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(54) MICROWAVE ON-CHIP RESONATOR AND ANTENNA STRUCTURE

(57) The invention provides a microwave on-chip resonator comprising at least one spherical dielectric resonator, an integrated circuit forming a chip, a surface layer forming a surface of the chip, the surface layer having at least one shallow indentation for placing one spherical dielectric resonator each, thereby holding the spherical dielectric resonator at a lower section thereof, a planar transmission line structure on the surface layer being adapted for coupling electromagnetic energy between the planar transmission line structure and the spherical dielectric resonator, a holding structure for holding the at least one spherical dielectric resonator in the shallow indentation of the surface layer, wherein the spherical dielectric resonator is engaged at its upper section opposite the lower section by the holding structure, the holding structure being at least partly made of metal or comprising metallized sections for influencing an electromagnetic field of the spherical dielectric resonator.

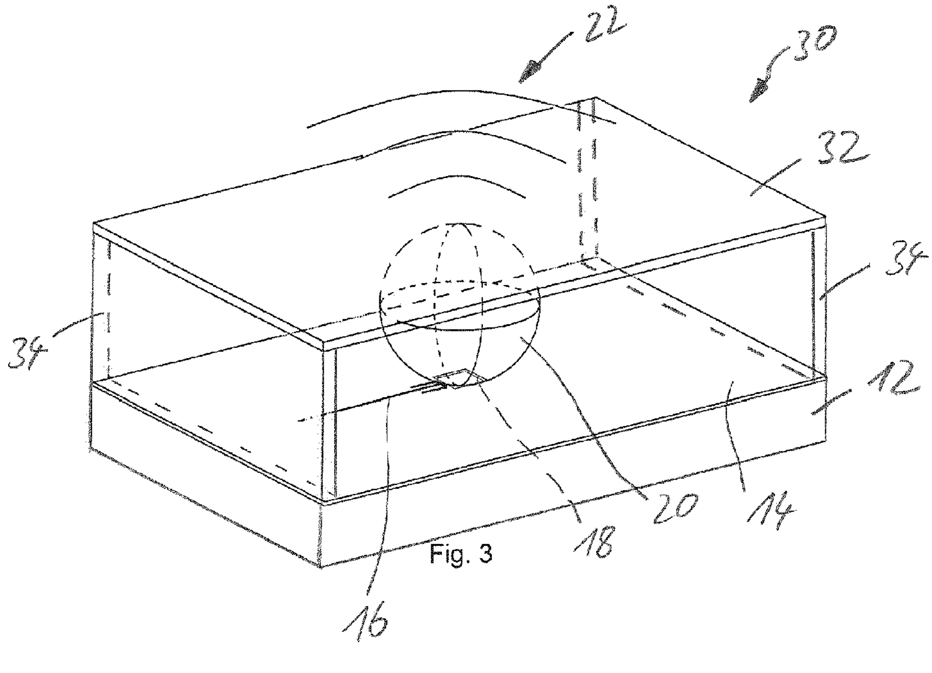

Fig. 3

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Description

[0001] The invention relates to a microwave on-chip resonator and an antenna structure comprising a microwave on-chip resonator.

[0002] Microwave dielectric resonators are known. In a dielectric volume structure, typically made of a ceramic or a crystal with high dielectric constant and low dielectric loss, a high-frequency electromagnetic wave can resonate at a specific frequency and in a specific mode. The dielectric constant forms the real part of the permittivity and the dielectric loss forms the imaginary part of the permittivity. The resonant mode denotes a specific distribution of electric and magnetic fields over space and time. In most practical applications, the dielectric resonator is connected by means of transmission lines to electronic circuitry. Many particular techniques were developed for the coupling between transmission lines and the dielectric resonator, on the one hand for using the dielectric resonator as an antenna coupling to free space and on the other hand for coupling between several close-by dielectric resonators, thereby forming a multi-resonant circuit or a filter.

[0003] The underlying problem of the invention is to improve the coupling of microwave dielectric resonators to electronic circuitry.

[0004] The underlying problem of the invention is solved by a microwave on-chip resonator having the features of claim 1 and by an antenna structure having the features of claim 14. Advantageous embodiments of the invention are mentioned in the subclaims.

[0005] According to the invention a microwave on-chip resonator comprises at least one spherical dielectric resonator, an integrated circuit forming a chip, a surface layer forming a surface of the chip, the surface layer having at least one shallow indentation for placing one spherical dielectric resonator each, thereby holding the spherical dielectric resonator at a lower section thereof, a planar transmission line structure on the surface layer being adapted for coupling electromagnetic energy between the planar transmission line structure and the spherical dielectric resonator and a holding structure for holding the at least one spherical dielectric resonator in the shallow indentation of the surface layer, wherein the spherical dielectric resonator is engaged at its upper section opposite the lower section by the holding structure, the holding structure being at least partly made of metal or comprising metallized sections for influencing an electromagnetic field of the spherical dielectric resonator.

[0006] Resonators in microwave circuits are used for frequency-selective applications, such as filters and oscillators, and for antenna radiators. The Q-value of a resonator relates the loss of energy per oscillation cycle to the stored energy in the resonator. Low-loss resonators are particularly useful for high-selectivity filters and high-stability oscillators. There is a general trade-off between Q-value and physical size of an electromagnetic resonator. Resonators with low loss and high Q-value exhibit a large geometrical size, i.e. a large volume. For a given geometrical size, the loss can be minimized to some extent by using metals of high conductivity, e.g. silver, and dielectric materials of low dielectric loss, e.g. air or low-loss ceramic. In most cases, the resonant mode of the electromagnetic wave resonating in a given resonator is relating the resonant frequency to the geometrical size of the resonator. In most practical cases, a resonator with high Q-value is somewhat smaller than a wavelength in geometrical extent. Much smaller resonators, but with much lower Q-values, can be made of short sections of planar transmission lines, of capacitors, of inductors, and of combinations of two or all three of them.

[0007] Monolithically integrated circuits, when operating at microwave frequency, suffer from on-chip resonators of very low Q-value due to very severe restrictions of size. In other words, there is only a limited chip area available. In many cases, the number of resonators needed in monolithically integrated electronic circuits can be reduced. For some applications, however, resonators cannot be foregone. These applications include high-stability oscillators, high-selectivity filters, and antenna radiators. In these cases, the resonator can be placed off-chip, i.e. somewhere on the circuit board but still close to the chip. The drawback then is that the high-frequency signal must be traced to the edge of the chip, then to the board, then to the resonator, and back. This adds complexity, size, loss by lowering the Q-value, and cost. Alternatively, a resonator can be placed atop the chip, as it has been shown for some on-chip antennas and for oscillators with an on-chip placed dielectric resonator. The drawback of this method is that accurate placement of the resonator is needed, which is expensive, and that a large fraction of the chip surface may become occupied by the resonator. A further drawback is that testing of the chip before mounting of the resonator may be compromised or impossible.

[0008] A resonator of potentially very high Q-value is the dielectric resonator. It resonates in specific modes which are only affected by the potentially very small dielectric loss, radiation loss, and a conductive loss of some close-by metal. Radiation loss is required for using the dielectric resonator as an antenna radiator. For other applications, radiation loss can be readily prevented by a metal shielding structure.

[0009] When using the dielectric resonator together with some coupling structure to couple the resonator to electronic circuitry, the size and dielectric constant of the dielectric resonator determine the resonance frequency and must be delicately controlled. The placement of the dielectric resonator with respect to the coupling structure must also be controlled very carefully as it determines the feed impedance of the resonator seen by the circuit. Controlling size, dielectric constant, and coupling geometry all to very high accuracy is a significant cost driver.

[0010] The dielectric constant of most crystals is known precisely, but the raw cost is typically much higher than the cost of ceramic. For some ceramic materials, the dielectric constant is well-defined, too. An example is alumina, an Al_2O_3 ceramic. Alumina also offers very low dielectric loss at microwave frequencies. In most practical applications, the dielectric resonator is of cylindrical shape. The use of a spherical dielectric resonator, however, has some advantages. Spheres can be manufactured to very high accuracy of the diameter at low cost. A sphere can be placed very accurately with respect to a plane structure by a shallow indentation, in other words a shallow crate, in the surface of the structure, provided that the position and shape of that shallow indentation or crate is accurate.

[0011] It is possible that a thin circuit board or layer with planar transmission lines is containing such a shallow crate for placing a spherical dielectric resonator. The circuit board will contain a planar transmission line structure for coupling electromagnetic energy between the spherical dielectric resonator and the planar transmission lines. At high microwave frequencies, where the spherical dielectric resonator is small, the circuit board can be the surface of a monolithically integrated circuit, and the shallow crate can be etched with the highest precision of semiconductor processing technology in the surface. By doing so, a cost-efficient precise coupling between electronic circuit and spherical dielectric resonator is possible, whereas the spherical dielectric resonator diameter can be controlled precisely and cost-efficiently. By using, for example, alumina ceramic, also the dielectric constant is well controlled.

[0012] The spherical dielectric resonator is placed on-chip in a shallow crate and is coupled to the on-chip electronic by a planar transmission line structure. This arrangement can be used for the application of an on-chip antenna. In this case, the electromagnetic wave resonating in the dielectric resonator radiates and a dielectric forms a dielectric resonator antenna. By using a different resonance mode of the sphere, a rectangular air-filled metal waveguide can be placed atop the on-chip mounted sphere and the resulting device couples the electromagnetic wave from the on-chip circuitry through the spherical dielectric resonator in the waveguide without radiation.

[0013] When practically realizing the on-chip mounted spherical dielectric resonator, the resonator can be aligned in the shallow crate and could be fixed in the crate with very little glue. Most glues are dielectric materials with high loss and poorly defined dielectric constant. Therefore, the application of much glue must be avoided. Therefore, a mechanical structure is needed to hold the on-chip mounted spherical dielectric resonator in place without compromising its electrical performance. The invention proposes such mechanical holding structure with the additional benefit of radiation suppression or radiation enhancement or additional coupling, as it is needed for the different applications.

[0014] The inventive microwave on-chip resonator comprises at least one spherical dielectric resonator, an integrated circuit forming a chip, a surface layer having at least one shallow indentation for placing one spherical dielectric resonator each, thereby holding the spherical dielectric resonator at a lower section thereof, a planar transmission line structure on the surface layer being adapted for coupling electromagnetic energy between the planar transmission line structure and the spherical dielectric resonator, and a holding structure for holding the at least one spherical dielectric resonator in the shallow indentation of the surface layer, wherein the spherical dielectric resonator is engaged at its upper section opposite the lower section by the holding structure, the holding structure being at least partly made of metal or comprising metallized sections for influencing an electromagnetic field of the spherical dielectric resonator.

[0015] By engaging the dielectric resonator at its upper section opposite the lower section by the holding structure, the spherical dielectric resonator can be held with high precision and without using glue or the like for fixing the lower section in the shallow indentation of the surface layer of the chip. As a consequence, the spherical dielectric resonator can be held with high accuracy, thereby providing a high electrical performance of the coupling between the transmission line structure and the spherical dielectric resonator. By making the holding structure at least partly of metal or by providing the holding structure with metallized sections, an electromagnetic field of the spherical dielectric resonator can be influenced to be perfectly adapted to different applications. The electromagnetic field comprises radiating fields and non-radiating fields and the holding structure can suppress radiation, can enhance radiation, can provide additional coupling and can also influence and thereby form a radiation pattern of the spherical dielectric resonator. The invention therefore provides a low-cost microwave on-chip resonator with high electrical performance.

[0016] According to an embodiment of the invention, the lowest resonance frequency of the at least one spherical dielectric resonator is in the frequency range between 30 GHz and 150 GHz.

[0017] Every spherical dielectric resonator has an unlimited number of resonance frequencies. In practical realizations, the lowest resonance frequency or, alternatively, the second, third or fourth lowest resonance frequency is used. Higher resonance frequencies are placed closer to each other on the frequency axis and can, for technical applications, not be separated anymore. For the purpose of this invention using the second lowest or third lowest resonance frequency of the spherical dielectric resonator has shown to be very advantageous. By doing so, the frequency range of the inventive microwave on-chip resonators and of the inventive antenna structures is in a frequency range between 60 GHz up to approximately 200 GHz. This frequency range is also called millimeter waves. In other words, for the purpose of the present invention, resonance frequencies of the spherical dielectric resonator between 60 GHz and approximately 200 GHz are used, especially up to 250 GHz.

[0018] According to an embodiment of the invention, the spherical dielectric resonator is made of ceramic, especially alumina.

[0019] Using alumina ceramic, in other words an Al_2O_3 ceramic, a dielectric resonator offering very low dielectric loss at microwave frequencies can be realized. In addition, the raw cost of alumina is not very high and alumina can be machined into spheres with very high accuracy and low cost.

[0020] According to an embodiment of the invention the holding structure comprises a dielectric board being arranged parallel to the circuit board and touching the upper section of the spherical dielectric resonator, thereby applying a holding force on the spherical dielectric resonator, the holding force being directed towards the circuit board.

[0021] By using a dielectric board as a holding structure, the spherical dielectric resonator can be securely held with very high precision and can at the same time be very efficiently coupled to the planar transmission line structure. The position of the spherical dielectric resonator is exactly determined by the shallow indentation in the surface layer forming a surface of the chip. The holding structure, namely the dielectric board, simply has to apply a holding force on the spherical dielectric resonator which is directed towards the surface layer. Such a holding force is surprisingly sufficient to hold the spherical dielectric resonator in the shallow indentation on the surface layer. The dielectric board, therefore, mechanically fixes the spherical dielectric resonator by applying pressure and prohibiting lateral displacement of the spherical dielectric resonator. The dielectric board, therefore, has to have a certain rigidity which is sufficient to apply the holding force directed towards the surface layer on the spherical dielectric resonator. At the same time the circuit board has to be soft enough or flexible enough to compensate for tolerances with respect to fixing the dielectric board to the integrated circuit forming a chip or to another base structure. The dielectric board of the holding structure can be fixed to the surface layer forming a surface of the chip by fixing the dielectric board to a spacer, which is then fixed to a structure carrying the chip or by fixing the dielectric board directly to the surface layer. It is possible to fix the dielectric board to the structure carrying the chip or to the spacer by gluing, screwing, soldering or brazing. Other holding means are possible, e.g. brackets or the like.

[0022] According to an embodiment of the invention, the dielectric board engages the uppermost point of the spherical dielectric resonator opposite the indentation.

[0023] The dielectric board does not necessarily have to have a fixing structure for the spherical dielectric resonator. If the dielectric board is slightly forced in the direction of the surface layer, it will exert a holding force on the spherical dielectric resonator which is sufficient to hold the spherical dielectric resonator in the shallow indentation and to prevent lateral displacement of the spherical dielectric resonator. In this case the dielectric board can be manufactured at very low cost.

[0024] According to an embodiment of the invention the dielectric board comprises a through-hole, an inner wall of the through-hole at least partly contacting the upper section of the spherical dielectric resonator.

[0025] By providing the dielectric board with a through-hole which contacts the spherical dielectric resonator in its upper section, the mechanical fixation of the spherical dielectric resonator can be improved. In addition, advantageous electrical properties of the dielectric board can be achieved, e.g. if an antenna structure is to be provided. The through-hole of the dielectric board can then allow radiation of the spherical dielectric resonator. The dielectric board can be manufactured by known precision machining techniques, e.g. milling, molding, etching, or, if a higher precision seems necessary, by known techniques of semiconductor processing technology, e.g., the through-hole can be etched into the dielectric board with very high precision. In this way, placement of the spherical dielectric resonator can be achieved with very high accuracy.

[0026] According to an embodiment of the invention the holding structure comprises a metal ring surrounding the upper section of the spherical dielectric resonator.

[0027] A metal ring surrounding the upper section of the spherical dielectric resonator affects the radiation of the spherical dielectric resonator. Using such a metal ring is especially advantageous when realizing an antenna structure. The metal ring can e.g. focus the upward radiation of the spherical dielectric resonator.

[0028] According to an embodiment of the invention the metal ring is arranged symmetrically with respect to the through-hole.

[0029] By arranging the metal ring symmetrically with respect to the through-hole, radiation of the spherical dielectric resonator can be positively affected. The metal ring can e.g. be placed concentrically to the through-hole. It can also be placed with its inner diameter extending up to the wall of the through-hole.

[0030] According to an embodiment of the invention the metal ring comprises two stubs extending in radial direction of the ring and being arranged opposite each other on the metal ring.

[0031] By providing the metal ring with two stubs, a break of symmetry of the ring can be achieved. Thereby, the radiation of the spherical dielectric resonator, especially the upward radiation, can be focused and the polarization of the radiation can be influenced. By using two stubs extending in radial directions of the ring and being arranged opposite each other on the metal ring, a circular polarization of the upward radiation can be achieved.

[0032] According to an embodiment of the invention the holding structure comprises at least two metal stripes being arranged in parallel to each other, the spherical dielectric resonator being arranged between the at least two metal stripes when viewed from above.

[0033] By means of two metal stripes the radiation of the spherical dielectric resonator is affected in a way that the upward radiation is focused.

[0034] According to an embodiment of the invention the holding structure comprises a board being arranged parallel to the surface layer and being made of metal, being fully metallized on at least one side thereof or being fully metalized apart from slot like structures on at least one side thereof.

[0035] By means of a metal board or a fully metallized board, radiation of the spherical dielectric resonator is prevented. The spherical dielectric resonator then acts as a low-loss resonator.

[0036] According to an embodiment of the invention the surface layer has two indentations being arranged proximate to each other, each indentation holding a spherical dielectric resonator, thereby forming a microwave on-chip filter.

[0037] The board of the holding structure being made of metal or being almost fully metallized prevents radiation. As a consequence, the two spherical dielectric resonators act as a low-loss resonator; however, coupling between the two spherical dielectric resonators takes place. The microwave on-chip resonator therefore acts as frequency-selective transmission device, e.g. a bandpass filter. To this end, every spherical dielectric resonator has a planar transmission line structure for coupling electromagnetic energy between the respective planar transmission line structure and the respective spherical dielectric resonator.

[0038] According to an embodiment of the invention the board has at least one cut-out in the metal, said at least one cut-out being arranged between the two spherical dielectric resonators when viewed from above.

[0039] The coupling slot or cut-out in the metal board or in the metallization of the board tunes the coupling such that a frequency-selective transmission is realized between the two feed lines, thereby forming a microwave on-chip filter, e.g. a bandpass filter.

[0040] The underlying problem of the invention is also solved by an antenna structure comprising a microwave on-chip resonator according to the invention, wherein a plurality of spherical dielectric resonators are provided, each resonator being held in a separate indentation of the surface layer forming a surface of the chip, the holding structure being formed by a dielectric board touching the plurality of spherical dielectric resonators.

[0041] Surprisingly, a dielectric board touching the plurality of spherical dielectric resonators can at the same time fix a plurality of spherical dielectric resonators. By means of the dielectric board, a holding force onto the plurality of dielectric resonators has to be provided, such holding force being directed towards the surface layer. By means of such a holding force, each spherical dielectric resonator is securely held in its respective indentation. Thereby, lateral displacement of each spherical dielectric resonator is prevented. By means of the invention, for example 1,000 spherical dielectric resonators can be held at the same time on the surface layer of a chip.

[0042] According to an embodiment of the invention a lens is arranged on top of the dielectric board forming the holding structure or a plane side of the lens forms the dielectric board.

[0043] By means of such a lens, the radiation of each spherical dielectric resonator can be directed, e.g. concentrated, expanded and/or directed into a new direction. The invention can thereby provide an antenna structure which is suitable to provide a base-station for millimeter-wave mobile communications. The lens can be formed as a dome-shaped gradient index lens focusing beams from all directions entering the lens in a single focal plane. Such a lens is arranged on top of the dielectric board forming the holding structure. The focal plane is then advantageously placed on the dielectric board forming the holding structure for the spherical dielectric resonators or directly contacts the plurality of spherical dielectric resonators and thereby forms the holding structure or at least part of the holding structure. The dielectric board forming the holding structure can thereby be an integral part of the dielectric material of the lens. In order to improve the transfer of electromagnetic fields and radiation from the spherical dielectric resonators through the dielectric board forming the holding structure to the lens, the dielectric board or the plane side of the lens can feature partial metallization in specific forms, e.g. rings and/or rectangles, for the purpose of radiation focusing. Examples of such metallization in specific forms are shown in fig. 5 to 8. An inventive antenna structure can, e.g., have a very high number of spherical dielectric resonators, especially 1,000 resonators.

[0044] Further advantages and features of the invention are apparent from the claims and the following description of advantageous embodiments of the invention in conjunction with the drawings. Individual features of various embodiments can be combined at will with other features without departing from the scope of the invention. In the drawings, the following is shown:

Fig. 1 schematically shows an integrated circuit forming a chip for realizing the invention,

fig. 2 shows the surface layer of the chip of fig. 1 with a spherical dielectric resonator placed thereon,

fig. 3 schematically shows a microwave on-chip resonator according to a first embodiment of the invention,

fig. 4 schematically shows a second embodiment of a microwave on-chip resonator according to the invention,

fig. 5 schematically shows a third embodiment of a microwave on-chip resonator according to the invention,

fig. 6 schematically shows a fourth embodiment of a microwave on-chip resonator according to the invention,

fig. 7 schematically shows a fifth embodiment of a microwave on-chip resonator according to the invention,

fig. 8 schematically shows a sixth embodiment of a microwave on-chip resonator according to the invention,

fig. 9 schematically shows a seventh embodiment of a microwave on-chip resonator according to the invention,

fig. 10 schematically shows an eight embodiment of a microwave on-chip resonator according to the invention, forming a microwave on-chip filter and

fig. 11 shows an antenna structure according to a further embodiment of the invention.

[0045] Fig. 1 schematically shows an integrated circuit 10 forming a chip 12 and having a surface layer 14. The surface layer 14 is made of plastic and forms the top layer of the chip 12. The surface layer 14 comprises a planar transmission line structure 16 which is connected to the integrated circuit within the chip 12. The planar transmission line structure 16 is adapted for coupling electromagnetic energy. The lower side of the surface layer 14, i.e. the side of the surface layer 14 facing the chip 12, is metallized.

[0046] The surface layer 14 has a shallow square indentation, in other words a shallow square crate 18. The indentation 18 has a depth which corresponds to the thickness of the surface layer 14. The indentation 18 is etched into the surface layer 14 and, therefore, can be manufactured with the highest precision of semiconductor processing technology.

[0047] Fig. 2 shows the surface layer 14 with a spherical dielectric resonator 20 placed in the indentation 18. The spherical dielectric resonator 20 is engaged by the sidewalls of the indentation 20 at its lower section. The indentation 18, in other words the side walls of the indentation 18, securely holds the spherical dielectric resonator 20 in place and prevents lateral displacement of the spherical dielectric resonator 20 as long as the spherical dielectric resonator 20 is not subjected to external forces. As soon as the spherical dielectric resonator 20 is excited by electromagnetic energy and resonates, the spherical dielectric resonator 20 will radiate an electromagnetic field, this being schematically indicated at 22. In case the spherical dielectric resonator 20 resonates, a separate holding force is needed to hold the spherical dielectric resonator 20 in its place within the indentation 18.

[0048] The spherical dielectric resonator 20 is made of alumina ceramic. Alumina ceramic offers very low dielectric loss at microwave frequencies. The frequency range of interest is in the case of the invention between approximately 60 GHz and up to approximately 200 GHz. In addition, spheres like the spherical dielectric resonator 20 can be manufactured to very high accuracy of their diameter at low cost. In addition, a sphere like the spherical dielectric resonator 20 can be placed very accurately with respect to a plane structure, namely the surface layer 14, by the shallow crate or indentation 18.

[0049] Fig. 3 schematically shows a microwave on-chip resonator according to a first embodiment of the invention. The microwave on-chip resonator 30 comprises the chip 12 with its surface layer 14, the planar transmission line structure 16 and the spherical dielectric resonator 20 being arranged in the shallow indentation 18 as has already been explained above.

[0050] To securely hold the spherical dielectric resonator 20 in place when it resonates, a dielectric board 32 is arranged parallel to the surface layer 14 in a distance to the surface layer 14 so that it engages the uppermost point of the spherical dielectric resonator 20, said uppermost point being arranged opposite the indentation 18.

[0051] The dielectric board 32 is part of a holding structure which comprises schematically shown side walls 34 which connect side edges of the dielectric board 32 to the chip 12. The side walls 34 and the dielectric board 32 form a holding structure for the spherical dielectric resonator 20. It should be noted that instead of the side walls 34 any other holding structure could be used to hold the dielectric board 32 in place, e.g. brackets, pillars or the like could be used.

[0052] The spherical dielectric resonator has its lowest resonance frequency in the frequency range between 30 GHz and 150 GHz. However, the second lowest or third lowest resonance frequency of the spherical dielectric resonator 20 is used in order to operate the microwave on-chip resonator 30 in a frequency range between 60 GHz to approximately 200 GHz. For different operating frequencies, of course a spherical dielectric resonator 20 of different size or different material has to be provided. By metallizing sections of the dielectric board 32 or, as is shown in fig. 3, by fully metallizing the backside of the dielectric board 32, said backside facing the surface layer 14 of the chip 12, an electromagnetic field of the spherical dielectric resonator 20 can be influenced. Thereby, radiation 22 of the spherical dielectric resonator 20 is influenced or even completely prevented. The dielectric board 32 is flexible enough or soft enough to slightly bend so that the point touching the uppermost point of the spherical dielectric resonator 20 forms the most elevated point of the dielectric board 32. On the other hand, the dielectric board 32 is rigid enough to generate a holding force and to apply said holding force on the spherical dielectric resonator 20, the holding force being directed towards the surface layer 14. By means of the dielectric board 32 the spherical dielectric resonator 20 can be mechanically fixed and lateral displacement of the spherical dielectric resonator 20 can be prevented. On the other hand, the dielectric board 32 itself does not disturb radiation of the spherical dielectric resonator 20. It is only the metallization of the dielectric board 32 which influences an electromagnetic field of the spherical dielectric resonator 20, namely influencing radiating fields, but also non-radiating fields.

[0053] Fig. 4 schematically shows a further embodiment of the microwave on-chip resonator according to the invention. Elements which are similar to the microwave on-chip resonator 30 of fig. 3 are not explained again.

[0054] The microwave on-chip resonator 40, which is partly shown in fig. 4, has a dielectric board 42 with a small through-hole 44 for alignment of the spherical dielectric resonator 20. The dielectric board 42 is arranged with respect to the surface layer 14 so that the through-hole 44 is exactly opposite the indentation 18. An inner wall of the through-hole 44 contacts the upper section of the spherical dielectric resonator 20, thereby prohibiting lateral displacement of the spherical dielectric resonator 20. As is the case with the dielectric board 32 shown in fig. 3, the dielectric board 42 applies a pressure onto the spherical dielectric resonator 20, said pressure being caused by a holding force which is directed towards the surface layer 14.

[0055] Fig. 5 schematically shows a microwave on-chip resonator 50 according to a further embodiment of the invention. Again, only elements which are different to the embodiments explained above will be described.

[0056] In the embodiment shown in fig. 5 the dielectric board 32 is provided with a metal ring 52 on its bottom side facing the surface layer 14. This metal ring is e.g. manufactured by etching the dielectric board 32. The dielectric board 32 mechanically fixes the spherical dielectric resonator 20, as has already been explained before. The metal ring affects the radiation of the spherical dielectric resonator 20. By means of the metal ring 52 the radiation 22 directed upwards can be focused.

[0057] Fig. 6 schematically shows a microwave on-chip resonator 60 according to a further embodiment of the invention. Again, only elements which are different from the embodiments explained above are described.

[0058] The dielectric board 32 has the metal ring 52, said metal ring 52 being provided with two stubs 62 and 64. The stubs 62, 64 extend in radial directions of the ring 52 and are arranged opposite each other on the ring 52. The stubs 62, 64 are manufactured together with the ring 52 and are electrically connected.

[0059] By means of the stubs 62, 64, a break of symmetry of the ring 52 is achieved and the upward radiation 22 of the spherical dielectric resonator 20 is, thereby, elliptically or circularly polarized.

[0060] Fig. 7 schematically shows a microwave on-chip resonator 70 according to a further embodiment of the invention. Again, only elements which are different from the embodiments already explained above will be described.

[0061] The dielectric board 42, which has already been explained in conjunction with fig. 4, is provided with two metal stripes 72, 74 which are arranged parallel to each other. When viewed from above, the spherical dielectric resonator 20 is arranged in-between the two metal stripes 72, 74. By means of the two metal stripes 72, 74 the upward radiation 22 of the spherical dielectric resonator 20 is focused.

[0062] Fig. 8 shows a microwave on-chip resonator 80 according to a further embodiment of the invention. Only elements will be described which are different from the embodiments already explained above.

[0063] The dielectric board 42 comprises two metal rectangles 82 which are arranged parallel to each other, the spherical dielectric resonator 20 being arranged, when viewed from above, in-between the two rectangles 82, 84. Each of the rectangles 82, 84 defines a rectangular slot 86, 88 which is in the plane of the dielectric board 42 and which is completely surrounded by metal. By means of the slotted metal rectangles 82, 84 a residual sideward radiation of the spherical dielectric resonator 20 is reduced and the upward radiation 22 is focused.

[0064] Fig. 9 shows a microwave on-chip resonator 90 according to a further embodiment of the invention. Again, only elements will be described which are different from the embodiments already described above.

[0065] The dielectric board 42 has a top metallization 92 which covers the entire upper surface of the dielectric board 42 or which is, as shown in fig. 9, in the form of a large circle, concentrically surrounding the through-hole 44. The metallization 92 is, when viewed from above, significantly bigger than the spherical dielectric resonator 20 and has, e.g., twice the radius of the spherical dielectric resonator 20. The metallization 92, therefore, prevents radiation of the spherical dielectric resonator 20 and causes the dielectric resonator 20 to act as a low-loss resonator.

[0066] Fig. 10 shows a microwave on-chip resonator according to a further embodiment of the invention which forms a microwave on-chip filter 100. A surface layer 104 of an integrated circuit, which is not shown, is provided with two planar transmission line structures 106 and 108. The planar transmission line structure 106 leads to a first indentation 110. The second planar transmission line structure 108 leads to a second indentation 112. The indentations 110, 112 correspond to the indentation 18 which has already been explained above. The two indentations 110, 112 are arranged side by side and in a distance to each other that a first spherical dielectric resonator 112 and a second spherical dielectric resonator 114 are also placed side by side, but in a predefined distance to each other. Each spherical dielectric resonator 112, 114 is held with its lower section within the respective indentation 110, 112, which has already been explained with respect to the indentation 18 and a spherical dielectric resonator 20 above.

[0067] A dielectric board 116 has two through-holes 118, 120 which are arranged in the same distance to each other as the two indentations 110, 112 in the surface layer 104. The through-holes 118, 120 touch the upper section of the spherical resonators 112, 114, thereby holding the spherical dielectric resonators 112, 114 in place, as has already been described with respect to the dielectric board 42, the through-hole 44 and the dielectric spherical resonator 20 according to fig. 4. The top side of the dielectric board 116 is completely metallized, apart from the area of the through-holes 120, 118 and apart from a coupling slot 122. The coupling slot 122 is arranged, when viewed from above, in-between the two through-holes 120, 118 and, therefore, also in-between the two spherical dielectric resonators 112, 114.

[0068] The top metallization of the dielectric board 116 prevents radiation of the two dielectric resonators 112, 114, thereby causing the spherical dielectric resonators 112, 114 acting as low-loss resonators. The coupling slot 122 tunes the coupling between the two spherical dielectric resonators 112, 114 such that a frequency-selective transmission is realized between the two feed lines, namely the two planar transmission line structures 106, 108. The microwave on-chip filter 100, therefore, acts as a filter, e.g. a bandpass filter between the two feed lines 106, 108.

[0069] Fig. 11 schematically shows an antenna structure 130 according to a further embodiment of the invention. The antenna structure 130 comprises a plurality, e.g. 1,000, microwave on-chip resonators 132. The resonators 132 comprise an integrated circuit or chip 134. On a surface layer 136 of the chip 134 a plurality, e.g. 1,000, spherical dielectric resonators 20 are arranged. The spherical dielectric resonators are held in place by a dielectric board 138. The surface layer 136 comprises a plurality of shallow indentations, one indentation for each spherical dielectric resonator 20, and the dielectric board 138 holds the spherical dielectric resonators 20 in place, as has already been explained above.

[0070] Each one of the spherical dielectric resonators radiates in the upward direction in fig. 11. On top of the dielectric board 138 a lens 140 is placed. The lens 140 has a focal plane which is placed on the dielectric board 138. The lens 140 is a dome-shaped gradient index lens focusing radiation beams from all directions entering the lens 140 in a single focal plane, i.e. in the plane of dielectric board 138. By means of the lens 140 the radiation beams of the spherical dielectric resonators 20 are entering the lens 140 and are leaving the lens 140 in all directions perpendicular to the outer dome-shaped contour of the lens 140. By means of the antenna structure 130, therefore, a wide angle coverage of radiation can be achieved. The antenna structure 140 can, therefore, form part of a concept of a millimeter-wave mobile communication base-station.

[0071] The lower plane side of the lens 140 can also be used to hold the spherical dielectric resonators 20 in place, thereby omitting the need for the dielectric board 138. The dielectric board 138 or the plane side of the lens 140 can be provided with partial metallization, e.g. in the form of rings, stripes and/or rectangles as shown in Fig. 5 to 8 in order to focus radiation.

Claims

1. Microwave on-chip resonator comprising

- at least one spherical dielectric resonator (20)
- an integrated circuit forming a chip,
- a surface layer (14) forming a surface of the chip, the surface layer having at least one shallow indentation (18; 110, 112) for placing one spherical dielectric resonator (20) each, thereby holding the spherical dielectric resonator at a lower section thereof,
- a planar transmission line structure (16; 106, 108) on the surface layer (14) being adapted for coupling electromagnetic energy between the planar transmission line structure (16; 106, 108) and the spherical dielectric resonator (20), and
- a holding structure for holding the at least one spherical dielectric resonator in the shallow indentation (18; 110, 112) of the surface layer (14),

characterized in that

- the spherical dielectric resonator (20) is engaged at its upper section opposite the lower section by the holding structure, the holding structure being at least partly made of metal or comprising metallized sections for influencing an electromagnetic field of the spherical dielectric resonator (20).

2. Microwave on-chip resonator according to claim 1, **characterized in that** the lowest resonance frequency of the at least on spherical dielectric resonator (20) is in the frequency range between 30GHz and 150 GHz.

3. Microwave on-chip resonator according to claim 1 or 2, **characterized in that** the spherical dielectric resonator (20) is made of ceramic, especially alumina.

4. Microwave on-chip resonator according to any of the preceding claims, **characterized in that** the holding structure comprises a dielectric board (32; 42; 116; 138) being arranged parallel to the suface layer (14) and touching the upper section of the spherical dielectric resonator (20), thereby applying a holding force on the spherical dielectric resonator (20), the holding force being directed towards the surface layer (14).

5. Microwave on-chip resonator according to claim 4, **characterized in that** the dielectric board (32) engages the uppermost point of the spherical dielectric resonator (20) opposite the indentation (18).

6. Microwave on-chip resonator according to claim 4,

characterized in that the dielectric board (42) comprises a through hole (44; 118, 120), an inner wall of the through hole (44; 118, 120) at least partly contacting the upper section of the spherical dielectric resonator (20).

7. Microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises a metal ring (52) surrounding the upper section of the spherical dielectric resonator (20).

8. Microwave on-chip resonator according to claim 6 and 7, **characterized in that** the metal ring (52) is arranged symmetrically with respect to the through hole (44).

9. Microwave on-chip resonator according to claim 7 or 8, **characterized in that** the metal ring (52) comprises two stubs (62, 64) extending in radial directions of the ring (52) and being arranged opposite each other on the metal ring (52).

10. Microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises at least two metal stripes (72, 74; 82, 84) being arranged in parallel to each other, the spherical dielectric resonator (20) being arranged between the at least two metal stripes (72, 74; 82, 84) when viewed from above.

11. Microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises a board (32; 42; 116) being arranged parallel to the surface layer (14) and being made of metal, being fully metallized or being fully metallized apart from slot like structures on at least one side thereof.

12. Microwave on-chip resonator according to claim 11, characterized that the surface layer (14) has two indentations (110, 112) being arranged proximate to each other, each indentation (110, 112) holding a spherical dielectric resonator (20), thereby forming a microwave on-chip filter (100).

13. Microwave on-chip resonator according to claim 12, **characterized in that** the board (116) has at least one cut-out (112) in the metal, said at least one cut-out (112) being arranged between the two spherical dielectric resonators (20), when viewed from above.

14. Antenna structure comprising a micro wave on-chip resonator according to at least one of the preceding claims, **characterized by** a plurality of spherical dielectric resonators (20), each resonator (20) being held in a separate indentation of the surface layer (136) forming a surface of the chip (134), the holding structure being formed by a dielectric board (138) touching the plurality of spherical dielectric resonators (20).

15. Antenna structure according to claim 14, **characterized in that** a lens (140) is arranged on top of the dielectric board (138) or **in that** a plane side of the lens (140) forms the dielectric board (138).

Amended claims in accordance with Rule 137(2) EPC.

1. Antenna radiator, having a microwave on-chip resonator comprising

   - at least one spherical dielectric resonator (20)
   - an integrated circuit forming a chip,
   - a surface layer (14) forming a surface of the chip, the surface layer having at least one shallow indentation (18; 110, 112) for placing one spherical dielectric resonator (20) each, thereby holding the spherical dielectric resonator at a lower section thereof,
   - a planar transmission line structure (16; 106, 108) on the surface layer (14) being adapted for coupling electromagnetic energy between the planar transmission line structure (16; 106, 108) and the spherical dielectric resonator (20), and
   - a holding structure for holding the at least one spherical dielectric resonator in the shallow indentation (18; 110, 112) of the surface layer (14), wherein
   - the spherical dielectric resonator (20) is engaged at its upper section opposite the lower section by the holding structure,

   characterized in that

   - the holding structure being at least partly made of metal or comprising metallized sections for influencing an electromagnetic field of the spherical dielectric resonator (20).

2. Antenna radiator, having a microwave on-chip resonator according to claim 1, **characterized in that** the lowest resonance frequency of the at least on spherical dielectric resonator (20) is in the frequency range between 30GHz and 150 GHz.

3. Antenna radiator, having a microwave on-chip resonator according to claim 1 or 2, **characterized in that** the spherical dielectric resonator (20) is made of ceramic, especially alumina.

4. Antenna radiator, having a microwave on-chip resonator according to any of the preceding claims, **characterized in that** the holding structure compris-

es a dielectric board (32; 42; 116; 138) being arranged parallel to the surface layer (14) and touching the upper section of the spherical dielectric resonator (20), thereby applying a holding force on the spherical dielectric resonator (20), the holding force being directed towards the surface layer (14).

5. Antenna radiator, having a microwave on-chip resonator according to claim 4, **characterized in that** the dielectric board (32) engages the uppermost point of the spherical dielectric resonator (20) opposite the indentation (18).

6. Antenna radiator, having a microwave on-chip resonator according to claim 4, **characterized in that** the dielectric board (42) comprises a through hole (44; 118, 120), an inner wall of the through hole (44; 118, 120) at least partly contacting the upper section of the spherical dielectric resonator (20).

7. Antenna radiator, having a microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises a metal ring (52) surrounding the upper section of the spherical dielectric resonator (20).

8. Antenna radiator, having a microwave on-chip resonator according to claim 7, **characterized in that** the metal ring (52) is arranged symmetrically with respect to the through hole (44).

9. Antenna radiator, having a microwave on-chip resonator according to claim 7 or 8, **characterized in that** the metal ring (52) comprises two stubs (62, 64) extending in radial directions of the ring (52) and being arranged opposite each other on the metal ring (52).

10. Antenna radiator, having a microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises at least two metal stripes (72, 74; 82, 84) being arranged in parallel to each other, the spherical dielectric resonator (20) being arranged between the at least two metal stripes (72, 74; 82, 84) when viewed from above.

11. Antenna radiator, having a microwave on-chip resonator according to at least one of the preceding claims, **characterized in that** the holding structure comprises a board (32; 42; 116) being arranged parallel to the surface layer (14) and being made of metal, being fully metallized or being fully metallized apart from slot like structures on at least one side thereof.

12. Antenna radiator having a microwave on-chip resonator according to at least one of the preceding claims, **characterized by** a plurality of spherical dielectric resonators (20), each resonator (20) being held in a separate indentation of the surface layer (136) forming a surface of the chip (134), the holding structure being formed by a dielectric board (138) touching the plurality of spherical dielectric resonators (20).

13. Antenna radiator according to claim 12, **characterized in that** a lens (140) is arranged on top of the dielectric board (138) or **in that** a plane side of the lens (140) forms the dielectric board (138).

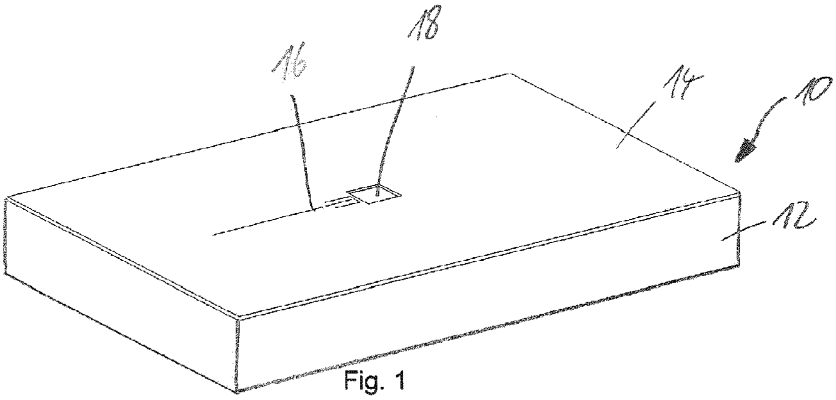


Fig. 1

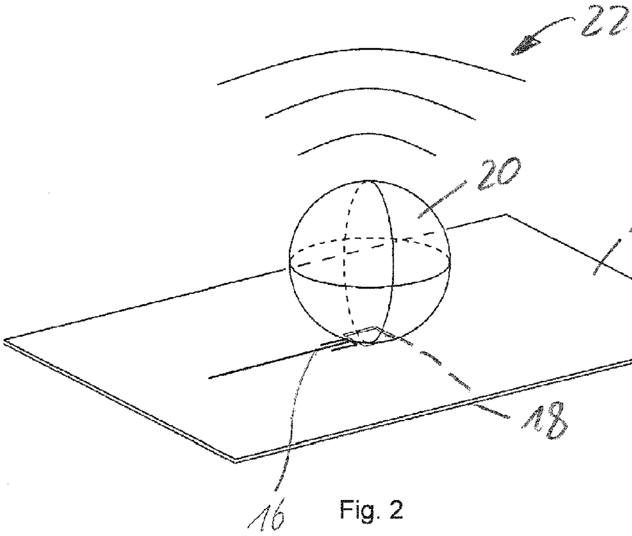


Fig. 2

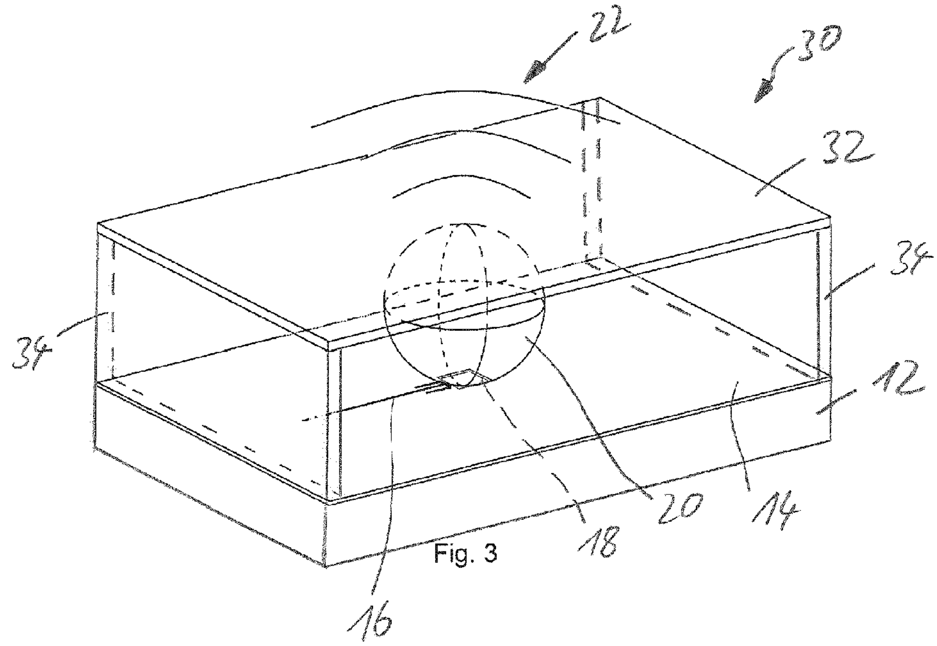


Fig. 3

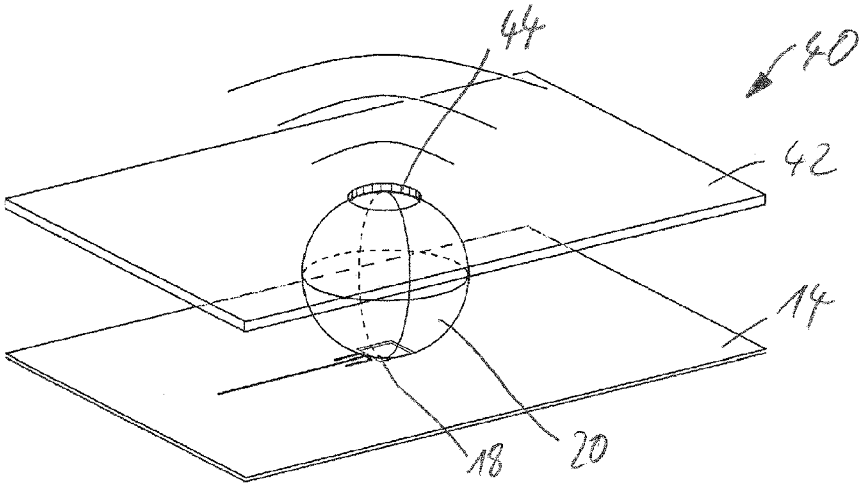


Fig. 4

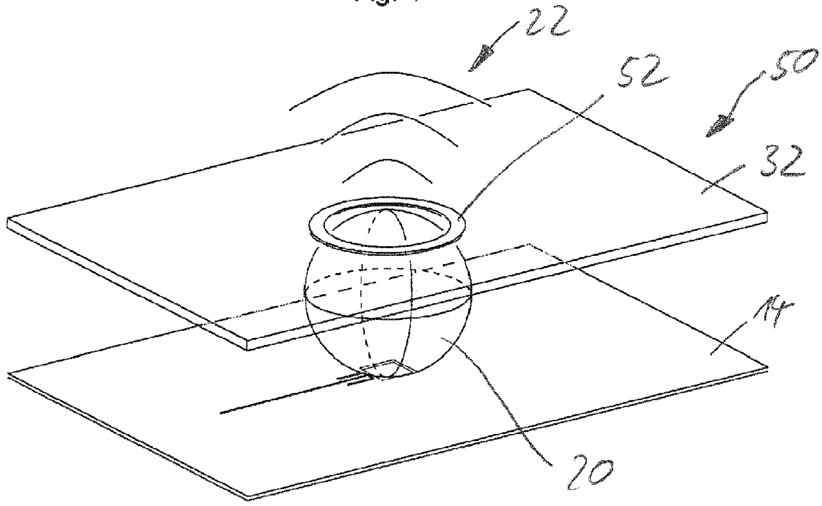


Fig. 5

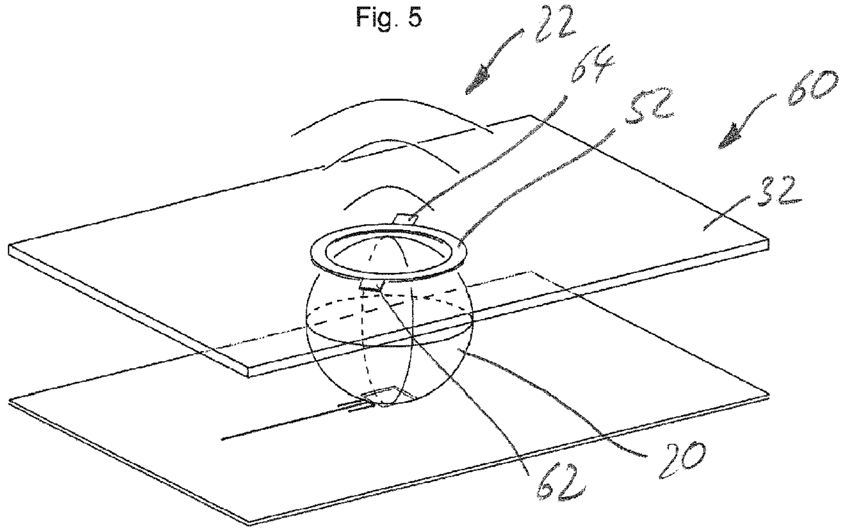


Fig. 6

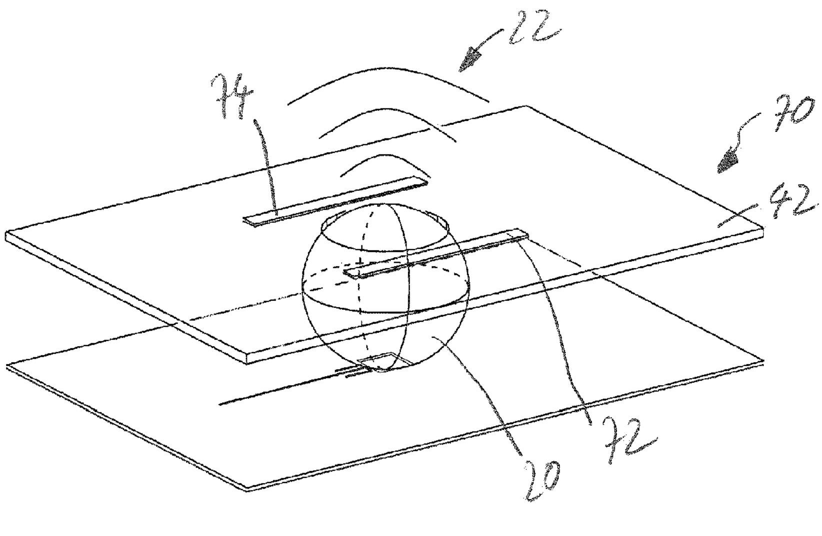


Fig. 7

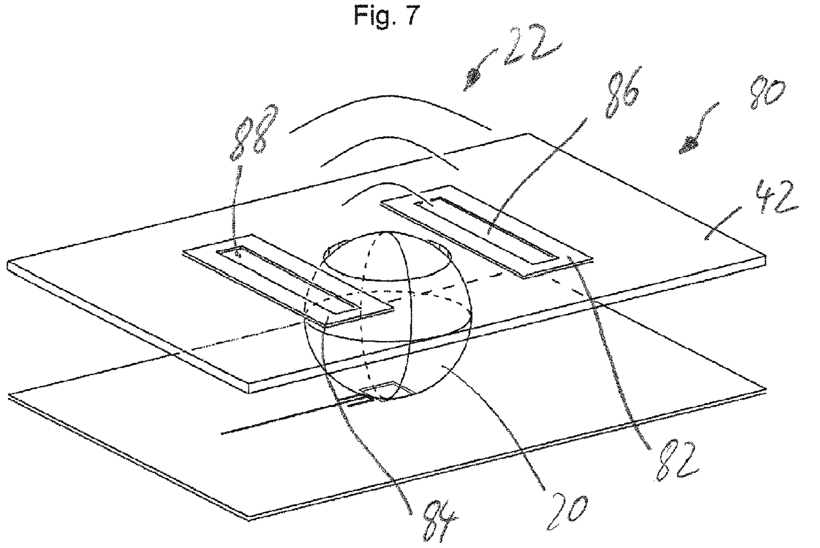


Fig. 8

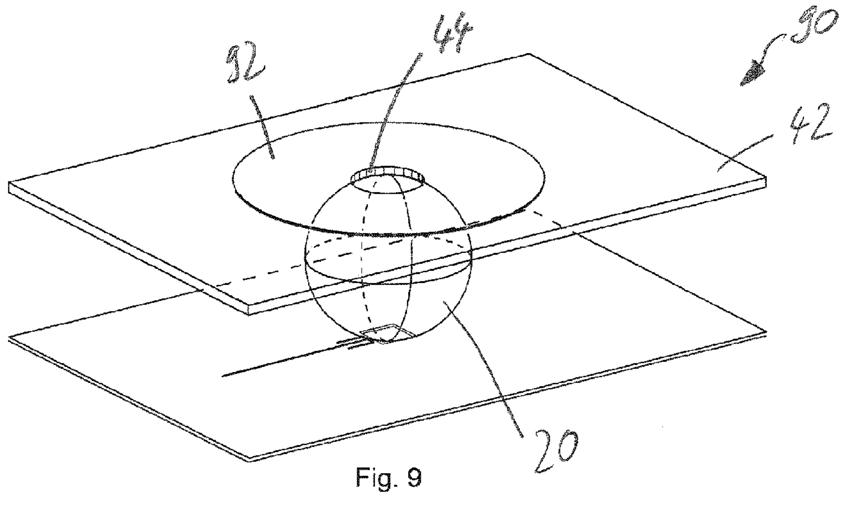
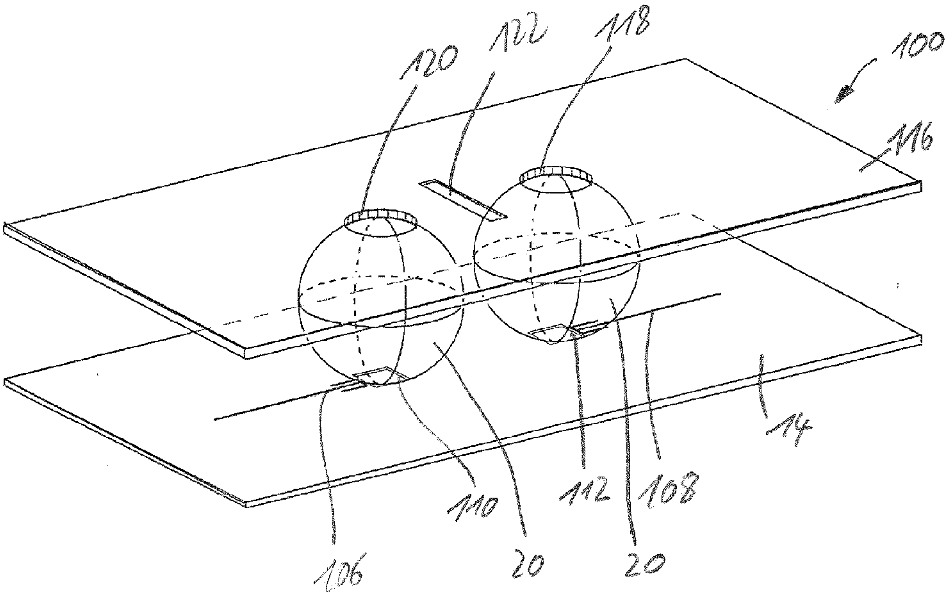


Fig. 9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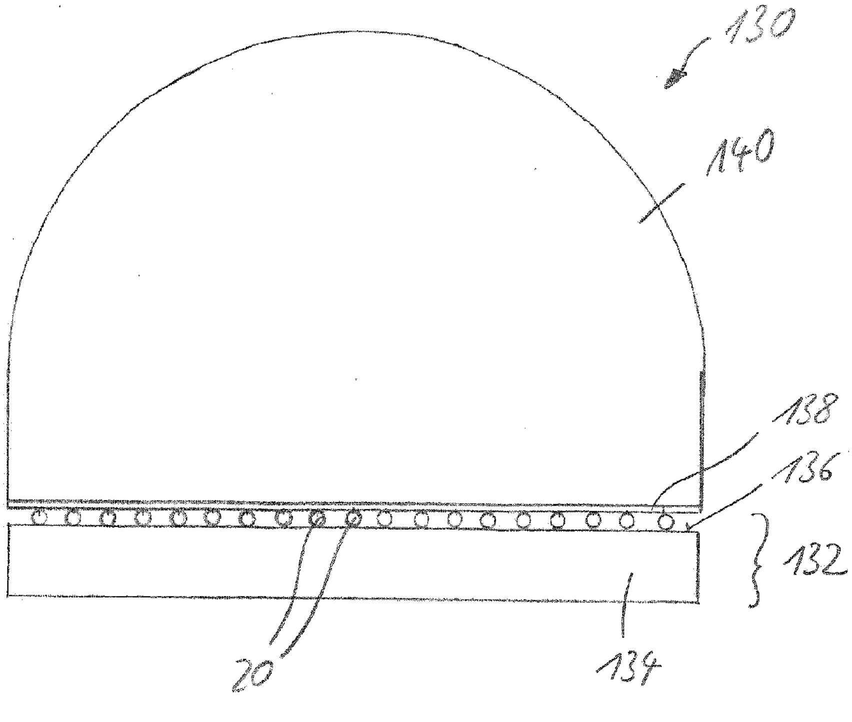
108

Fig. 10


130
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132
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134

Fig. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 16 16 3922

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	CUENCA DANIEL LOPEZ ET AL: "Measurement of complex permittivity of anisotropic dielectric spheres", 2016 GERMAN MICROWAVE CONFERENCE (GEMIC), INSTITUT FÜR MIKROWELLEN UND ANTENNENTECHNIK - IMA, 14 March 2016 (2016-03-14), pages 461-464, XP032897033, DOI: 10.1109/GEMIC.2016.7461655	1-6	INV. H01P5/02 H01Q1/22 H01Q9/04
Y	* page 461, right-hand column, line 15 - page 462, left-hand column, line 17;	7,8,10, 11	
A	figures 1,2 *	9,12-15	
A	LOPEZ CUENCA D ET AL: "Self-aligned microstrip-fed spherical dielectric resonator antenna", 2015 - 9TH EUROPEAN CONFERENCE ON ANTENNAS AND PROPAGATION (EUCAP) LISBON, PORTUGAL, 13 May 2015 (2015-05-13), - 17 May 2015 (2015-05-17), pages 1-5, XP002763170, IEEE PISCATAWAY, NJ, USA ISBN: 978-88-907018-5-6 * the whole document *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
Y	EP 0 343 835 A2 (HEWLETT PACKARD CO [US]) 29 November 1989 (1989-11-29)	7,8	H01P H01Q H04B
A	* page 4, line 7 - line 30; figures 7A-8C *	1-6	
Y	US 2009/179717 A1 (STERNS MICHAEL [DE] ET AL) 16 July 2009 (2009-07-16)	10,11	
A	* paragraph [0001] - paragraph [0003] * * paragraph [0098] - paragraph [0101]; figures 22-25 *	1-6	

-/--

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	21 October 2016	Pastor Jiménez, J

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
EP 16 16 3922

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2008/186239 A1 (ITSUJI TAKEAKI [JP]) 7 August 2008 (2008-08-07) * paragraph [0029] - paragraph [0035]; figures 1-2B * * paragraph [0065] - paragraph [0067]; figures 7,8 * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	21 October 2016	Pastor Jiménez, J

EPO FORM 1503 03.82 (P04C01)

CATEGORY OF CITED DOCUMENTS

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page 2 of 2

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21-10-2016

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0343835 A2	29-11-1989	DE 68917373 D1	15-09-1994
		DE 68917373 T2	01-12-1994
		EP 0343835 A2	29-11-1989
		JP 2871725 B2	17-03-1999
		JP H0223701 A	25-01-1990
		US 4888569 A	19-12-1989
US 2009179717 A1	16-07-2009	AT 513325 T	15-07-2011
		EP 2100343 A1	16-09-2009
		US 2009179717 A1	16-07-2009
		WO 2008068025 A1	12-06-2008
US 2008186239 A1	07-08-2008	JP 4977048 B2	18-07-2012
		JP 2008211778 A	11-09-2008
		US 2008186239 A1	07-08-2008
		US 2009267858 A1	29-10-2009

EPO FORM P0459

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