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(71) **Applicants**: **UNIVERSITY OF SASKATCHEWAN** [CA/CA]; 501-121 Research Drive, Saskatoon, Saskatchewan S7N 1K2 (CA). **KARLSRUHER INSTITUT FUR TECHNOLOGIE** [DE/DE]; Kaiserstrasse 12, 76131 Karlsruhe (DE).

(72) **Inventors**: **TAYFEH ALIGODARZ, Mohammadreza**; 704 Arlington Avenue, Saskatoon, Saskatchewan S7H 2X4 (CA). **RASHIDIAN, Atabak**; 201-1000 Markham Road, Winnipeg, Manitoba R3T 2M2 (CA). **KLYMYSHYN, David Mathew**; 254 Emerald Terrace, Saskatoon, Saskatchewan S7J 4J1 (CA). **SCHULZ, Michael**; Theodor-Fontane-Str. 3, 76297 Stutensee (DE). **BOERNER, Martin**; Sudetenstrasse 21, 76297 Stutensee (DE). **HANEMANN, Thomas**; Bruehlstrasse 39A, 76297 Stutensee (DE).

(74) **Agent**: **BERESKIN & PARR LLP/S.E.N.C.R.L., S.R.L.**; Scotia Plaza, 40 King Street West, 40th Floor, Toronto, Ontario M5H 3Y2 (CA).

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(54) **Title**: COMPOSITE MATERIALS FOR DIELECTRIC-BASED MICROWAVE APPLICATIONS

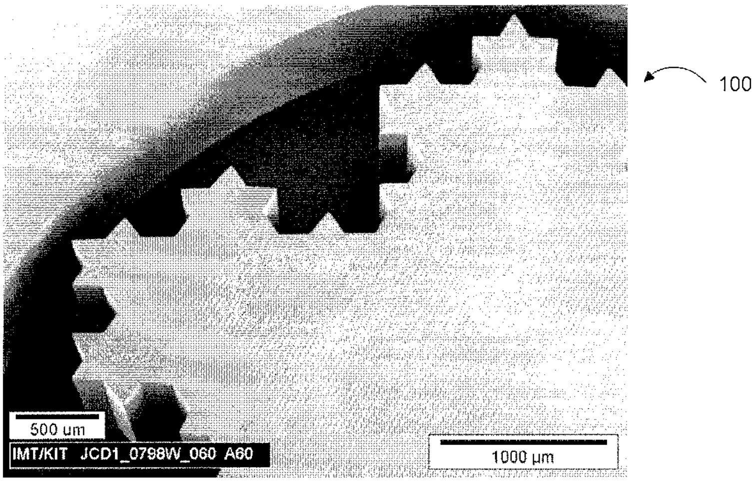

FIG. 1A

(57) **Abstract**: Composite materials with dielectric properties for use in microwave applications, and methods of fabrication, are described. The composite materials include a filler, for example a ceramic, with high relative permittivity and a polymer constituent. The resulting composite material has a relative permittivity suitable for use in microwave applications. Dielectric resonator antennas using the composite material are also described.

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Title: Composite Materials for Dielectric-Based Microwave Applications

Field

[1] The embodiments described herein relate to composite materials for use in dielectric-based microwave applications and methods for fabricating microwave devices with the composite materials. In particular, some embodiments relate to use of the composite material in dielectric resonator antennas.

Background

[2] Contemporary integrated circuit antennas are often based on thin metallic microstrip “patch” structures, which can occupy large lateral areas. A microstrip antenna consists of a metallic strip or patch placed above a grounded substrate and generally fed through a coaxial probe or an aperture.

[3] Recently, dielectric resonator antennas (DRAs) have attracted increased attention for miniaturized wireless and sensor applications at microwave frequencies. Microwave frequencies are generally in the range of 0.3 GHz to 300 GHz. DRAs are three-dimensional structures with lateral dimensions that can be several times smaller than traditional planar patch antennas, and which may offer superior performance in terms of radiation efficiency and bandwidth.

[4] DRAs are becoming increasingly important in the design of a wide variety of wireless applications from military to medical usages, from low frequency to very high frequency bands, and from on-chip to large array applications. As compared to other low gain or small metallic structure antennas, DRAs offer higher radiation efficiency (due to the lack of surface wave and conductor losses), larger impedance bandwidth, and compact size. DRAs also offer design flexibility and versatility. Different radiation patterns can be achieved using various different geometries or resonance modes, wideband or compact antennas can be provided by different dielectric constants, and excitation of DRAs can be achieved using a wide variety of feeding structures.

[5] Despite the superior electromagnetic properties of DRAs, microstrip antennas are still extensively used for low-gain microwave applications. The widespread use of microstrip antennas may stem primarily from the relatively low fabrication cost of the modern printed-circuit technology used to manufacture these antennas. By comparison, ceramic-based DRAs can involve a more complex and costly fabrication process due in part to their three-dimensional structure and in part due to the difficulty of working with the ceramic materials.

[6] These fabrication difficulties limit the wider use of DRAs as well as use of dielectric applications in general, especially for high volume commercial applications.

[7] In addition, while microstrip patch antennas can easily be produced in various complicated shapes by lithographic processes, DRAs have been mostly limited to simple structures (such as rectangular and circular shapes).

[8] Indeed, fabrication of dielectric materials for use in microwave applications, such as for known dielectric resonators (DRs) and DRAs, can be particularly challenging as they have traditionally been made of high relative permittivity ceramics, which are naturally hard and extremely difficult to machine. Batch fabrication by machining can be difficult, as the hardness of ceramic materials can require diamond cutting tools, which can wear out relatively quickly due to the abrasive nature of the ceramic materials. In addition, ceramics are generally sintered at high temperatures in the range of 900-2000°C, further complicating the fabrication process and possibly restricting the range of available materials for other elements of the circuits comprising dielectric elements. Array structures can be even more difficult to fabricate due to the requirement of individual element placement and bonding to the substrate. Accordingly, they cannot easily be made using known automated manufacturing processes.

[9] Further problems appear at high microwave frequencies, such as the frequencies in the range of 30 GHz to 300 GHz. At these high microwave frequencies, the dimensions of dielectric applications, such as the DR or DRA, are reduced to the millimetre or sub-millimetre range, and acceptable manufacturing tolerances are reduced accordingly. These fabrication difficulties have heretofore limited the wider use of dielectric applications, especially for high volume commercial applications.

Summary

[10] In a broad aspect, there is provided a composite material with dielectric properties for use in microwave applications, the composite material comprising a filler with a relative permittivity of at least 4, and a polymer constituent, wherein the composite material has a relative permittivity of at least 3 for microwave frequencies. In some embodiments, the filler comprises a ceramic constituent.

[11] In some embodiments, the microwave frequencies have a range of 0.3 GHz to 300 GHz.

[12] In some embodiments, the microwave applications comprise dielectric resonator applications. In some embodiments, the microwave applications comprise dielectric resonator antenna applications.

[13] In some embodiments, the filler and the polymer constituent form a mixture. In some embodiments, the mixture is homogeneous. In some embodiments, the mixture is inhomogeneous. In some embodiments, the filler is distributed at a gradient or other varying profile in the inhomogeneous mixture.

[14] In some embodiments, the composite material comprises a plurality of layers, and at least one of the layers comprises a different mixture than the respective other layers.

[15] In some embodiments, the filler comprises particles having a mean diameter corresponding to at least 1/10 of a minimum size of a functional pattern of the microwave application.

[16] In some embodiments, the filler is a powder prior to mixing with the polymer constituent.

[17] In some embodiments, the filler comprises a material with a high dielectric constant κ. In some embodiments, the filler has a relative permittivity greater than 1000. In some embodiments, the filler has a relative permittivity of at least 4. In some embodiments, the filler has a relative permittivity between 4 and 10000.

[18] In some embodiments, the filler constitutes at least 5% by weight of the composite material. In some embodiments, the filler constitutes less than 70% by weight of the composite material.

[19] In some embodiments, the filler constitutes at least 3% by volume of the composite material. In some embodiments, the filler constitutes less than 80% by volume of the composite material.

[20] In some embodiments, the polymer constituent has a relative permittivity less than 5 when in substantially pure form.

[21] In some embodiments, the polymer constituent comprises a resin. In some embodiments, the resin comprises a thermosetting material.

[22] In some embodiments, the polymer constituent comprises a curable polymer.

[23] In some embodiments, the polymer constituent comprises a positive photoresist polymer, for instance comprising polymethyl methacrylate (PMMA). In some embodiments, the polymer constituent comprises a negative photoresist polymer, for instance comprising SU-8.

[24] In a further broad aspect, there is provided a dielectric resonator antenna for use in microwave applications, the dielectric resonator antenna comprising: a substrate with at least a first planar surface; a resonator body disposed on the first planar surface, the resonator body formed of the composite material described herein; and an excitation structure for exciting the resonator body.

[25] In some embodiments, the resonator body has a thickness in a range of 1 to 6000 microns.

[26] In some embodiments, the resonator body is comprised of one or more layers of composite material stacked vertically.

[27] In some embodiments, the resonator body is comprised of one or more laterally defined segments of composite material.

[28] In a further broad aspect, there is provided a method of fabricating a composite material for use in microwave dielectric applications, the method comprising mixing a filler with a relative permittivity of at least 4, and a polymer constituent to form the composite material, wherein the composite material has a relative permittivity of at least 3 for microwave frequencies.

[29] In some embodiments, fabricating a composite material further comprises curing the composite material at a temperature below about 100°C.

[30] In some embodiments, fabricating a composite material further comprises curing the composite material at a temperature below about 65°C.

[31] In some embodiments, mixing the filler and the polymer constituent further comprises compounding the filler and the polymer constituent.

[32] In some embodiments, mixing the filler and the polymer constituent further comprises stirring the filler and the polymer constituent.

[33] In a further broad aspect, there is provided a method of fabricating a dielectric resonator antenna, the method comprising providing a substrate with at least a first planar surface; providing a mold on the substrate, the mold defining a cavity therewithin; depositing the composite material described herein within the cavity.

[34] In some embodiments, the mold comprises a polymer-based material.

[35] In some embodiments, the deposited composite material has a thickness in a range of 1 to 6000 microns.

[36] In some embodiments, the deposited composite material is comprised of one or more layers stacked vertically.

[37] In some embodiments, each of at least one cavity defines one or more laterally defined segments of deposited composite material.

[38] In some embodiments, liquid crystal polymer (LCP) or an LCP composite is deposited within the cavity. A further polymer layer may be applied to the top of the cavity.

[39] In some embodiments, the mold is provided by forming a polymer-based body; exposing the polymer-based body to a lithographic source via a pattern mask, wherein the pattern mask defines the cavity to be formed in the polymer-based body; developing a portion of the polymer-based body; and removing one of an exposed portion and an unexposed portion of the polymer-based body to reveal the cavity. In some embodiments, for example in the positive-type photoresist, the exposed portion is removed. In some other embodiments, for example in the case of a negative-type photoresist, the inverse cavity structure will result.

[40] In some embodiments, the method of fabricating a dielectric resonator antenna further comprises removing the mold to leave the composite material.

[41] In some embodiments, the mold is retained as one of a protective frame and a packaging.

[42] In some embodiments, the composite material is deposited by injection.

Brief Description of the Drawings

[43] For a better understanding of the embodiments described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings which show at least one exemplary embodiment, and in which:

FIG. 1A illustrates a third order Koch Island fractal structure polymer-based antenna element fabricated with deep X-ray lithography;

FIG. 1B illustrates the antenna element of FIG. 1A at a higher magnification showing sidewall detail;

FIGS. 2A and 2B illustrate exemplary plots of the relative permittivity and dielectric loss tangent for pure polymethyl methacrylate (PMMA), as a function of frequency;

FIGS. 3A and 3B illustrate exemplary plots of the relative permittivity and dielectric loss tangent for SU-8, as a function of frequency;

FIGS. 4A and 4B illustrate exemplary plots of the relative permittivity and dielectric loss tangent for pure polyester-styrene (PSS) and an example composite material based on PSS with Barium Titanate comprising 50% of the composite by weight, as a function of frequency;

FIGS. 5A and 5B illustrate an example dielectric resonator antenna formed using composite materials described herein;

FIGS. 6A and 6B illustrate examples of resonator bodies formed using composite materials described herein;

FIG. 7 illustrates a plan view of another example dielectric resonator antenna;

FIG. 8 illustrates a plot of frequency responses of exemplary dielectric resonator antennas formed using composite materials described herein;

FIG. 9 illustrates an exploded isometric view of an example dielectric resonator antenna; and

FIGS. 10A and 10B illustrate an example mold for fabricating dielectric applications using composite materials described herein.

[44] The skilled person in the art will understand that the drawings, described below, are for illustration purposes only. It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

Description of Exemplary Embodiments

[45] Described herein are composite materials for use in dielectric applications, and methods for fabricating the same. The dielectric applications may include dielectric resonator applications and dielectric resonator antennas (DRAs). The composite materials include a filler with high relative permittivity (e.g., a ceramic constituent) and a polymer constituent. When the filler and the polymer constituent are mixed, the resulting composite materials can offer desirable performance characteristics and can facilitate greater use of dielectric applications in commercial operations.

[46] Currently, one of the biggest obstacles to the continued miniaturization of radio frequency (RF) wireless devices is antenna structure, which accounts for a large portion of total device sizes. Recently, ceramic-based dielectric resonator antennas have attracted increased attention for miniaturized wireless and sensor applications at microwave frequencies. DRAs are three-dimensional structures with lateral dimensions that can be several times smaller than traditional antennas, and which may offer superior performance. Despite the superior properties of ceramic-based DRAs, they have not been widely adopted for commercial wireless applications due to the complex and costly fabrication processes related to their three-dimensional structure and difficulties in fabricating and shaping the hard ceramic materials.

[47] In contrast, when composite materials are used to fabricate dielectric applications, such as compact RF antennas and devices, the compact RF antennas enable improved performance and increased functionality for various emerging wireless communication and sensor devices (e.g., miniature radios/transmitters, personal/wearable/embedded wireless devices, etc., automotive radar systems, small satellites, RFID, sensors and sensor array networks, and bio-compatible wireless devices and biosensors). An example direct fabrication of the composite material is described by Müller et al. in "Fabrication of ceramic microcomponents using deep X-ray lithography" (Microsystem Technologies, vol.11, pp. 271-277; Published: April 1, 2005).

[48] The composite materials described herein facilitate easier fabrication of devices such as antennas, while retaining many of the benefits of ceramic-based materials. For example, the natural softness of polymers can dramatically simplify fabrication of dielectric elements, for example by enabling the use of lithographic batch fabrication (e.g., X-ray lithography, UV lithography, stereo lithography, e-beam lithography, laser lithography, etc.) or other fabrication, printing or micromachining processes used to form elements of the present devices. Examples of other processes include known microwave and antenna manufacturing techniques in addition to known semiconductor manufacturing techniques, additive techniques (3D printing, masking, casting, screen printing, electroplating, extrusion, vacuum deposition, etc.), subtractive techniques (etching, ablation, laser cutting, milling, cutting, erosion, etc.), and other technologies. However, the composite materials require that the resulting dielectric materials be effectively excited to guide, resonate and/or radiate at microwave frequencies.

[49] As described, the use of a polymer-based component in the composite material can dramatically simplify fabrication of devices due to the natural softness of the polymer-based materials. Moreover, the use of polymer-based materials can provide wide impedance bandwidth, given very low relative permittivity of the polymer materials used. In particular, various diverse polymer types with selected parameters can be used to fulfill the requirements of particular applications or to achieve desired performance characteristics. For example, elastic polymers (e.g. polydimethylsiloxane (PDMS)) can be used to make pliable low profile polymer-based DRAs. Furthermore, known photolithographic techniques have evolved to enable fabrication of passive devices with small features. Use of photoresist polymers (e.g., polymethyl methacrylate or PMMA) and/or photosensitive polymers may therefore facilitate lithographic fabrication of precise features on DRAs.

[50] However, extension of these lithographic techniques to fabricate high performance passive microwave components – which typically account for more than 75% of circuit elements in wireless transceivers – has been heretofore hindered because the penetration depth of UV light is typically not sufficient for patterning tall structures in common, thick photoresist materials. While, in general, thick structures can improve the performance of various metallic components (e.g., by making tall, low loss compact structures), the fabrication of thick structures is particularly desirable for dielectric components suitable for use at high microwave frequencies, due to the absence of surface currents and metallic loss, and further due to the difficulty of fabricating tiny three-dimensional structures.

[51] In some embodiments, X-ray lithography has been found to be a suitable fabrication technique to enable the patterning of tall structures in thick materials with suitable precision and batch fabrication ability.

[52] X-ray lithography is a technique that can utilize synchrotron radiation to fabricate three-dimensional structures. Structures can be fabricated with a height up to a few millimetres (e.g., typically a maximum of 3 to 4 mm with current techniques) and with minimum lateral structural features (i.e., layout patterns) in the micrometer or sub-micrometer range. As compared to other fabrication techniques such as UV lithography, X-ray lithography can produce much taller structures (up to several millimetres) with better sidewall verticality and finer features.

[53] Referring now to FIGS. 1A and 1B, there are shown exemplary scanning electron microscope (SEM) images of a polymer-based antenna element 100, demonstrating the ability of X-ray lithography in fabrication of high quality miniature structures. The polymer-based antenna element 100 may be formed using a composite material described herein, such as, for example, a composite incorporating a high-κ ceramic material (e.g., barium titanate).

[54] FIG. 1A illustrates a third order Koch Island fractal structure polymer-based antenna element 100 fabricated with deep X-ray lithography. Antenna element 100 shown in FIGS. 1A and 1B has a thickness of 1.8 mm, excellent sidewall verticality, typically better than 89.7°, and smooth sidewalls. FIG. 1B illustrates the same antenna element 100 at a higher magnification showing sidewall detail.

[55] X-ray lithography may also be used to fabricate tall metallic structures (e.g., capacitors, filters, transmission lines, cavity resonators, and couplers, etc.) and therefore can allow for the fabrication of integrated metal and dielectric structures, including polymer-based resonator antenna circuits (e.g., array structures, feeding networks, and other microwave components), on a common substrate.

[56] X-ray lithography can use more energetic and higher frequency radiation than more traditional optical lithography, to produce very tall structures with minimum dimension sizes smaller than one micron. X-ray lithography fabrication comprises a step of depositing or gluing a photoresist material on a substrate, exposing the synchrotron radiation through a mask, and developing the material using a suitable solvent or developer.

[57] X-ray lithography can also be an initial phase of the so-called LIGA process, where LIGA is the German acronym for Lithographie, Galvanoformung, Abformung (lithography, electrodeposition, and moulding). A LIGA process may further comprise electroforming of metals and moulding of plastics, which is not strictly required to produce dielectric structures.

[58] Suitable polymer-based materials for X-ray lithography microfabrication can be selected so that the deposition process is simplified, and to exhibit sensitivity to X-rays in order to facilitate patterning. Generally, pure photoresist polymer materials may best facilitate X-ray lithography fabrication. Examples of photoresist materials suitable for X-ray lithography include PMMA and Epon SU-8.

[59] PMMA is a positive one-component resist commonly used in electron beam and X-ray lithography. It may exhibit relatively poor sensitivity, thus requiring high exposure doses to be patterned. However, the selectivity (i.e., contrast) achievable with specific developers can be very high, resulting in excellent structure quality. Very thick PMMA layers are sometimes coated on a substrate by gluing. However, patterning thick layers may require hard X-rays and special adjustments for beamline mirrors and filters.

[60] PMMA exhibits relatively little absorption in the ultraviolet spectrum, which can make it less desirable as a candidate for optical lithography. However, PMMA exhibits excellent optical transparency in the visible light range, which makes it useful in micro-optics applications.

[61] Referring now to FIGS. 2A and 2B, there shown a plot 200 of the relative permittivity for pure PMMA and a plot 250 of the dielectric loss tangent for pure PMMA, as a function of frequency, respectively. These electrical properties of PMMA were measured using the two-layer microstrip ring resonator technique. At 10 GHz, the relative permittivity and dielectric loss tangent were measured to be 2.65 and 0.005, respectively. The relative permittivity decreases with increased frequency, reaching 2.45 at 40 GHz. In contrast, the dielectric loss tangent increases with increased frequency, reaching 0.02 at 40 GHz.

[62] However, as described herein, the low relative permittivity of pure PMMA may make it less suitable for some dielectric applications, such as antennas.

[63] Epon SU-8 is a negative three-component resist suitable for ultraviolet and X-ray lithography. SU-8 exhibits maximum sensitivity to wavelengths between 350-400 nm. However, the use of chemical amplification allows for very low exposure doses. Accordingly, SU-8 may also be used with other wavelengths, including X-ray wavelengths between 0.01-10 nm.

[64] The high viscosity of SU-8 allows for very thick layers to be cast or spin coated in multiple steps. However, side effects such as T-topping may result in defects such as unwanted dose contributions at the resist top, stress induced by shrinking during crosslinking, and incompatibility with electroplating.

[65] Various values for the dielectric properties of SU-8 have been reported in the known art. For example, the dielectric constant of SU-8 has been reported as between 2.8 and 4. The variation in these reported electrical properties may be due to several factors, including use of different commercial types of SU-8 (e.g. SU-8(5), SU-8(10), SU-8(100), etc.), pre-bake and post-bake conditions (e.g. time and temperature), and exposure dose. Accordingly, the use of SU-8 may require careful characterization of the electrical properties for a particular selected type of SU-8 and corresponding adjustment of fabrication steps.

[66] Referring now to FIGS. 3A and 3B, there shown a plot 300 of the relative permittivity for SU-8 and a plot 350 of dielectric loss tangent for SU-8, as a function of frequency, respectively. These electrical properties of SU-8 were independently measured using the two-layer microstrip ring resonator technique. At 10 GHz, the relative permittivity and dielectric loss tangent were measured to be 3.3 and 0.012, respectively. The relative permittivity decreases with increased frequency, reaching 3.1

at 40 GHz. In contrast, the dielectric loss tangent increases with increased frequency, reaching 0.04 at 40 GHz.

[67] As illustrated herein, pure photoresist materials may be less than optimal for some dielectric applications, such as microwave and antenna applications, since pure polymer materials generally have low relative permittivity. Certain fabrication techniques, such as X-ray lithography fabrication, for example, can be modified and optimized for different materials and structural requirements. Accordingly, materials used in dielectric applications can be selected to satisfy both lithographic properties required for the various fabrication techniques, and the resultant electrical properties of the fabricated device.

[68] For the composite materials described herein, the electrical characteristics to be selected include relative permittivity and dielectric loss. For example, with conventional excitation methods, a dielectric material can perform as a suitable antenna if the material has fairly high relative permittivity and low loss (e.g., relative permittivity that is typically greater than 5 and loss tangent typically less than 0.1).

[69] As noted herein, pure polymer materials generally have low relative permittivity, and this contributes to a lower relative permittivity for polymer-based composite materials. For example, the polymer constituent of a composite material can be a photochemically or thermally hardenable polymer that has a relative permittivity that is typically less than 5 when in substantially pure form. The polymer constituent may include at least one of synthetic resin or curable polymer. For example, the resin may include a polyester-based material (such as polyester styrene). The resin may be thermosetting and include a hardener material, and the curable polymer may be a positive or negative photoresist polymer. In the case of a positive-type photoresist, a mold is provided by forming a polymer-based body; exposing the polymer-based body to a lithographic source via a pattern mask, such that the pattern mask defines the cavity to be formed in the polymer-based body; and developing a portion of the polymer-based body and removing either an exposed portion of the polymer-based body or an unexposed portion of the polymer-based body to reveal the cavity. In the case of a positive-type photoresist, the exposed portion of the polymer-based body is removed. In the case of a negative-type photoresist, the inverse process is used such that the pattern mask defines the material to be retained and therefore, an unexposed portion of the polymer-based body is removed to reveal the cavity.

[70] To counterbalance the lower relative permittivity value of the polymer constituent, a filler material with a higher relative permittivity can be used in order to enhance the dielectric properties of the composite material. For example, a filler such as a ceramic constituent can have a relative permittivity greater than 9 when the ceramic constituent is in substantially pure solid form. In some embodiments, the relative permittivity of the composite material can be selected to be at least 3 for microwave frequencies, which is generally a practical lower limit for microwave applications. For example, in the case of DRAs, a relative permittivity of at least 3 is generally required to excite the resonant elements. A practical upper limit for the relative permittivity may be the κ value for pure Barium Titanate ($1250 < \kappa < 10000$, depending on frequency and temperature), because an ideal composite would consist of very high filler loads approaching that of a pure ceramic. Another practical upper limit may be the κ value for $BaTiO_3$ in Polyimide ($k > 125$ @ 10 Hz), as this describes a real composite, and κ generally decreases with increasing frequency. The κ value for $BaTiO_3$ in Polyimide was described by Devaraju et al. in "The Synthesis and Dielectric Study of $BATiO_3$/polyimide nanocomposite films" (Microelectronic Engineering, vol. 82, pp. 71-83; Published: September 2005) and by Schumacher et al. in "Temperature treatment of nano-scaled barium titanate filler to improve the dielectric properties of high-κ polymer based composites" (Microelectronic Engineering, vol. 87, pp. 1978-1983; Published: December 21, 2009).

[71] The filler may include structural or functional ceramics. The filler may include high-κ materials with a relative permittivity between 4 and 1000 (e.g. zirconia, alumina) or above 10^3 (perowskite-type ceramics e.g. barium titanate, potassium sodium tartrate, barium strontium titanate, etc.).

[72] There may be a high contrast in density between the polymer constituent and the filler. Thus, when mixing the polymer and ceramic constituents, the weight or volume percentage of the filler with respect to the composite material may be relatively high.

[73] In some embodiments, the filler can be in a range of 5-70% of the weight of the composite material. In some other embodiments, the filler can be in a range of 3- 80% of the volume of the composite material.

[74] The composite material can be fabricated by mixing the filler with the polymer constituent using a mixer device with variable speed settings. The step of mixing the composite material may include at least one act of compounding or stirring the filler and the polymer constituent, and may involve the use of other materials to aid in mixing.

[75] For example, a certain amount of dispersant may be added to the polymer constituent, based on the weight of the polymer constituent. The amount and type of dispersant may vary depending on the characteristics of the polymer and filler constituents. The polymer constituent and the dispersant may be mixed for a desired period of time. The time and the mixing environment (speed, temperature, etc.) will depend on the specific constituents.

[76] A hardener material may also be added to the mixture of the polymer constituent and the filler to facilitate the setting of the composite material. The amount of hardener material may correspond to values as recommended by the vendor of the hardener material. The hardener material is mixed with the mixture of the polymer constituent and the filler. To remove air bubbles, the mixture of the polymer constituent and the filler may be placed in a vacuum prior to or after the hardener material is added. Ultrasonic agitation can also assist in removing air bubbles.

[77] In some embodiments, the mixture should be baked as the final step of material preparation. In some embodiments, the baking of the mixture may occur at a temperature below 100°C. In particular, the baking of the mixture may occur at a temperature below 65°C.

[78] Preparation of composite materials is described by Hanemann et al. in "Development of new polymer- $BaTiO_3$-composites with improved permittivity for embedded capacitors" (Microsystem Technologies, vol. 17, pp. 195-201; Published: January 6, 2011) and by Schumacher et al. in "Temperature treatment of nano-scaled barium titanate filler to improve the dielectric properties of high-κ polymer based composites" (Microelectronic Engineering, vol. 87, pp. 1978-1983; Published: December 21, 2009).

[79] The size of filler particles suitable for use in a composite material is generally related to a functional pattern size for the dielectric application. In some embodiments, the size of the filler particles may correspond to a minimum size of the functional pattern for the dielectric application. For example, filler particles may be selected to have a size of 1/10 of the resonator body of a DRA, in one or both dimensions perpendicular to a feeding structure, in order to produce useful anisotropies that can improve antenna performance.

[80] In some embodiments, the filler material may be provided in the shape of a disc. The filler material may also include one or more layers. In the example of a DRA, the filler material may be oriented with an elongate portion substantially perpendicular to the feeding structure of the dielectric resonator antenna.

[81] For ceramic filler materials, the ceramic particles may include ceramic powder, micro-powder and/or nano-powder. The ceramic constituent may include ceramic particles having a size determined by the functional pattern size for the dielectric application and elements of the antenna. For example, in some embodiments, the ceramic constituent may have a mean diameter in a range of 50 nm to 5 μm prior to being mixed with the polymer constituent. In some embodiments, the ceramic constituent may have a mean diameter in a range of 300nm to 900nm.

[82] The composite material may also include other fillers, such as fiber materials, carbon nanotubes and CdS nanowires and active ferroelectric materials, which can be selected to form materials with desired properties, such as enhanced tunability or power-harvesting ability. The resulting composite materials can provide a broader group of viable materials suitable for dielectric applications. In some cases, the use of such composites may alter photoresist properties, requiring adjustment of lithographic processing, or additional steps in the fabrication process.

[83] An example of a composite material is a PSS composite incorporating Barium Titanate ($BaTiO_3$). The $BaTiO_3$ may comprise 30-60% of the composite material by weight.

[84] Referring now to FIGS. 4A and 4B, there is shown a plot 400 of the relative permittivity and a plot 450 of the dielectric loss tangent as a function of frequency for a composite based on PSS and $BaTiO_3$ comprising 50% of the composite material by weight. These electrical properties of the PSS and $BaTiO_3$ composite were measured up to 1.5 GHz using an Agilent™ 4291B RF Impedance/Material Analyzer. The electrical properties of the PSS and $BaTiO_3$ composite at 8.5 GHz were also measured using Agilent's 85070E dielectric probe kit and are provided in the table below:

Material	***Ceramic***	***Ceramic Content [wt%]***	***Permittivity @ 8.5GHz***
Pure PSS	-	0	2.2-2.6
PSS/ $BaTiO_3$ Composite	$BaTiO_3$	30	5.4-5.7
	$BaTiO_3$	40	6.4-6.7
	$BaTiO_3$	50	7.2-7.6
	$BaTiO_3$	60	9.6-10.1

Table 1: Electrical Properties of PSS/ $BaTiO_3$ Composite at 8.5GHz

[85] As illustrated in FIG. 4A and Table 1, compared to the relative permittivity of pure PSS, improvements are observable for the PSS and $BaTiO_3$ composite. For example, as shown in FIG. 4A, the relative permittivity at 1 GHz is about 8 for the PSS and $BaTiO_3$ composite, compared to approximately 2 for pure PSS. Similarly, as provided in Table 1, each of the relative permittivity at 8.5GHz for the various PSS and $BaTiO_3$ composites is substantially higher than the relative permittivity of pure PSS.

[86] Various composites can be used, which may incorporate other base polymer materials (including photoresist materials) or other electrical property enhancing fillers. The polymer materials and electrical property enhancing fillers can be combined in various ratios, depending on the desired electrical properties and fabrication process. For example, a composite material can include PSS and Zirconia (ZrO_2). Unlike the PSS and $BaTiO_3$ composite material, the PSS and Zirconia composite material may not yield a sufficiently high relative permittivity to be used in a monolithic dielectric antenna application. Instead, the PSS and Zirconia composite material may be used in the fabrication of multi-segment structures for which a lower relative permittivity might be needed. Electrical properties of an example PSS and Zirconia composite measured at 8.5 GHz using an Agilent™ 85070E dielectric probe kit are provided in the table below:

Mixture	***Ceramic***	***Ceramic Content [wt%]***	***Permittivity @ 8.5GHz***
Pure PSS	-	0	2.2-2.6
PSS/ZrO_2 Composite	ZrO_2	10	3.3-3.5
	ZrO_2	35	4.6-4.9
	ZrO_2	50	5.7-6.0

Table 2: Electrical Properties of PSS/ZrO_2 Composite at 8.5GHz

[87] Based on the values of the relative permittivity provided in each of Tables 1 and 2, it can be observed that the relative permittivity of the PSS/ZrO_2 composite is generally less than the relative permittivity of the PSS/ $BaTiO_3$ composite. For example, a PSS/ $BaTiO_3$ composite with 50% $BaTiO_3$ by weight has a relative permittivity in the range of 7.2-7.6 and a PSS/ZrO_2 composite with 50% ZrO_2 by weight has a relative permittivity in the range of 5.7-6.0.

[88] The filler and the polymer constituent may form a mixture. The mixture may be homogeneous or inhomogeneous. An inhomogeneous mixture may result from delaying a pre-baking process of the composite mixture, since particles tend to move to a lower region of the composite mixture before drying, or through a controlled and gradual change of a density of the filler. The use of the inhomogeneous mixture as the composite material can provide additional advantages to dielectric applications. For example, for antenna applications, each of the impedance bandwidth, the coupling level, and the realized gain of the antenna can be enhanced, and the cross-polarization patterns may be improved. These improvements to the antenna applications may result from constituents in the composite material providing an impedance transformer through one of the segments. As well, improvements in antenna applications may be realized from constituents in the composite material having suitable polarizations and directions such that the electric near-field patterns exhibit desirable characteristics.

[89] The filler in the inhomogeneous mixture can be distributed within the composite material based on its weight. In some embodiments, the filler can be distributed in one or more layers of the inhomogeneous mixture. For example, one or more different types of composite materials may be stacked one over the other. In some other embodiments, the filler can be distributed at a gradient or other similar distribution profiles in the inhomogeneous mixture. For example, the distribution profiles may include a linearly increasing or decreasing density, or a logarithmically increasing or decreasing density.

[90] The described embodiments are not limited to photoresist-based polymer materials (e.g., pure photoresist materials such as SU-8 and PMMA, and photoresist composite materials such as SU-8 and PMMA mixed with ceramic or other fillers). However, photoresist-based materials are suitable for lithographic fabrication of antenna structures with precise features in thick layers, particularly if they facilitate the use of deep penetrating lithographies, such as thick resist UV lithography or deep X-ray lithography (DXRL).

[91] DRAs generally include a substrate with at least a first planar surface on which a resonator body is disposed and an excitation structure for exciting the resonator body. The resonator body may be formed using the composite material described herein. The resonator body may have a thickness in a range of 1 to 6000 microns.

[92] Various fabrication methods may be employed, including direct fabrication, or by injecting the composite materials into lithographically fabricated molds or templates formed of photoresist materials, for fabricating DRAs using the composite material described herein. The use of such molds enables the use of complicated shapes with a wide range of composite materials that might otherwise be very difficult to produce using other fabrication techniques.

[93] An alternative material to the resin-based composites that could be injected into the molds is liquid crystal polymer (LCP). LCP is a low loss material that can be used for frequencies over 60 GHz while exhibiting a very low loss characteristic. As a result, use of the liquid crystal polymer can result in highly efficient dielectric materials.

[94] Although LCP is not generally a “curable” polymer, it may also be injected into mold structures, as a low-loss microwave dielectric material for high frequencies. A composite or polymer “lid” layer may be provided to hold the LCP within the mold after fabrication.

[95] Referring now to FIGS. 5A and 5B, there are shown an exploded isometric view and a perspective view, respectively, of an example DRA 500 formed using the composite material described herein.

[96] DRA 500 comprises a ground layer 510, substrate 525, feedline 515, and a resonator body 532.

[97] DRA 500 is illustrated with a microstrip feeding structure, however other arrangements, feeding structures and shapes may be used. In particular, since a DRA formed using the composite materials as described herein may benefit from high relative permittivity, more conventional feeding structures, such as a coplanar transmission line coupling, slot coupling and probe coupling can also be used.

[98] Substrate 525 may be a microwave or millimeter-wave substrate material, and ground layer 510 may be attached to this substrate material. Depending on the fabrication process used, substrate 525 may be, for example, a layer of alumina, glass, or silicon that may be doped in accordance with the process requirements.

[99] Reference is made to FIGS. 6A and 6B, in which there are shown different embodiments of the resonator body 532 formed from the composite material described herein. For example, as shown in FIG. 6A, a resonator body 532a may comprise a single layer 610 of the composite material. In other embodiments, such as the example shown in FIG. 6B, a resonator body 532b may comprise multiple layers, such as layers 610a to 610c, shown stacked vertically. It will be understood that a resonator body 532 may be formed using fewer or more layers of the composite material described herein.

[100] The composite material in each layer 610 (or 610a to 610c) of the resonator body 532 may comprise a filler that is uniformly distributed, distributed at a gradient or otherwise distributed according to a distribution profile. For example, the distribution profile may include a gradual variation in one or more dimensions, linear variation or nonlinear variation.

[101] Variations in the distribution profile produce anisotropy, which can significantly improve polarization of an antenna and its pattern. Such anisotropic composites can also be fabricated by exploiting anisotropy of the filler material or its orientation within the composite material.

[102] Referring now to FIG. 7, there is shown a plan view of another example DRA 700. Similar to DRA 500, DRA 700 is illustrated with a microstrip feeding structure. However, unlike DRA 500, feedline 715 of DRA 700 extends into resonator body 732 by a feedline extension portion 770.

[103] FIG. 8 is a plot illustrating frequency responses of three different microstrip-fed DRAs formed using the composite material described herein.

[104] The dimensions of the components of the three different DRAs are consistent. The resonator body has a length of 2mm, a width of 2mm and a height of 0.9mm. The dimension of the substrate is 8mm x 8mm and a width of the feedline is 1.2mm. The substrate has a thickness of 0.381mm and a relative permittivity of 2.2. The feedline extension portion is 0.4mm. The resonant frequency is also fixed at approximately 50 GHz.

[105] Frequency response 810 is generated by simulating a DRA with a resonator body formed using a composite material with a uniformly distributed filler and a relative permittivity of 5.5. For example, the filler may include $BaTiO_3$ which comprises 30% by weight of the composite material. As illustrated with frequency response 810, the return loss at the resonant frequency is barely -12.9 dB. The DRA associated with the frequency response 810, therefore, is minimally excited by the microstrip feed.

[106] Frequency response 820 is generated by a DRA with a resonator body formed using a composite material comprising a filler that is distributed according to a linearly varied gradient. The composite material has a relative permittivity that varies in a direction substantially perpendicular to a planar surface of the substrate, such as the Z-direction, from 7.5 to 3.5. In this example, the filler comprises inhomogeneous $BaTiO_3$. As illustrated with frequency response 820, the return loss at resonance is -20 dB. The DRA associated with the frequency response 820 also has a 10 dB bandwidth of 17% from 46 GHz to 54.5 GHz,

[107] As illustrated with frequency response 810 and 820, the coupling level of a DRA formed using the composite material described herein may increase with the use of a filler that is more inhomogeneous and non-uniformly distributed within the composite material. A further example is illustrated with frequency response 830.

[108] Frequency response 830 is generated by a DRA with a resonator body formed using five layers of composite material. In this example, each of the five layers comprises a different composite material, namely $BaTiO_3$ at 60% by weight of the composite material with a relative permittivity of 10, $BaTiO_3$ at 50% by weight of the composite material with a relative permittivity of 7.5, ZrO_2 at 50% by weight of the composite material with a relative permittivity of 5.7, ZrO_2 at 35% by weight of the composite material with a relative permittivity of 4.6, and pure PSS with a relative permittivity of 2.5. As illustrated with frequency response 830, the return loss at resonance for the associated DRA is -32 dB. The DRA associated with the frequency response 830 also has a 10 GHz bandwidth.

[109] Some dielectric applications, such as those for military uses, require a return loss of at least -20dB. The DRA associated with the frequency response 830, therefore, exhibits dielectric characteristics that are suitable for military applications.

[110] Referring now to FIG. 9, there is shown an exploded isometric view of another example DRA 900 formed using the composite material described herein.

[111] Similar to DRA 500, DRA 900 comprises a ground layer 910, substrate 925, feedline 915, and a resonator body 932. DRA 900, unlike DRA 500, comprises a tall metal vertical feeding structure 920.

[112] Mold 950 may be a first body portion that defines an aperture or cavity 952 therein. The mold 950 may be formed of a photoresist material if fabricated in a lithographic process. Aperture 952 can be filled with a resonator body 932, or second body portion, which may be comprised of a composite dielectric material. Preferably, resonator body 932 has a higher relative permittivity than mold 950.

[113] In some embodiments, the cavity may be filled with one or more different composite materials. The cavity may therefore define multiple lateral segments of composite materials.

[114] In some embodiments, mold 950 may be removed in a later stage of fabrication, although in other embodiments the mold 950 can be retained.

[115] Resonator body 932 may have a square or rectangular topology. In other embodiments, different shapes can be used, such as circular, fractal, or other complex shapes. Due to the use of the mold 950 and the filling technique used to form resonator body 932, materials that would not ordinarily be suitable for use in a lithographic fabrication process, such as non-photoresist polymers and composites, can be used to form resonator body 932.

[116] Aperture 952 can be formed using, for example, X-ray or deep UV lithography as described herein.

[117] Feeding structure 920 can have a substantially flattened rectangular shape and be positioned near to the outer wall of resonator body 932, and either outside or inside the inner wall of mold 950, so that the elongated edge of feeding structure 920 is substantially parallel to the outer wall. In some alternative embodiments, feeding structure 920 can have other lateral shapes and positioning, as described herein.

[118] Mold 950 need not necessarily have a "thin" or "narrow" wall structure as depicted in FIG. 9, and in some embodiments the walls of mold 950 may be relatively thick, extending in one or more directions for a large distance. In some cases, mold 950 may comprise larger sheets of photoresist material (e.g., "hole templates"), in which the "hole templates" can be filled with polymer-composite materials (and, where the low permittivity photoresist template sheet may remain following fabrication).

[119] Feeding structure 920 is formed of a conductive material (e.g., metal) and extends substantially perpendicularly from the surface of substrate 925. That is, feeding structure 920 can be 10-100% the height of mold 950.

[120] Feeding structure 920 is electrically coupled to feedline 915, and may have a width generally corresponding to the width of feedline 915.

[121] In some embodiments, dielectric resonator antennas can be fabricated using non-lithographic techniques, but employing the same mold approach illustrated in FIG. 9. For example, a mold can be formed having one or more recesses for receiving the composite material. The recesses can have a rectangular shape or other shapes, such as circular or partial circular.

[122] Reference is now made to FIGS. 10A and 10B, therein illustrated different views of an example mold 1000. Mold 1000 has a main body 1010 that may be formed of a plastic material, such as PMMA or any other plastics. Example recesses 1002a to 1002h are formed in mold 1000 in the main body 1010. As shown in FIGS. 10A and 10B, the recesses 1002 may be formed of various different shapes and sizes. It will be understood that the illustrated recesses 1002 are merely for illustrative purposes and that different configurations of the recesses may be formed in the molds.

[123] To fabricate the DRAs, the mold 1000 may be filled with the composite materials described herein using known techniques, such as injection or tape casting. The fabricated DRA structure may be used with or without the mold 1000. The mold 1000 may be retained after the DRA structure is fabricated as a protective frame or as a packaging. To remove the mold 1000 from the DRA structure, various known methods may be applied. For example, the mold 1000 may be removed using a lift-off process with carbon coated wafers or via X-ray exposure if mold 1000 is formed of a photoresist-type polymer. A sacrificial substrate or release layer (film) holding the mold may also be dissolved to release the mold.

[124] In some embodiments, the fabricated molds with filled composite materials can be lapped/polished to control the final structure height add/or improve the top surface quality/homogeneity.

[125] Numerous specific details are set forth herein in order to provide a thorough understanding of the exemplary embodiments described herein. However, it will be understood by those of ordinary skill in the art that these embodiments may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the description of the embodiments. Various modifications and variations may be made to these exemplary embodiments without departing from the scope of the invention, which is limited only by the appended claims.

We claim:

1. A composite material with dielectric properties for use in microwave applications, the composite material comprising:

a filler with a relative permittivity of at least 4, and

a polymer constituent,

wherein the composite material has a relative permittivity of at least 3 for microwave frequencies.

2. The composite material of claim 1, wherein the filler relative permittivity is between 4 and 10000.

3. The composite material of claim 1 or claim 2, wherein the filler comprises a ceramic constituent.

4. The composite material of any one of claims 1 to 3, wherein the microwave frequencies have a range of 0.3 GHz to 300 GHz.

5. The composite material of any one of claims 1 to 4, wherein the microwave applications comprise dielectric resonator applications.

6. The composite material of any one of claims 1 to 5, wherein the microwave dielectric applications comprise dielectric resonator antenna applications.

7. The composite material of any one of claims 1 to 6, wherein the filler and the polymer constituent form a mixture.

8. The composite material of claim 7, wherein the mixture is homogeneous.

9. The composite material of claim 7, wherein the mixture is inhomogeneous.

10. The composite material of claim 9, wherein the filler is distributed at a gradient or other varying profile in the inhomogeneous mixture.

11. The composite material of any one of claims 1 to 10, wherein the composite material comprises a plurality of layers, and wherein at least one of the layers comprises a different mixture than the respective other layers.

12. The composite material of any one of claims 1 to 11, wherein the filler comprises particles having a mean diameter corresponding to at least 1/10 of a minimum size of a functional pattern of the microwave applications.

13. The composite material of any one of claims 1 to 12, wherein the filler is a powder prior to mixing with the polymer constituent.

14. The composite material of any one of claims 1 to 13, wherein the filler has a relative permittivity greater than 1000.

15. The composite material of any one of claims 1 to 13, wherein the filler has a relative permittivity between 4 and 1000.

16. The composite material of any one of claims 1 to 15, wherein the filler constitutes at least 5% by weight of the composite material.

17. The composite material of claim 16, wherein the filler constitutes less than 70% by weight of the composite material.

18. The composite material of any one of claims 1 to 15, wherein the filler constitutes at least 3% by volume of the composite material.

19. The composite material of claim 18, wherein the filler constitutes less than 80% by volume of the composite material.

20. The composite material of any one of claims 1 to 19, wherein the polymer constituent has a relative permittivity less than 5 when in substantially pure form.

21. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises a resin.

22. The composite material of claim 21, wherein the resin comprises a thermosetting material.

23. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises a curable polymer.

24. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises a positive photoresist polymer.

25. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises a negative photoresist polymer.

26. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises polymethyl methacrylate (PMMA).

27. The composite material of any one of claims 1 to 20, wherein the polymer constituent comprises SU-8.

28. A dielectric resonator antenna for use in microwave applications, the antenna comprising:

a substrate with at least a first planar surface;

a resonator body disposed on the first planar surface, the resonator body formed of the composite material of any one of claims 1 to 27; and

an excitation structure for exciting the resonator body.

29. The dielectric resonator antenna of claim 28, where the resonator body has a thickness in a range of 1 to 6000 microns.

30. The dielectric resonator antenna of claim 28 or claim 29, wherein the resonator body is comprised of one or more layers of composite material stacked vertically.

31. The dielectric resonator antenna of any one of claims 28 to 30, wherein the resonator body is comprised of one or more laterally defined segments of composite material.

32. A method of fabricating a composite material for use in microwave dielectric applications, the method comprising:

mixing a filler with a relative permittivity of at least 4 and a polymer constituent to form the composite material, wherein the composite material has a relative permittivity of at least 3 for microwave frequencies.

33. The method of fabricating a composite material of claim 32, further comprising curing the composite material at a temperature below about 100°C.

34. The method of fabricating a composite material of claim 32, further comprising curing the composite material at a temperature below about 65°C.

35. The method of fabricating a composite material of any one of claims 32 to 34, wherein mixing the filler and the polymer constituent further comprises compounding the filler and the polymer constituent.

36. The method of fabricating a composite material of any one of claims 32 to 34, wherein mixing the filler and the polymer constituent further comprises stirring the filler and the polymer constituent.

37. A method of fabricating a dielectric resonator antenna, the method comprising:

providing a substrate with at least a first planar surface;

providing a mold on the substrate, the mold defining at least one cavity therewithin;

depositing the composite material of any one of claims 1 to 27 within the cavity.

38. The dielectric resonator antenna of claim 37, wherein the mold comprises a polymer-based material.

39. The dielectric resonator antenna of claim 37 or claim 38, wherein the deposited composite material has a thickness in a range of 1 to 6000 microns.

40. The dielectric resonator antenna of any one of claims 37 to 39, wherein the deposited composite material is comprised of one or more layers stacked vertically.

41. The dielectric resonator antenna of any one of claims 37 to 40, wherein each of at least one cavity defines one or more laterally defined segments of deposited composite material.

42. The dielectric resonator antenna of any one of claims 37 to 41, wherein the deposited composite material comprises a liquid crystal polymer composite.

43. The dielectric resonator antenna of claim 42, wherein a polymer layer is deposited over the liquid crystal polymer composite within the cavity.

44. The method of any one of claims 37 to 41, wherein the mold is provided by:

forming a polymer-based body;

exposing the polymer-based body to a lithographic source via a pattern mask, wherein the pattern mask defines the cavity to be formed in the polymer-based body;

developing a portion of the polymer-based body; and removing one of an exposed portion and an unexposed portion of the polymer-based body.

45. The method of any one of claims 37 to 44, further comprising removing the mold to leave the composite material.

46. The method of any one of claims 37 to 44, wherein the mold is retained as one of a protective frame and a packaging.

47. The method of any one of claims 37 to 46, wherein the composite material is deposited by injection.

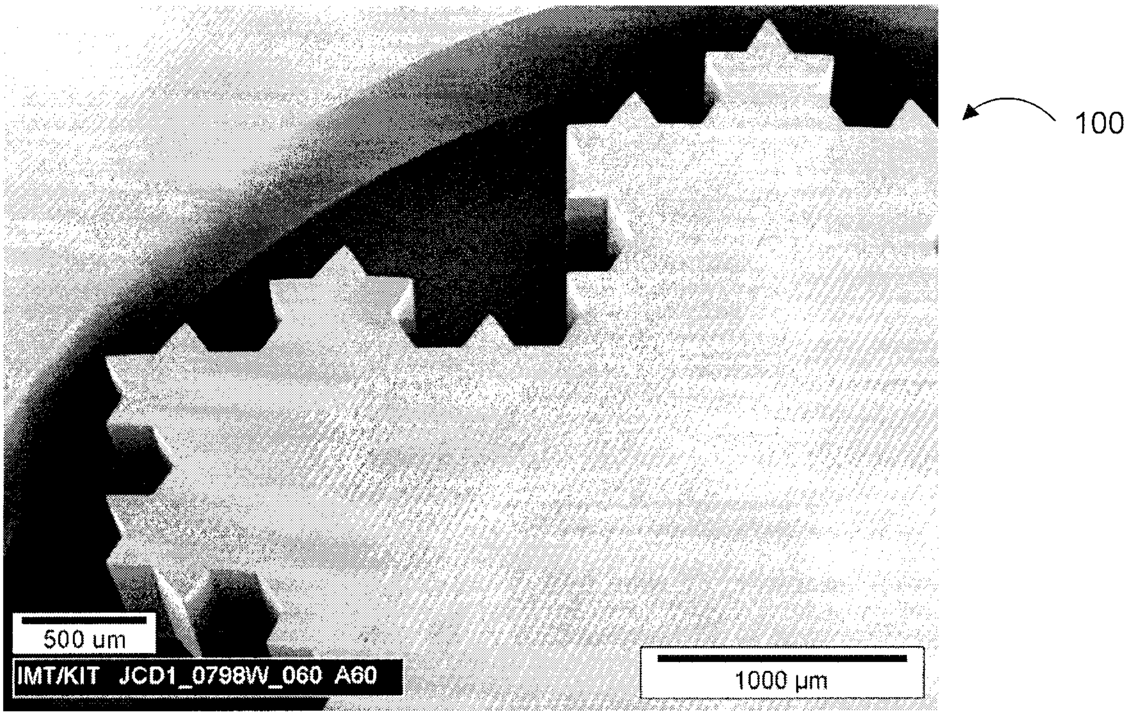
100
500 um
IMT/KIT JCD1_0798W_060 A60
1000 µm

FIG. 1A

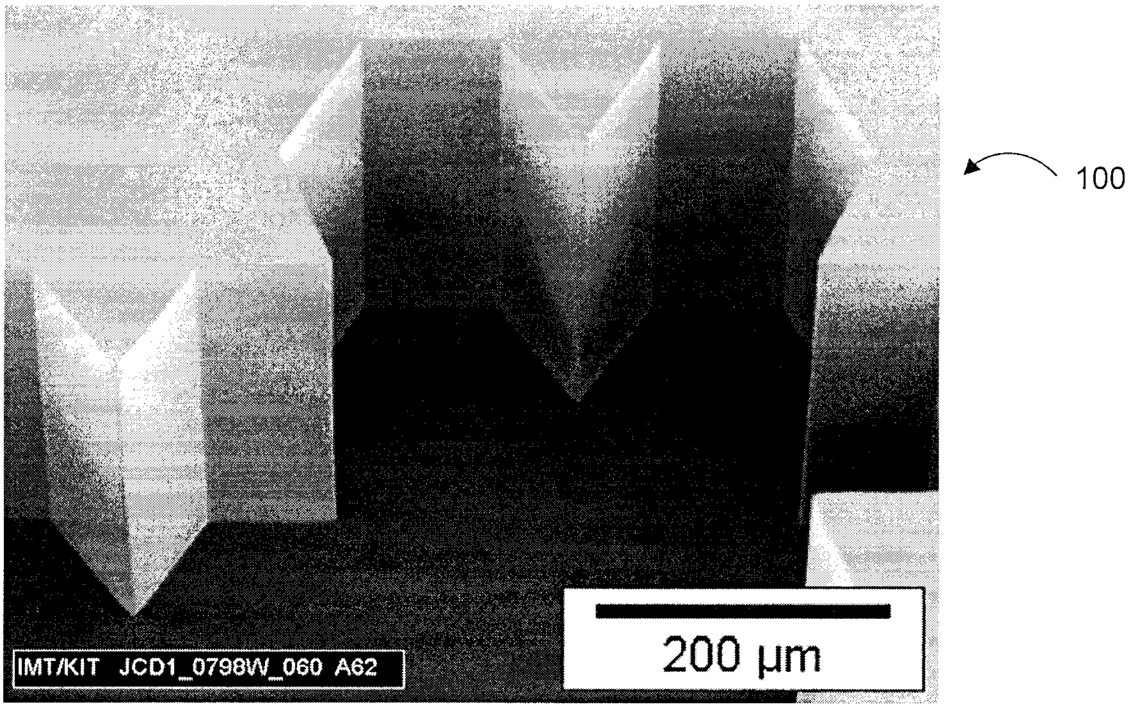
100
IMT/KIT JCD1_0798W_060 A62
200 µm

FIG. 1B

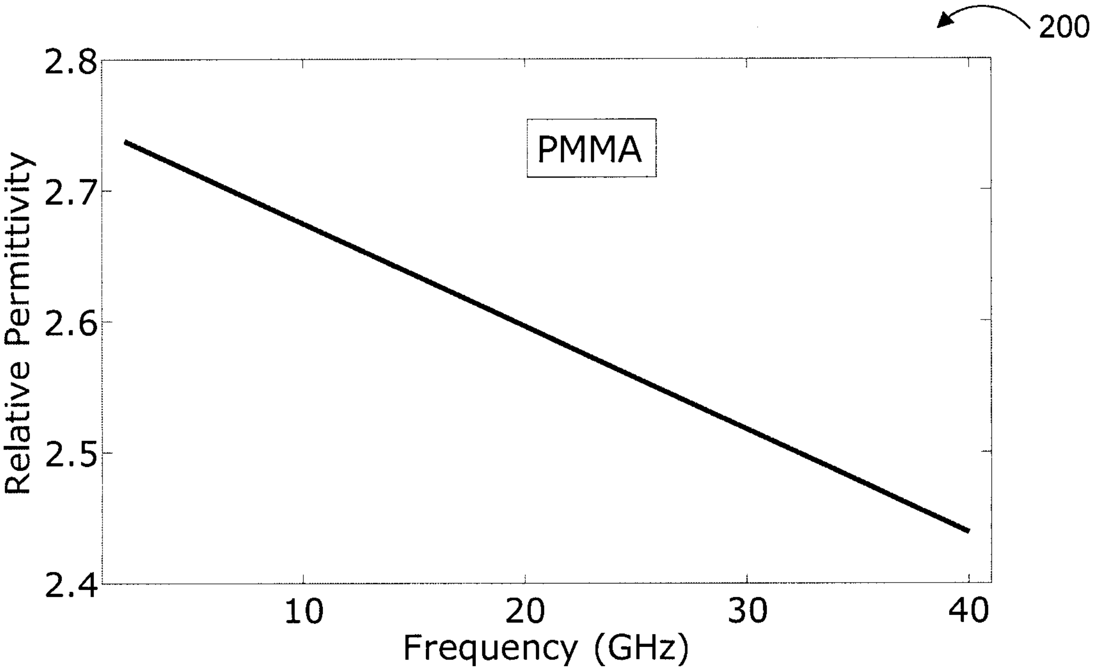
200
PMMA
Relative Permittivity
2.8
2.7
2.6
2.5
2.4
10
20
30
40
Frequency (GHz)

FIG. 2A

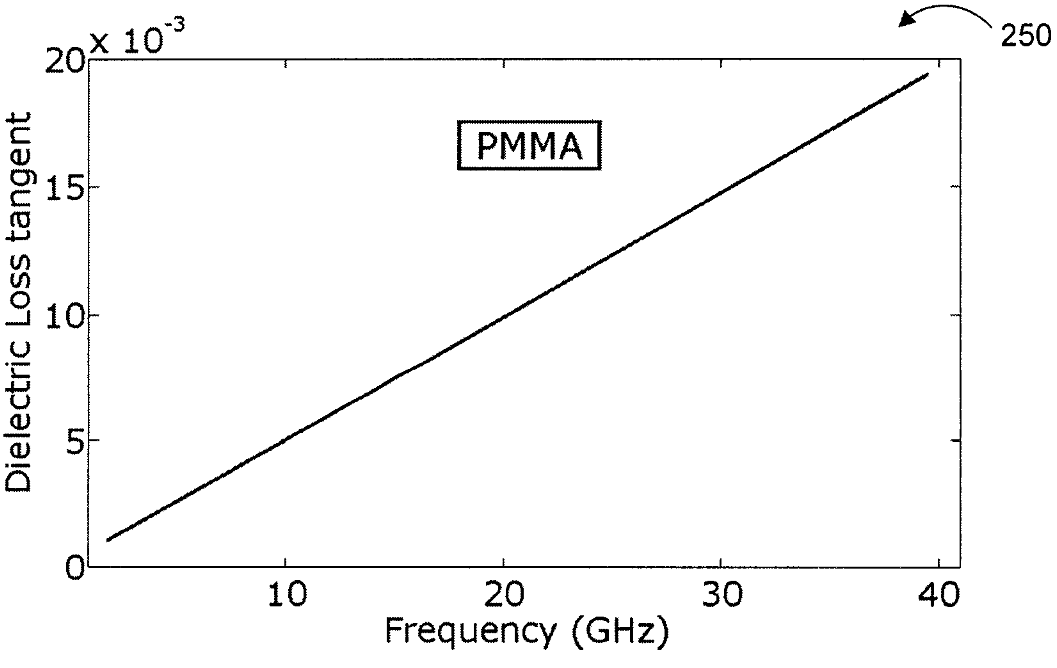
250
x 10^{-3}
PMMA
Dielectric Loss tangent
20
15
10
5
0
10
20
30
40
Frequency (GHz)

FIG. 2B

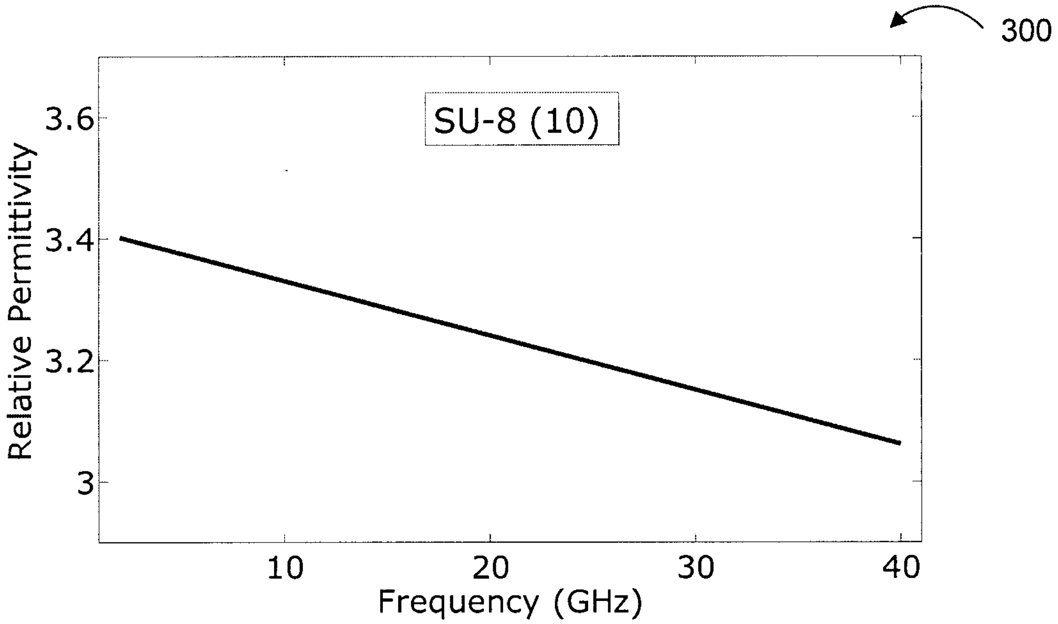
300
SU-8 (10)
Relative Permittivity
3.6
3.4
3.2
3
10
20
30
40
Frequency (GHz)

FIG. 3A

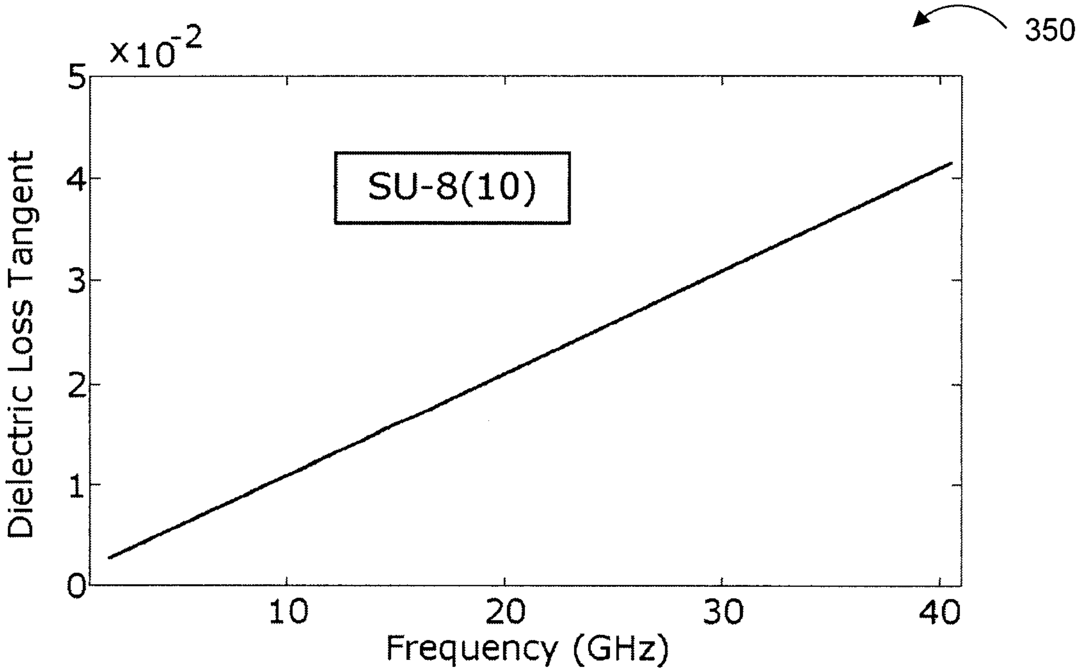
350
$\times 10^{-2}$
SU-8(10)
Dielectric Loss Tangent
5
4
3
2
1
0
10
20
30
40
Frequency (GHz)

FIG. 3B

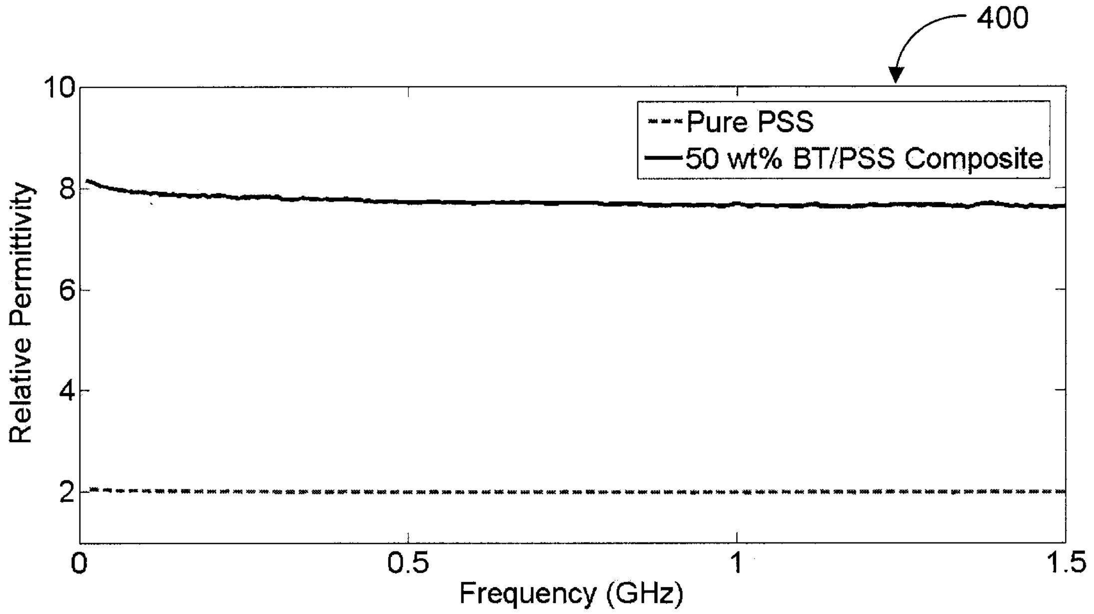
400
Relative Permittivity
10
8
6
4
2
0
0.5
1
1.5
Frequency (GHz)
Pure PSS
50 wt% BT/PSS Composite

FIG. 4A

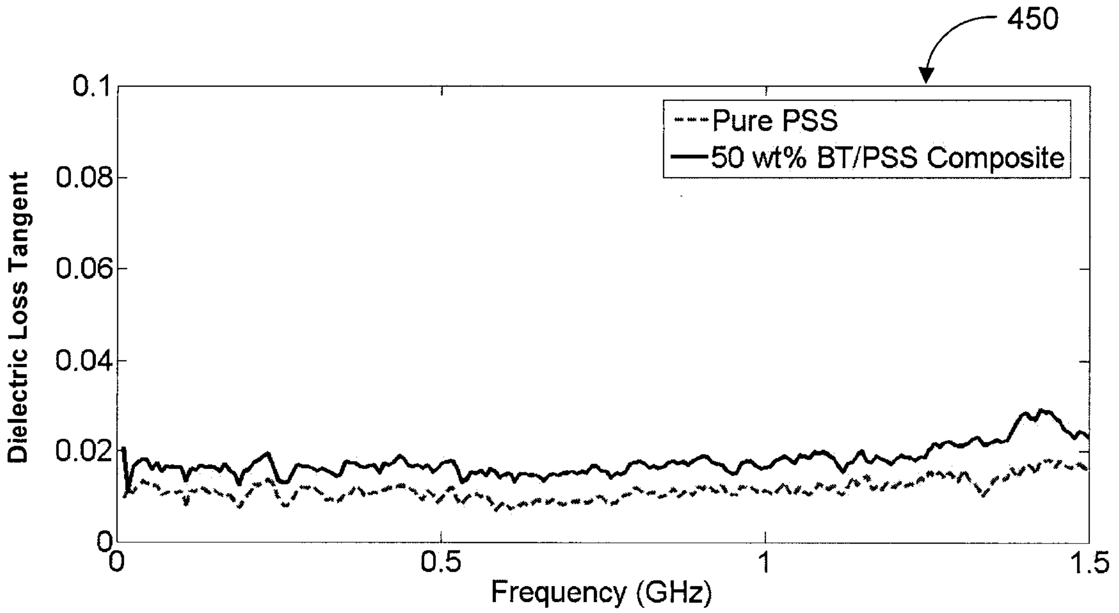
450
Dielectric Loss Tangent
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
Frequency (GHz)
Pure PSS
50 wt% BT/PSS Composite

FIG. 4B

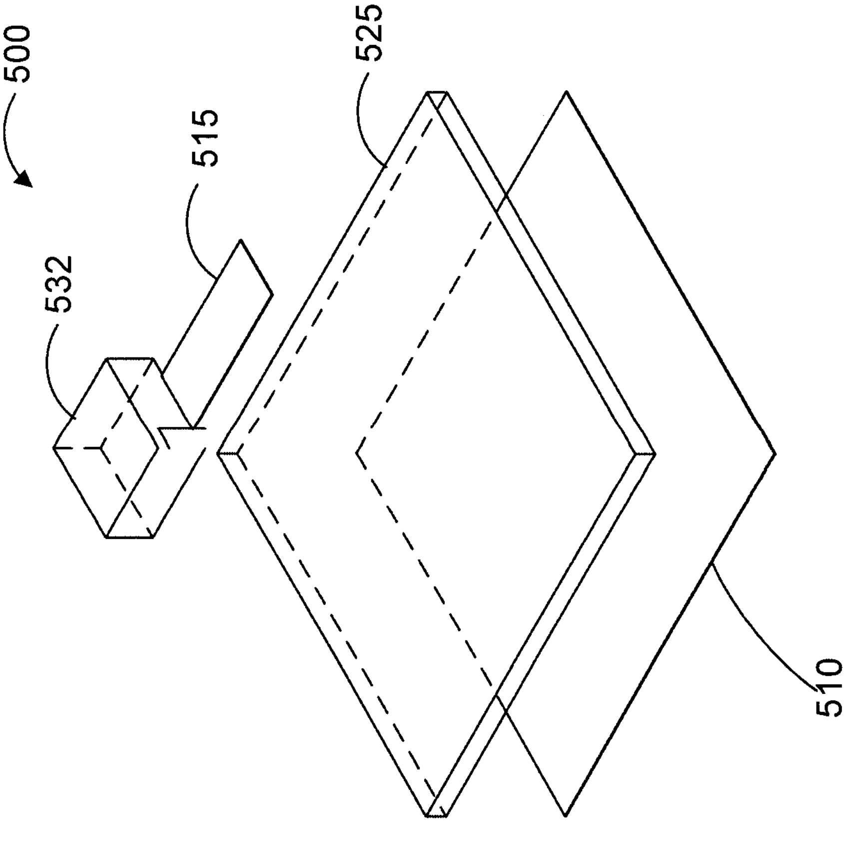

FIG. 5A

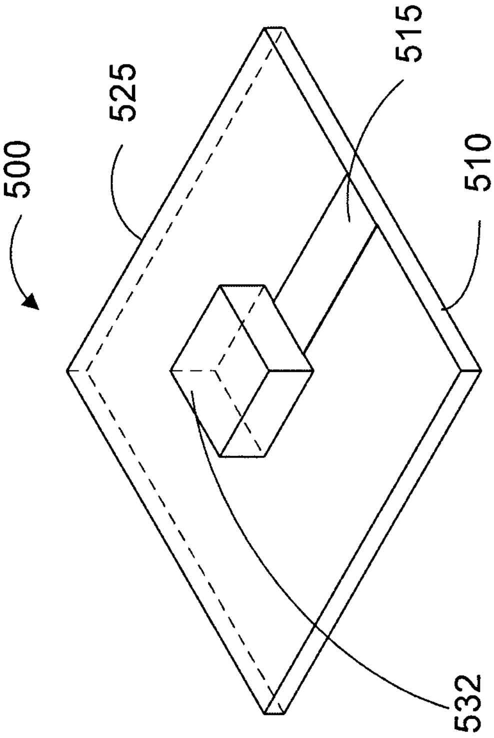

FIG. 5B

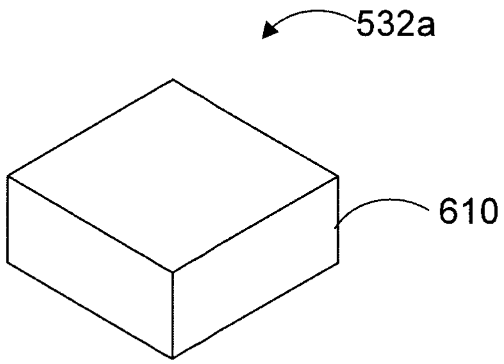

FIG. 6A

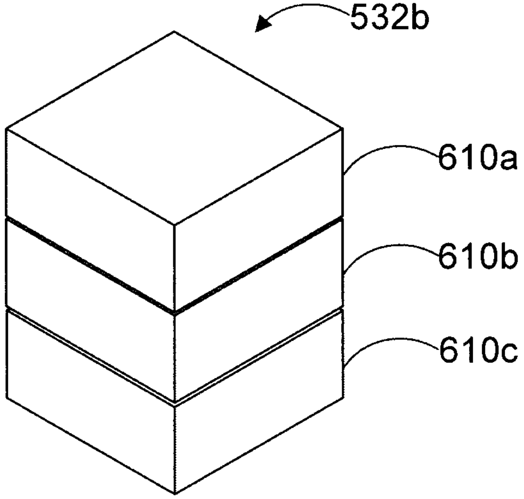

FIG. 6B

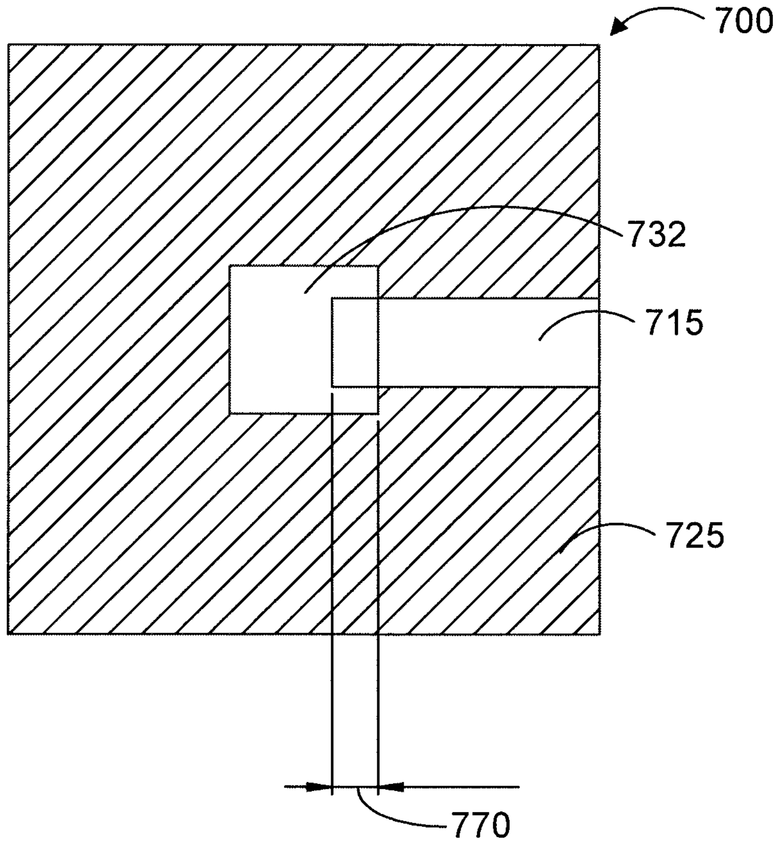

FIG. 7

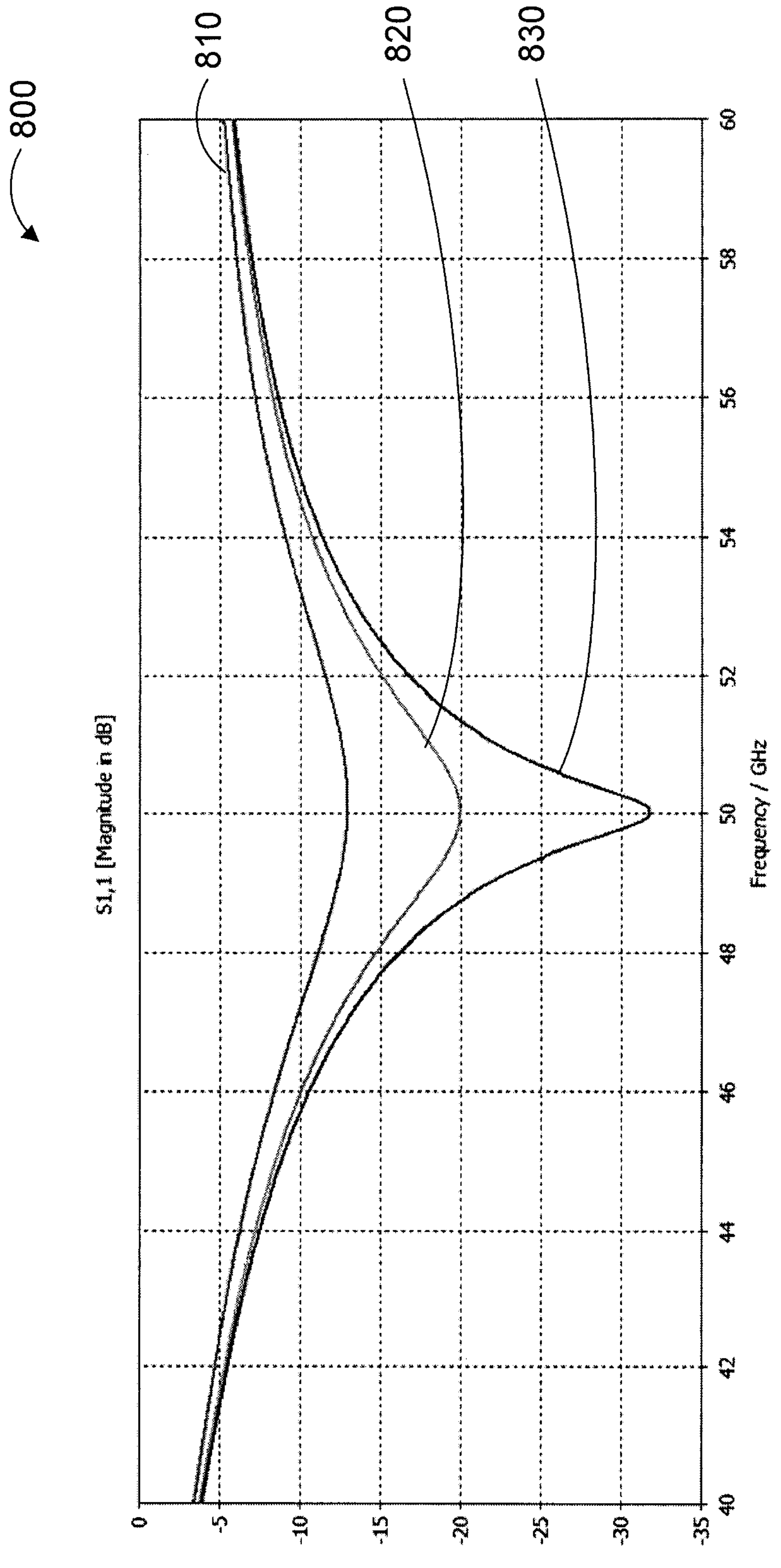
800
810
820
830
S1,1 [Magnitude in dB]
0
-5
-10
-15
-20
-25
-30
-35
40
42
44
46
48
50
52
54
56
58
60
Frequency / GHz

FIG. 8

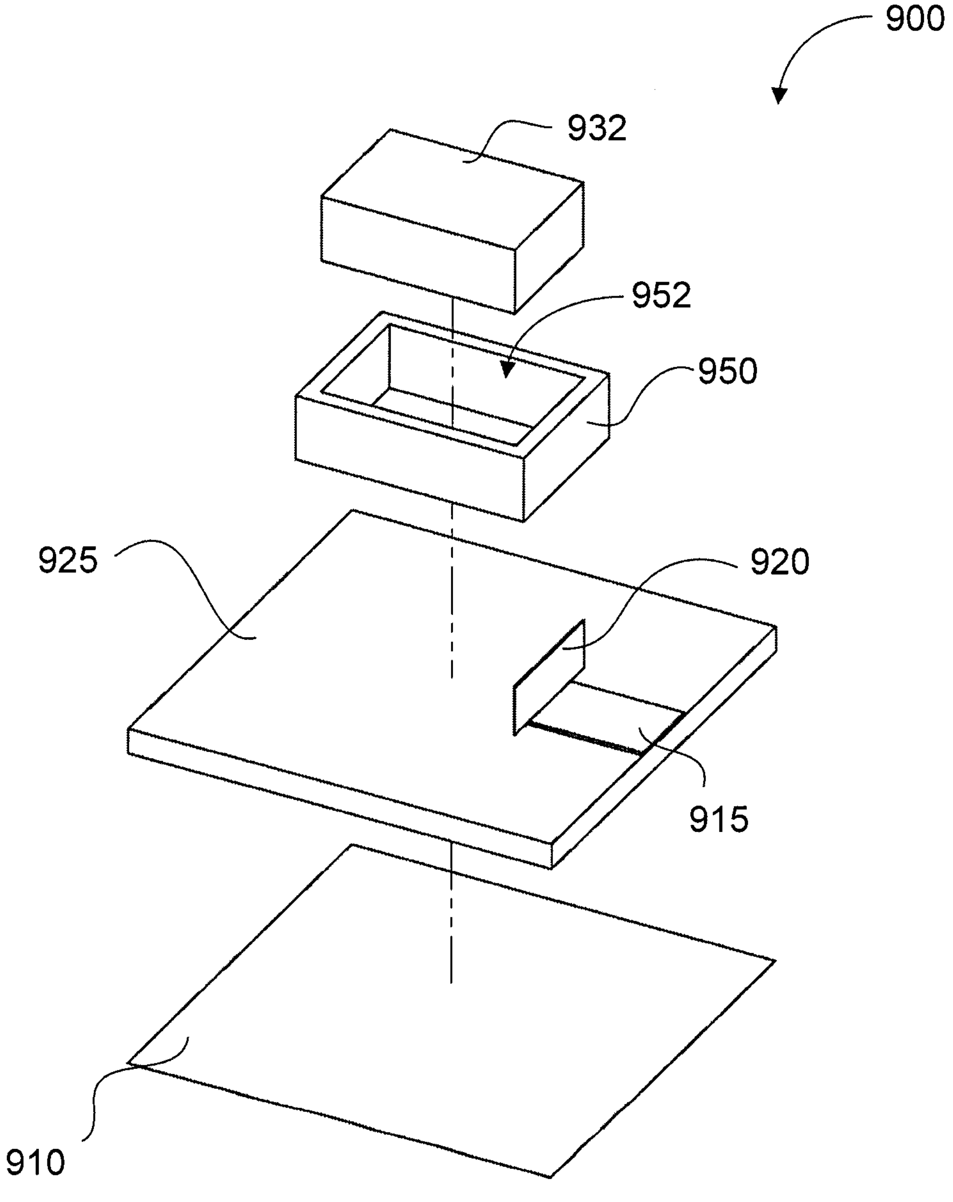

FIG. 9

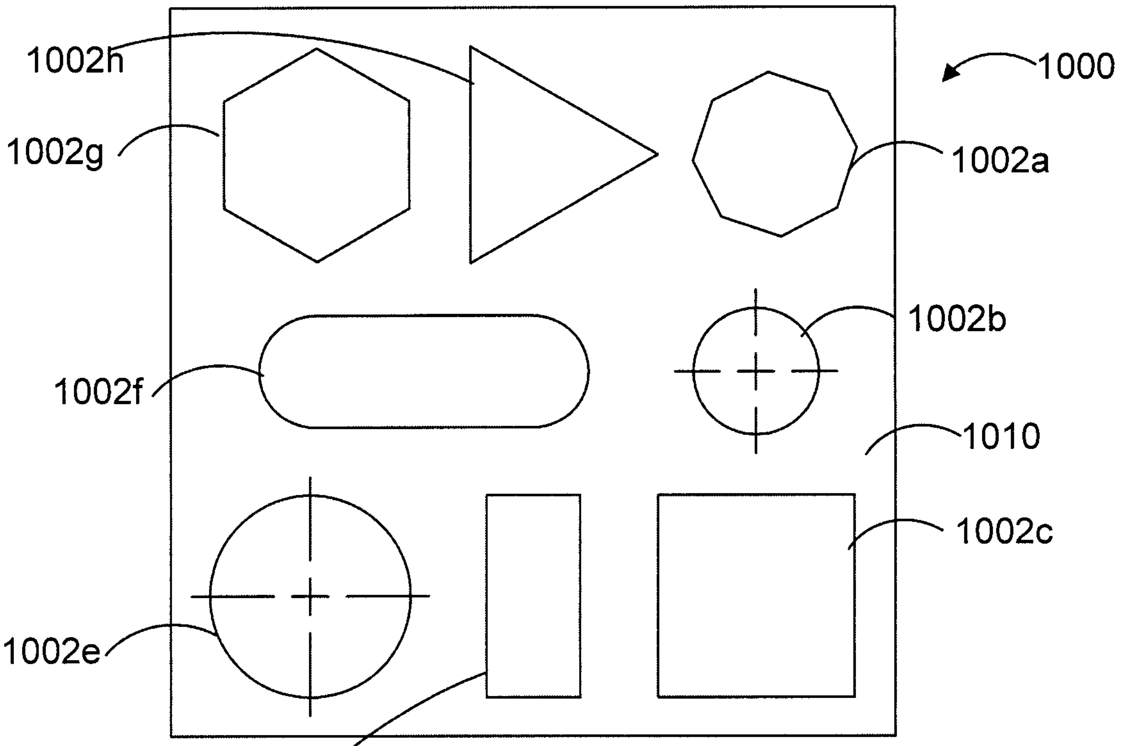

FIG. 10A

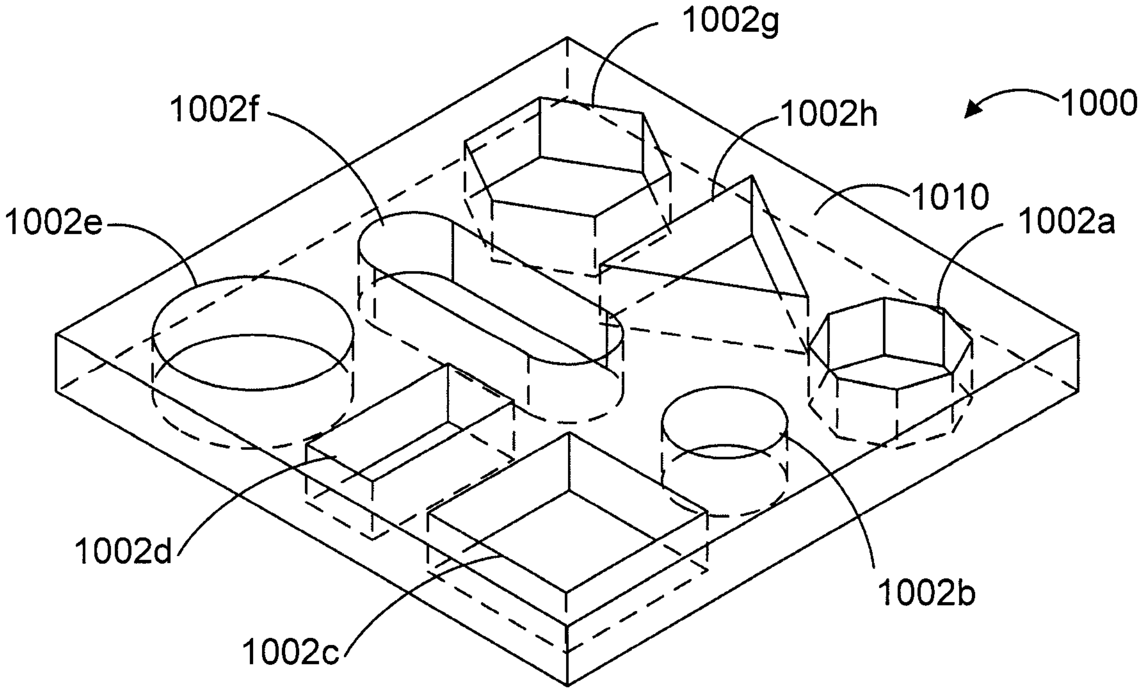

FIG. 10B

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***H01B 3/12*** (2006.01) , ***B32B 18/00*** (2006.01) , ***B32B 27/04*** (2006.01) , ***C08J 3/20*** (2006.01) , ***C08K 3/00*** (2006.01) , ***C08L 33/12*** (2006.01) , ***H01B 3/30*** (2006.01) , ***H01Q 1/38*** (2006.01) , ***H01Q 9/04*** (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: H01B 3/12 (2006.01) , B32B 18/00 (2006.01) , B32B 27/04 (2006.01) , C08J 3/20 (2006.01) , C08K 3/00 (2006.01) , C08L 33/12 (2006.01) , H01B 3/30 (2006.01) , H01Q 1/38 (2006.01) , H01Q 9/04 (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
TotalPatent, Canadian Patent Database, Google Patent
Keywords: composite, material, dielectric, permittivity, resonator, antenna

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2012/0245016 27 September 2012 (27-09-2012) Curry et al. (whole document)	1-23, 32-36 28-31
Y	"Wideband Two-layer Rectangular Dielectric Resonator Antenna with (Zr 0.8Sn0.2)TiO4-Epoxy Composite System Chaudhary et al. *Special Materials Group, DMSRDE (DRDO Lab) Kanpur, Uttar Pradesh, India 2011* (figure 2, abstract)	28-31
Y	EP 1767 582 B1 28 March 2012 (28-03-2012) Oohira et al (figure 1)	28-31

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
25 September 2014 (23.09.2014)

Date of mailing of the international search report
02 October 2014 (02-10-2014)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
Thomas KC. Tang (819) 997-2189

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		US2007182640A1	09 August 2007 (09-08-2007)
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		WO2005123841A1	29 December 2005 (29-12-2005)