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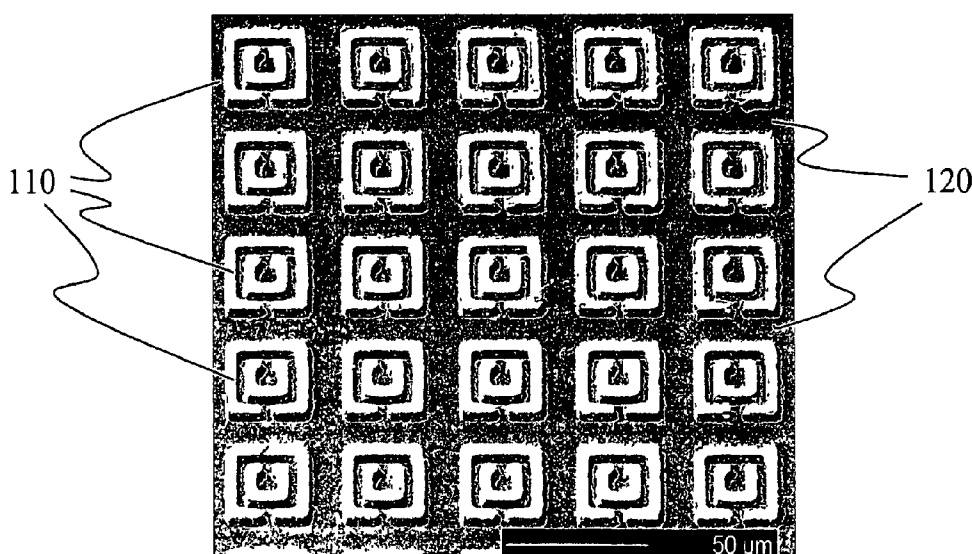
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(54) Title: DYNAMICAL/TUNABLE ELECTROMAGNETIC MATERIALS AND DEVICES

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(57) **Abstract:** A composite material that is responsive to either electromagnetic or thermal radiation. The composite has a controllable structure that is either dynamically or tunably responsive to such radiation and comprises a metamaterial. Sensors, such as a bolometer, that incorporate the composite are also described.

WO 2007/103560 A2

DYNAMICAL/TUNABLE ELECTROMAGNETIC MATERIALS AND DEVICES

RELATED APPLICATIONS

This application claims the benefit of Provisional Application Serial No. 60/780,109 filed March 8, 2006.

STATEMENT REGARDING FEDERAL RIGHTS

[0001] This invention was made with government support under Contract No. DE-AC52-06NA25396, awarded by the U.S. Department of Energy. The government has certain rights in the invention.

BACKGROUND OF INVENTION

[0002] The invention relates to composites that are responsive to either electromagnetic or thermal radiation. More particularly, the invention relates to such responsive composites that comprise metamaterials. Even more particularly, the invention relates to such composites in which the response is controllable.

[0003] Artificial materials, also known as metamaterials, that exhibit a designed electromagnetic response have recently generated great interest, due in part to the ability of these materials to exhibit an electromagnetic response not readily available in naturally occurring materials. Another advantage of such materials is that resonant structures can be designed over a large portion of the electromagnetic spectrum. Regions in which there is normally no response by naturally occurring materials can thus be targeted for metamaterial applications.

[0004] Switching capabilities at different frequencies, ranging from microwave to terahertz (THz), in the electromagnetic spectrum are among the potential application for metamaterials. It would be desirable to create metamaterials that exhibit a controlled, active response, such as dynamic and tunable responses. Whereas the dynamic control of metamaterials has been demonstrated at microwave frequencies, however, dynamic or tunable metamaterial response has not been demonstrated at THz frequencies.

[0005] High frequency devices comprising metamaterials are not capable of either dynamic or tunable control. Therefore, what is needed is a material that exhibits such control and is responsive to high frequencies. What is also needed is a device comprising such materials.

SUMMARY OF INVENTION

[0006] The present invention meets these and other needs by providing a composite material that is responsive to either electromagnetic or thermal radiation. The composite has a controllable structure that is either dynamically or tunably responsive to such radiation and comprises a metamaterial. Sensors, such as a bolometer, that incorporate the composite are also described.

[0007] Accordingly, one aspect of the invention is to provide a sensor. The sensor comprises: a composite capable of generating an electromagnetic or a thermal signal in response to an electromagnetic stimulus or a thermal stimulus; and either a dielectric substrate upon which the controllable structure is disposed, or a dielectric material within which the composite is embedded. The composite comprises a controllable structure. The controllable structure comprises a metamaterial and has a major dimension that is less than or equal to a predetermined wavelength. The sensor is capable of detecting an optical pulse, a magnetic pulse, a thermal pulse, or an electrical pulse.

[0008] A second aspect of the invention is to provide a composite that is capable of generating an electromagnetic or a thermal signal in response to an electromagnetic stimulus or a thermal stimulus. The composite comprises: a controllable structure; and either a dielectric substrate upon which the controllable structure is disposed, or a dielectric material within which the controllable structure is embedded. The controllable structure comprises a metamaterial and has a major dimension that is less than or equal to a predetermined wavelength.

[0009] A third aspect of the invention is to provide a bolometer. The bolometer comprises: a composite capable of generating an electromagnetic or a thermal signal in response to an electromagnetic stimulus or a thermal stimulus; and a

temperature sensor in communication with the composite. The composite comprises: a controllable structure; and either a dielectric substrate upon which the controllable structure is disposed, or a dielectric material within which the controllable structure is embedded. The controllable structure comprises a metamaterial and has a major dimension that is less than or equal to a predetermined wavelength.

[0010] These and other aspects, advantages, and salient features of the present invention will become apparent from the following detailed description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIGURE 1 is a photograph of a focal plane array of split ring resonators;

[0012] FIGURE 2 is a schematic representation of two artificial "atoms" for metamaterials design;

[0013] FIGURE 3 is a schematic representation of metamaterial constructs: a) a split ring resonator (SRR) having a double ring structure; b) an electric dipole active structure; c) a composite structure comprising a SRR and a dipole; and d) "active" regions of the SRR shown in FIG. 3a;

[0014] FIGURE 4 is a schematic representation of: a) a first embodiment of a bolometer; and b) a second embodiment of a bolometer;

[0015] FIGURE 5 includes: a) frequency dependent transmission spectra; b) the corresponding phase of the transmission; c) calculated surface current at $\alpha - \omega$; and d) calculated surface current at ω ;

[0016] FIGURE 6 is a plot of transmission spectra of the magnetic response of split ring resonators (SRRs); and

[0017] FIGURE 7 includes: a) transmission spectra as a function of photo-doping influence for electric resonance of SRRs; and b) corresponding change of the real dielectric constant of the SRRs as a function of power;

DETAILED DESCRIPTION

[0018] In the following description, like reference characters designate like or corresponding parts throughout the several views shown in the figures. It is also understood that terms such as "top," "bottom," "outward," "inward," and the like are words of convenience and are not to be construed as limiting terms. In addition, whenever a group is described as either comprising or consisting of at least one of a group of elements and combinations thereof, it is understood that the group may comprise or consist of any number of those elements recited, either individually or in combination with each other.

[0019] Referring to the drawings in general and to FIG. 1 in particular, it will be understood that the illustrations are for the purpose of describing a particular embodiment of the invention and are not intended to limit the invention thereto.

[0020] Turning to FIG. 1, a focal plane array 100 of the composite of the present invention is shown. Composite 110 generates an electromagnetic signal or a thermal signal in response to either a thermal stimulus or an electromagnetic stimulus such as, for example, electromagnetic radiation of a selected wavelength, an electric charge, or a potential. Composite 110 comprises a controllable structure 120. In one embodiment, shown in FIG. 1, controllable structure 120 is disposed on a surface of a dielectric substrate 130. In another embodiment, controllable structure 120 is embedded within a dielectric material (not shown).

[0021] Dielectric substrate 130, as well as the dielectric material into which controllable substrate 120 may be embedded, may comprise any one of polytetrafluoroethylene (Teflon®), polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, and combinations thereof. Dielectric substrate 120 may be an active substrate such as, for example, gallium arsenide (GaAs) or heterostructures, such as gallium arsenide/erbium arsenide (GaAsrErAs). Alternatively dielectric substrate 130 may be a thin film such as a ferroelectric, including, barium titanate (BaTiO₃), strontium titanate (SrTiO₃), lead zirconium

titanate - lead lanthanum zirconium titanate (PZT-PLZT), lanthanum strontium titanate, bismuth lanthanum titanate, combinations thereof, and the like.

[0022] Controllable structure 110 comprises a metamaterial and, in some embodiments, a dielectric such as those described hereinabove. A metamaterial is an object or collection of objects, arranged in an array, that acquire electromagnetic properties from its structure rather than inheriting directly from the materials comprising the metamaterial. The objects or array of objects have features that are comparable to or significantly smaller than the wavelength of the electromagnetic radiation that interacts with the metamaterial. Metamaterials interact with the electromagnetic radiation as would atoms; different units or objects in an array of metamaterials play the role of atomic dipoles, or "artificial atoms." The metamaterial may comprise highly conductive materials such as, but not limited to, copper, silver, gold, platinum, tungsten, combinations (such as, for example, alloys of these elements) thereof, and the like. Alternatively, the metamaterial may comprise at least one less conductive metal, alloys, and semi-metals such as lead, tin, or brass. Also, the metamaterial may comprise at least one semiconductor such as, but not limited to, silicon and gallium arsenide, where GaAs may be either undoped, n-doped, or p-doped. In another embodiment, the metamaterial may comprise at least one of a high temperature superconductor, a low temperature superconductor, magnesium diboride (MgB_2), or conductive transition metal oxides such as rhenium oxide (ReOs). In yet another embodiment, the metamaterial may comprise at least one of a ferromagnet, an antiferromagnet, or a paramagnet such as, for example, iron difluoride, manganese difluoride, and the like. Conventional photolithographic techniques that are known in the art may be used to form controllable structure 110 on substrate 120.

[0023] Two artificial "atoms" for metamaterials design are schematically shown in FIG. 2. A straight wire segment 210, which acts as an electric dipole, is shown in FIG. 2a. FIG. 2b shows a wire loop 220, or split ring resonator (also referred to herein as "SRR"), having a gap 222, that acts as a magnetic dipole. A focal plane array 100 of split ring resonators is schematically shown in FIG. 1. Alternatively, the split ring resonator pixels may be arranged in a non-periodic array for interferometric imaging. These SRR pixels may comprise either a single SRR or

an array of a plurality of SRRs. The SRRs shown in FIG. 1 have a double ring structure, which provides additional capacitance. Each of these fundamental building blocks is loaded with impedance (Z_{Load}) for two reasons. First, the Z_{Load} allows the particles to display resonant behavior at wavelengths (λ) much greater than their dimensions (as with real atoms). Secondly, the appropriate choice of load can lead to tunable behavior. For tunable terahertz metamaterials, semiconductor or ferroelectric materials will be incorporated into the active regions (e.g., 340 in FIG. 3b) of the artificial atoms, thus permitting tuning of the constituent metamaterials with photons, a DC electric field, pressure, magnetic field, electric current, or temperature.

[0024] A variety of metamaterial constructs that may be lithographically fabricated are schematically shown in FIG. 3. A split ring resonator 310, having a double ring structure that provides additional capacitance, is shown in FIG. 3a. FIG. 3b shows an electric dipole active structure 320. Planar arrays, such as that shown in FIG. 1b of SRR 310 and dipole 320 may be fabricated as well. Composite structures comprising at least one of SRR 310 and at least one of dipole 320 may also be formed (FIG. 3c). "Active" regions 340 of SRR 310 are shown in FIG. 3d.

[0025] Controllable structure 120 has a major dimension (e.g., length, width, diameter) that is less than or equal to a predetermined wavelength of radiation. In one embodiment, the predetermined wavelength is in a range from about 1 mm to about 25 nm. In another embodiment, the major dimension of the controllable structure is less than or equal to one half of the predetermined wavelength.

[0026] Controllable structure 120 may have a controlled dynamic response, a controlled tunable response, or both, to electromagnetic radiation in the range from radio frequencies to near optical frequencies. A dynamic controlled response is one in which the resonance of metamaterials is activated or deactivated (i.e., switched on or off) in a controlled manner. This is accomplished by, for example, photoexcitation of free carriers in substrate 120, which short out gap 322 in SRR 220, or by similar processes.

[0027] The dynamic controlled response may be switchable over a wide range of predetermined frequencies. In one embodiment, the predetermined frequency is in a range from about 100 Hz to about 500 THz (5×10^{14} Hz). In a second embodiment, the predetermined frequency is in a range from about 10^6 Hz to about 500 Hz. In another embodiment, the predetermined frequency is in a range from about 10^{-6} THz to about 500 THz.

[0028] Controllable structure 120 may also have a controlled tunable response; the dielectric properties of SRR gap 322 are modified, which in turn modifies the capacitive loading and hence the resonant response of the magnetic dipole. The host dielectric medium, intra-gap dielectric properties, and semiconducting SRR materials may act as means of controlling the electromagnetic properties of the metamaterials.

[0029] The invention also provides a switching device or sensor that includes composite 110, described hereinabove. The metamaterials of controllable structure 120 may act as switches for high rate signal processing. The sensor may be capable of far-infrared or thermal imaging and detection.

[0030] In one embodiment, schematically shown in FIG. 4a, the sensor is a bolometer 400 comprising composite 110 and a temperature sensor 420 in communication with composite 110. Temperature sensor 420 may be a standard analog or digital surface-mount temperature sensor known in the art, such as a thermistor, a thermocouple, or the like. In another embodiment, shown in FIG. 4b, bolometer 440 may further include either a thermal link 460, located between composite 110 and temperature sensor 420, through which composite 220 is in communication with temperature sensor 420. Thermal link 460 is a layer having a predetermined thickness. The layer comprises at least one material selected from the group consisting of metals, semiconductors, semi-metals, porous silicon, polymers, oligomers, organic-inorganic composites, oxides, borides, carbides, nitrides, suicides, and combinations thereof. For example, thermal link 460 may comprise alumina or zirconia. Bolometer 440 may further include a thermal bath 480, which may comprise a heat sink or thermoelectric cooler such as, for example a Peltier device,

which is coupled to either composite 110 or temperature sensor 420 and dissipates heat from composite 110 and temperature sensor 420. The heat sink may be selected from those known in the art, and may comprise a metal object that is in contact with the object to be cooled. Contact between the heat sink and the object may, in one embodiment, may be made by pressure only, or may be made by means of a gel or other media known in the art to improve thermal conductance.

[0031] In one embodiment, composite 110 may be assembled into a focal plane array 100 (FIG. 1) or a pixel (not shown) that is capable of hyperspectral imagery in which frequency information is contained in each pixel. Each pixel acts as a spectrometer and able to record the imaging as a function of frequency, wavelength, or energy.

[0032] In another embodiment, composite 110 is arranged in a non-periodic order to provide an interferometric imaging capability. Interferometric imaging uses fewer pixels while providing increased resolution. The pixels are arranged in a pattern and an algorithm is used to convert these points, via Fourier transform, to virtual spatial points, thus providing an increased resolution compared to the actual number of pixels.

[0033] The following example illustrates the features and advantages of the invention, and is in no way intended to limit the invention thereto.

Example 1

[0034] Terahertz time domain spectroscopy (THz-TDS) is used to characterize the electromagnetic response of a planar array of SRRs fabricated on semi-insulating gallium arsenide substrate. In addition to characterizing the response of the magnetic ($\mu(\omega)$) and electric ($\epsilon(\omega)$) resonances, the example demonstrates the potential for creating dynamic SRR structures that may act as terahertz switches. This is accomplished through photoexcitation of free carriers in the substrate which short out the SRR gap, thereby turning off the electric resonance.

[0035] A planar array of SRRs is fabricated from 3 μm thick copper on a 670 μm thick high resistivity gallium arsenide (GaAs) substrate. The outer dimension of an individual SRR is 36 μm , and the unit cell is 50 μm .

[0036] Using THz-TDS, the transmitted electric field is measured for the SRR sample and a suitable reference which, in this case, is a bare GaAs substrate.

[0037] The SRR response without photoexcitation is first considered. The transmission spectra and corresponding phase are shown in FIGS. 5(a) and Fig. 5(b), respectively. Since the measurements are obtained at normal incidence and the magnetic field lies completely in the SRR plane, the measurements focus solely on the electric resonant response. Curves 1 and 2 in FIGS. 5a and 5b represent the response obtained with the electric field (E) is oriented perpendicular to the SRR gap. This orientation of the electric field is depicted in FIG. 5c. Curves 3 and 4 in FIGS. 5a and 5b represent the response when the electric field is oriented parallel to the SRR gap. At low frequencies, the transmission is high, approaching 95% for both polarizations. With the electric field perpendicular to the SRR gap, a pronounced resonance at $\alpha_0 = 0.5$ THz is observed where the transmission decreases to about 15 %. In addition, a second absorption resonance is observed near $\alpha_1 = 1.6$ THz.

[0038] Numerical simulations of the SRR response were performed in order to understand the origin of the α_0 and α_1 resonances. FIGS. 5c and 5d show the results of the calculated surface currents at α_0 and α_1 , respectively. The low energy α_0 THz absorption due to an electric response $\epsilon(\omega)$ of the SRRs occurs at the same frequency as the magnetic $\mu(\omega)$ resonance, as evidenced by the observation of the circulating currents shown in FIG. 5c. These circulating currents are produced from the incident time-varying electric field, which generates a magnetic field polarized parallel to the surface normal of the SRR. This is not surprising, since SRRs are bianisotropic, meaning that the electric and magnetic responses of the SRR are coupled. In contrast, the higher energy α_1 resonance at 1.6 THz originates from the half wave resonance due to the side length $L=36\mu\text{m}$ of the SRR, and is consistent with the calculated surface currents shown in FIG. 5d.

[0039] A different electrical resonant behavior is observed when the SRR sample is rotated by 90 degrees such that the electric field E is parallel to the SRR gap, as seen in curves 3 and 4 in FIGS. 5a and 5b. A single broad absorption at $\omega_{\parallel}$ is observed in curves 3 and 4 in FIGS. 5a and 5b. Simulations have verified that this resonance is analogous to the ω_i half-resonance. The red shift and broadening of the $\omega_{\parallel}$ resonance in comparison to the ω_i resonance is consistent with the fact that there are now two $L=36\ \mu\text{m}$ side lengths per unit cell resulting from dipolar coupling along with radiation induced-damping. There is no electric resonance that is analogous to the ω_o resonance for this orientation; i.e. there is no response with E producing circulating currents with an associated magnetic field directed perpendicular to the GaAs substrate.

[0040] To further investigate the nature of the ω_o resonance, the SRR response was measured at various angles of incidence. Measurements were performed with the electric field E parallel to the SRR gap (e.g., 222 in FIG. 2b), so that there is no electrically active ω_o resonance to complicate determination of the $\mu(\omega)$ response. In particular, the SRR is rotated about an axis parallel to the split gap of the SRR. This permits characterization of the magnetic response of the SRR, since $\mu(\omega)$ increases for increasing angles with a maximum occurring for $\Theta = 90^\circ$. The results for angles of incidence $\Theta = 0^\circ$, 23° , and 45° are shown in FIG. 6. The normal incidence data for E perpendicular to the SRR gap (from Fig 5a) is replotted as a dashed line (curve 1 in FIG. 6) as a reference. For normal incidence ($\Theta = 0^\circ$) there is no discernable feature at 0.5 THz. At the incident angle $\Theta = 23^\circ$, however, a slight dip begins to develop at ω_o . The magnetic coupling to this mode can be further strengthened by increasing the incident angle. Such coupling is apparent for $\Theta = 45^\circ$, where there is a well developed absorption in transmission at approximately 0.5 THz. This behavior is consistent with the development of a resonant $\mu(\omega)$ response since, with an increasing angle of incidence, a correspondingly larger component of the incident THz magnetic field is projected normal to the plane of the SRRs (i.e., perpendicular to the GaAs substrate). In addition, as the dashed vertical line in FIG. 6 reveals, the $\mu(\omega)$ and $\epsilon(\omega)$ response both occur at ω_o , as discussed above. The combined results of Figures 5 and

6 provide a fairly complete description of the electromagnetic response of the SRRs in the absence of photoexcitation.

[0041] Induced changes in the electric resonant response (i.e., α_o and ω_{oi}) following photoexcitation have also been investigated. Since the α_o resonance shown in Fig. 5a has been shown to focus strong electric fields within the split gap of the SRR, it is expected that the resonance at ω_{oo} would strongly depend upon materials placed in or near the gap. The approach used to study the change in resonant response of the SRR is to change the background dielectric of the substrate material as a function of photo-doping. The dielectric function of GaAs is changed dynamically with an optical pulse of about 50 femtosecond (fs) that creates free carriers in the conduction band. The resulting effect on the resonant SRR response is studied as a function of pump power. The pump pulse is timed to arrive 5 picoseconds (ps) before the peak of the THz waveform, thus ensuring that a long-lived carrier density has been established. Since the lifetime of carriers in GaAs is significantly longer than the THz waveform, this allows the quasi-steady state response of the SRRs to be characterized as a function of incident power (i.e., carrier density in the GaAs substrate).

[0042] In FIG. 7a the dependence of both electric resonances, ω_{oo} and ω_{oi} , on pump power in transmission is shown. Curve 1 in FIG. 7 is the SRR response re-plotted from Fig. 5a; i.e., the electric response of the SRRs at zero pump power. At a pump power of 0.5 mW (curve 2 in FIG. 7), the overall transmission decreases and the strength of the ω_{oo} resonance significantly weakens. In these experiments, a pump power of 0.5 mW corresponds to a fluence of $1 \mu\text{J}/\text{cm}^2$, which results in a photo-excited carrier density n of about $2 \times 10^{16} \text{cm}^{-3}$. While ω_{oo} is strongly affected by pump powers as small as 0.5 mW, it is interesting to note that ω_{oi} is not significantly altered. When the pump power is increased to 1 mW ($n \sim 4 \times 10^{16} \text{cm}^{-3}$) the low energy resonance α_o associated with circulating currents in the SRRs is nearly entirely quenched. In this case, the transmission at ω_{oo} increases from approximately 15% to over 70%. Further, $T(\omega_{oi})$ continues to decrease over all frequencies characterized. This is due, in part, to the free carrier response of the photo-excited GaAs. Note that although ω_{oo} has been short circuited, there is still little change in α_{oi} . At 5 mW of

pump power, $T(\omega)$ further decreases and ω_1 finally begins to weaken. The dependence of ω_{coo} and ω_{coi} on pump power can be understood by considering the different nature of these two resonances. As previously mentioned, the lower energy resonance is attributed to circulating currents within the SRR. Thus, by providing free charges within the substrate, it becomes possible to short circuit the response and, as the gap in the SRR is relatively small ($\sim 2 \mu\text{m}$), only low pump powers are required. However, ω_{coi} is due to the side length of the SRR and therefore more charges (and thus more power) are required to effectively screen this resonance.

[0043] The real part of the dielectric function $\epsilon_1(\omega)$ is displayed in Fig. 7b. This further highlights that, for low excitation densities, the α_o resonance completely disappears while the α_i survives to slightly higher fluences. For zero pump power, the SRR metamaterials obtain a region of negative $\epsilon(\omega)$ for both the α_o and α_i resonances. The region of negative ϵ for α_o spans from 550 GHz to 600 GHz and reaches a maximum negative value of $\epsilon = -2.5$ at $\omega = 560$ GHz, while ω_i spans from 1.6 THz to 1.66 THz and obtains a slightly greater value of $\epsilon = -2.6$. For a pump power of 0.5 mW, the α_o resonance is reduced greatly and the $\epsilon < 0$ response destroyed. Thus, one scenario permitting these metamaterials to be used as dynamical devices involves photo-induced band-pass response. A 1 mW pump pulse, if used at $\omega = 560$ GHz, where the transmission has a minimum, for example, increases $T(\omega)$ by $\sim 60\%$ and consequently changes the SRR metamaterial medium from absorbing to transparent.

[0044] The results shown in FIG. 7 were obtained for SRRs fabricated on intrinsic GaAs substrates. In this case, the recombination time of the carriers in GaAs is greater than 1 nanosecond (ns), meaning that the switched state of the SRR structure (i.e. the photoinduced increase in transmission) is long-lived. It would, however, be possible to fabricate identical SRR structures on gallium arsenide grown at low temperature or GaAsErAs semiconductor heterostructures, the latter of which allows for engineered picosecond (1 ps to 10 ps) carrier recombination times. This would enable picosecond on/off switching times of the SRR electric response, thereby enabling optically controlled high frequency modulation of narrow band THz sources.

Furthermore, with electrical carrier injection, another possibility would be to create all-electrical THz modulators.

[0045J] Dynamical control of SRR metamaterials at THz frequencies has been demonstrated. The full characterization of the biaxial electric response of the SRRs has been given, and all expected absorption dips in the spectra have been identified. These are the first results characterizing SRRs using THz-TDS which take full advantage of the ability to measure the electric field amplitude and phase. In addition, through photoexcitation of carriers in the GaAs substrate, control of the main α_0 resonance associated with both an electric $\epsilon(\omega)$ and magnetic $\mu(\omega)$ response has been shown. These results indicate the possibility of using SRRs as an active narrowband THz switch.

[0046] While typical embodiments have been set forth for the purpose of illustration, the foregoing description should not be deemed to be a limitation on the scope of the invention. Accordingly, various modifications, adaptations, and alternatives may occur to one skilled in the art without departing from the spirit and scope of the present invention.

CLAIMS

1. A sensor, the sensor comprising:
 - a. a composite capable of generating an electromagnetic signal or a thermal signal in response to one of an electromagnetic stimulus and a thermal stimulus, the composite comprising a controllable structure, the controllable structure comprising a metamaterial and having a major dimension that is less than or equal to a predetermined wavelength, and
 - b. one of a dielectric substrate upon which the controllable structure is disposed and a dielectric material within which the composite is embedded, wherein the sensor is capable of detecting one of an optical pulse, a magnetic pulse, a thermal pulse, and an electrical pulse.
2. The sensor according to Claim 1, wherein the sensor is a bolometer comprising the composite and a temperature sensor in communication with the composite.
3. The sensor according to Claim 2, wherein the temperature sensor is in communication with the composite through a thermal link disposed between the composite and the temperature sensor.
4. The sensor according to Claim 3, wherein the thermal link is a layer having a predetermined thickness, and wherein the layer comprises at least one material selected from the group consisting of metals, semiconductors, semi-metals, porous silicon, polymers, oligomers, organic-inorganic composites, oxides, borides, carbides, nitrides, suicides, and combinations thereof.
5. The sensor according to Claim 2, further including a thermal bath for dissipating heat from the composite and the temperature sensor, wherein the thermal bath is coupled to at least one of the composite and the temperature sensor.
6. The sensor according to Claim 5, wherein the thermal bath comprises is one of a heat sink and a thermoelectric cooler.

7. The sensor according to Claim 2, wherein the composite is arranged in a focal plane array.
8. The sensor according to Claim 2, wherein the composite is arranged in a non-periodic order for interferometric imaging.
9. The sensor according to Claim 1, wherein the dielectric material comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.
10. The sensor according to Claim 1, wherein the controllable structure is tunable.
11. The sensor according to Claim 1, wherein the controllable structure is dynamic.
12. The sensor according to Claim 11, wherein the controlled structure is switchable at a predetermined frequency.
13. The sensor according to Claim 12, wherein the controlled structure is capable of hyperspectral imagery.
14. The sensor according to Claim 12, wherein the predetermined frequency is a range from about 10^6 Hz to about 500 THz.
15. The sensor according to Claim 14, wherein the predetermined frequency is a range from about 10^6 Hz to about 500 THz.
16. The sensor according to Claim 15, wherein the predetermined frequency is a range from about 10^{-6} THz to about 500 THz.
17. The sensor according to Claim 1, wherein the controlled structure comprises at least one resonant structure.

18. The sensor according to Claim 17, wherein the at least one resonant structure further includes a dielectric.

19. The sensor according to Claim 18, wherein the dielectric comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, and combinations thereof.

20. The sensor according to Claim 1, the major dimension of the controllable structure is less than or equal one half of the predetermined wavelength.

21. The sensor according to Claim 20, wherein the predetermined wavelength is in a range from about 1 m to about 25 nm.

22. The sensor according to Claim 1, wherein the dielectric substrate comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.

23. The sensor according to Claim 1, wherein the metamaterial comprises at least one material selected from the group consisting of transition metals and alloys thereof, semi-metals, semiconductors, high temperature superconductors, low temperature superconductors, magnesium diboride, conductive transition metal oxides, ferromagnets, antiferromagnets, paramagnets, and combinations thereof.

24. The sensor according to Claim 23, wherein the metamaterial comprises at least one of copper, silver, gold, platinum, tungsten, and combinations thereof.

25. A composite, the composite comprising:

a. a controllable structure comprising a metamaterial and having a major dimension that is less than or equal to a predetermined wavelength; and

b. one of a dielectric substrate upon which the controllable structure is disposed and a dielectric material within which the controllable structure is embedded, wherein the composite is capable of generating an electromagnetic signal or a thermal signal in response to one of an electromagnetic stimulus and a thermal stimulus.

26. The composite according to Claim 25, wherein the controllable structure is tunable.

27. The composite according to Claim 25, wherein the controllable structure is dynamic.

28. The composite according to Claim 27, wherein the controlled structure is switchable at a predetermined frequency.

29. The composite according to Claim 27, wherein the controlled structure is capable of hyperspectral imagery.

30. The composite according to Claim 27, wherein the predetermined frequency is a range from about 100 Hz to about 500 THz.

31. The composite according to Claim 30, wherein the predetermined frequency is a range from about 10^6 Hz to about 500 THz.

32. The composite according to Claim 30, wherein the predetermined frequency is a range from about 10^{-6} THz to about 500 THz.

33. The composite according to Claim 25, wherein the controlled structure comprises at least one resonant structure.

34. The composite according to Claim 33, wherein the at least one resonant structure includes a dielectric.

35. The composite according to Claim 34, wherein the dielectric comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, and combinations thereof.

36. The composite according to Claim 25, the major dimension of the controllable structure is less than or equal one half of the predetermined wavelength.

37. The composite according to Claim 36, wherein the predetermined wavelength is in a range from about 1 m to about 25 nm.

38. The composite according to Claim 25, wherein the dielectric substrate comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.

39. The composite according to Claim 25, wherein the composite is arranged in a focal plane array.

40. The composite according to Claim 25, wherein the dielectric material comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.

41. The composite according to Claim 25, wherein the metamaterial comprises at least materials selected from the group consisting of transition metals and alloys thereof, semi-metals, semiconductors, high temperature superconductors, low temperature superconductors, magnesium diboride, conductive transition metal oxides, ferromagnets, antiferromagnets, paramagnets, and combinations thereof.

42. The composite according to Claim 41, wherein the metamaterial comprises at least one of copper, silver, gold, platinum, tungsten, and combinations thereof.

43. A bolometer, the bolometer comprising:

a. a composite capable of generating an electromagnetic or a thermal signal in response to one of an electromagnetic stimulus and a thermal stimulus, the composite comprising:

i. a controllable structure, the controllable structure comprising a meta material and having a major dimension that is less than or equal to a predetermined wavelength; and;

ii. one of a dielectric substrate upon which the controllable structure is disposed, and a dielectric material within which the controllable structure is embedded; and

b. a temperature sensor in communication with the composite.

44. The bolometer according to Claim 43, wherein the temperature sensor is in communication with the composite through a thermal link disposed between the composite and the temperature sensor.

45. The bolometer according to Claim 43, wherein the thermal link is a layer having a predetermined thickness, and wherein the layer comprises at least one material selected from the group consisting of a metals, semiconductors, semi-metals, porous silicon, polymers, oligomers, organic-inorganic composites, oxides, borides, carbides, nitrides, suicides and combinations thereof.

46. The bolometer according to Claim 43, further including a thermal bath for dissipating heat from the composite and the temperature sensor, wherein the thermal bath is coupled to at least one of the composite and the temperature sensor.

47. The bolometer according to Claim 43, wherein the composite is arranged in a focal plane array.

48. The bolometer according to Claim 43, wherein the dielectric material comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.

49. The bolometer according to Claim 43, wherein the controllable structure is tunable.

50. The bolometer according to Claim 43, wherein the controllable structure is dynamic.

51. The bolometer according to Claim 50, wherein the controlled structure is switchable at a predetermined frequency.

52. The bolometer according to Claim 50, wherein the controlled structure is capable of hyperspectral imagery.

53. The bolometer according to Claim 50, wherein the predetermined frequency is a range from about 100 Hz to about 500 THz.

54. The bolometer according to Claim 53, wherein the predetermined frequency is a range from about 10^6 Hz to about 500 THz.

55. The bolometer according to Claim 54, wherein the predetermined frequency is a range from about 10^{-6} THz to about 500 THz.

56. The bolometer according to Claim 43, wherein the controlled structure comprises at least one resonant structure.

57. The bolometer according to Claim 56, wherein the at least one resonant structure includes a dielectric.

58. The bolometer according to Claim 57, wherein the dielectric comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, and combinations thereof.

59. The bolometer according to Claim 43, wherein the major dimension of the controllable structure is less than or equal one half of the predetermined wavelength.

60. The bolometer according to Claim 59, wherein the predetermined wavelength is in a range from about 1 m to about 25 nm.

61. The bolometer according to Claim 43, wherein the dielectric substrate comprises at least one material selected from the group consisting of polytetrafluoroethylene, polyimide, polypropylene, thermoplastic materials, poly(dimethyl siloxane), ferromagnetic materials, functional transition metal oxides, pyroelectric materials, semiconductors, ferroelectric materials, and combinations thereof.

62. The bolometer according to Claim 43, wherein the metamaterial comprises at least materials elected from the group consisting of transition metals and alloys thereof, semi-metals, semiconductors, high temperature superconductors, low temperature superconductors, magnesium diboride, conductive transition metal oxides, ferromagnets, antiferromagnets, paramagnets, and combinations thereof.

63. The bolometer according to Claim 62, wherein the metamaterial comprises at least one of copper, silver, gold, platinum, tungsten, and combinations thereof.

FIG. 1

100

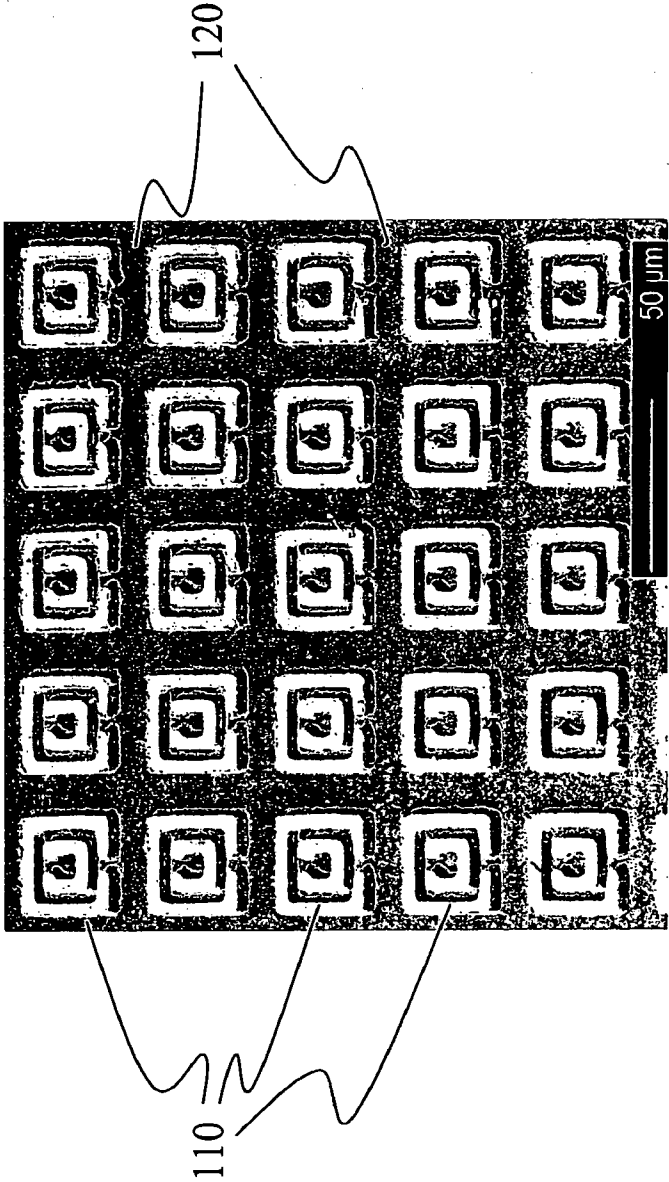


FIG. 2

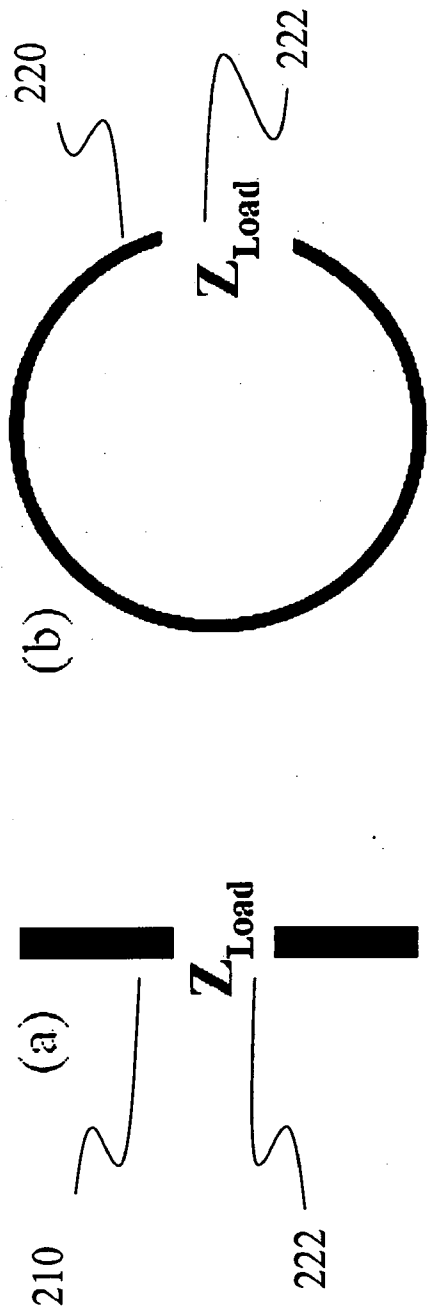


FIG. 3

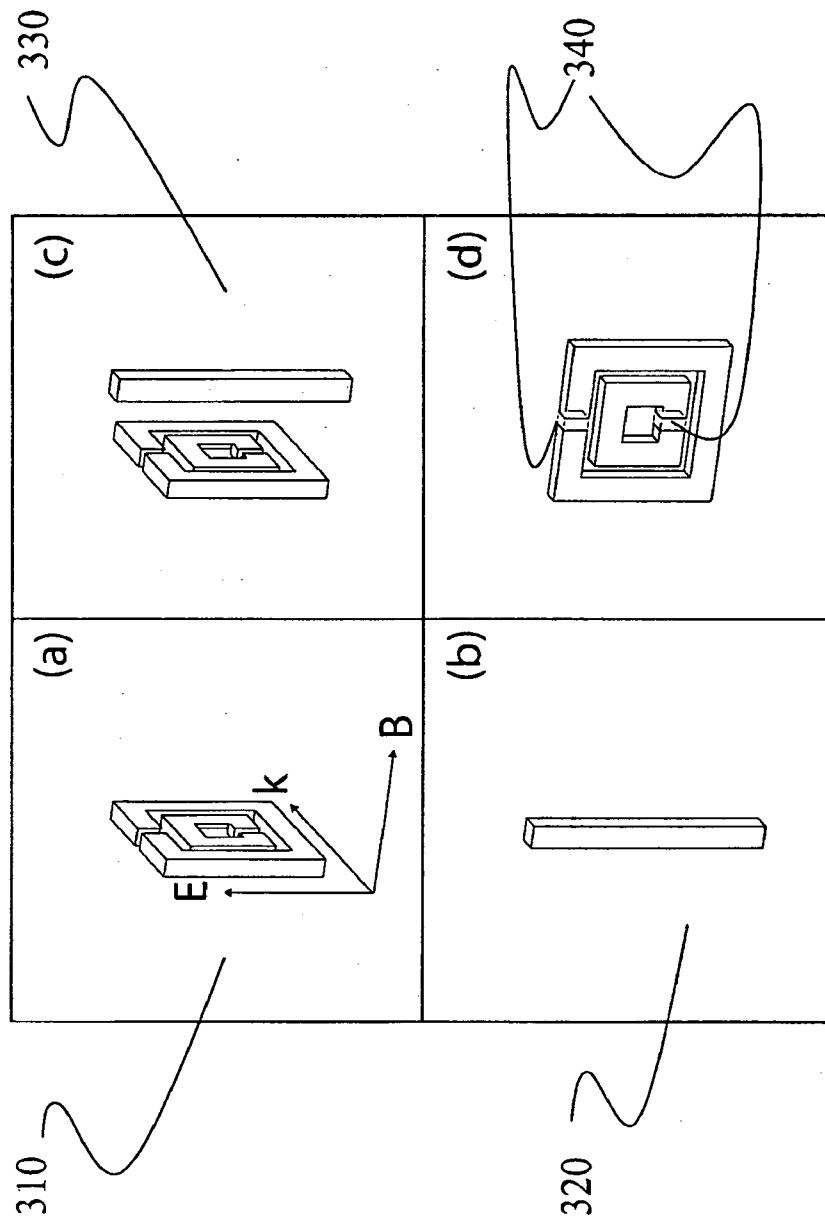


FIG. 4

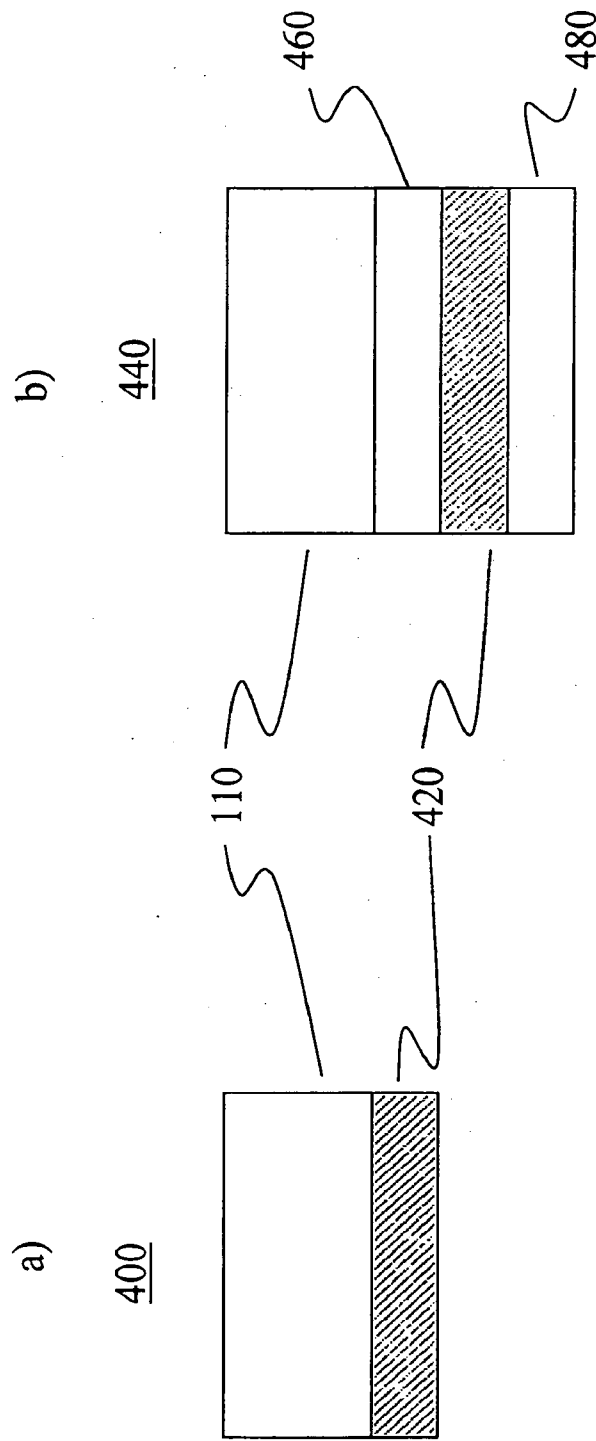


FIG. 5

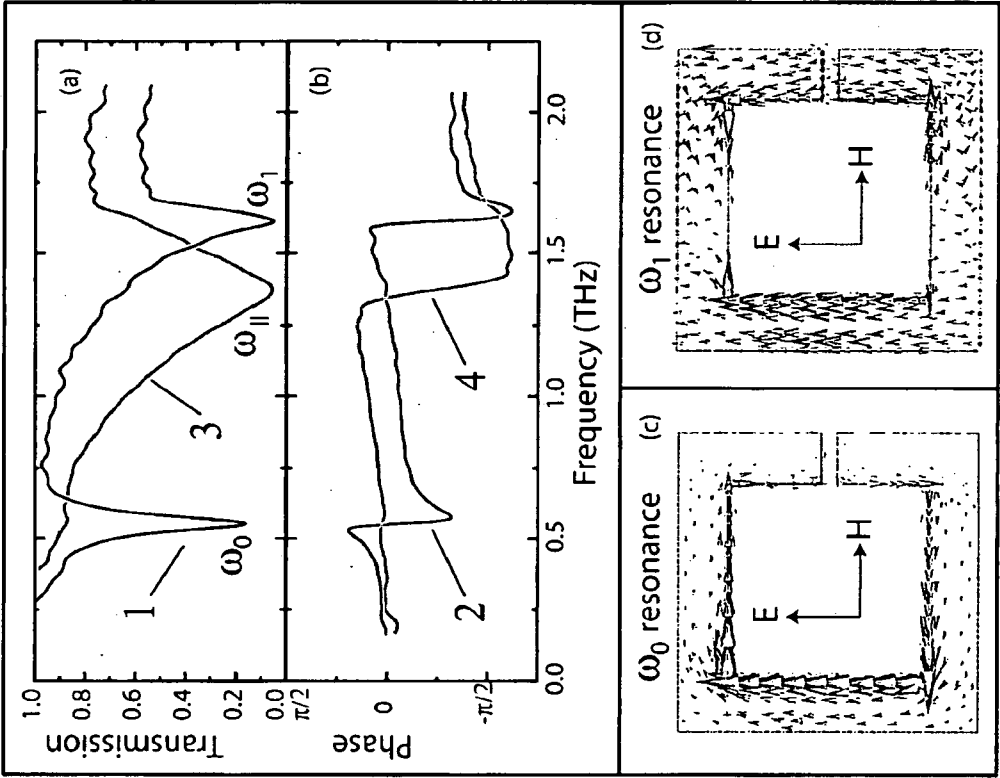


FIG. 6

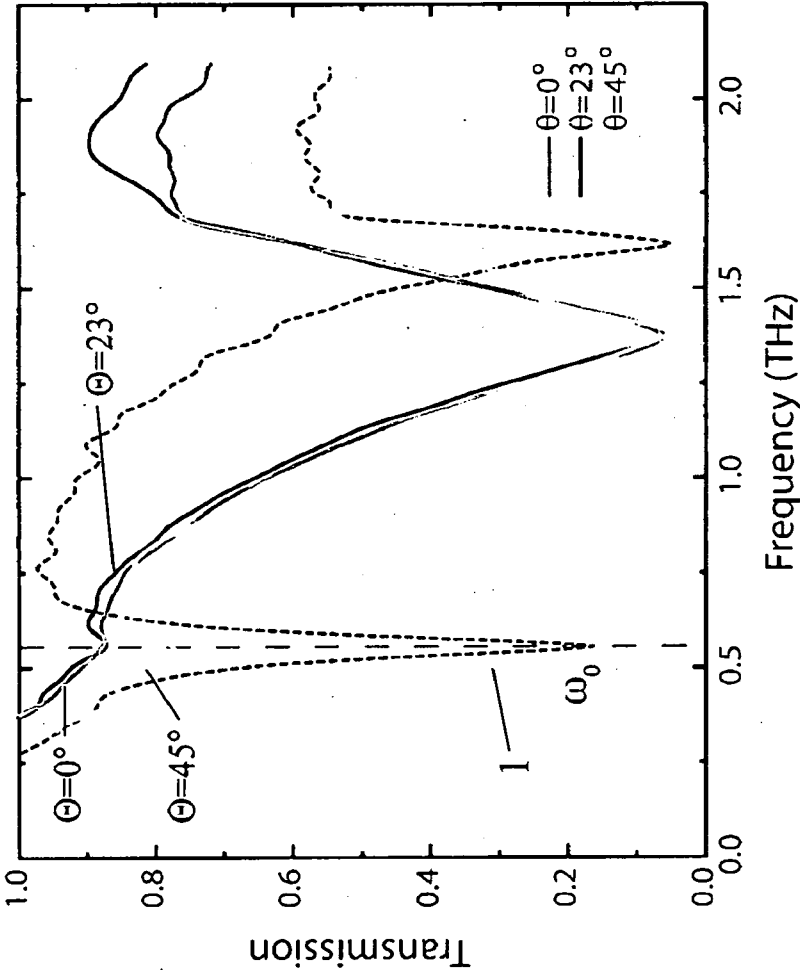


FIG. 7

