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(54) ANTENNA STRUCTURE AND ANTENNA STRUCTURE MANUFACTURING METHOD

(57) The present disclosure generally pertains to an antenna structure including at least two antennas arranged in an array, the antenna structure further including:
an encapsulated cavity including:
at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

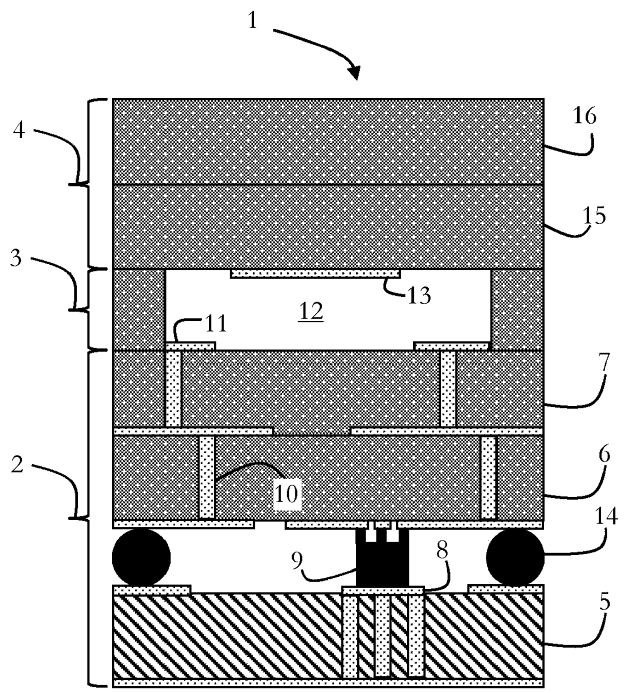

Fig. 1a

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Description

TECHNICAL FIELD

[0001] The present disclosure generally pertains to an antenna structure and to an antenna structure manufacturing method.

TECHNICAL BACKGROUND

[0002] Generally, radar antenna structures are known. System-in-package (SiP) may be considered as a current trend for manufacturing antennas, which may provide for more functionality into a smaller volume and for applications operating in millimeter-wave and sub-terahertz regions.

[0003] In known SiP structures, a heterogeneous integration of integrated circuitry along with sensors, microelectromechanical components, passive devices, filters, antennas, and the like may be present.

[0004] A high-resolution mm-wave SiP transceiver may be able to transmit and receive mm-wave signals in an efficient way, in case an adequate antenna gain is provided and a radiation pattern/efficiency over an operating frequency range of the IC is aligned.

[0005] Although there exist techniques for producing an antenna structure, it is generally desirable to provide an antenna structure and an antenna structure manufacturing method.

SUMMARY

[0006] According to a first aspect, the disclosure provides an antenna structure comprising at least two antennas arranged in an array, the antenna structure further comprising:
an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

[0007] According to a second aspect, the disclosure provides an antenna structure manufacturing method for providing an antenna structure including at least two antennas arranged in an array, the method comprising:
providing an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

[0008] Further aspects are set forth in the dependent claims, the drawings and the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Embodiments are explained by way of example with respect to the accompanying drawings, in which:

Fig. 1a depicts a cross-sectional view of an antenna structure according to the present disclosure;

Fig. 1b depicts a cross-sectional view of an antenna structure according to the present disclosure including a TX and an RX antenna;

Fig. 2a depicts an RF microstrip line/distribution network including an IC signal routing and antenna feed routing according to the present disclosure;

Fig. 2b depicts a top view of an aperture coupling structure (with a bowtie shape) according to the present disclosure;

Fig. 2c depicts a top view of EBG structures enclosed in an air-cavity according to the present disclosure;

Fig. 2d depicts a top view of a patch antenna array according to the present disclosure;

Fig. 2e depicts a top view of GND vias according to the present disclosure;

Fig. 2f depicts a top view of EBG vias according to the present disclosure;

Fig. 2g depicts a top view of an overlay of the elements of Figs. 2a to 2f; and

Fig. 3 depicts a block diagram of an embodiment of an antenna array manufacturing method according to the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0010] Before a detailed description of the embodiments starting with Fig. 1a is given, general explanations are made.

[0011] As mentioned in the outset, antenna structures are generally known. However, it has been recognized that for operating frequencies above 100 GHz, a coupling between more antennas may be too high, such that a desired antenna gain may not be reached for known antenna structures.

[0012] Moreover, it has been recognized that it may be desirable to suppress surface waves which may degrade radiation characteristics of antennas.

[0013] According to the present disclosure, wide bandwidth, high gain, surface wave suppression within an antenna array and packed may be achieved by using air-filled antennas on top of an EBG structure and integrating a feed distribution, radiating elements and embedded air-filled cavities into a multilayer ceramic LTCC mm-wave package. The EBG structures may be placed between aperture coupling feeding and radiating antenna elements. 1TX x 1RX radar channels may be considered. There may be separate cavities for TX and RX antenna channels and within one common encapsulated (or embedded) cavity (which may be sandwiched in a SiP), a spacing between antennas may be $\lambda/2$ (wherein λ may be a transmission/reception wavelength).

[0014] It has further been recognized that, among different packaging technologies available today, LTCC (Low-Temperature-Co-Fired-Ceramics) technology (multilayer substrate technology) may particularly be attractive, firstly because all System-in-Package components (conducting lines, vias, air cavities, fluidic channels, etc) can be stacked vertically and integrated in a single, compact, three-dimensional (3D) LTCC module. Secondly, the LTCC modules may be highly resistant against thermal stress, mechanical stress, shock and vibration.

[0015] A package based on a ceramic substrate may provide for system reliability under harsh environmental conditions, e.g., wide temperature range, humidity, corrosive gases, etc. Fourthly, an LTCC-based SiP may efficiently dissipate heat generated by an IC by using thermal vias.

[0016] According to the present disclosure, for the integration into an LTCC (Low-Temperature-Co-Fired-Ceramics) package, air-filled mm-wave antennas on top of mm-wave periodic structures may be provided. Dense signal interconnect on the package may be achieved due to transmission line routing on the high ceramic permittivity substrate. Routing all RF signals from the RF chip to the antennas may result in an optimal performance in terms of loss and matching. A package may include a transmit (TX) and receive (RX) antenna array. The transmit and receive antenna arrays may be formed inside separate air-filled cavities to reduce crosstalk between a transmit path and a receive path.

[0017] In some embodiments, the antennas may be arranged in a two-times-two half wavelength spacing in air for the transmit and receive array. Such a configuration may support different short-range applications like vital sign detection, gesture recognition or multiple object detection. High aperture efficiencies and clean radiation patterns may be important to achieve high performance radars with high unambiguousness.

[0018] For example, aperture shape and size may be important parameters for aperture-coupled microstrip antennas according to the present disclosure. A small aperture (slot) located under the antenna patch may allow coupling of the patch to the feed line which has may have a form of an open-circuit stub. In such embodiments, a stub termination may allow a (circuit) designer to match an input impedance response of the aperture coupled patch and to control an amount of coupling to a patch radiator. For maximum coupling, the feed line may need to be placed perpendicular to a center of the slot.

[0019] An input impedance may be controlled by the size, position, and shape of the aperture and openended stub length. Since different shapes of the aperture may have different coupling, it may be desirable to use an aperture shape which has maximum coupling for the smallest area to reduce back radiation. If the aperture coupling is maximized, it may be possible to achieve greater impedance bandwidth. Moreover, H and bowtie shapes may be used in combination in order to reduce sharp discontinuities and to make a field distribution inside the aperture more uniform.

[0020] Due to a common (air-filled) cavity, the antenna array may show mutual coupling (i.e., different antennas may be coupled with each other).

[0021] According to the present disclosure, an approach for eliminating such unwanted radiation inside the air cavity is presented. Moreover, the air -filled antenna which may be placed on top or above of an EBG periodic structure may present an improved gain compared to known coupled antennas.

[0022] EBG structures may show a unique band gap characteristics at certain frequency ranges (preventing the propagation of electromagnetic waves). They may be based on periodical structures of densely packed planar conducting patches separated from a solid metal plane by a dielectric layer.

[0023] In some embodiments, metallic pins (or vias) are introduced to prevent electromagnetic waves from traveling in the waveguide between the array and the ground. Each unit cell (i.e., each periodic repetition) of an antenna array, may basically behave as a microwave resonant LC circuit. The plurality of resonant elements may be parameterized to substantially block surface wave propagation in the structure within a predetermined frequency band gap.

[0024] According to the present disclosure, a mm-wave aperture coupled antenna array may show a broadband behavior and a high gain (due to the air-filled antenna cavity and the inclusion of the EBG structure below the air-filled cavity).

[0025] Therefore, some embodiments pertain to an antenna structure including at least two antennas arranged in an array, the antenna structure further including: an encapsulated cavity including: at least two antenna elements at a top wall section of the cavity, and an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

[0026] The antenna structure may be provided for transmission (TX) or reception antennas (RX). For example, all antennas of the antenna structure may be TX antennas or all antennas may be RX antennas. Also, in some embodiments, a mixture of both antennas types may be present in the antenna structure.

[0027] For example, the TX antennas and the RX antennas may structurally correspond, but may differ in how they are controlled, i.e., it may depend on their configuration whether they are RX or TX antennas.

[0028] However, in some embodiments TX antennas and RX antennas may structurally differ.

[0029] In some embodiments, the at least two antennas may be provided in an array which may have any shape, such as rectangular, circular, oval, or the like. Moreover, if different antenna types are present in the array, the antenna types may be arranged in a predetermined pattern, for example.

[0030] Accordingly, some embodiments pertain to an antenna array including an antenna structure as described herein.

[0031] In some embodiments, the antenna structure includes an encapsulated cavity, which may include at least two antenna elements at a top wall section.

[0032] For example, the cavity may have a rectangular cross-section (from a side view) and may be confined by an upper layer, such that a top wall of the cavity may be formed by the upper layer. Hence, at a top section (e.g., directly at the top wall), the at least two antenna elements may be provided in the same cavity.

[0033] The antenna elements may be based on an electrically conductive material such as to function as a radiating part of the antenna, as generally known.

[0034] Moreover, at a bottom wall section of the cavity, an electronic band gap (EBG) structure may be provided. In the example mentioned above (rectangular cross-section-shaped cavity), a bottom wall may be defined by a lower layer and the bottom wall section may, for example, correspond to that wall.

[0035] Hence, in such embodiments, at least two antenna elements and the EBG structure may lie within the cavity and may be fixed at the cavity's walls, without limiting the present disclosure in that regard.

[0036] In some embodiments, the antenna structure further includes: a circuitry layer below the encapsulated cavity.

[0037] For example, the circuitry layer may include circuitry for controlling the at least two antenna elements and may, for example, define a radiation characteristics, as commonly known. Moreover, the lower layer, as mentioned above, may be included in the circuitry layer, such that the EBG may be connected to the circuitry of the circuitry layer.

[0038] The circuitry may be based on an integrated circuit (IC), a processor (e.g., CPU (central processing unit), GPU (graphics processing unit)), or the like. Moreover, corresponding wiring may be provided in the circuitry layer for connecting the IC (as an example) with the EBG structure.

[0039] Moreover, the circuitry layer may include redistribution elements which may further define the radiation characteristics.

[0040] Hence, in some embodiments, the EBG structure is provided at an interface of the encapsulated cavity and the circuitry layer.

[0041] In some embodiments, the antenna further includes: a top layer above the encapsulated cavity, as discussed herein.

[0042] In some embodiments, the at least two antenna elements are provided at an interface of the encapsulated cavity and the top layer, as discussed herein.

[0043] However, it should be noted that the layered structure, as described herein, is only used for explanatory purposes and should not be considered as binding since any other way than layering for providing the circuitry, cavity, and antennas may be used.

[0044] In some embodiments, the encapsulated cavity is an air-filled cavity.

[0045] In some embodiments the EBG structure includes at least two decoupling elements, wherein each decoupling elements is provided for each antenna, as will be discussed further below.

[0046] In some embodiments, the EBG structure is based on a bowtie-shape aperture ground plane, in other words based on an aperture ground plane with bowtie-shape slots.

[0047] In some embodiments, an aperture (slot) pattern is provided in a bowtie-shape in a ground plane, e.g., for transferring the mm-waves from an IC to an antenna.

[0048] At least one layer above the ground plane, the EBG may be provided. In some embodiments, the EBG structure may be based on multiple unit cells, each unit cell having a rectangular shape, and being connected to the ground plane of the antenna by EBG vias.

[0049] It has been recognized that a bowtie shape or an H-shape or a combined H-bowtie shape may result in an EBG structure which provides optimal or best decoupling characteristics of the at least two antennas. Hence, a coupling of the at least two antennas may be avoided based on the shape of the EBG structure which is provided based on the H-/bowtie-shape of the aperture ground plane. For example, the EBG structure may have a mushroom with a rectangular patch on top.

[0050] The bowtie shape may, from a top view, be based on four arms extending from a center point, as will be discussed further below.

[0051] In some embodiments, the antenna structure further includes: a plurality of layers, wherein the plurality of layers is based on low-temperature co-fired ceramics.

[0052] In some embodiments, at least two antennas are configured to operate in a range starting at 100 GHz.

[0053] Some embodiments pertain to an antenna structure manufacturing method for providing an antenna structure including at least two antennas arranged in an array, the method including: providing an encapsulated cavity including: at least two antenna elements at a top wall section of the cavity, and an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section, as discussed herein.

[0054] In some embodiments, the antenna structure manufacturing method further includes: providing a circuitry layer below the encapsulated cavity, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing the EBG structure at an interface of the encapsulated cavity and the circuitry layer, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing a top layer above the encapsulated cavity, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing the at least two antenna elements at an interface of the encapsulated cavity and the top layer, as discussed herein. In some embodiments, the encapsulated cavity is an air-filled cavity, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing a decoupling element for each antenna as part of the EBG structure, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing the EBG structure based on a bowtie-shape aperture ground plane, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing a plurality of layers based on low-temperature co-fired ceramics, as discussed herein. In some embodiments, the antenna structure manufacturing method further includes: providing the at least two antennas such that they are configured to operate in a range starting at 100 GHz, as discussed herein.

[0055] Returning to Fig. 1a, there is depicted a schematic diagram of an antenna structure 1 according to the present disclosure.

[0056] In this embodiment, the antenna structure 1 is a packaged antenna array including a plurality of layers which are manufactured based on low-temperature cofired ceramics (LTCC).

[0057] The antenna structure 1 includes a circuitry layer 2, a cavity layer 3, and a top 4, which are stacked on top of each other, i.e., in a stacking direction, the cavity layer 3 is stacked on the circuitry layer 2 and the top layer 4 is stacked on the cavity layer 3.

[0058] Moreover, the circuitry layer 2 is includes three further layers: an IC contacting layer 5, a first redistribution layer 6 and a second redistribution layer 7.

[0059] The IC contacts 8 provide a heat sink concept to avoid overheating of the IC 9, i.e., the back-side of the IC is thermally (hence, electrically) connected to the IC contacts 8 to provide a heat transfer..

[0060] The IC 9 is further electrically connected with a first redistribution layer 6, i.e., with a microstrip line, which is further connected to a redistribution element 10 (in this embodiment, a GROUND via), which is configured to redistribute a signal of the IC 9 to the second redistribution layer 7 and to ground the circuitry. mm-wave signals propagating along the microstrip lines are coupled via a slot (having a bowtie-shape) to the second redistribution layer 7. Moreover, the first redistribution layer 6 connects the IC 9 to power, digital, and mm-wave pads. The second redistribution layer 7 includes further redistribution elements (in this embodiment, an EBG via) which are connected to decoupling elements 11 of an EBG structure, which are provided on a bottom wall of an air-filled cavity 12.

[0061] On a top wall of the air-filled cavity 12, two antennas 13 are provided, of which only one is shown due to the cross-sectional view of Fig. 1. The antenna 13 is provided as a patch antenna. However, generally, at least two antennas may be provided and thus, the present disclosure is not limited to two antennas. For example, an array may include two-times-two antennas, two-times-four antennas, four-times-four antennas, or the like.

[0062] The top wall of the air-filled cavity is defined due to the top layer 4 which includes on two "sub"-layers 15 and 16, wherein the upmost layer is provided for mechanical stability.

[0063] Moreover, the IC contacting layer 5, and thereby the IC 9, and the redistribution layer 6 are further contacted with bumps 14 to further provide mechanical stability, without limiting the present disclosure in that regard: for example, solder balls may be used. The bumps 14 are based on a ball grid array (BGA)

[0064] It should be noted that, in some embodiments, it is sufficient to only provide layers 5, 6, 3, and 15 (together with an IC) to provide the functionality of the present disclosure.

[0065] In this embodiment, each LTCC layer (i.e., the layers 3, 6, 7, 15, 16) have a thickness of ninety-eight micrometers, but the present disclosure is not limited to any thickness of the respective layers. Also, different thicknesses of the layers may be envisaged according to the circumstances.

[0066] Fig. 1b depicts a cross-sectional view of an antenna structure 100 according to the present disclosure, which includes a TX antenna 101 and an RX antenna 102 which each have similar elements as already discussed under reference of Fig. 1a, such that a repetitive description thereof is omitted.

[0067] As can be taken from Fig. 1b, the TX antenna 101 and the RX antenna 102 may share certain layers, but the air-filled cavities are provided separately for each antenna to reduce crosstalk between the transmit and receive path. On each cavity, the corresponding EBG structures prevent coupling between neighboring antenna elements.

[0068] Figs. 2a to 2f depicts cross-sectional top views of different planes, as already discussed under reference of Fig. 1a or 1b, of an antenna structure according to the present disclosure.

[0069] Fig. 2a depicts an RF (radio frequency) package signal routing structure 20 (including an IC signal routing and antenna feed routing), wherein the package signal routing structure 20 includes a power divider structure 21 configured to split a signal into four branches to feed, for example, four antenna elements.

[0070] Fig. 2a shows a complete RF package signal routing structure (including an IC signal routing and antenna feed routing) as carried out by an interface layer between the LTCC package and the mm-wave IC.

[0071] In the present embodiment, 1TX and 1RX radar channels are considered, without limiting the present disclosure in that regard. To each channel, one feeding microstrip line is connected. Moreover, for each branch, the microstrip line is divided twice to feed 4 radiating elements (arranged in a 2x2 matrix).

[0072] Fig. 2b depicts an aperture coupling structure 22. Fig. 2b represents the antenna and package ground plane. For guiding the mm-waves from the feed network to the radiating elements, aperture or slots (bow-tie shape) are etched in the ground plane.

[0073] Fig. 2c depicts EBG structures 23 inside the cavity. Fig. 2c represents the EBG unit cells embedded in the air cavity for surface wave suppression. An antenna package according to the present disclosure may include a transmit and a receive antenna array. The transmit and receive antenna arrays may be formed inside separate air-filled cavities to reduce crosstalk between a transmit path and receive path, as depicted in Fig. 2c.

[0074] Location of TX and RX cavities in Fig. 2c are depicted by the rectangles which are placed around the EBG patches.

[0075] Fig. 2d depicts the patch antenna array 24. Fig. 2d represent 2x2 antenna radiating elements connecting to each TX or RX channels.

[0076] Fig. 2e depicts the GND vias 25 configured to connect IC GND pads to a common ground which is common for the antenna(s) and the package.

[0077] Fig. 2f depicts the EBG vias 26 that connect the mushroom type EBG unit cells to the ground plane.

[0078] Fig. 2g depicts a top view of an overlay 27 of the elements of Figs. 2a to 2f.

[0079] Regarding Figs. 2a to 2g, the following general remarks should be noted:

Figs. 2a to 2g show a an LTCC-based package concept including the antenna array, as discussed under Fig. 1. Feeding techniques may play a major role for an efficient operation of each antenna.

[0080] This may help in improving gain, impedance mismatch, efficiency, and directivity. The most common techniques may be based on contacted or non-contacted feeding.

[0081] For example, a non-contacting technique may be aperture coupled feeding. The proposed aperture coupled feed design of Figs. 2a to 2g may provide for a wideband behavior of each antenna, may improve return loss, result in smaller chip size and a radiation performance of the antenna may not be disrupted by the radiation of the feeding networks.

[0082] Figs. 2a to 2g provide a type of multilayer feeding mechanism that may isolate radiating elements and the feed (low loss LTCC-based feeding networks on the bottom side of the package may transfer the mm-waves from the radar IC to the antennas). An aperture (slot) may be placed in a ground plane which may be common to a pair of dielectric substrates through which energy may be coupled from one layer to another layer.

[0083] A thickness of the substrates supporting the radiating element and feeding networks may be chosen independently to optimize the distinct electrical functions of radiation and circuitry. For example, the substrate supporting the radiating element should be relatively thick, in order to improve the impedance bandwidth of an antenna. In contrast, the feed should be designed on a relatively thin substrate so that an associated EM (electromagnetic) field is tightly bound to the substrate, thereby minimizing an undesired radiation and EM coupling. The radiating element is shielded from the spurious feed radiation due to the presence of an intermediate ground plane, separating the two substrates.

[0084] Fig. 3 depicts an antenna structure manufacturing method 30 according to the present disclosure in a block diagram.

[0085] At 31, a plurality of layers is provided based on LTCC, as discussed herein.

[0086] At 32, a circuitry layer is provided, as discussed herein.

[0087] At 33, a cavity is provided above the circuitry layer, as discussed herein.

[0088] At 34, an EBG structure including decoupling elements is provided on a bottom wall of the cavity, as discussed herein.

[0089] At 35, a top layer is provided above the cavity as discussed herein, including at least two antennas, such that they are provided at a top wall of the cavity, 36, as discussed herein.

[0090] It should be recognized that the embodiments describe methods with an exemplary ordering of method steps. The specific ordering of method steps is however given for illustrative purposes only and should not be construed as binding. For example the ordering of 32 and 33 in the embodiment of Fig. 3 may be exchanged. Also, the ordering of 33, 34 and 32 in the embodiment of Fig. 3 may be exchanged. Further, also the ordering of 35 and 36 in the embodiment of Fig. 3 may be exchanged. Other changes of the ordering of method steps may be apparent to the skilled person.

[0091] It should be noted that the present disclosure may have at least the following effects (also in addition to the effects as described above):

- In package air-filled antennas on top of in package EBG periodic structures may be provided

- $\lambda/2$ antenna spacing in one common encapsulated cavity may be achieved.

- EBG structures may be placed between aperture coupling feeding and radiating antenna elements.

- A multilayer ceramic package with embedded cavities and patches may be provided

- Separate cavities for TX and RX antenna channels elements may be envisaged

- Heat generated by the IC may be dissipated by attaching the IC to a large metal pad, backed by multiple thermal vias

- A multi-layer wafer package (LTCC ceramic package with multiple redistribution layers, RDLs for antenna and RF signal lines) with vertically and horizontally stacked elements may be provided.

- The band-gap features of EBG structures may be useful in suppressing surface waves. The surface waves may reduce the antenna efficiency and gain since they may propagate along a ground plane instead of radiating into free space. A diffraction of surface waves may raise mutual coupling levels in array designs, increase the back lobe radiation, which may deteriorate the signal to noise ratio, resulting in blind scanning angles in phased array systems, for example.

- Interaction between the mm-wave antenna and feeding network/mm-wave IC may be minimized due EBG shielding capability.

- Different type of EBG unit cells may be provided, such as mushroom type EBG, uni-planar EBG, polarization dependent EBG, compact spiral EBG, stacked EBG, miniaturized EBG, interdigital capacitor EBG.

- A dense integration may be achieved due to small antenna and interconnect footprint.

- A wideband antenna integration in a LTCC package may be achieved

- A high gain antenna may be provided due to the trench edge (air-filled cavity) into the LTCC and low loss interconnect.

- The (highly) compact antenna design may ensure that the antenna array may be arranged in a half wavelength array configuration (support grating free antenna array operation).

[0092] The present disclosure may be at least applied in the context of the following technology, without limiting the present disclosure in that regard:

- optical cameras, security cameras, TVs, game consoles

- industrial sensors, e.g., for distance detection (e.g., radar)

- radar based motion detection, vital sign detection

- communication devices (e.g. 60 GHz (or more or less) short range, wireless backhaul)

[0093] All units and entities described in this specification and claimed in the appended claims can, if not stated otherwise, be implemented as integrated circuit logic, for example on a chip, and functionality provided by such units and entities can, if not stated otherwise, be implemented by software.

[0094] In so far as the embodiments of the disclosure described above are implemented, at least in part, using software-controlled data processing apparatus, it will be appreciated that a computer program providing such software control and a transmission, storage or other medium by which such a computer program is provided are envisaged as aspects of the present disclosure.

[0095] Note that the present technology can also be configured as described below.

(1) An antenna structure comprising at least two antennas arranged in an array, the antenna structure further comprising:
an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

(2) The antenna structure of (1), further comprising:
a circuitry layer below the encapsulated cavity.

(3) The antenna structure of (2), wherein the EBG structure is provided at an interface of the encapsulated cavity and the circuitry layer.

(4) The antenna structure of anyone of (1) to (3), further comprising:
a top layer above the encapsulated cavity.

(5) The antenna structure of (4), wherein the at least two antenna elements are provided at an interface of the encapsulated cavity and the top layer.

(6) The antenna structure of anyone of (1) to (5), wherein the encapsulated cavity is an air-filled cavity.

(7) The antenna structure of anyone of (1) to (6), wherein the EBG structure includes at least two decoupling elements, wherein each decoupling elements is provided for each antenna.

(8) The antenna structure of anyone of (1) to (7), wherein the EBG structure is based on bowtie-shape aperture ground plane.

(9) The antenna structure of anyone of (1) to (8),

further comprising:
a plurality of layers, wherein the plurality of layers is based on low-temperature co-fired ceramics.

(10) The antenna structure of anyone of (1) to (9), wherein the at least two antennas are configured to operate in a range starting at 100 GHz.

(11) An antenna structure manufacturing method for providing an antenna structure including at least two antennas arranged in an array, the method comprising:
providing an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

(12) The antenna structure manufacturing method of (11), further comprising:
providing a circuitry layer below the encapsulated cavity.

(13) The antenna structure manufacturing method of (12), further comprising:
providing the EBG structure at an interface of the encapsulated cavity and the circuitry layer.

(14) The antenna structure manufacturing method of anyone of (11) to (13), further comprising:
providing a top layer above the encapsulated cavity.

(15) The antenna structure manufacturing method of (14), further comprising:
providing the at least two antenna elements at an interface of the encapsulated cavity and the top layer.

(16) The antenna structure manufacturing method of anyone of (11) to (15), wherein the encapsulated cavity is an air-filled cavity.

(17) The antenna structure manufacturing method of anyone of (11) to (16), further comprising:
providing a decoupling element for each antenna as part of the EBG structure.

(18) The antenna structure manufacturing method of anyone of (11) to (17), further comprising:
providing the EBG structure based on a bowtie-shape aperture ground plane.

(19) The antenna structure manufacturing method of anyone of (11) to (18), further comprising:
providing a plurality of layers based on low-temperature co-fired ceramics.

(20) The antenna structure manufacturing method of anyone of (11) to (19), further comprising:
providing the at least two antennas such that they are configured to operate in a range starting at 100 GHz.

Claims

1. An antenna structure comprising at least two antennas arranged in an array, the antenna structure further comprising:
an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

2. The antenna structure of claim 1, further comprising:
a circuitry layer below the encapsulated cavity.

3. The antenna structure of claim 2, wherein the EBG structure is provided at an interface of the encapsulated cavity and the circuitry layer.

4. The antenna structure of anyone of claims 1 to 3, further comprising:
a top layer above the encapsulated cavity.

5. The antenna structure of claim 4, wherein the at least two antenna elements are provided at an interface of the encapsulated cavity and the top layer.

6. The antenna structure of anyone of claims 1 to 5,

wherein the encapsulated cavity is an air-filled cavity; and or
wherein the EBG structure includes at least two decoupling elements, wherein each decoupling elements is provided for each antenna.

7. The antenna structure of anyone of claims 1 to 6, wherein the EBG structure is based on bowtie-shape aperture ground plane.

8. The antenna structure of anyone of claims 1 to 7, further comprising:
a plurality of layers, wherein the plurality of layers is based on low-temperature co-fired ceramics.

9. The antenna structure of anyone of claims 1 to 8, wherein the at least two antennas are configured to operate in a range starting at 100 GHz.

10. An antenna structure manufacturing method for providing an antenna structure including at least two antennas arranged in an array, the method comprising:
providing an encapsulated cavity including:

at least two antenna elements at a top wall section of the cavity, and
an electronic band gap (EBG) structure at a bottom wall section of the cavity, the bottom wall section being on an opposing side of the cavity with respect to the top wall section.

11. The antenna structure manufacturing method of claim 10, further comprising:
providing a circuitry layer below the encapsulated cavity.

12. The antenna structure manufacturing method of claim 11, further comprising:
providing the EBG structure at an interface of the encapsulated cavity and the circuitry layer.

13. The antenna structure manufacturing method of anyone of claims 10 to 12, further comprising:
providing a top layer above the encapsulated cavity.

14. The antenna structure manufacturing method of claim 13, further comprising:
providing the at least two antenna elements at an interface of the encapsulated cavity and the top layer.

15. The antenna structure manufacturing method of anyone of claims 10 to 14,

wherein the encapsulated cavity is an air-filled cavity; and or
wherein the method further comprises:
providing a decoupling element for each antenna as part of the EBG structure;
and/or
wherein the method further comprises:
providing the EBG structure based on a bowtie-shape aperture ground plane; and/or wherein the method further comprises:
providing a plurality of layers based on low-temperature co-fired ceramics; and/or wherein the method further comprises:
providing the at least two antennas such that they are configured to operate in a range starting at 100 GHz.

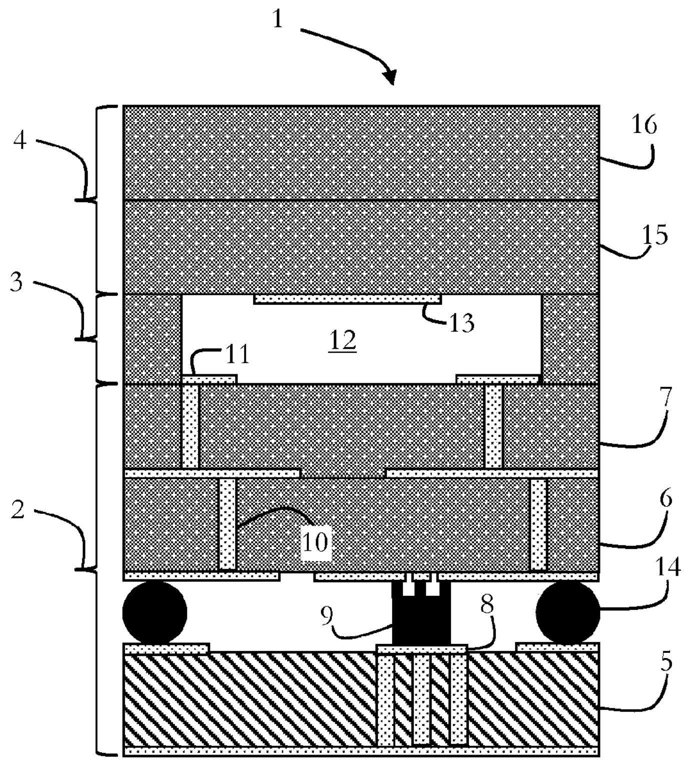

Fig. 1a

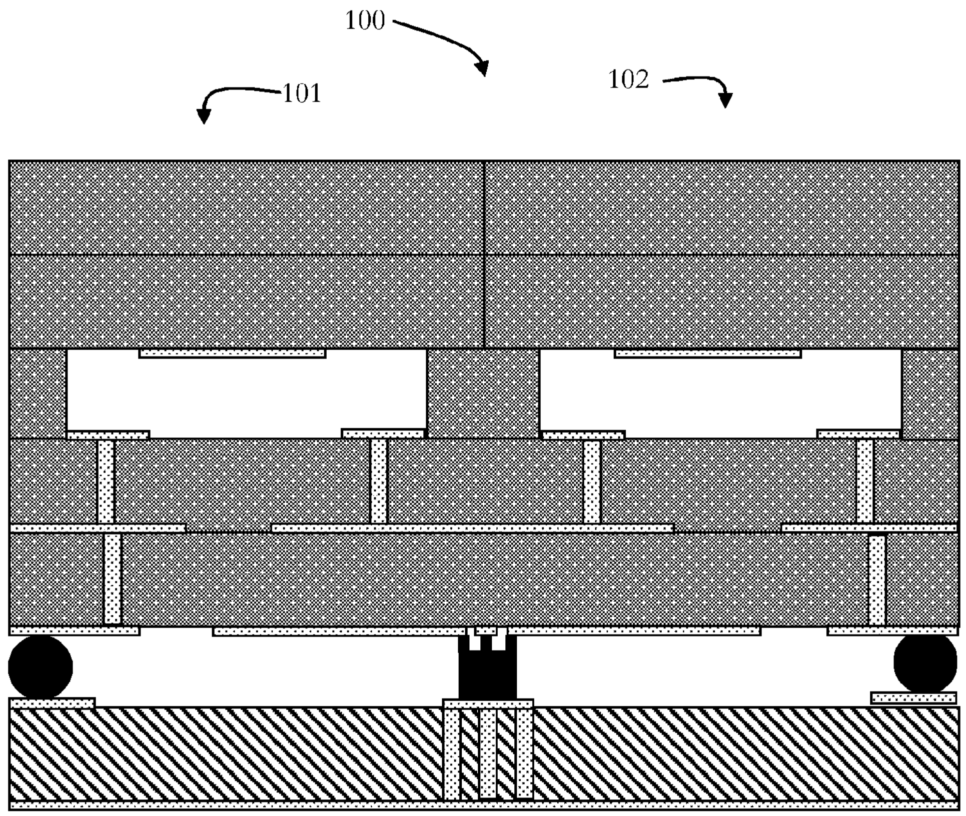

Fig. 1b

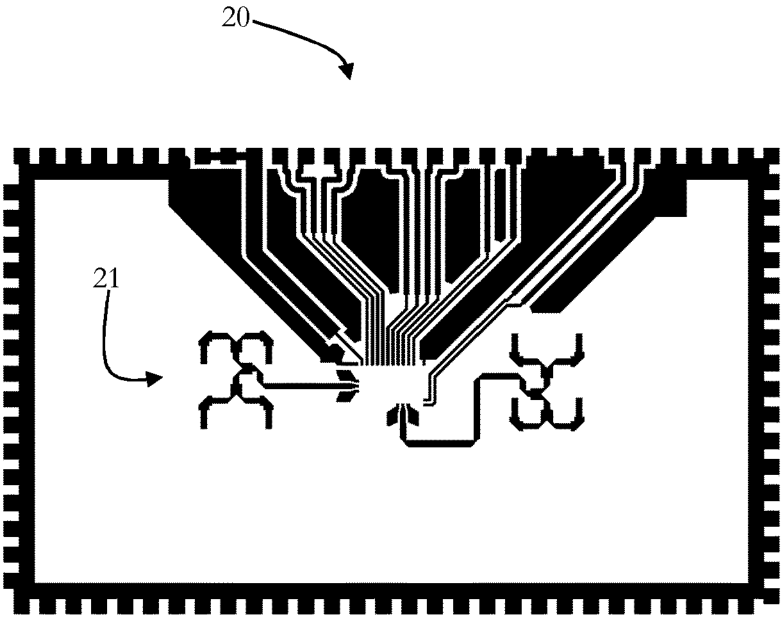

Fig. 2a

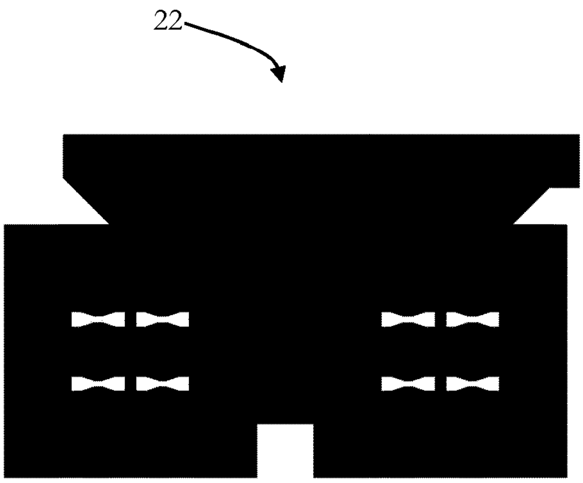

Fig. 2b

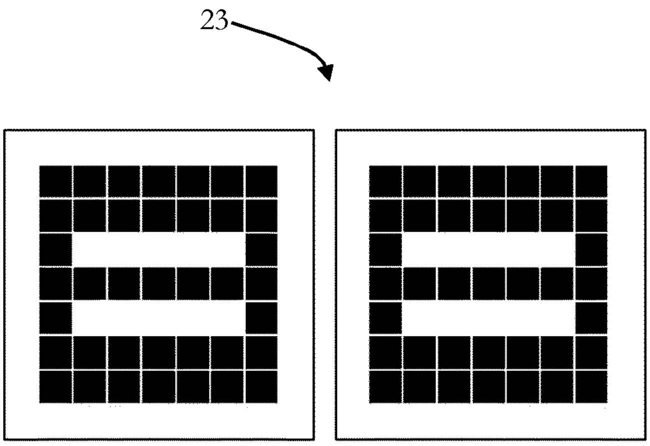

Fig. 2c

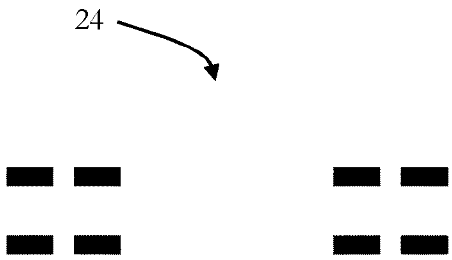

Fig. 2d

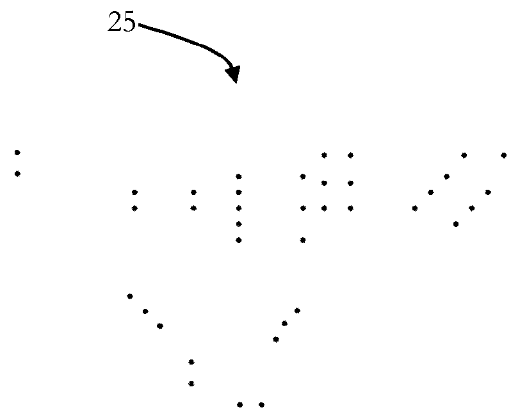

Fig. 2e

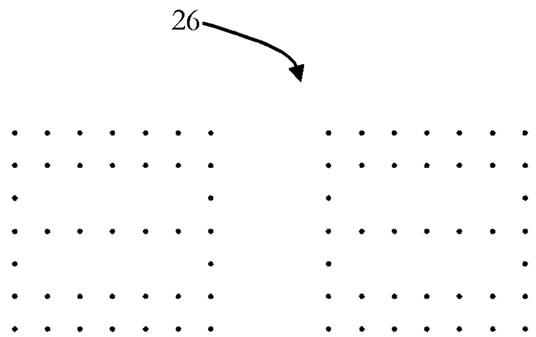

Fig. 2f

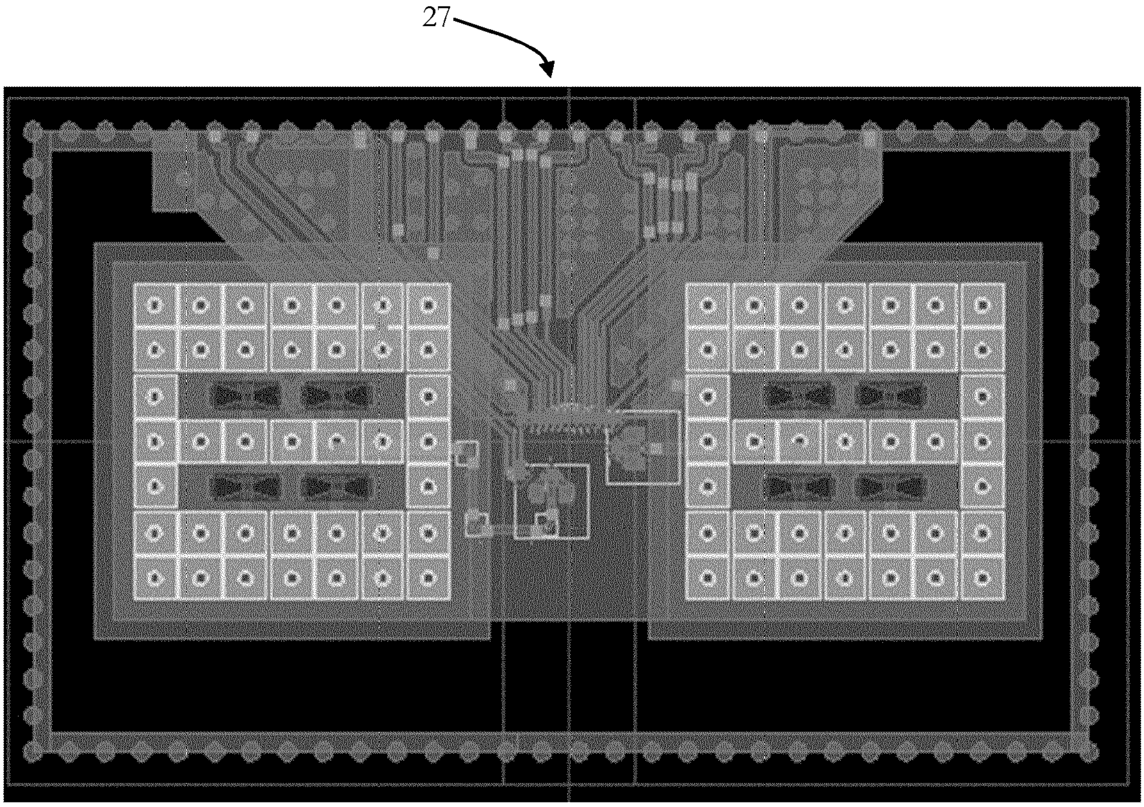

Fig. 2g

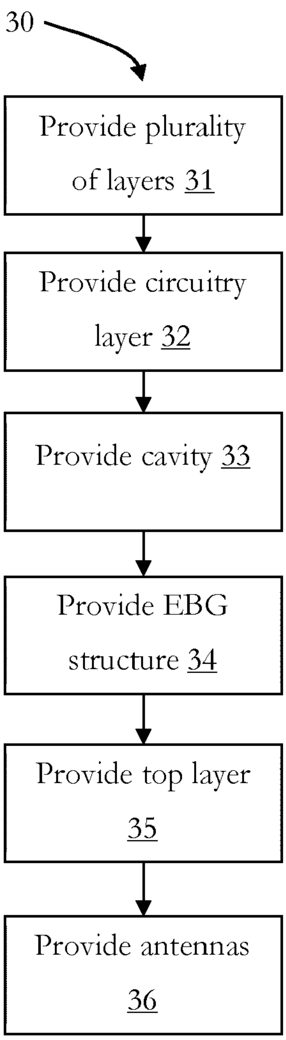
30
Provide plurality of layers 31
Provide circuitry layer 32
Provide cavity 33
Provide EBG structure 34
Provide top layer 35
Provide antennas 36

Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	21 February 2024	Hüschelrath, Jens

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