coaxial cable 42 and a third waveguide 43. The output coaxial cable 42 is electrically connected to the slow-wave transmission line 20 and the second mode converter 41. The output coaxial cable 42 is configured to convert the waveguide mode of the electromagnetic wave from the quasi-TEM mode to the TEM mode, so that a mode of the electromagnetic wave transmitted through the slow-wave transmission line 20 to the second mode converter 41 is the TEM mode. Two ends of the output coaxial cable 42 may be respectively electrically connected to the slow-wave transmission line 20 and the second mode converter 41. The input coaxial cable 32 may be directly connected to a single second metal portion 411 that is located at an end and that is in the plurality of second metal portions 411. The plurality of second metal portions 411 and at least part of the output coaxial cable 42 are located in the third waveguide 43, and the third waveguide 43 is configured to couple the electromagnetic wave, so that the amplified electromagnetic wave is output from the slow-wave transmission line 20.

[0074] Both the input coaxial cable 32 and the output coaxial cable 42 may extend along straight lines, and both an extension direction of the input coaxial cable 32 and an extension direction of the output coaxial cable 42 may be parallel to the first plane 26. In comparison with a case in which both the extension direction of the input coaxial cable 32 and the extension direction of the output coaxial cable 42 are angled relative to the first plane 26, space occupied by the input coupler 30 and the output coupler 40 along the first direction (the Z direction in FIG. 4) is reduced. This helps simplify a manner of disposing the input coaxial cable 32 and the output coaxial cable 42, and fully utilize space of the slow-wave structure 100 in the first plane 26.

[0075] In an implementation, refer to FIG. 4, FIG. 5, and FIG. 6. Both the input coupler 30 and the output coupler 40 are located on a same side of the slow-wave transmission line 20 along the first direction (the Z direction in FIG. 4 to FIG. 6). In other words, both the input coupler 30 and the output coupler 40 are located on a same side of the slow-wave transmission line 20 in the stacking direction. When the input coupler 30 and the output coupler 40 are processed, the input coupler 30 and the output coupler 40 can be integrated at the same time. This helps simplify the production and the assembly of the input coupler 30 and the output coupler 40. In addition, in comparison with a case in which the input coupler 30 and the output coupler 40 are respectively located on two opposite sides of the slow-wave transmission line 20 along the first direction, space occupied by the slow-wave transmission line 20, the input coupler 30, and the output coupler 40 along the first direction is reduced. This helps implement the miniaturization of the slow-wave structure 100.

[0076] The input coupler 30 and the output coupler 40 may be respectively directly connected to two ends of the slow-wave transmission line 20. In other words, the input coupler 30 and the output coupler 40 may be respectively directly in contact with the two ends of the slow-wave transmission line 20, so that an extension length of the slow-wave transmission line 20 along the second direction is fully utilized. This helps implement the miniaturization of the slow-wave structure 100.

[0077] The slow-wave transmission line 20 extends along the second direction (the Y direction in FIG. 4 to FIG. 6), and both the input coaxial cable 32 and the output coaxial cable 42 may extend along a third direction (an X direction in FIG. 4 to FIG. 6). The third direction is perpendicular to both the second direction and the first direction. In this case, the two ends of the input coaxial cable 32 are respectively connected to the plurality of first metal portions 311 and the slow-wave transmission line 20, and the two ends of the output coaxial cable 42 are respectively connected to the plurality of second metal portions 411 and the slow-wave transmission line 20. In this way, both the plurality of first metal portions 311 and the plurality of second metal portions 411 are disposed at spacings with the slow-wave transmission line 20, to provide space for disposing of the slow-wave transmission line 20 and electron transmission in the first waveguide 13. The input coupler 30 and the output coupler 40 may be respectively located on two sides of the slow-wave transmission line 20 along the third direction, so that the input coupler 30 and the output coupler 40 are disposed in a staggered manner relative to the slow-wave transmission line 20. This is convenient for identification when an input apparatus 203 and an output apparatus 204 are respectively connected to the input coupler 30 and the output coupler 40 of the slow-wave structure 100.

[0078] In a possible implementation, FIG. 7 is a diagram of a structure of a slow-wave structure 100 that has a single transmission line segment and a single attenuator 60 and in which no housing 10 is disposed according to an implementation of this application, and FIG. 8 is a diagram of a structure of a slow-wave structure 100 that has two transmission line segments and two attenuators 60 and in which no housing 10 is disposed according to an implementation of this application. The slow-wave structure 100 includes at least one attenuator 60, and the attenuator 60 is configured to absorb an electromagnetic wave. The single attenuator 60 is electrically connected to the input coupler 30 or the output coupler 40, the single attenuator 60 is indirectly electrically connected to the input coupler 30 through the slow-wave transmission line 20, and the slow-wave transmission line 20 is located between the input coupler 30 and the attenuator 60. The single attenuator 60 may be indirectly electrically connected to the output coupler 40 through the slow-wave transmission line 20, or may be directly electrically connected to the output coupler 40. When the attenuator 60 is directly electrically connected to the output coupler 40,

the single attenuator 60 is connected to the output coupler 40 through direct contact.

[0079] In an embodiment, refer to FIG. 7. The slow-wave transmission line 20 is the single transmission line segment, and the input coupler 30 and the output coupler 40 are respectively directly connected to the two ends of the slow-wave transmission line 20. The slow-wave structure 100 includes the single attenuator 60, and the single attenuator 60 is directly connected to the output coupler 40. When electromagnetic waves are transmitted from the input coupler 30 to the output coupler 40 through the slow-wave transmission line 20, most electromagnetic waves can be output from the output coupler 40. To avoid that part of electromagnetic waves are reflected to the slow-wave transmission line 20 at the output coupler 40 and consequently electromagnetic waves in the slow-wave transmission line 20 are affected during transmission, the output coupler 40 is electrically connected to the attenuator 60, and the attenuator 60 absorbs a redundant electromagnetic wave at the output coupler 40. This helps avoid that the electromagnetic wave is reflected to the slow-wave transmission line 20, improve stability of electromagnetic wave transmission at the slow-wave transmission line 20, and ensure the amplification effect of the slow-wave structure 100 on the electromagnetic wave.

[0080] In an embodiment, refer to FIG. 8 and FIG. 9. FIG. 9 is a diagram of a structure of a slow-wave structure 100 that has three transmission line segments and four attenuators 60 and in which no housing 10 is disposed according to an implementation of this application. The slow-wave transmission line 20 includes at least two transmission line segments. The at least two transmission line segments are sequentially disposed along the second direction, two adjacent transmission line segments are disposed at a spacing, and two adjacent transmission line segments are spaced along the second direction. The input coupler 30 and the output coupler 40 are located at the two ends of the slow-wave transmission line 20, and the input coupler 30 and the output coupler 40 are respectively electrically connected to two transmission line segments located at the two ends. When the slow-wave transmission line 20 includes at least two transmission line segments, the electromagnetic wave is sequentially transmitted at the at least two transmission line segments, and two adjacent transmission line segments are disposed at a spacing. A spacing distance between two adjacent transmission line segments is set, so that truncation of a transmission path of the electromagnetic wave can be implemented at the spacing between the two adjacent transmission line segments. In addition, an electron beam used to interact with the electromagnetic wave at the spacing may enter a next segment of slow-wave line without interception under magnetic confinement, and excite a corresponding electromagnetic field to continue to interact with the electromagnetic wave. This helps improve the amplification effect on the electromagnetic wave.

[0081] The slow-wave structure 100 further includes at least two couplers 50 at spacings. The coupler 50 at the spacing is electrically connected to ends that are of two adjacent transmission line segments and that are at the spacing. Two ends of one of the two transmission line segments at the two ends are respectively electrically connected to the input coupler 30 and the coupler 50 that is at the spacing, and two ends of the other transmission line segment are respectively electrically connected to the output coupler 40 and the coupler 50 that is the spacing.

[0082] The slow-wave structure 100 includes at least two attenuators 60. The attenuator 60 is electrically connected to the coupler 50 at the spacing, and a quantity of couplers 50 at spacings is the same as a quantity of attenuators 60. Both the input coupler 30 and the output coupler 40 are indirectly electrically connected to the attenuator 60 through the transmission line. The coupler 50 at the spacing is directly electrically connected to the attenuator 60. In other words, the coupler 50 at the spacing is in direct contact with the attenuator 60. The coupler 50 at the spacing is electrically connected to both the transmission line and the attenuator 60, so that the coupler 50 at the spacing is located between the transmission line and the attenuator 60. Each transmission line segment is electrically connected to at least one attenuator 60, so that the attenuator 60 is disposed at each transmission line segment to absorb a redundant electromagnetic wave. This avoids that the electromagnetic wave is reflected at each transmission line segment, and helps improve stability of amplification of the electromagnetic wave at each transmission line segment.

[0083] A quantity of transmission lines included in the slow-wave transmission line 20 is n , and a quantity of attenuators 60 in the slow-wave structure 100 is m . When the slow-wave transmission line 20 includes at least two transmission line segments, the quantity of transmission lines and the quantity of attenuators 60 satisfy a relational expression: $m=2 \times (n-1)$. The slow-wave structure 100 satisfies the foregoing relational expression, so that each transmission line segment is electrically connected to at least one attenuator 60. This helps improve transmission stability of the electromagnetic wave at each transmission line segment.

[0084] For example, refer to FIG. 8. The slow-wave transmission line 20 includes two transmission line segments. The two transmission line segments are respectively a first transmission line 21 and a second transmission line 22. Two ends of the first transmission line 21 are respectively electrically connected to the input coupler 30 and a coupler 51 at a first spacing, and two ends of the second transmission line 22 are respectively electrically connected to the output coupler 40 and a coupler 52 at a second spacing. The slow-wave structure 100 includes two attenuators 60. The two attenuators 60 are respectively a first attenuator 61 and a second attenuator 62. The first attenuator 61 is electrically connected to the

coupler 51 at the first spacing, and the second attenuator 62 is electrically connected to the coupler 52 at the second spacing.

[0085] For example, refer to FIG. 9. The slow-wave transmission line 20 includes three transmission line segments. The three transmission line segments are respectively a first transmission line 21, a second transmission line 22, and a third transmission line 23. The first transmission line 21 and the second transmission line 22 are respectively located at the two ends of the slow-wave transmission line 20, and the third transmission line 23 is located in a middle area of the slow-wave transmission line 20. Two ends of the first transmission line 21 are respectively electrically connected to the input coupler 30 and the coupler 51 at the first spacing, two ends of the second transmission line 22 are respectively electrically connected to the output coupler 40 and the coupler 52 at the second spacing, and two ends of the third transmission line 23 are respectively electrically connected to a coupler 53 at a third spacing and a coupler 54 at a fourth spacing. The slow-wave structure 100 includes four attenuators 60. The four attenuators 60 are respectively the first attenuator 61, the second attenuator 62, a third attenuator 63, and a fourth attenuator 64. The first attenuator 61 is electrically connected to the coupler 51 at the first spacing, the second attenuator 62 is electrically connected to the coupler 52 at the second spacing, the third attenuator 63 is electrically connected to the coupler 53 at the third spacing, and the fourth attenuator 64 is electrically connected to the coupler 54 at the fourth spacing, so that the two ends of the third transmission line 23 are respectively electrically connected to the third attenuator 63 and the fourth attenuator 64.

[0086] In a possible implementation, refer to FIG. 8 and FIG. 9. Neither the input coupler 30 nor the output coupler 40 is coplanar with the first plane 26, so that disposition directions of both the input coupler 30 and the output coupler 40 have good consistency with the stacking direction. Both the input coupler 30 and the output coupler 40 can implement integration with another structure in the slow-wave structure 100 in the stacking direction. This helps simplify the manner of depositing the input coupler 30 and the output coupler 40, and improve the integration of the input coupler 30 and the output coupler 40.

[0087] The couplers 50 at the spacings are all coplanar with the first plane 26, so that disposing directions of the couplers 50 at the spacings are all parallel to the first plane 26. This helps provide space for disposing of the attenuator 60. In comparison with a case in which the coupler 50 at the spacing is not coplanar with the first plane 26, when the attenuator 60 is electrically connected to the coupler 50 at the spacing that is coplanar with the first plane 26, space occupied by the attenuator 60 and the coupler 50 at the spacing is small along the first direction. This helps implement the miniaturization of the slow-wave structure 100.

[0088] For example, refer to FIG. 8. Both the input

coupler 30 and the output coupler 40 are perpendicular to the first plane 26. Both the two couplers 50 at the spacings are parallel to the first plane 26, and disposition directions of the coupler 50 at the spacing and the attenuator 60 electrically connected to the coupler 50 at the spacing are parallel to the first plane 26. This helps fully utilize space parallel to the first plane 26 of the slow-wave structure 100, reduce space occupied by the attenuator 60 and the coupler 50 at the spacing along the first direction, and implement the miniaturization of the slow-wave structure 100.

[0089] The coupler 50 at the spacing includes a third mode converter 55, a coaxial cable 56 at the spacing, and a fourth waveguide. The third mode converter 55 includes a plurality of third metal portions 551, the plurality of third metal portions 551 are sequentially connected, two adjacent third metal portions 551 form a stepped structure, and an arrangement direction of the plurality of third metal portions 551 is parallel to the first plane 26. The coaxial cable 56 at the spacing is electrically connected to the slow-wave transmission line 20 and the third mode converter 55. Two ends of the coaxial cable 56 at the spacing may be respectively electrically connected to the slow-wave transmission line 20 and the third mode converter 55. The coaxial cable 56 at the spacing is electrically connected to the plurality of third metal portions 551. The coaxial cable 56 at the spacing may be directly connected to a single third metal portion 551 that is located at an end and that is in the plurality of third metal portions 551. The coaxial cable 56 at the spacing may extend along the third direction. The plurality of third metal portions 551 and at least part of the coaxial cable 56 at the spacing are located in the fourth waveguide, and the fourth waveguide is configured to couple the electromagnetic wave, so that part of amplified electromagnetic waves are absorbed by the attenuator 60.

[0090] In a possible implementation, refer to FIG. 8 and FIG. 9. The slow-wave transmission line 20 includes at least two repeating units, and a single transmission line segment includes at least one repeating unit, so that the single transmission line segment includes at least one periodicity. In other words, a periodicity quantity of the single transmission line segment is the same as a quantity of repeating units in the single transmission line segment. A plurality of repeating units are connected in a head-to-tail manner along the second direction (the Y direction in FIG. 8 and FIG. 9), and a minimum length of a single repeating unit along the second direction is one periodicity length. In other words, a periodicity length of the single transmission line segment is the minimum length of the single repeating unit in the single transmission line segment along the second direction.

[0091] The slow-wave transmission line 20 includes at least two transmission line segments, and the at least two transmission line segments are different in at least one of periodicity quantity and periodicity length, so that a reduction rate of a phase velocity of the electromagnetic wave at each transmission line segment varies. This

helps improve the amplification effect of the slow-wave structure 100 on the electromagnetic wave.

[0092] For example, refer to FIG. 8. The slow-wave transmission line 20 includes the first transmission line 21 and the second transmission line 22, a periodicity length of the first transmission line 21 is the same as a periodicity length of the second transmission line 22, and a periodicity quantity of the first transmission line 21 is less than a periodicity quantity of the second transmission line 22, so that a length of the first transmission line 21 along the second direction is less than a length of the second transmission line 22 along the second direction.

[0093] In an implementation, the repeating unit in the slow-wave transmission line 20 is a curved line, at least two curved lines have a same shape and a same size, and the shape of the at least two curved lines includes but is not limited to a U shape, a V shape, or an S shape.

[0094] In a possible implementation, refer to FIG. 7, FIG. 8, and FIG. 9. The attenuator 60 is in a wedge shape. A cross-sectional area of the attenuator 60 on a side close to the coupler 50 at the spacing is larger than a cross-sectional area of the attenuator 60 on a side away from the coupler 50 at the spacing, and the cross section is perpendicular to a direction from the coupler 50 at the spacing to the attenuator 60. The attenuator 60 is in the wedge shape. This helps reduce reflection of the electromagnetic wave in the attenuator 60, so that the attenuator 60 can absorb an electromagnetic wave with a larger frequency range and larger power.

[0095] For example, the direction from the coupler 50 at the spacing to the attenuator 60 is parallel to the second direction, and a cross-sectional area of the side that is of the attenuator 60 and that is close to the coupler 50 at the spacing in a direction perpendicular to the second direction is greater than a cross-sectional area of the side that is of the attenuator 60 and that is away from the coupler 50 at the spacing in the direction perpendicular to the second direction, so that an extension direction of the attenuator 60 is parallel to the extension direction of the slow-wave transmission line 20. This helps fully utilize space of the slow-wave structure 100 and implement the miniaturization of the slow-wave structure 100.

[0096] In a possible implementation, refer to FIG. 2, FIG. 3, and FIG. 4. The first housing cover 11 includes a first accommodation cavity 114, a second accommodation cavity 115, and a third accommodation cavity 116 that communicate with each other. The first accommodation cavity 114 is a cavity of the first waveguide 13, and the first accommodation cavity 114 is for accommodating the slow-wave transmission line 20 and for electrons to pass through. The first accommodation cavity 114 may form the cavity of the first waveguide 13, and the first housing cover 11 independently forms the first waveguide 13, so that the slow-wave transmission line 20 is integrated only with the first housing cover 11. Alternatively, the first housing cover 11 and the second housing cover 12 may jointly form the cavity of the first waveguide 13

through enclosing, and the first housing cover 11 and the second housing cover 12 jointly form the second waveguide 33, so that the slow-wave transmission line 20 is integrated with both the first housing cover 11 and the second housing cover 12.

[0097] Both the second accommodation cavity 115 and the third accommodation cavity 116 communicate with the first accommodation cavity 114, the second accommodation cavity 115 forms a cavity of the second waveguide 33, the first housing cover 11 forms the second waveguide 33, the second accommodation cavity 115 is for accommodating the plurality of first metal portions 311, and the input coaxial cable 32 is located at a junction between the second accommodation cavity 115 and the first accommodation cavity 114, so that an end that is of the input coaxial cable 32 and that is electrically connected to the plurality of first metal portions 311 is located in the second accommodation cavity 115, and an end that is of the input coaxial cable 32 and that is electrically connected to the slow-wave transmission line 20 is located in the first accommodation cavity 114. The third accommodation cavity 116 forms a cavity of the third waveguide 43, the first housing cover 11 forms the third waveguide 43, the third accommodation cavity 116 is for accommodating the plurality of second metal portions 411, and the output coaxial cable 42 is located at a junction between the third accommodation cavity 116 and the first accommodation cavity 114, so that an end that is of the output coaxial cable 42 and that is electrically connected to the plurality of second metal portions 411 is located in the third accommodation cavity 116, and an end that is of the output coaxial cable 42 and that is electrically connected to the slow-wave transmission line 20 is located in the first accommodation cavity 114.

[0098] The first housing cover 11 forms the second waveguide 33 and the third waveguide 43. This helps implement integration of the input coupler 30 and the output coupler 40 with the first housing cover 11. When the first housing cover 11 and the second housing cover 12 are assembled in the stacking direction, the integration of the input coupler 30 and the output coupler 40 with the slow-wave structure 100 can be synchronously implemented. This helps implement the assembly of the input coupler 30 and the output coupler 40 in the stacking direction, and simplify the manner of disposing the input coupler 30 and the output coupler 40. In addition, in comparison with separately disposing a housing cover structure to form the second waveguide 33 and the third waveguide 43 and then integrating the second waveguide 33 and the third waveguide 43 with the first housing cover 11, a quantity of structures of the slow-wave structure 100 is reduced, and the integration of the input coupler 30 and the output coupler 40 is improved, helping implement the miniaturization of the slow-wave structure 100.

[0099] In an implementation, refer to FIG. 7. The attenuator 60 is electrically connected to the output coupler 40, and the attenuator 60 electrically connected to the

output coupler 40 is accommodated in the third accommodation cavity 116. This helps improve integration of the attenuator 60 and the output coupler 40.

[0100] In an implementation, refer to FIG. 8. The first housing cover 11 further includes a fourth accommodation cavity, the fourth accommodation cavity communicates with the first accommodation cavity 114, the fourth accommodation cavity forms a cavity of the fourth waveguide, the first housing cover 11 forms the fourth waveguide, the fourth accommodation cavity is for accommodating the plurality of third metal portions 551 and the attenuator 60, and the coaxial cable 56 at the spacing is located at a junction between the fourth accommodation cavity and the first accommodation cavity 114, so that an end that is of the coaxial cable 56 at the spacing and that is electrically connected to the plurality of third metal portions 551 is located in the fourth accommodation cavity, and an end that is of the coaxial cable 56 at the spacing and that is electrically connected to the slow-wave transmission line 20 is located in the first accommodation cavity 114.

[0101] The first housing cover 11 forms the fourth waveguide. This helps implement integration of the coupler 50 and the attenuator 60 at the spacing with the first housing cover 11. When the first housing cover 11 and the second housing cover 12 are assembled in the stacking direction, integration of the coupler 50 at the spacing with the slow-wave structure 100 can be synchronously implemented, and accommodation space can be provided for the disposing of the attenuator 60. This helps implement assembly of the coupler 50 at the spacing and the attenuator 60 in the stacking direction and simplify a manner of disposing the coupler 50 at the spacing and the attenuator 60. In addition, the quantity of structures of the slow-wave structure 100 is reduced, and integration of the coupler 50 at the spacing and the attenuator 60 is improved. This helps implement the miniaturization of the slow-wave structure 100.

[0102] For example, the fourth accommodation cavity is located on two sides of the slow-wave transmission line 20 along the second direction, so that the coupler 50 at the spacing and the attenuator 60 are located on the two sides of the slow-wave transmission line 20 along the second direction. This helps fully utilize edge space of the first housing 10 and implement the miniaturization of the slow-wave structure 100.

[0103] In a possible implementation, FIG. 10 is a diagram of a structure of a slow-wave structure 100 that has an energy transmission window and a reflecting member according to an implementation of this application, and FIG. 11 is an exploded view of a slow-wave structure 100 according to the implementation shown in FIG. 10. The first housing cover 11 has a first input hole 111 and a first output hole 112, the first input hole 111 and the first output hole 112 are disposed at a spacing, the input coupler 30 is fixed to an inner wall of the first input hole 111, and the output coupler 40 is fixed to an inner wall of the first output hole 112, so that at least part of the input coupler 30 and at

least part of the output coupler 40 are accommodated in a housing layer of the first housing 10. A thickness of the first housing 10 is fully utilized to provide accommodation space for the input coupler 30 and the output coupler 40. This improves integration of the input coupler 30 and the output coupler 40 with the first housing 10, and helps implement the miniaturization of the slow-wave structure 100.

[0104] Both a penetration direction of the first input hole 111 and a penetration direction of the first output hole 112 are angled relative to the first plane 26, so that the penetration direction of the first input hole 111 and the penetration direction of the first output hole 112 have good consistency with the stacking direction, so that at least one of the input coupler 30 and the output coupler 40 is not coplanar with the first plane 26. In this way, at least one of the input coupler 30 and the output coupler 40 can implement integration with another structure in the slow-wave structure 100 in the stacking direction, and the manner of disposing the input coupler 30 and/or the output coupler 40 is simplified.

[0105] The slow-wave structure 100 further includes a first energy transmission window 34 and a second energy transmission window. The first energy transmission window 34 seals the first input hole 111, and the second energy transmission window seals the first output hole 112, so that the first input hole 111 and the first output hole 112 are sealed, to ensure that the first waveguide 13 is in a sealed state, and help provide a vacuum environment for the electron transmission in the first waveguide 13. The first energy transmission window 34 is located between the input coupler 30 and an opening of the first input hole 111, the second energy transmission window is located between the output coupler 40 and an opening of the first output hole 112, and the first energy transmission window 34 and the second energy transmission window respectively implement sealing of the first waveguide 13 at the first input hole 111 and the first output hole 112.

[0106] In an implementation, the slow-wave structure 100 further includes an input waveguide interface 35 and an output waveguide structure. The input waveguide interface 35 is configured to electrically connect the input coupler 30 to the input apparatus 203, and the output waveguide interface 44 is configured to electrically connect the output coupler 40 to the output apparatus 204. The input waveguide interface 35 is inserted into the first input hole 111 and is in contact with the first energy transmission window 34, and the first energy transmission window 34 is configured to electrically connect the input coupler 30 to the input waveguide interface 35, so that an electromagnetic wave at the input apparatus 203 can be transmitted to the input coupler 30 through the first energy transmission window 34. The output waveguide interface 44 is inserted into the second output hole 122 and is in contact with the second energy transmission window, and the second energy transmission window is configured to electrically connect the output coupler 40 to the output waveguide, so that an electromagnetic wave

at the output coupler 40 can be transmitted to the output apparatus 204 through the second energy transmission window.

[0107] In an implementation, FIG. 12 is a schematic perspective view of a structure of an inner wall of a first input hole 111 and a first energy transmission window 34 according to an implementation of this application, and FIG. 13 is an exploded view of an inner wall of a first input hole 111 and a first energy transmission window 34 according to the implementation shown in FIG. 12. An inner wall of at least one of the first input hole 111 and the first output hole 112 has a flange 113. To be specific, both an inner wall of the first input hole 111 and an inner wall of the first output hole 112 may have flanges 113; or an inner wall of the first input hole 111 may have a flange 113, and an inner wall of the first output hole 112 may not have a flange 113; or an inner wall of the first input hole 111 may not have a flange 113, and an inner wall of the first output hole 112 may have a flange 113.

[0108] The flange 113 supports and is connected to at least one of the first energy transmission window 34 and the second energy transmission window, so that the first energy transmission window 34 and/or the second energy transmission window are/is disposed at a more stable position in the slow-wave structure 100, and it is ensured that the first energy transmission window 34 seals the first input hole 111 and the second energy transmission window seals the first output hole 112. This helps maintain the first waveguide 13 in a sealed state.

[0109] The inner wall of the first input hole 111 may include at least two flanges 113. The at least two flanges 113 are disposed at a spacing along the first direction, so that the first energy transmission window 34 is sandwiched between the at least two flanges 113. The at least two flanges 113 implement position limiting of the first energy transmission window 34 along the first direction, and the inner wall of the first input hole 111 implements position limiting of the first energy transmission window 34 in a direction perpendicular to the first direction. This helps further improve stability of a position of the first energy transmission window 34. Similarly, the inner wall of the first output hole 112 may also include at least two flanges 113. The at least two flanges 113 are disposed at a spacing along the first direction, so that the second energy transmission window is sandwiched between a plurality of flanges 113, to further improve stability of a position of the second energy transmission window. The flange 113 may be disposed around a central axis parallel to the first direction. The flange 113 may be an annular flange 113, or may be a plurality of flanges 113 disposed at a spacing. The plurality of flanges 113 are disposed around the central axis.

[0110] Refer to FIG. 11. The second housing cover 12 has a second input hole 121 and a second output hole 122, and the second input hole 121 and the second output hole 122 are disposed at a spacing. The first input hole 111 and the second input hole 121 communicate with each other along the first direction. In other words, an

orthographic projection of an area enclosed by the inner wall of the first input hole 111 on an area enclosed by an inner wall of the second input hole 121 at least partially overlaps the area enclosed by the inner wall of the second input hole 121. The first output hole 112 and the second output hole 122 communicate with each other along the first direction. In other words, an orthographic projection of an area enclosed by the inner wall of the first output hole 112 on an area enclosed by an inner wall of the second output hole 122 at least partially overlaps the area enclosed by the inner wall of the second output hole 122.

[0111] The slow-wave structure 100 further includes a first reflecting member 36 and a second reflecting member 45. The first reflecting member 36 seals the second input hole 121, and the second reflecting member 45 seals the second output hole 122, so that the second input hole 121 and the second output hole 122 are sealed, to ensure that the first waveguide 13 is in the sealed state, and help provide the vacuum environment for the electron transmission in the first waveguide 13. The first reflecting member 36 is located between the input coupler 30 and an opening of the second input hole 121, the second reflecting member 45 is located between the output coupler 40 and an opening of the second output hole, and the first reflecting member 36 and the second reflecting member 45 respectively implement sealing of the first waveguide 13 at the second input hole 121 and the second output hole 122. The first reflecting member 36 may be fixed to the inner wall of the second input hole 121, and the second reflecting member 45 may be fixed to the inner wall of the second output hole 122, so that the first reflecting member 36 and the second reflecting member 45 are accommodated in the housing layer of the second housing 10. The thickness of the second housing 10 is fully utilized to provide accommodation space for the first reflecting member 36 and the second reflecting member 45. This helps implement the miniaturization of the slow-wave structure 100.

[0112] The first reflecting member 36 is configured to cause phase cancellation to occur between an electromagnetic wave transmitted to and then reflected by the first reflecting member 36 and an original electromagnetic wave, and the second reflecting member 45 is configured to cause phase cancellation to occur between an electromagnetic wave transmitted to and then reflected by the second reflecting member 45 and an original electromagnetic wave. This helps improve stability of the electromagnetic wave in a transmission process.

[0113] In an embodiment, refer to FIG. 10 and FIG. 11. One of the first housing cover 11 and the second housing cover 12 includes a circuit layer 14. The circuit layer 14 may belong to the first housing cover 11, or may belong to the second housing cover 12. The circuit layer 14 is connected to the other one of the first housing cover 11 and the second housing cover 12 in a stacked manner along the first direction. The slow-wave transmission line

20 is disposed at the circuit layer 14, and the slow-wave transmission line 20 is fixed to an inner wall of the housing 10 at the circuit layer 14, so that the slow-wave transmission line 20 can implement integration with another structure in the slow-wave structure 100 in the stacking direction. In this way, a manner of disposing the slow-wave transmission line 20 is simplified, and assembly of the slow-wave transmission line 20 is more convenient for industrial production. In addition, the slow-wave transmission line 20 is integrated with the first housing cover 11 or the second housing cover 12. This improves integration of the slow-wave transmission line 20 with the housing 10, and helps implement the miniaturization of the slow-wave structure 100.

[0114] The circuit layer 14 may include an upper tube housing 142, a slow-wave transmission line layer 141, and a lower tube housing 143. The slow-wave transmission line layer 141 is sandwiched between the upper tube housing 142 and the lower tube housing 143. The slow-wave transmission line layer 141 has an accommodation hole of the slow-wave transmission line 20 conducted along the first direction, the slow-wave transmission line 20 is disposed in the accommodation hole of the slow-wave transmission line 20, and the upper tube housing 142 and the lower tube housing 143 respectively seal the accommodation hole of the slow-wave transmission line 20 on two sides of the slow-wave transmission line layer 141 along the first direction, to form the first accommodation cavity 114.

[0115] In an embodiment, the first housing cover 11 may include a coupling layer 15, the coupling layer 15 may include a first coupling layer 151 and a second coupling layer 152, the input coupler 30 is disposed at the first coupling layer 151, and the output coupler 40 is disposed at the second coupling layer 152. The first coupling layer 151, the second coupling layer 152, and the circuit layer 14 may be sequentially connected in a stacked manner along the first direction, and the first coupling layer 151 and the second coupling layer 152 may be located on a same plane parallel to the first plane 26. Similarly, the first housing cover 11 may further include an energy transmission window layer 16. The energy transmission window layer 16 may include a first energy transmission window layer 161 and a second energy transmission window layer 162. The first energy transmission window 34 is disposed at the first energy transmission window layer 161, and the second energy transmission window is disposed at the second energy transmission window layer 162. The first energy transmission window layer 161, the second energy transmission window layer 162, the first coupling layer 151, the second coupling layer 152, and the circuit layer 14 may be sequentially connected in a stacked manner along the first direction, and the first energy transmission window layer 161 and the second energy transmission window layer 162 may be located on a same plane parallel to the first plane 26.

[0116] In an embodiment, the second housing cover 12

may include a reflecting member layer 17, the reflecting member layer 17 may include a first reflecting member layer 171 and a second reflecting member layer 172, the first reflecting member 36 is disposed at the first reflecting member layer 171, and the first reflecting member 36 is disposed at the second reflecting member layer 172. The first energy transmission window layer 161, the second energy transmission window layer 162, the first coupling layer 151, the second coupling layer 152, the circuit layer 14, the first reflecting member layer 171, and the second reflecting member layer 172 may be sequentially connected in a stacked manner along the first direction, and the first reflecting member layer 171 and the second reflecting member layer 172 may be located on a same plane parallel to the first plane 26.

[0117] In a possible implementation, refer to FIG. 4. The slow-wave transmission line 20 is parallel to the first plane 26, there are at least two slow-wave transmission lines 20, the at least two slow-wave transmission lines 20 are disposed at a spacing in a stacked manner along the first direction, and the at least two slow-wave transmission lines 20 are all configured to transmit electromagnetic waves. This helps generate electric fields in a same direction and improve the amplification effect of the slow-wave structure 100 on the electromagnetic wave.

[0118] In a possible implementation, refer to FIG. 1. Materials of the slow-wave transmission line 20, the input coupler 30, the output coupler 40, and the housing 10 include at least one of molybdenum, tungsten, tungsten-/molybdenum alloy copper, stainless steel, nickel-based alloy, and copper, so that the materials of the slow-wave transmission line 20, the input coupler 30, the output coupler 40, and the housing 10 are all metal.

[0119] The slow-wave structure 100 may use a dielectric-supported rod to support the slow-wave transmission line 20. Alternatively, a structure of the slow-wave transmission line 20 may be set, so that in a process in which the metal housing 10 is connected to and supports the slow-wave transmission line 20, an effect that is the same as that of the dielectric-supported rod on the slow-wave transmission line 20 can be implemented.

[0120] In an implementation, refer to FIG. 4. The slow-wave transmission line 20 includes a transmission main line 24 and a plurality of stubs 25. The transmission main line 24 extends along the second direction, and the input coupler 30 and the output coupler 40 are respectively electrically connected to two ends of the transmission main line 24. An end of each of the plurality of stubs 25 is electrically connected to the transmission main line 24, and the other end is connected to the inner wall of the housing 10. The plurality of stubs 25 are disposed at a spacing along the second direction, and the housing 10 supports the plurality of stubs 25, so that the slow-wave transmission line 20 is supported by the housing 10. When the slow-wave transmission line 20 transmits a high-frequency electromagnetic wave, the high-frequency electromagnetic wave is equivalent to being disconnected at the plurality of stubs 25. Consequently, the

high-frequency electromagnetic wave cannot be transmitted from the plurality of stubs 25 to the housing 10, and a mode of the slow-wave structure 100 is the TEM mode or the quasi-TEM mode. In the foregoing disposing manner, the quantity of structures in the slow-wave structure 100 is reduced, so that a material of each structure in the slow-wave structure 100 is metal. This helps simplify processing of the slow-wave structure 100 and improve integration of each structure in the slow-wave structure 100, and helps implement the miniaturization of the slow-wave structure 100.

[0121] This application further provides a traveling-wave tube 200. FIG. 14 is a diagram of a structure of a traveling-wave tube 200 according to an implementation of this application. The traveling-wave tube 200 includes an electron gun 201, a collector 202, an input apparatus 203, an output apparatus 204, and the slow-wave structure 100 according to any one of the foregoing implementations. Both the electron gun 201 and the collector 202 are fixed to a housing 10 of the slow-wave structure 100. The electron gun 201 is configured to emit electrons into a first waveguide 13 of the slow-wave structure 100. The collector 202 is configured to collect the electrons in the first waveguide 13. The input apparatus 203 is electrically connected to an input coupler 30 of the slow-wave structure 100, the input apparatus 203 is configured to send an electromagnetic wave to the input coupler 30, the output apparatus 204 is electrically connected to an output coupler 40 of the slow-wave structure 100, and the output coupler 40 is configured to send an amplified electromagnetic wave to the output apparatus 204.

[0122] In an embodiment, the electron gun 201 and the collector 202 are respectively located on two sides of the slow-wave structure 100 along a second direction (a Y direction in FIG. 14), and electrons arrive at the collector 202 from the electron gun 201 along the second direction through the slow-wave structure 100. The input apparatus 203 and the output apparatus 204 are respectively located on two sides of the slow-wave structure 100 along a third direction (an X direction in FIG. 14).

[0123] In an embodiment, the traveling-wave tube 200 further includes a focusing system 205. The focusing system 205 is configured to confine a magnetic field in the first waveguide 13 of the slow-wave structure 100, so that an electron beam emitted by the electron gun 201 passes through the slow-wave structure 100 without interception. This helps improve an amplification effect of the traveling-wave tube 200 on the electromagnetic wave.

[0124] In an embodiment, refer to FIG. 1. The housing 10 has an electron emission hole 117. The electron gun 201 corresponds to the electron emission hole 117, and emits the electrons from the electron emission hole 117 into the first waveguide 13. The electron gun 201 is connected to the housing 10, and seals the electron emission hole 117.

[0125] It may be understood that the traveling-wave tube 200 in this embodiment has the slow-wave structure

100 in the foregoing embodiments. Therefore, the traveling-wave tube 200 in this embodiment has all technical effects of the slow-wave structure 100 in the foregoing embodiments. Because the technical effects of the slow-wave structure 100 are fully described in the foregoing embodiments, details are not described herein again.

[0126] This application further provides a network device 300. FIG. 15 is a diagram of a system of a network device 300 according to an implementation of this application. The network device 300 includes an antenna 301 and the foregoing traveling-wave tube 200. The antenna 301 is electrically connected to the traveling-wave tube 200, and the antenna 301 is configured to send an electromagnetic wave amplified by the traveling-wave tube 200.

[0127] It may be understood that the network device 300 in this embodiment has the traveling-wave tube 200 in the foregoing embodiment. Therefore, the network device 300 in this embodiment has all technical effects of the traveling-wave tube 200 in the foregoing embodiment. Because the technical effects of the traveling-wave tube 200 are fully described in the foregoing embodiment, details are not described herein again.

[0128] The foregoing embodiments are merely intended for describing the technical solutions of this application, but not for limiting this application. Although this application is described in detail with reference to the foregoing embodiments, a person of ordinary skill in the art should understand that modifications may still be made to the technical solutions described in the foregoing embodiments or equivalent replacements may be made to part of technical features thereof, without departing from the spirit and scope of the technical solutions of embodiments of this application, and these modifications and replacements shall fall within the protection scope of this application.

Claims

1. A slow-wave structure, comprising:

a housing, comprising a first housing cover and a second housing cover that are connected in a stacked manner along a first direction;
a slow-wave transmission line, extending along a first plane perpendicular to the first direction, wherein the slow-wave transmission line is fixed in a first waveguide formed by the first housing cover and the second housing cover; and
an input coupler and an output coupler, both electrically connected to the slow-wave transmission line, wherein at least one of the input coupler and the output coupler is not coplanar with the first plane.

2. The slow-wave structure according to claim 1, wherein the input coupler comprises a plurality of

first metal portions sequentially connected, the output coupler comprises a plurality of second metal portions sequentially connected, two adjacent first metal portions or two adjacent second metal portions form a stepped structure, and at least one of an arrangement direction of the plurality of first metal portions and an arrangement direction of the plurality of second metal portions is angled relative to the first plane.

3. The slow-wave structure according to claim 2, wherein the input coupler further comprises an input coaxial cable and a second waveguide, the input coaxial cable is electrically connected to the slow-wave transmission line and the plurality of first metal portions, the plurality of first metal portions and at least part of the input coaxial cable are located in the second waveguide, and the second waveguide is configured to couple an electromagnetic wave.

4. The slow-wave structure according to any one of claims 1 to 3, further comprising at least one attenuator, wherein the at least one attenuator is electrically connected to the output coupler or the input coupler, and the at least one attenuator is configured to absorb an electromagnetic wave.

5. The slow-wave structure according to any one of claims 1 to 4, wherein the slow-wave transmission line comprises at least two transmission line segments, two adjacent transmission line segments among the at least two transmission line segments are disposed at a spacing, each transmission line segment is electrically connected to at least one attenuator, and the transmission line and the at least one attenuator are electrically connected to a coupler located at the spacing.

6. The slow-wave structure according to claim 5, wherein neither the input coupler nor the output coupler is coplanar with the first plane, and each coupler at the spacing is coplanar with the first plane.

7. The slow-wave structure according to either claim 5 or 6, wherein the at least two transmission line segments are different in at least one of periodicity quantity and periodicity length.

8. The slow-wave structure according to any one of claims 1 to 7, wherein the attenuator is in a wedge shape.

9. The slow-wave structure according to any one of claims 5 to 8, wherein a cross-sectional area of the attenuator on a side close to the coupler at the spacing is larger than a cross-sectional area of the attenuator on a side away from the coupler at the spacing, and the cross section is perpendicular to a

direction from the coupler at the spacing to the attenuator.

10. The slow-wave structure according to any one of claims 4 to 9, wherein the attenuator, the input coupler, and the output coupler are all integrated with the first housing cover. 5
11. The slow-wave structure according to any one of claims 1 to 10, wherein the first housing cover has a first input hole and a first output hole, the input coupler is fixed to an inner wall of the first input hole, and the output coupler is fixed to an inner wall of the first output hole. 10
12. The slow-wave structure according to claim 11, further comprising a first energy transmission window and a second energy transmission window, wherein the first energy transmission window seals the first input hole, the second energy transmission window seals the first output hole, the first energy transmission window is electrically connected to the input coupler and an input waveguide interface, and the second energy transmission window is electrically connected to the output coupler and an output waveguide interface. 15 20 25
13. The slow-wave structure according to claim 12, wherein an inner wall of at least one of the first input hole and the first output hole has a flange, and the flange supports and is connected to at least one of the first energy transmission window and the second energy transmission window. 30
14. The slow-wave structure according to any one of claims 11 to 13, wherein the second housing cover has a second input hole and a second output hole, the first input hole and the second input hole communicate with each other along the first direction, and the first output hole and the second output hole communicate with each other along the first direction; and the slow-wave structure further comprises a first reflecting member and a second reflecting member, the first reflecting member seals the second input hole, and the second reflecting member seals the second output hole. 35 40 45
15. The slow-wave structure according to any one of claims 1 to 14, wherein one of the first housing cover and the second housing cover comprises a circuit layer, and the circuit layer is connected to the other one of the first housing cover and the second housing cover in a stacked manner along the first direction. 50
16. The slow-wave structure according to any one of claims 1 to 15, wherein the slow-wave transmission line is parallel to the first plane, there are at least two slow-wave transmission lines, and the at least two 55

slow-wave transmission lines are disposed at a spacing in a stacked manner along the first direction.

17. The slow-wave structure according to any one of claims 1 to 16, wherein the input coupler and the output coupler are located on a same side of the slow-wave transmission line along the first direction.
18. A traveling-wave tube, comprising an electron gun, a collector, a focusing system, an input apparatus, an output apparatus, and the slow-wave structure according to any one of claims 1 to 17, wherein both the electron gun and the collector are fixed to a housing of the slow-wave structure, the electron gun is configured to emit electrons into a first waveguide of the slow-wave structure, the collector is configured to collect the electrons in the first waveguide, the focusing system is configured to cause the electrons to pass through the slow-wave structure, the input apparatus is electrically connected to an input coupler of the slow-wave structure, the input apparatus is configured to send an electromagnetic wave to the input coupler, the output apparatus is electrically connected to an output coupler of the slow-wave structure, and the output coupler is configured to send an amplified electromagnetic wave to the output apparatus.
19. A network device, comprising an antenna and the traveling-wave tube according to claim 18, wherein the antenna is electrically connected to the traveling-wave tube, and the antenna is configured to send an electromagnetic wave amplified by the traveling-wave tube.

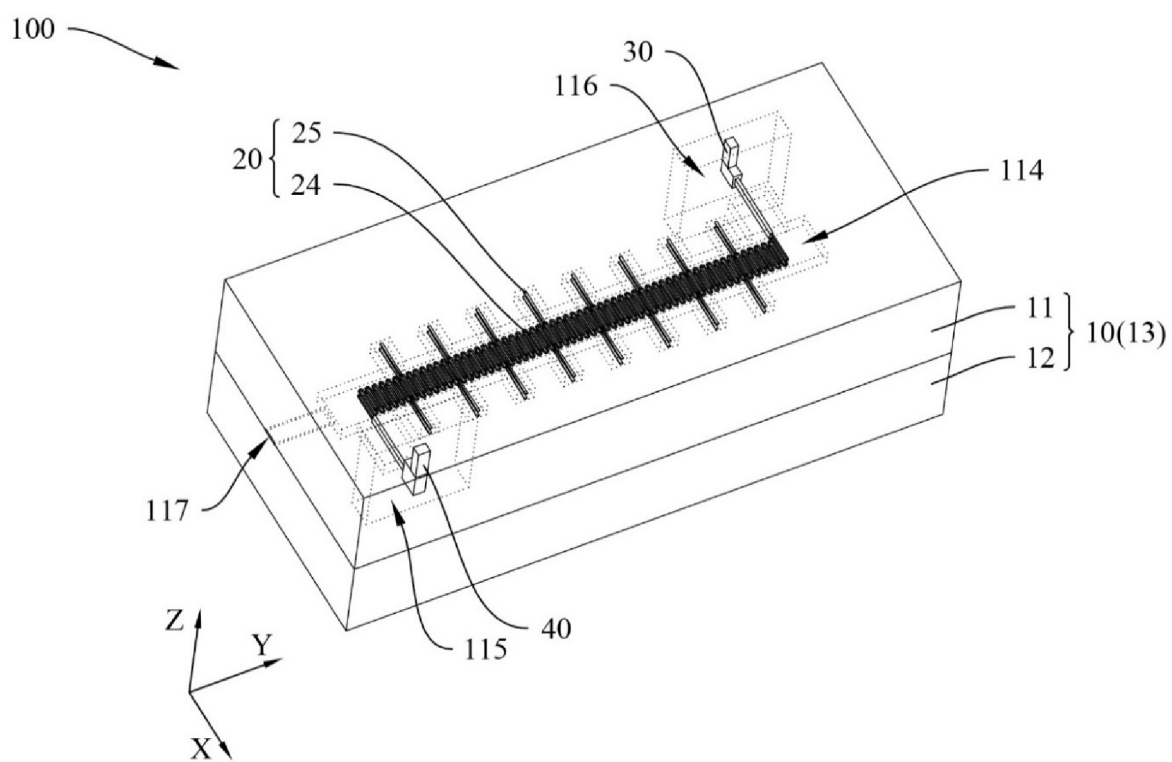


FIG. 1

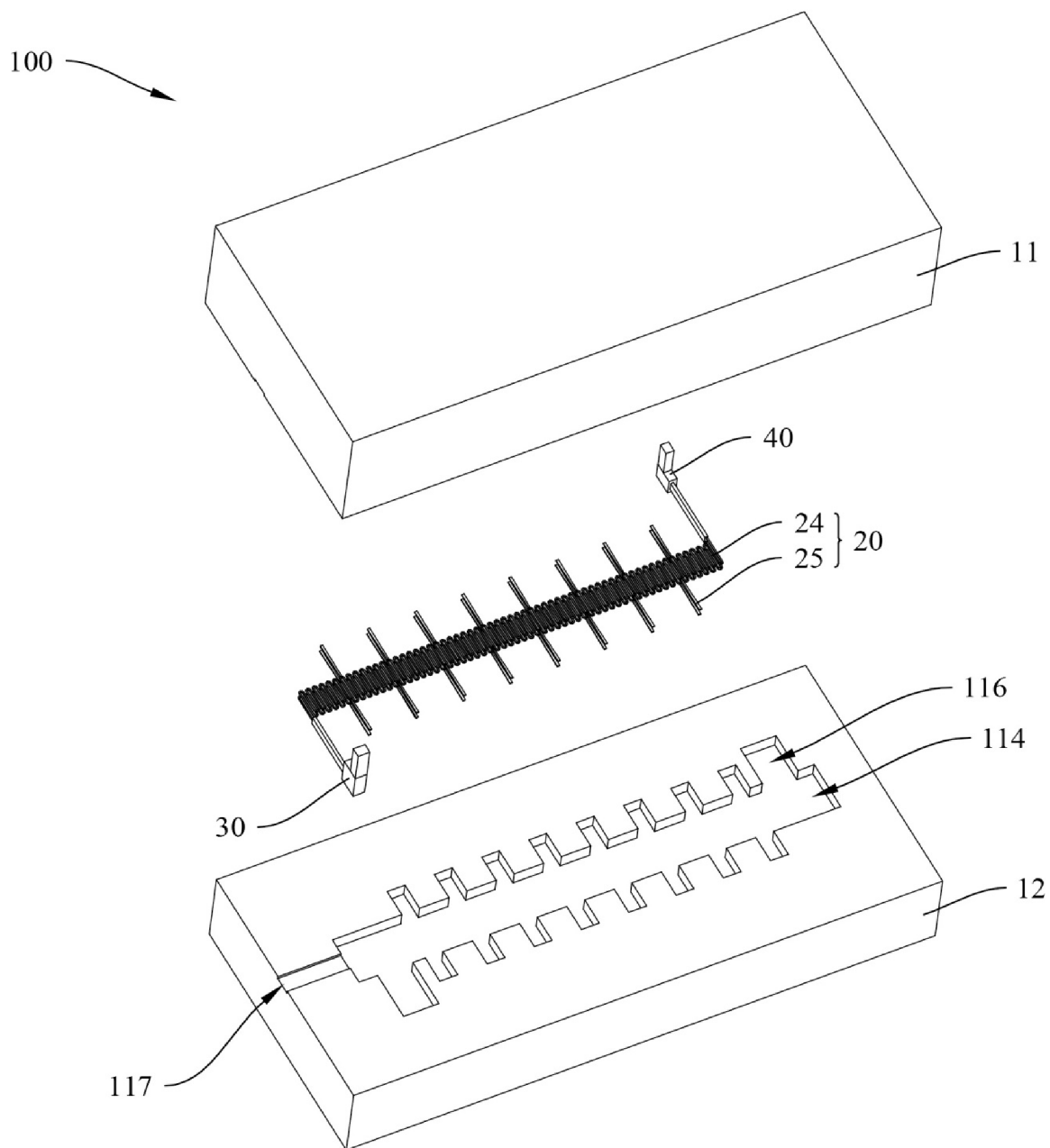


FIG. 2

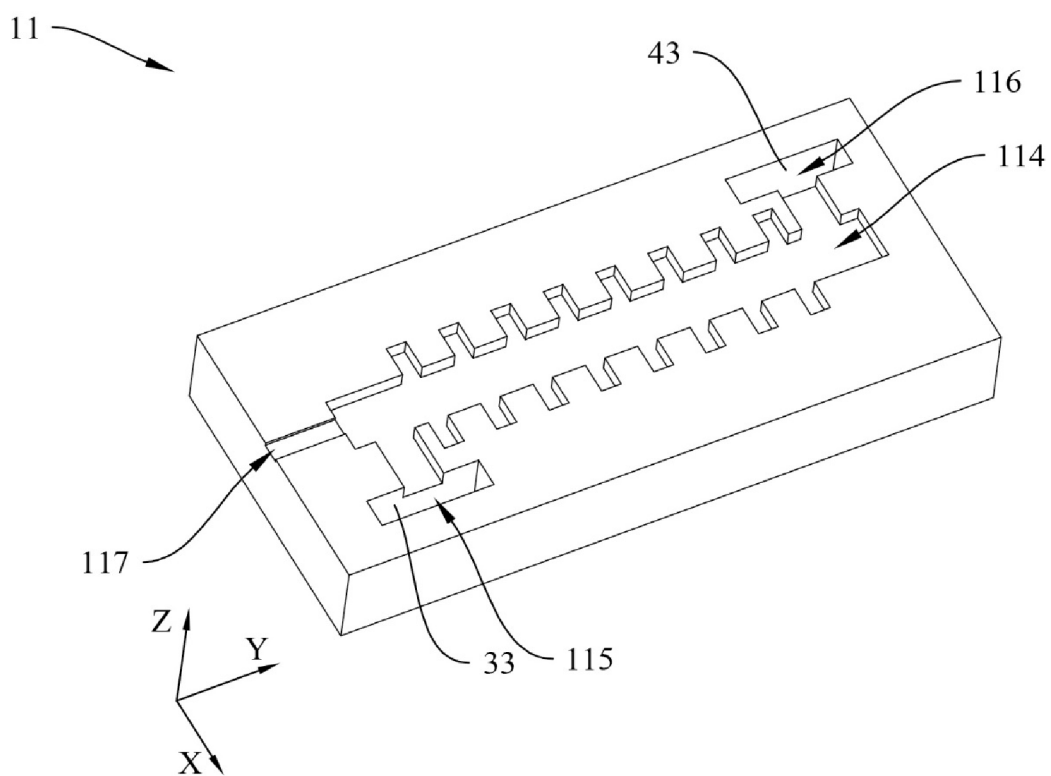


FIG. 3

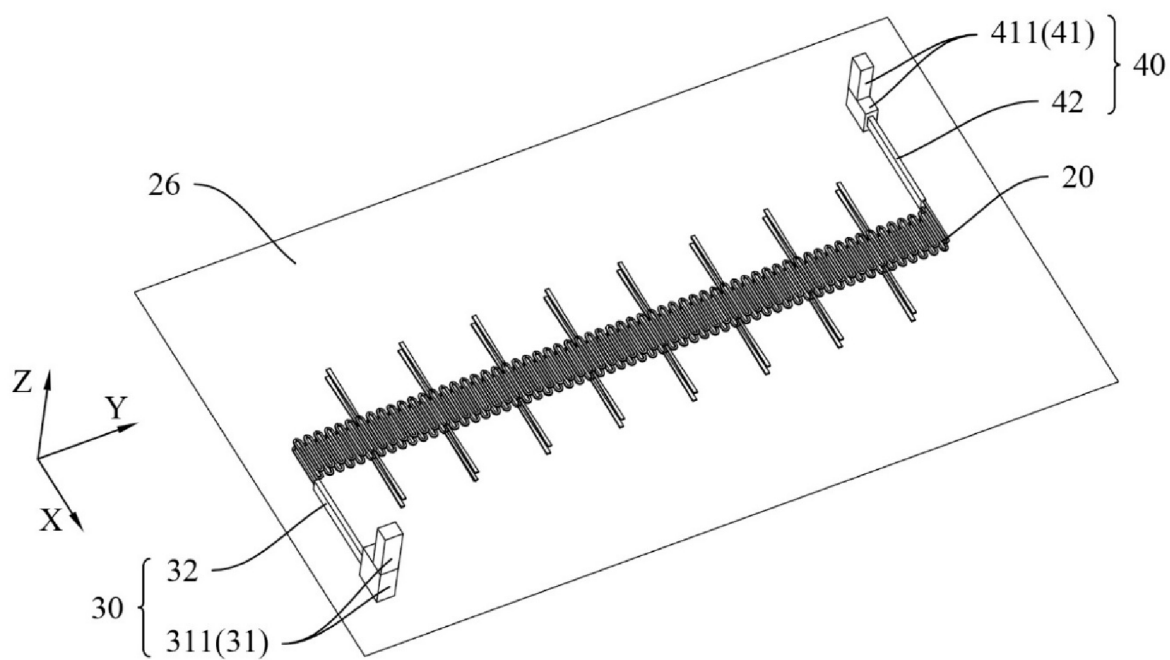


FIG. 4

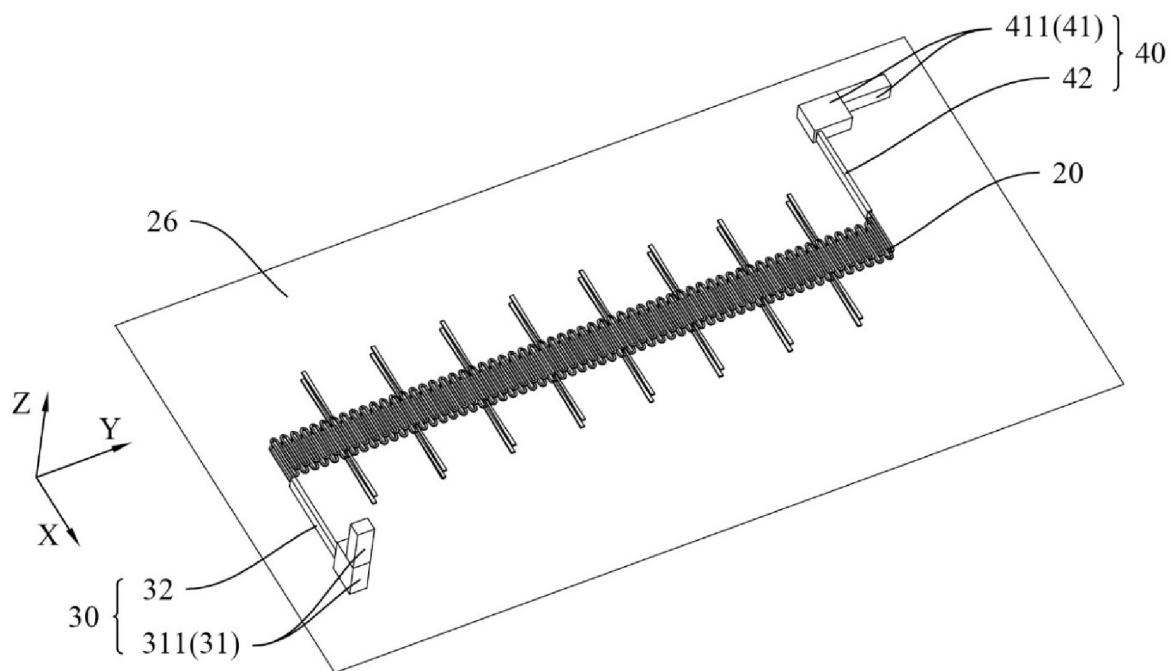


FIG. 5

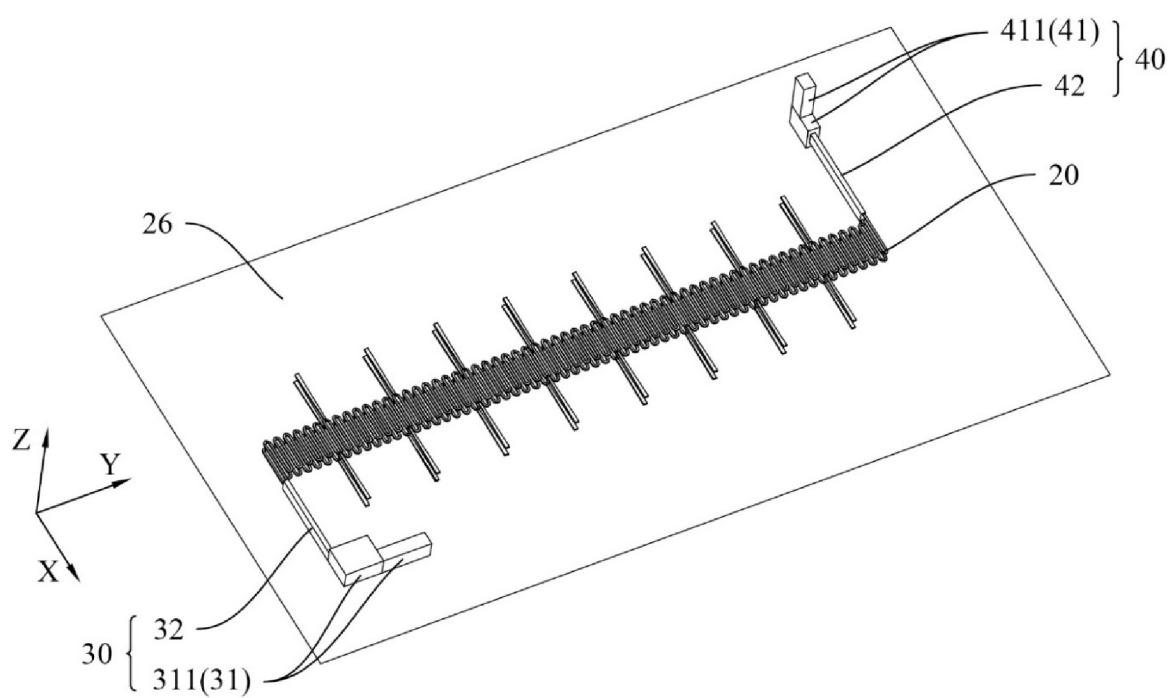


FIG. 6

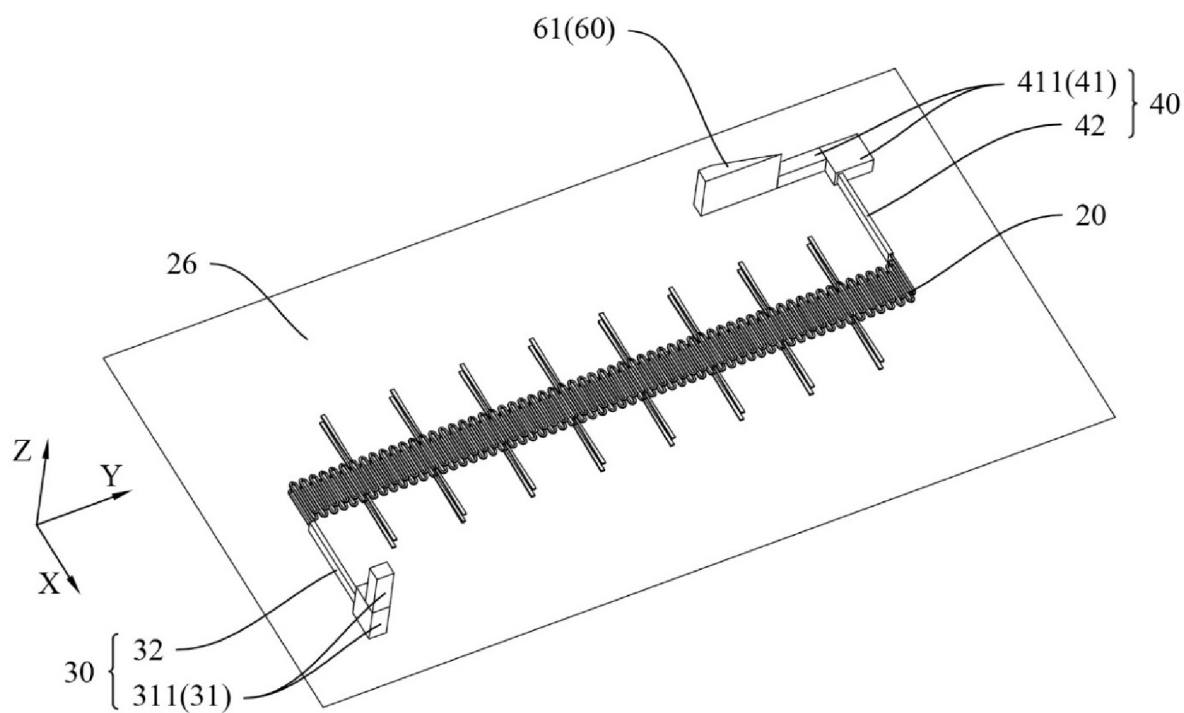


FIG. 7

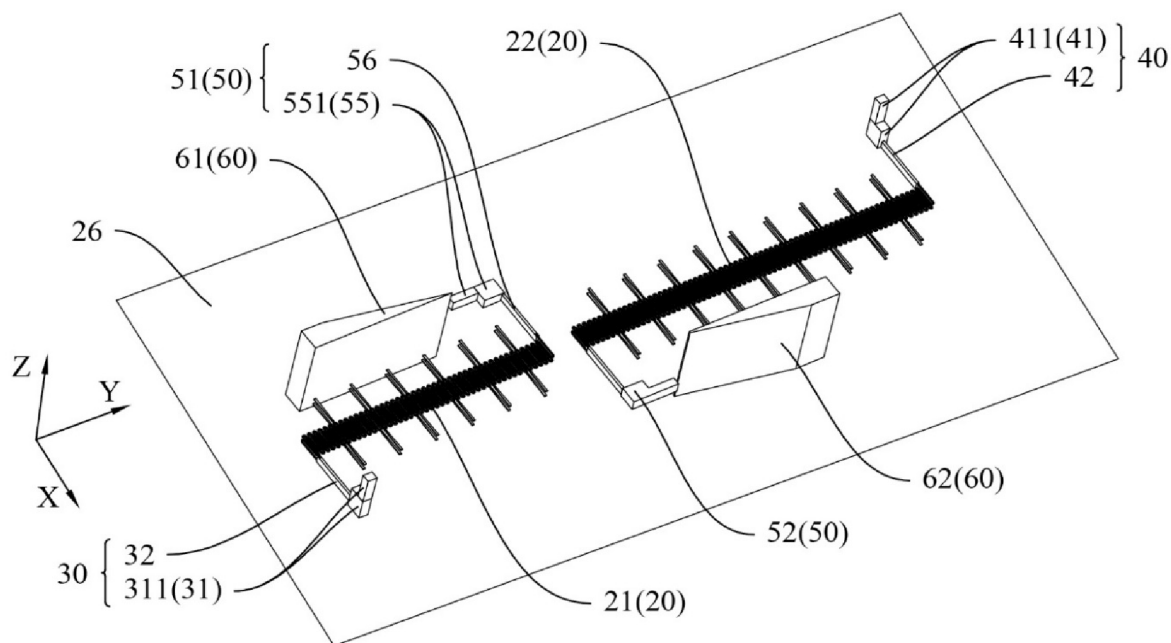


FIG. 8

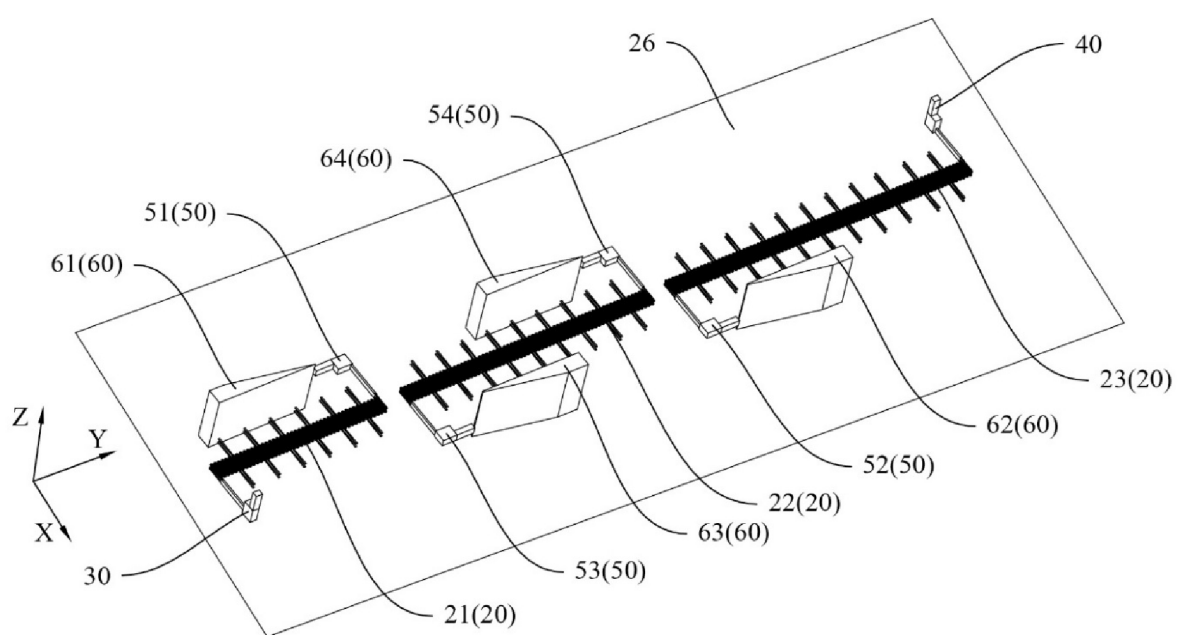


FIG. 9

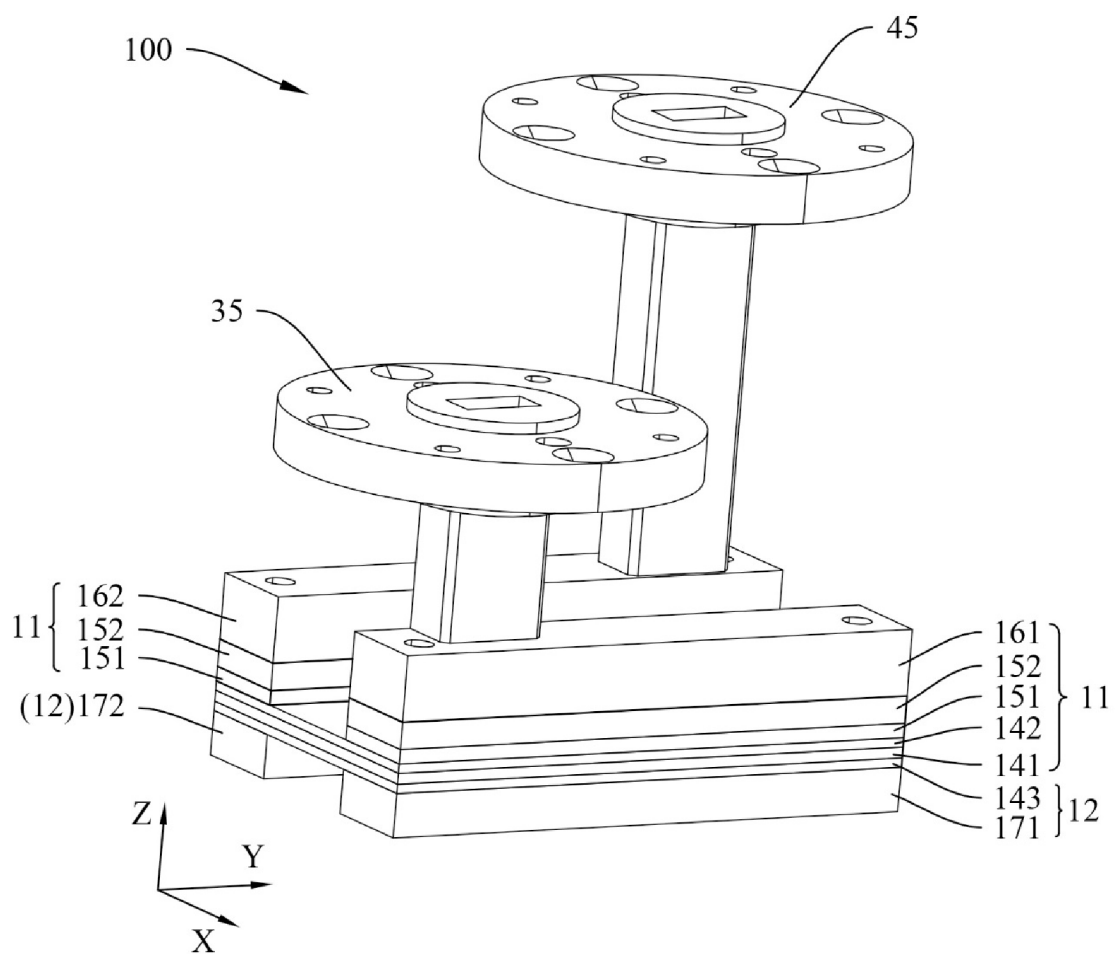


FIG. 10

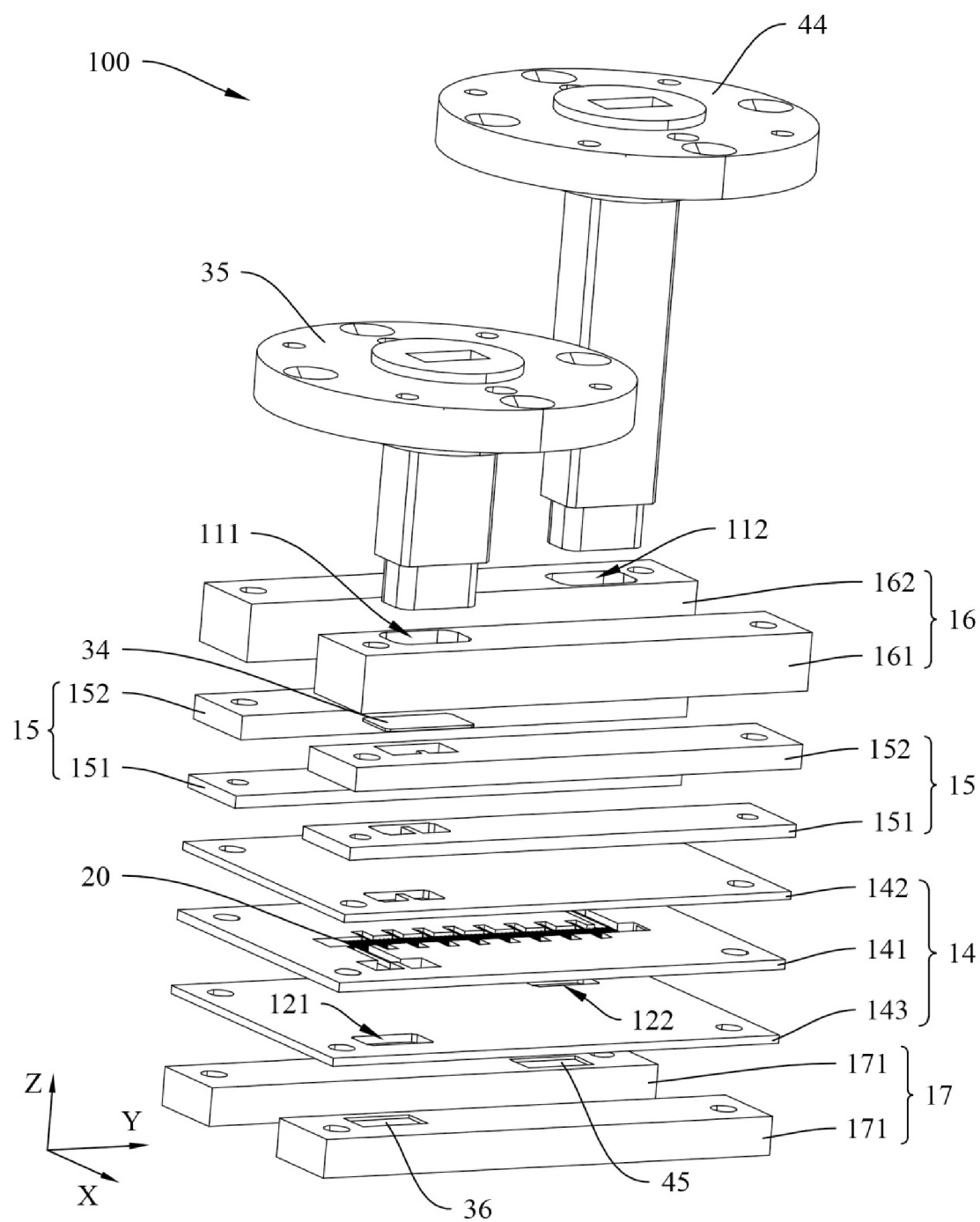


FIG. 11

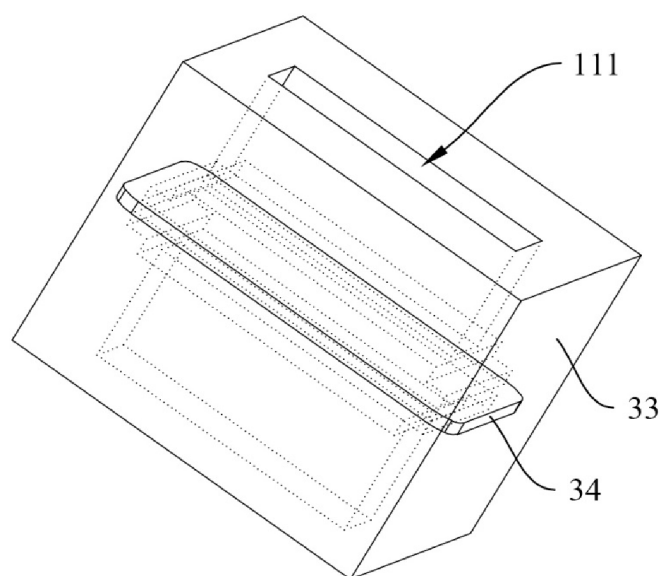


FIG. 12

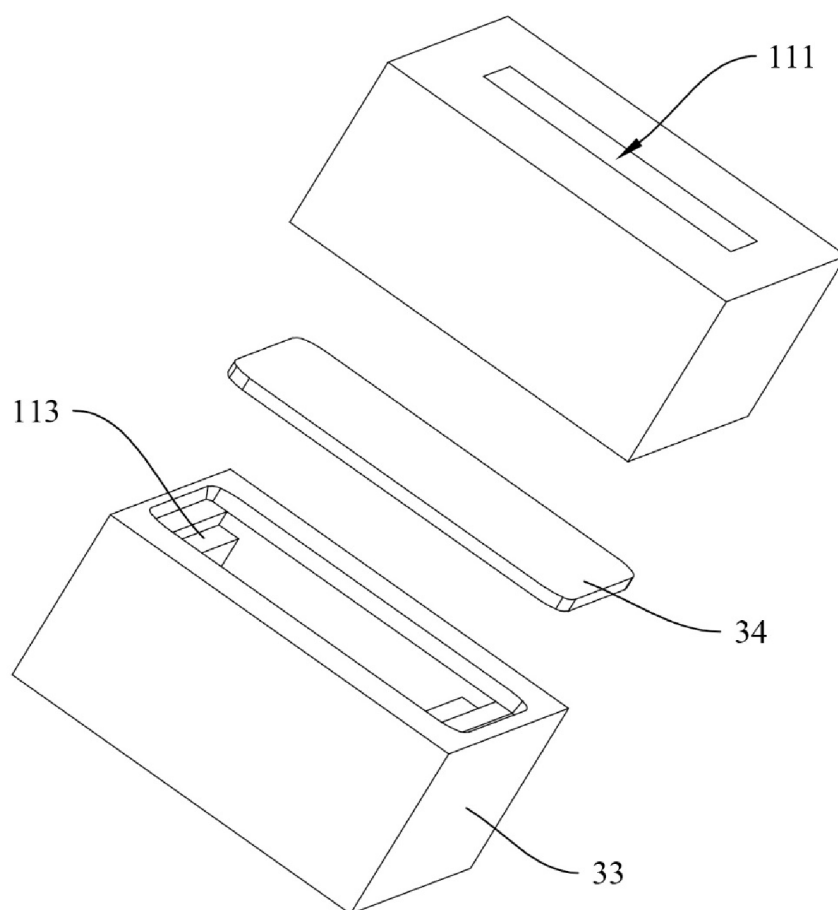


FIG. 13

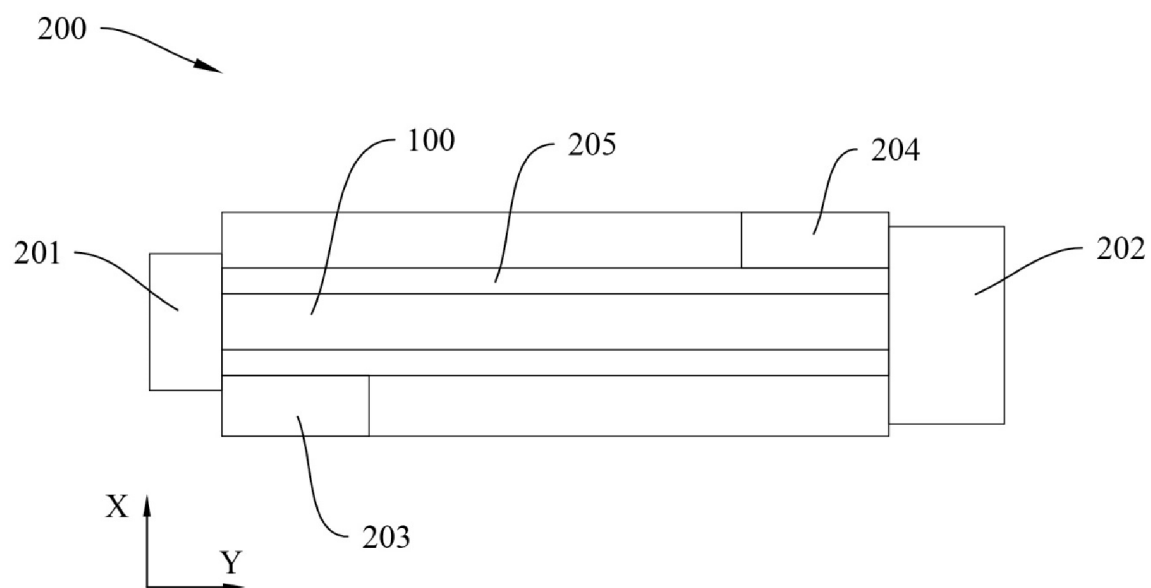


FIG. 14

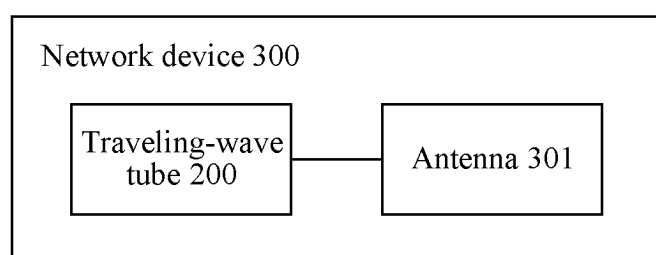


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/130604

A. CLASSIFICATION OF SUBJECT MATTER

H01J23/24(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

VEN, CNABS, CNTXT, WOTXT, EPTXT, USTXT, CNKI, IEEE: 慢波, 层叠, 第一壳, 第一盖, 上盖, 上壳, 传输线, 耦合器, 共面, 垂直, slow wave, stack, laminate, first cover, first casing, upper, transfer line, coupling, coplanar, perpendicular

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 114203502 A (UNIVERSITY OF ELECTRONIC SCIENCE AND TECHNOLOGY OF CHINA) 18 March 2022 (2022-03-18) description, paragraphs [0007]-[0058], and figures 2-17	1-19
Y	CN 116031121 A (UNIVERSITY OF ELECTRONIC SCIENCE AND TECHNOLOGY OF CHINA) 28 April 2023 (2023-04-28) description, paragraphs [0007]-[0050], and figures 2-12	1-19
Y	US 2013200789 A1 (SAMSUNG ELECTRONICS CO., LTD.) 08 August 2013 (2013-08-08) description, paragraphs [0049]-[0069], and figures 1-5B	1-19
A	CN 113345779 A (UNIVERSITY OF ELECTRONIC SCIENCE AND TECHNOLOGY OF CHINA) 03 September 2021 (2021-09-03) entire document	1-19
A	US 2021367573 A1 (WISCONSIN ALUMNI RESEARCH FOUNDATION et al.) 25 November 2021 (2021-11-25) entire document	1-19
A	US 8242696 B1 (HWU, Ruey-Jen et al.) 14 August 2012 (2012-08-14) entire document	1-19

☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D" document cited by the applicant in the international application	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 06 January 2025	Date of mailing of the international search report 17 January 2025
Name and mailing address of the ISA/CN China National Intellectual Property Administration (ISA/CN) China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2024/130604

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CN 114203502 A	18 March 2022	None	
CN 116031121 A	28 April 2023	None	
US 2013200789 A1	08 August 2013	KR 20130091199 A	16 August 2013
		KR 101919417 B1	19 November 2018
		US 9082579 B2	14 July 2015
		EP 2626883 A1	14 August 2013
		EP 2626883 B1	14 February 2018
		JP 2013161794 A	19 August 2013
		JP 6340163 B2	06 June 2018
CN 113345779 A	03 September 2021	None	
US 2021367573 A1	25 November 2021	US 11588456 B2	21 February 2023
		WO 2021242473 A1	02 December 2021
US 8242696 B1	14 August 2012	None	

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REFERENCES CITED IN THE DESCRIPTION

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- CN 202311615520 [0001]