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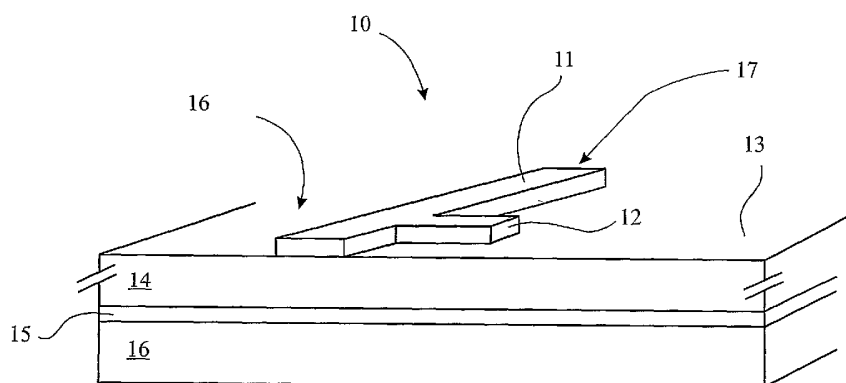
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(54) Title: BAND STOP FILTER



(57) Abstract: A method and apparatus are disclosed for providing a terahertz band filter. The apparatus includes a dielectric layer and a microstrip line deposited on the dielectric layer having at least one stub extending therefrom on the dielectric layer. The length of the stub is selected to determine a centre frequency for the Band Stop Filter.

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BAND STOP FILTER

The present invention relates to an apparatus and method for providing a Band Stop Filter. In particular, but not
5 exclusively, the present invention relates to a Band Stop Filter operable in the terahertz (THz) frequency range which can be utilised for a broad range of electronic uses, including but not limited to molecular sensing operations.

10

It is well known that Band Stop Filters have a broad range of uses. However the development of Band-Stop Filters working in the terahertz (THz) frequency range at for example a centre frequency near 600 Giga Hertz has
15 proved difficult to achieve.

It is also known that on-chip sensing of a range of bio molecules is desirable. Such studies have a broad range of applications. In particular the current enthusiasm
20 for bio research has lead to a high demand for ever more sensitive and accurate analysis tools.

The excitation and detection of terahertz (THz) radiation into free-space using sub-picosecond acting photo-
25 conductive switches is a well established spectroscopic technique. Both free-space and on-chip techniques can theoretically be used for the spectroscopic investigation of a range of bio molecules. For example free space studies have shown that hybridised (double-stranded) DNA
30 and denatured (single-stranded) DNA exhibit different dielectric constants in the terahertz frequency range. When DNA is placed on or near a filtering structure through which a terahertz pulse is propagated the fringing fields are perturbed by this change in the

dielectric environment and the change in transmission response can be used to determine the presence of single-stranded or hybridised DNA. Such studies may also be used to determine the presence of other bio-molecules or
5 other such targets.

Compared with free space studies the length of interaction between an electromagnetic signal and sample may be extended in an on-chip scheme making the technique
10 particularly sensitive and therefore useful in the context of genetic assay. However the development of an on-chip scheme has proved problematical. In particular it is known that the active area of Band Stop Filters must be one or two orders of magnitude smaller than
15 existing Band Pass Filter designs to allow integration of a large number of filter elements on a single chip. It is known that such integration would be advantageous to permit a large number of targets to be tested rapidly to thus compete with existing gene-chip detection
20 technologies. The attainment of this goal has however until now proved elusive.

It is an aim of the present invention to at least partly mitigate the above-mentioned problems.

25

It is an aim of embodiments of the present invention to provide a terahertz Band Stop Filter.

It is an aim of embodiments of the present invention to
30 provide a terahertz Band Stop Filter on a micro strip geometry which enables a large number of filter elements to be located on a single chip.

It is an aim of embodiments of the present invention to provide an on-chip structure including terahertz Band Stop Filters to enable the analyses of bio molecules.

- 5 It is an aim of embodiments of the present invention to provide a method for fabricating an on-chip terahertz Band Stop Filter.

According to a first aspect of the present invention
10 there is provided an apparatus for providing a terahertz band stop

filter, comprising:

a dielectric layer;

a micro strip line deposited on said dielectric layer;

15 and

at least one stub extending from said micro strip line on said dielectric layer; wherein

the length of said stub is selected to determine the centre frequency for said band stop filter.

20

According to a second aspect of the present invention there is provided a terahertz Band Stop Filter, comprising:

a dielectric layer;

25 a micro strip line deposited on said dielectric layer; and

at least one stub extending from said micro strip line on said dielectric layer; wherein

the length of said stub is selected to provide a band
30 stop filter for the terahertz frequency range.

According to a third aspect of the present invention there is provided an on-chip band stop filter, comprising:

35 a substrate;

a dielectric layer;
a microstrip line deposited on said dielectric layer;
and

at least one stub extending from said micro strip line
5 on said dielectric layer; wherein
the length of said stub is selected to determine the
centre frequency for said band stop filter.

According to a fourth aspect of the present invention
10 there is provided a method for detecting the presence of
a target substance in at least one test sample,
comprising the steps of:

providing a terahertz band stop filter;
applying a test sample to a portion of the band stop
15 filter; and

determining a change in response of the band stop
filter, said change in response indicating the presence
of said target substance.

20

Embodiments of the present invention provide a structure
in which several terahertz Band Stop Filters can be
cascaded along the same micro strip line. The active
area of each Band-Stop Filter is less than 50 square
25 micrometers which is nearly two orders of magnitude
smaller than pre-existing Band Pass Filter designs.

Embodiments of the present invention permit the
integration of a resonant structure into a micro strip
30 line which allows the local sensing of the dielectric
environment and therefore provides an increased
sensitivity for molecular sensing over known techniques.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

5 Figure 1 illustrates a stub filter architecture;

 Figure 2 illustrates a cascaded stub filter architecture;

10 Figure 3 illustrates an on-chip fabrication process;

 Figure 4 illustrates propagation of a terahertz pulse along a micro strip line;

15 Figure 5 illustrates band stop filter characteristics;

 Figure 6 illustrates Fourier Transforms of the time domain results;

20

 Figure 7 illustrates cascaded band stop filters;

 Figure 8 illustrates multiple Fourier Transform results;

25

 Figure 9 illustrates different dielectric constants;

 Figure 10 illustrates a Micrograph of filter array formed from two band-stop stubs with centre resonant
30 frequencies of 260 GHz (stub length 194 μm) and 600 GHz (stub length 82 μm). Inset: Schematic of whole device including LT-GaAs regions (light grey squares) at excitation point 100, and detection points 200 and 300.

Contact pads are shown for the switch bias arms (A, C, D, F) and for the microstrip (B and E);

Figure 11 illustrates, main figure: solid line is the transmission parameter S_{21} calculated from the pulses shown in (a) and (b); dashed line the response S_{21} measured after 15 resist deposition and cleaning cycles. The arrows indicate the expected positions of the maximum loss points from the electromagnetic simulation. (a) Input THz pulse generated at excitation point 100 (see Fig. 10) and measured by photoconductive gating of detection point 200. (b) THz pulse generated at excitation point 100 and measured, after transmission down microstrip and filter array, at detection point 300;

15

Figure 12 illustrates, main figure: Comparison of transmission parameter S_{21} for both filters (260 GHz and 600 GHz) unloaded (solid line) and 600 GHz filter loaded (dashed line) with 12.8- μm -thick layer of optical resist. The insets show the change in frequency response as a function of deposited resist thickness for (a) the 260 GHz filter, and (b) the 600 GHz filter. Solid lines are the response for loading with a dielectric of relative permittivity $\epsilon_r = 2.75$, dashed lines above and below are the response for loading with dielectrics of permittivity $\epsilon_r = 3.5$ and $\epsilon_r = 2$, for comparison.

In the drawings like reference numerals refer to like parts. It is to be noted that the illustrations are not drawn to scale but are made for the purposes of
5 illustration and explanation only.

Figure 1 illustrates a stub filter 10 designed for operation in the terahertz frequency range. Such a frequency range typically has a centre frequency around
10 600 Giga Hertz although the whole terahertz (THz) frequency range extends from 300 Giga Hertz to higher than 5 terahertz (THz). It is to be understood that embodiments of the present invention are applicable to Band Stop Filters operating in any region of this range.

15

The stub filter 10 includes a micro strip line portion 11 and shorter stub portion 12 extending substantially at right angles from the longitudinal length of the micro strip line. The stub filter is fabricated so as to have
20 a strong resonance at an approximate frequency given by:

$$\frac{v_p}{4\ell}$$

Where ℓ is the length of the stub 12 and v_p is the velocity of pulse propagation in the micro strip. It
25 will be understood that rather than selecting the length of the spur/stub the material of the micro strip line or stub may be selected to provide the desired band stop effects since different dielectric materials will produce different pulse velocities and therefore different
30 resonant frequencies.

The stub filter is fabricated on an upper surface 13 of a dielectric layer 14. This dielectric layer is deposited on a metal later 15 which is evaporated onto a substrate

16 such as a silicon wafer. The metal layer may be Gold having a thickness of preferably greater than 200nm. This helps confine the terahertz pulse.

- 5 A first transmitter end 16 of the micro strip line can be stimulated with a terahertz frequency pulse as will be described hereinafter in more detail. The pulse is transmitted along the elongate length of the micro strip line where it may be detected at a second end region 17.

10

- Figure 2 illustrates a cascaded array of filters 20 each of which may be fed from the same terahertz excitation point and uses the same detector to detect a resulting pulse which is a combination of the effects of all
15 filters in the cascade of filters. With such an array of filters the active area of the on-chip Band Stop Filter which may be as small as $30 \mu\text{m}^2$ is nearly two orders of magnitude smaller than existing band pass filter designs. As such better integration of a large number of filter
20 elements can be provided on a chip so as to provide the requisite packing density to enable such terahertz filters to compete with existing gene-chip DNA detection technologies.

- 25 As illustrated in Figure 2 a plurality of stubs $12_0 - 12_4$ extend from the micro strip line 11. The micro strip line and stubs are deposited on a dielectric layer 14. At a first end region 16 of the cascaded band stop filter there is located an emitter 21 and at a second remaining
30 end of the micro strip line there is located a detector element 22.

- The band stop filter employs a micro strip geometry using an organic dielectric bezo-cyclo-butene (BCB) which is
35 known to have relatively low loss at terahertz

frequencies. Other such dielectrics, including plastic films such as polypropylene may be used. The emitter 21 and detector switches 22 are photo conductive elements. The devices are processed according to a method of
5 firstly depositing a 20/80 nanometres nickel chromium (NiCr) / Gold (Au) layer on a high conductivity (5 Ohm cm) silicon (Si) wafer. Other metal layers may be used to produce similar results. Next BCB is spun on the gold surface and the whole structure is cured in a Nitrogen
10 atmosphere at 250°C. After curing, the BCB layer thickness is approximately 6 microns. This is illustrated in figure 3b.

Separately a low-temperature-grown Gallium Arsenide (LT-
15 GaAs) layer is grown at 200°C and annealed in situ at 600°C to a thickness of 350 nanometres by molecular beam epitaxy on a Gallium Arsenide (GaAs) substrate 34 with a 100 nanometre AlAs sacrificial layer 35. This is illustrated in Figure 3a. Next epitaxial lift off is
20 used to remove this AlAs layer and release the LT-GaAs from its growth substrate. Black wax 36 (Apiezon W) is melted at a temperature of 75°C onto the LT-GaAs surface after which its thickness is 0.5 millimetres covering an area of around 40 mm². The wax acts as both a mask in
25 the following etch step and as a support for the delicate epitaxial film. The wax is then removed from the perimeter of the chip by dragging the edges of the sample across a clean room tissue soaked in trichloroethylene. The sample is immersed in a sulphuric acid/hydrogen
30 peroxide/water etch (1:8:40 by volume) which exposes the AlAs side walls. This is illustrated by the removed hatched region 37 in figure 3a. An approximately 24 hour etch in dilute (10%) hydrofluoric acid at 3°C acts to remove the AlAs selectively which releases the LT-GaAs
35 layer. This can then be manipulated without cracking

since it is supported by the black wax. After washing the epitaxial film in deionised water it is pushed onto the upper surface of the BCB 32 to initiate Van Der Waals bonding. The bonded films are left under vacuum over
5 night to aid removal of excess water from between the substrate and improve adhesion. The black wax is then removed by soaking the sample in trichloroethylene as shown by removing the hatched region in figure 3b.

10 The LT-GaAs switches 21, 22 are then defined into a square geometry by an optical lithography step. This is illustrated in figure 3c. Shipley 1830 photo resist is spun on at 5500rpm and baked at 90°C for one minute which acts as a mask for a sulphuric acid: hydrogen peroxide:
15 water (1:8:800) etch. This dilute etch composition is chosen since it produces isotropic sloped side walls 38 which are suitable for the subsequent overlay of metallization forming the micro strip signal conductor. The metallization 39 is illustrated in fig 3c. A further
20 photolithography step forms the filter by providing the stubs and micro strip lines from 350 nm thick Au deposited on the BCB by thermal evaporation after an in-situ plasma ash which has been found to improve metal adhesion to the BCB surface. Lines may be defined on the
25 BCB down to a size of 5 microns with edge roughness of around ± 0.5 microns.

The processing sequence forms switches using optical lithography to remove unwanted LT-GaAs and leave islands
30 at any desired location on the dielectric substrate rendering micro positioning of the LT-GaAs material after epitaxial lift off unnecessary. This is in contrast to known processes where individual switches are formed by generating individual islands at selected locations.
35 Once lithography is complete samples are mounted on an X,

Y, Z stage at the focal position of two lenses through which pump and time-delayed probe near-infrared laser pulses are directed. The laser spot which is focused to a size of around 10 microns is directed onto the photoconductive switches and then the magnitude of the photocurrent generated in the switches may be used for fine alignment of the two beams. The strength of the photocurrent indicates how well aligned the laser beams are to the terahertz generating gap in each switch.

10

In this way a method for fabricating an on-chip band stop filter is provided which includes the steps of providing a substrate, providing a dielectric layer over the substrate, defining a micro strip layer on an upper surface of the dielectric layer and defining a stub extending from the micro strip line on the dielectric layer. The length of the stub may be selected to determine the centre frequency of the band stop filter. The centre frequency of the band stop filter is in the terahertz frequency range. An emitter for emitting a terahertz pulse may be generated at one end of the micro strip line. A detector for detecting terahertz frequency radiation may be generated at a remaining end of the micro strip line.

25

The method may further include the steps of bonding a low-temperature-grown Gallium Arsenide (LT-GaAs) layer onto an upper surface of the dielectric layer and defining one or more islands of the LT-GaAs layer where an emitter and/or detector is to be located. Preferably the method includes the steps of overlaying metallization to form a micro strip signal conductor. The steps of providing the LT-GaAs layer may include the steps of growing a LT-GaAs layer by molecular beam epitaxy on a sacrificial layer disposed over a Gallium Arsenide (LT-

35

GaAs) substrate, melting wax on to an upper surface of the LT-GaAs layer and releasing the LT-GaAs layer from the sacrificial layer and the Gallium Arsenide (LT-GaAs) substrate by removing the sacrificial layer via an acid
5 etch.

Figure 4 illustrates the output response from the detection switches for two micro strip lines without filter between them. Each device is stimulated with a
10 100 fs pulse length by generating a rapid laser pulse at the emitter site 21 of the respective device. Such pulses can be provided by an 800 nanometre wavelength, 80 Mega Hertz repetition rate pulsed laser. As noted above separate LT-GaAs switches are used for emission and
15 detection of the terahertz pulses along the micro strip line. The time delay between excitation and detection laser pulses is varied using a mechanical translation time delay stage. The excitation switch 21 in each device is biased at 10 volts and 8 milli Watts per switch
20 optical laser power is used. First a large (tens of mV) pulse of FWHM duration 1.3ps is observed, followed some tens of picoseconds later by a series of increasingly broad reflections. It is to be noted that the amplitude of the voltage transience measured across the detection
25 switch is found to be linear in both the excitation power and applied switch voltage. Figure 4 shows typical pulses measured between switches separated by 4mm in two micro strip devices. Taking an expected value of effective permittivity for BCB at 400GHz of 2.57 a
30 propagation velocity of 0.624c is obtained. This value permits the determination and assignation of several reflections which are observed from the sample geometry. The first main reflection occurs at $t_0 + 25ps$ and originates from a biased pad. The expected arrival time
35 of this and other reflections from other discontinuity in

the sample geometry are shown by arrows and it may be seen that these agree well with measured reflections.

Figure 5 illustrates propagation of a pulse down a single device including a stub. As may be seen a clear peak with oscillating tail occurs. The oscillating tail is due to the modification of the pulse by the filter element. By computing the Fourier Transform of the measured signals the frequency dependent attenuation provided by the filter may be determined. This may be achieved by comparison with the Fourier Transform (FFT) of a pulse measured proximate to the excitation point. The result is shown in Figure 6. The dotted line shows the Fourier Transform achieved with only a micro strip and no stub. The full line illustrates the response from a fabricated stub filter having an 83 micron long stub having a centre frequency around 596GHz with a peak loss of -31dB. As will be understood this provides a band stop filter in the terahertz frequency range. The usable signal measured in the micro strip line by photo conductive switches extends to 1.2THz. It will be appreciated by those skilled in the art that use of a lower loss dielectric such as for example Polypropylene will further increase the frequency range.

Figure 7 illustrates an application of the band stop filters cascaded on a micro strip line. Figure 7 illustrates three band stop filters 70₀ to 70₂. These stubs extend from a micro strip line 11 extending in an elongate fashion between an emitter 21 and detector 22. A terahertz pulse is generated at the emitter by a pulsed laser 71 which is focused to a predetermined spot size via optics 72. The length of each of the stubs 70 is predetermined. The length selects the particular centre frequency for the band stop filter associated with that

particular stub. The length of the stubs increases one after another from a first end to another end, but may be in any order of length along the micro strip line.

Figure 8 illustrates the Fourier Transform of the magnitude of the electrical pulse measured at the detector 22. The respective troughs are illustrated. Each of these troughs is due to a respective one of the filters in the cascaded array. Each of the troughs 80₀ to 80₂ occurs at a respective centre frequency 81₀ to 81₂. The cascaded filter shown in Figure 7 may be used to detect the presence of bio molecules. This is achieved because the presence of such bio molecules or other such target items introduces a change in the dielectric constant around the filter. This is detected by a shift in the location of the trough 80 for a specific filter. In order to achieve this a drop or film of the target substance is located on the respective filter in the cascaded array. It will be understood that any number of test samples may be tested simultaneously by providing a cascaded array having many stub filters. One test sample is duly located on the stub of a respective stub filter. Prior to the application of the sample to the stub one or more test runs are carried out to identify the response of the cascade filter without any test samples. Such a result would be shown in Figure 8. Next samples are deposited on respective stubs for example by a plurality of micro-pipettes each of which is accurately located with respect to the cascade filters chip. After duly locating a sample on the required stubs the laser 71 is pulsed to stimulate the emitter switch 21. A pulse is generated which travels along the micro strip line 11 towards the detector 22. In each instance the stubs modify a respective component part of the pulse as it travels along.

Figure 9 illustrates how the dielectric constant of double stranded DNA and single stranded DNA is different in the terahertz frequency range. Because of this samples containing hybridised DNA located on respective stubs will have a different effect on the filter characteristics than stubs to which a sample containing single-stranded DNA are applied. It would be understood that embodiments of the present invention are not limited to the detection of particular types of DNA. Rather any sample may be tested so long as the existence of a particular target is notable by a change in the dielectric constant. The shift in dielectric constant is detected by determining a shift in centre frequency of a trough 80 in the Fourier Transform of the detected pulse. Where a shift in centre frequency occurs it can be determined that the sample applied to the stub associated with that trough contains a dielectric constant altering material. For example in Figure 8 the dotted line 82 is shifted so that the trough has a centre frequency 83 different from that without the target sample. As a result the existence of a predetermined target in the sample applied to the test stub 70, can be detected.

Figure 10 illustrates a further embodiment of the present invention which provides a technique for the on-chip sensing of dielectric materials in the terahertz frequency range. An array of band-stop filters, excited by integrated ultrafast photoconductive switches, can be used to sense dielectric loading at a number of distinct lithographically-defined locations on a chip simultaneously, each location sensing a different

terahertz frequency. This technique has a range of applications in the field of on-chip terahertz systems, such as the analysis of DNA and other molecular films.

5 More particularly the design of a cascaded filter is shown in figure 10. Each filter is composed of a ~ 5 μm -wide filter stub attached to a 30 μm -wide microstrip line. The length of each stub determines the centre frequency of its resonance, which is given by $v_p/4l$,
10 where l is the stub length and v_p is velocity of pulses in the microstrip. Stubs of length 82 μm and 194 μm are chosen to give centre frequencies of 260 GHz and 600 GHz respectively. An organic polymer, benzocyclobutene (BCB), is used as the dielectric material in the
15 microstrip. The BCB is spun onto a backplane formed from a gold (500 nm) coated silicon substrate to give a dielectric thickness of 6 μm after curing at 250° C for one hour in a nitrogen atmosphere. The photoconductive material used in the switches is grown by molecular beam
20 epitaxy on a GaAs substrate, and comprises a 350-nm-thick layer of low-temperature-grown (LT) GaAs on a 100-nm-thick layer of AlAs. The LT-GaAs layer is grown at 200°
C and then annealed at 600 °C *in situ* and post growth. The LT-GaAs layer is supported by a wax layer during
25 sacrificial etching of the AlAs in dilute (10%) HF acid in an epitaxial lift-off process. The LT-GaAs film is

then attached onto the BCB surface using van der Waals bonding before being optically patterned and etched into 50 × 50 μm areas, each of which formed the photoconductive substrate for two THz switches. The cascaded filters and interconnecting microstrip are then fabricated in one optical lithography step using a 350-nm-thick Au layer. The microstrip is positioned to overrun the LT-GaAs switches, and additional contact points are formed to apply bias to the THz photoconductive switches (see figure 10). Each THz switch then comprises a bias contact, the region of microstrip in close proximity to the bias point (the microstrip is connected to the gold backplane at each end), and the photoconductive LT-GaAs substrate material between these two points.

Pulsed excitation of the switches may be achieved by a Ti:Sapphire laser system which gives ~100 fs pulses at a centre wavelength of 800 nm and at a repetition rate of 80 MHz. The laser output is divided into two parts using a beamsplitter and attenuated by neutral density filters to give an incident power of ~10 mW per switch. A commercial CCD camera is used to focus accurately the laser spots onto the switches. The two filters may be measured in the following way. A THz pulse is generated in the microstrip line by exciting switch 100, biased at

50 V (between contacts A and B in Fig. 10). This THz pulse is measured at switch 200 using photoconductive sampling by measuring the induced voltage (between contacts C and B in figure 10) whilst sweeping the position of the translation stage, mapping out the THz pulse as a function of time (see Fig. 11(a)). The arrival time of the time-delayed optical pulse at this switch is adjusted and zeroed by a mechanical translation stage. The time-delayed optical pulse is next focussed on switch 300, and the voltage measured across this switch (between contacts D and E) as a function of time delay to map out the THz pulse shape after propagation through the array of two filters (see Fig. 11(b)). The Fourier transforms of the input and output pulses are finally calculated and used to determine the frequency dependent transmission parameter S_{21} across the filter array, using the same method as described in M. Nagel, F. Richter, P. Haring Bolivar and H. Kurz, Phys. Med. Biol. 48 3635 (2003) and J. Cunningham, C. Wood, A. G. Davies, I. Hunter, E. H. Linfield and H. E. Beere, APL 86 213503 (2005).

Figure 11 (main figure) shows the THz transmission through the two filters. The three resonances correspond to the fundamental mode of the two filters (260 GHz and

600 GHz) and the third harmonic of the lower frequency filter (780 GHz).

To demonstrate independence of the response of the two spatially separated filters, a layer of optical photoresist (Shipley 1813, 12.8 μm thick after solvent evaporation) may be deposited onto the higher frequency filter stub. Resist droplets are deposited using a micro injector with glass micro capillary tubes drawn out on a tip puller (Narishige PC10) giving an average internal tip diameter of $\sim 1.3\mu\text{m}$. After drawing, tips are treated by vapour deposition of Trimethylchlorosilane (Sigma) for 5 mins to prevent adhesion of resist to the outside of the tip during deposition. As shown in figure 12, the loading of the filter by the dielectric film causes its resonance to shift to a lower frequency, whilst the resonance from the unloaded 260 GHz filter (together with its harmonic) remains unaffected. This demonstrates the principle of simultaneous, independent measurement of filter response at separate locations addressed by the same THz emitter and detector.

The effect of loading a filter element is now discussed in more detail. The interaction between the evanescent electric field above the on-resonance filter element with

the deposited dielectric material leads to the observed change in filter resonance frequency. In order to characterise and quantify the loading of the filter more fully, the change in resonance frequency of the filters is measured as a function of the thickness of the deposited dielectric. Resist is deposited by micropipetting drops of sufficient size to cover both filter elements, and the substrate then spun to planarise the resist. The resist is next soft baked at 110 °C for 5 minutes to remove excess solvent, and the thickness of the resist over the filter stubs measured using a surface profilometer. It is possible to obtain resist thicknesses in the range 1 to 16 μm by adjusting the spin speed and volume of resist deposited on the stubs. The frequency shift induced by the resist loading of the two filters is measured, as above, by evaluating S_{21} for each thickness of resist. The resist is then removed using acetone and, before depositing a new resist layer, the device response compared with the original unloaded response. In all cases less than ~1 dB difference in attenuation in the frequency range 0.1 to 1.2 THz is noted, and no measurable shift in the resonance frequencies of the filters compared with the first unloaded measurement (see Fig. 11). This indicates complete removal of the resist layer between runs and the potential for reusability of such filter structures in a

sensing environment. The results of the resist loading are shown in Figs. 12(a) and (b), along with the simulated effects of loading for comparison. The loaded response is calculated using a suitably modified geometry
5 with dielectric covering both filter elements. The frequency shifts obtained for both the 260 GHz and 600 GHz filters is obtained with a relative dielectric constant of $\epsilon_r = 2.75$ for the resist. It should be noted that a nearly linear dependence of frequency shift on the
10 loading dielectric thickness for small ($<5 \mu\text{m}$) thicknesses of resist is observed. For larger thickness, the frequency shift saturates since the electric field is already almost fully enclosed within the resist layer, causing the addition of further resist to have
15 increasingly less impact on the frequency response.

The active area of the band-stop THz filters is small ($5 \times 82 \mu\text{m}$) compared with existing band-pass and ring resonator designs, and this reduction in area (by around
20 two orders of magnitude) along with the simplicity of the filter design, makes them preferable in a range of dielectric sensing applications. Also the present methodology can allow many band-stop THz stub filters to be fed from the same microstrip line, forming a cascade.
25 In applications such as that presented in M. Nagel, P. Haring Bolivar, M. Brucherseifer and H. Kurtz, APL 80,

154, (2002), where the THz refractive index of a deposited film provides a detection mechanism, the present filter arrays thus provide an attractive alternative to band-pass THz filter technology.

- 5 Embodiments of the present invention have been described here and above by way of description only. It will be understood that modifications may be made without departing from the scope of the present invention.
- 10 Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of the words, for example "comprising" and "comprises", means "including but not limited to", and is not intended to (and does not) exclude other moieties,
- 15 additives, components, integers or steps.

- Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the
- 20 indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

- Features, integers, characteristics, compounds, chemical
- 25 moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith.

30

5

CLAIMS:

1. Apparatus for providing a terahertz band stop
filter, comprising:
10 a dielectric layer;
a micro strip line deposited on said dielectric layer;
and
at least one stub extending from said micro strip line on
said dielectric layer; wherein
15 the length of said stub is selected to determine the
centre frequency for said band stop filter.

2. The apparatus as claimed in claim 1 wherein said at
least one stub comprises a plurality of stubs extending
20 from the micro strip line, each stub having a different
length, the length of said stubs consecutively increasing
from a first end of the micro strip line.

3. The apparatus as claimed in claim 1 or claim 2
25 further
comprising:
a photo conductor switch located at a first end of the
micro strip line and arranged to emit a terahertz pulse
responsive to an incident laser pulse.

30

4. The apparatus as claimed in any one of claims 1 to
further comprising:

a detection point located at a remaining end of the micro strip line arranged to permit detection of a terahertz pulse propagated along said micro strip line.

5 5. The apparatus as claimed in any preceding claim further comprising a cascade of more than one band stop filter disposed along said micro strip line.

6. The apparatus as claimed in any preceding claim
10 wherein said apparatus is fabricated on-chip.

7. A terahertz Band Stop Filter, comprising:
a dielectric layer;
a micro strip line deposited on said dielectric layer;
15 and

at least one stub extending from said micro strip line on said dielectric layer; wherein
the length of said stub is selected to provide a band stop filter for the terahertz frequency range.
20

8. The band stop filter as claimed in claim 7 wherein said filter has a centre frequency near 600 Giga Hertz.

9. The band stop filter as claimed in claim 7 or 8
25 further comprising:

a plurality of terahertz band stop filters fabricated along a micro strip line each responsive to a common excitation point.

30 10. The band stop filter as claimed in claim 9 wherein an output from the plurality of filters is generated at an end of the micro strip line, said output including components consequent upon each of the filters disposed on said micro strip line.

35

11. An on-chip band stop filter, comprising:
a substrate;
a dielectric layer;
a micro strip line deposited on said dielectric layer;
5 and

at least one stub extending from said micro strip line
on said dielectric layer; wherein
the length of said stub is selected to determine the
centre frequency for said band stop filter.

10

12. The on-chip band stop filter as claimed in
claim 11

further comprising:

a photoconductor switch arranged to emit terahertz
15 pulses along the micro strip line.

13. The on-chip band stop filter as claimed in claim
12 wherein at least one low-temperature-grown Gallium
Arsenide (LT-GaAs) island is bonded on said dielectric
20 layer in contact with said micro strip line.

14. A method for detecting the presence of a target
substance in at least one test sample, comprising the
steps of:

25 providing a terahertz band stop filter;
applying a test sample to a portion of the band stop
filter; and
determining a change in response of the band stop
filter, said change in response indicating the presence
30 of said target substance.

15. The method as claimed in claim 14 wherein said
band stop filter comprises at least one on-chip stub
filter and said step of applying at least one test sample
35 comprises the steps of:

applying the at least one test sample to a stub region of the at least one stub filter.

16. The method as claimed in claim 14 wherein said
5 band stop filter comprises a cascade of stub filters and said step of applying a test sample comprises the steps of:

applying a plurality of test samples to the band stop filter each of the test samples in said plurality of test
10 samples being applied to a respective only one stub portion.

17. The method as claimed in claim 16 further comprising the steps of simultaneously applying the
15 plurality of test samples to the respective only one stub portions.

18. The method as claimed in claim 14 further comprising the steps of:
20 applying each test sample to a respective portion of the band stop filter via a respective one or a plurality of pipettes.

19. The method as claimed in anyone of claims 14 to
25 18 wherein said target substance is a bio-molecule.

20. The method as claimed in anyone of claims 14 to 19 wherein said test sample comprises a fluid including single stranded and/or double stranded DNA.

30

21. A method substantially as hereinbefore described with reference to the accompanying drawings.

22. Apparatus constructed and arranged substantially as hereinbefore described with reference to the accompanying drawings.

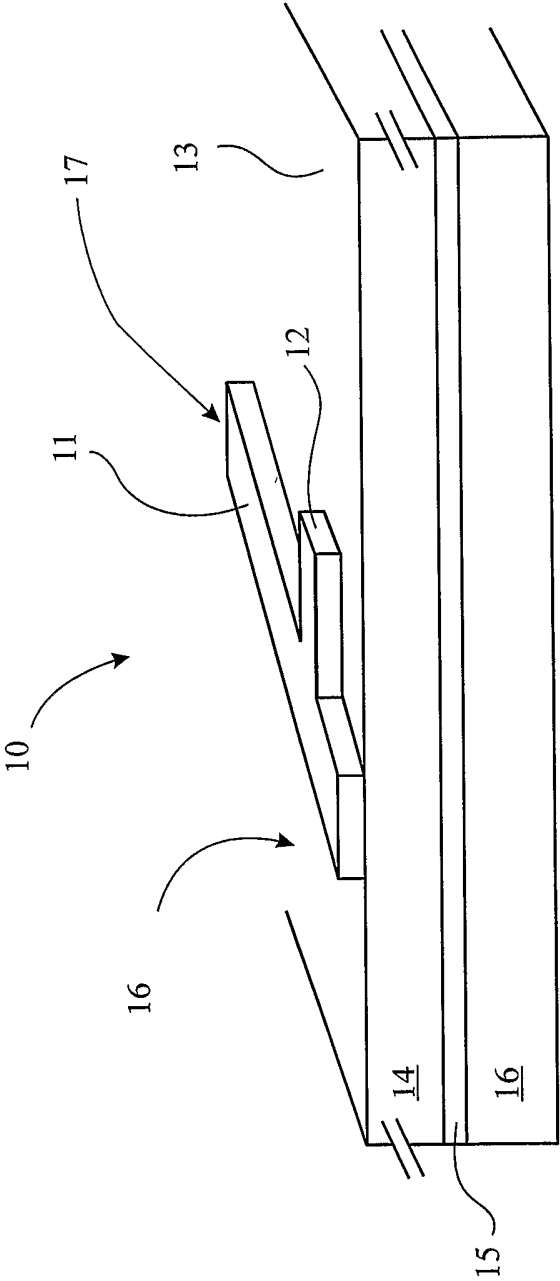


Fig. 1

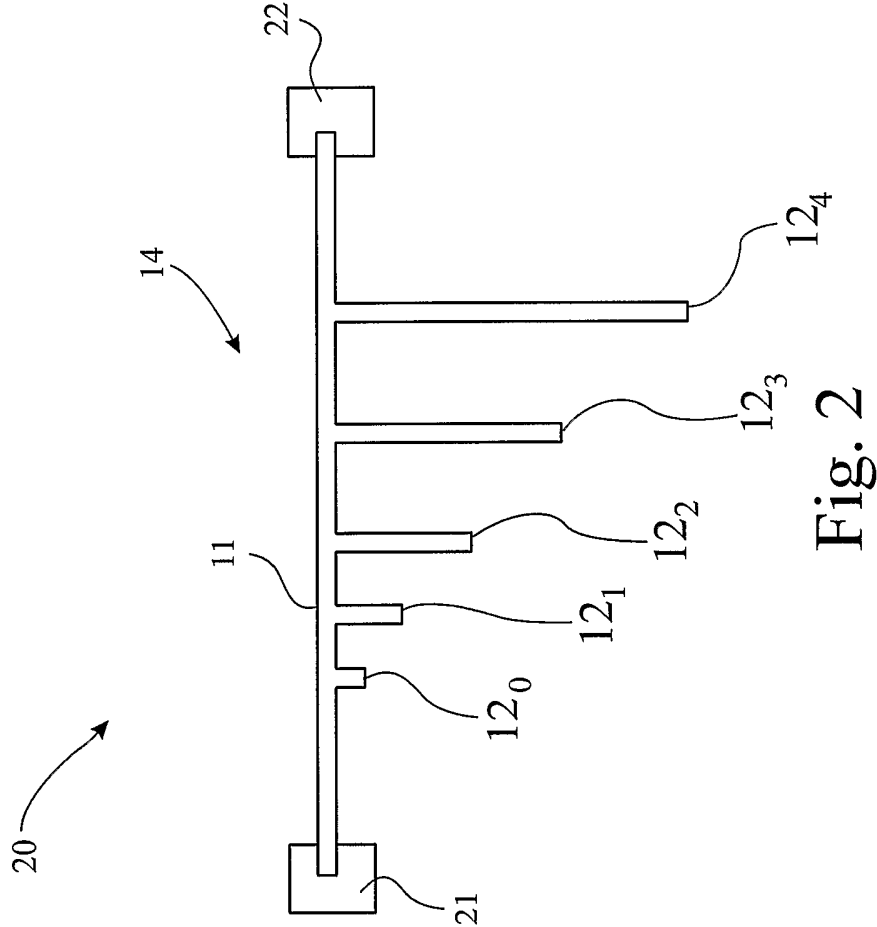


Fig. 2

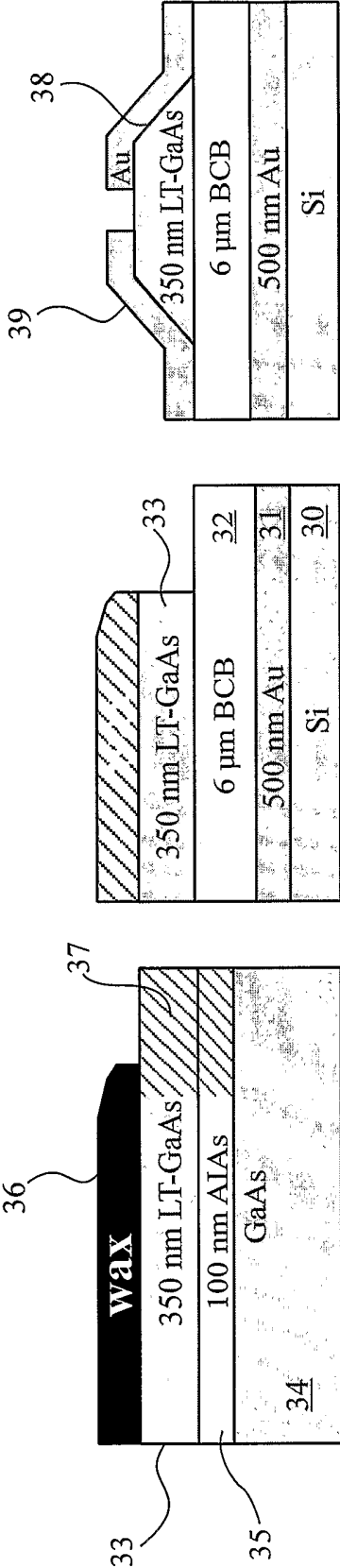
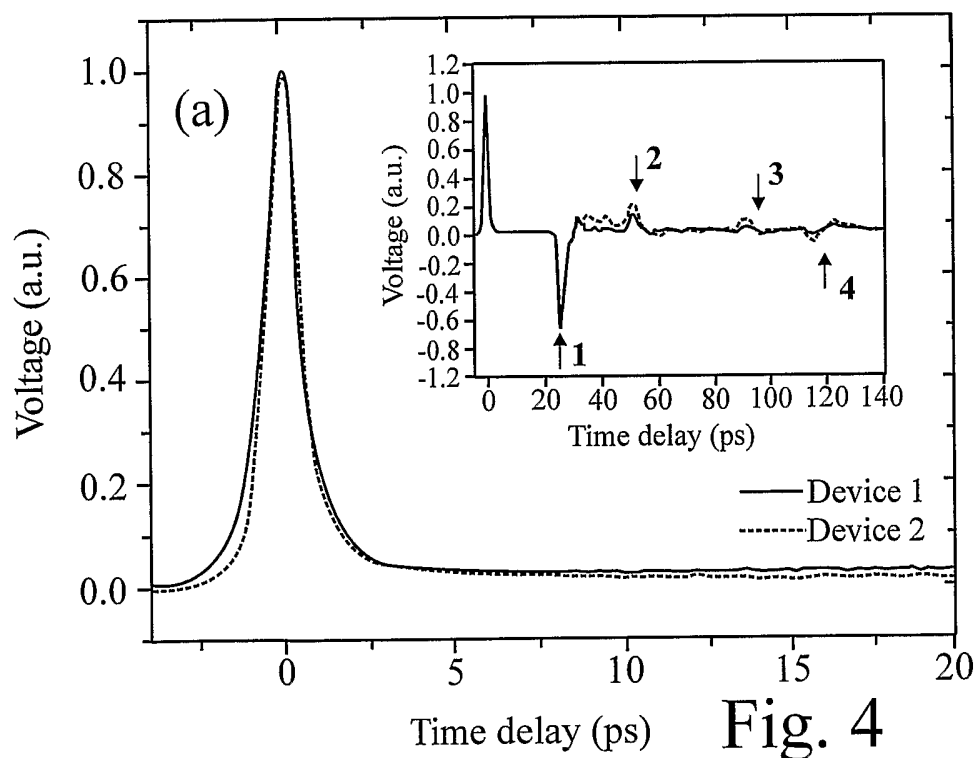
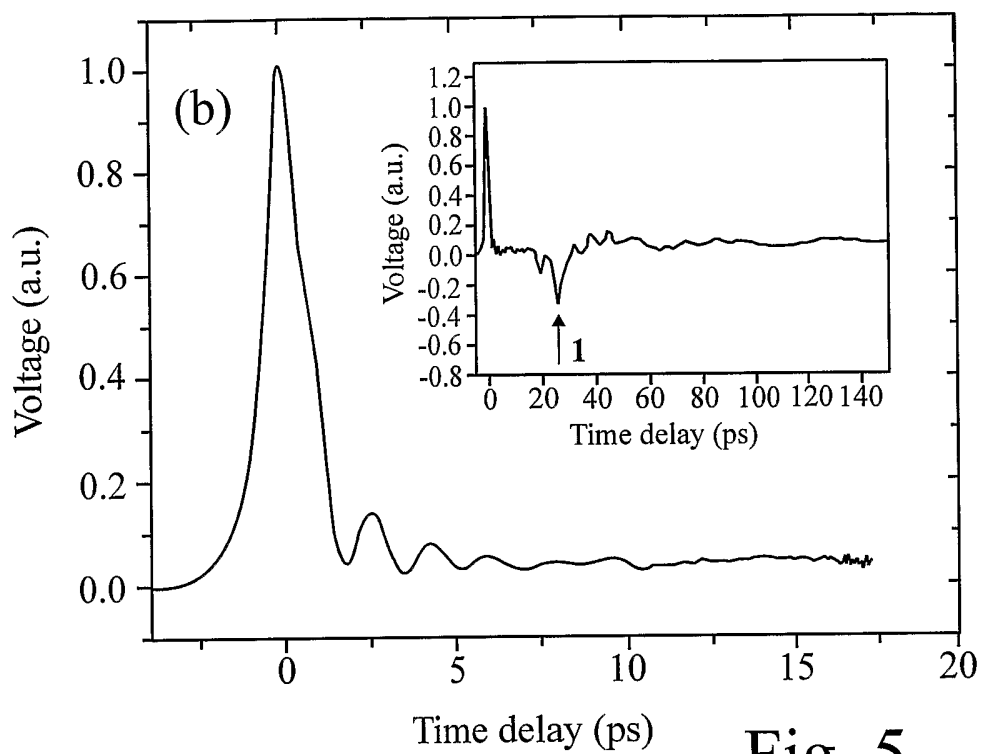


Fig. 3c

Fig. 3b

Fig. 3a

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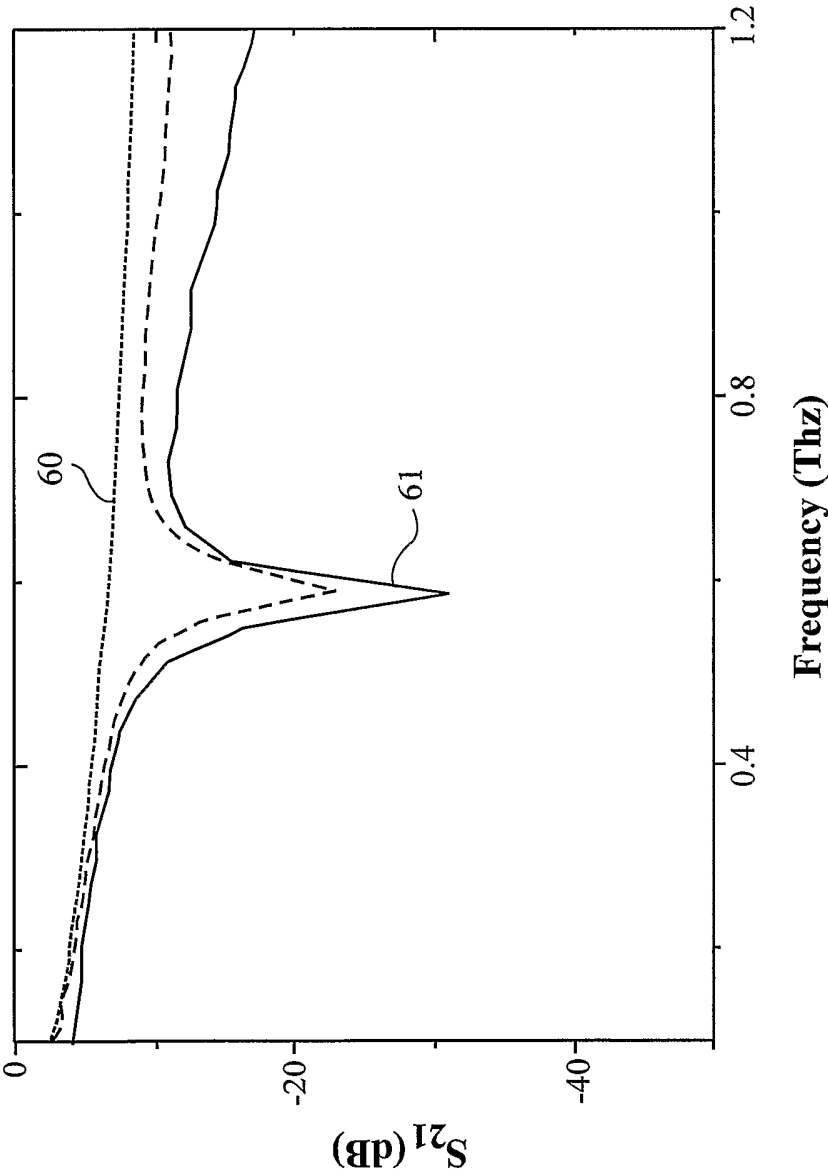


Fig. 6

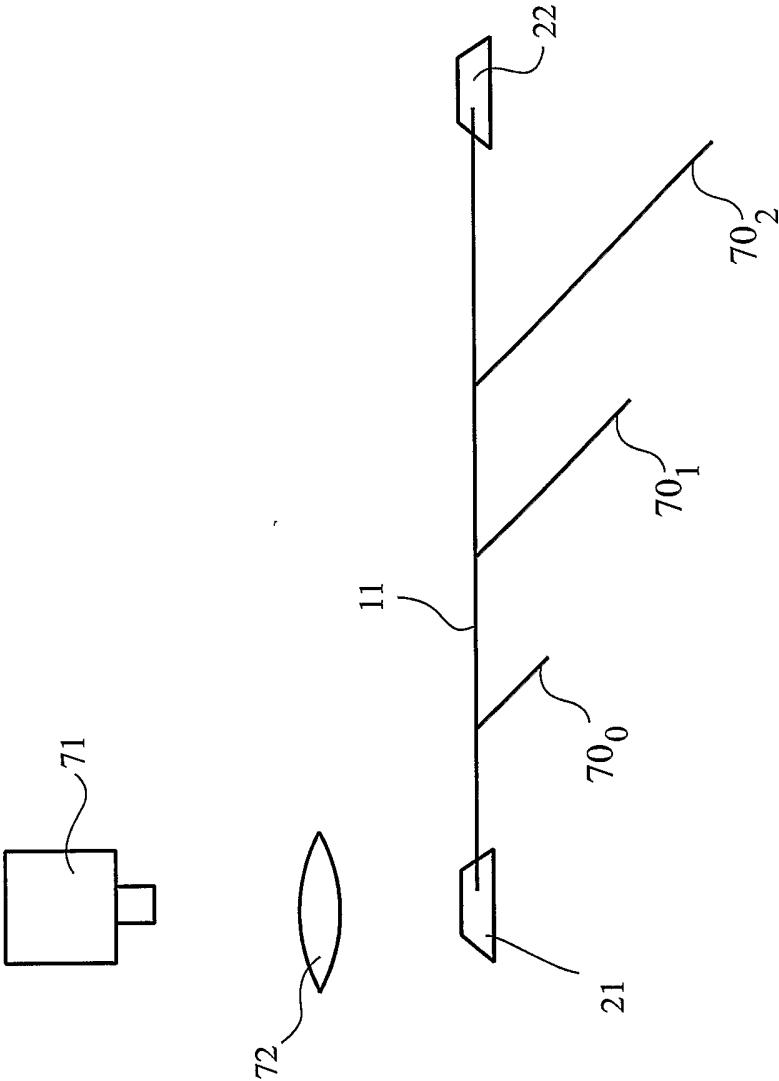


Fig. 7

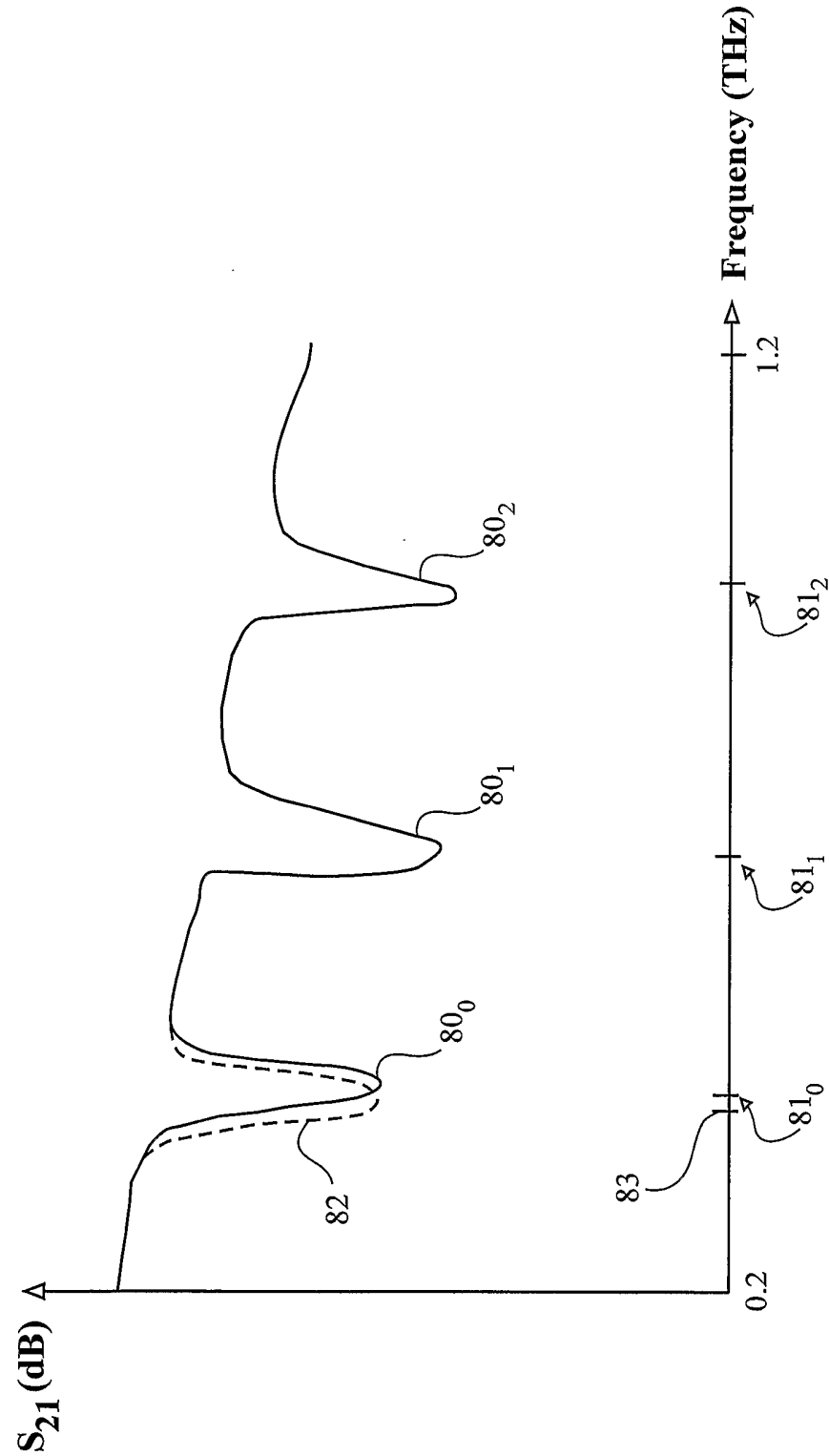


Fig. 8

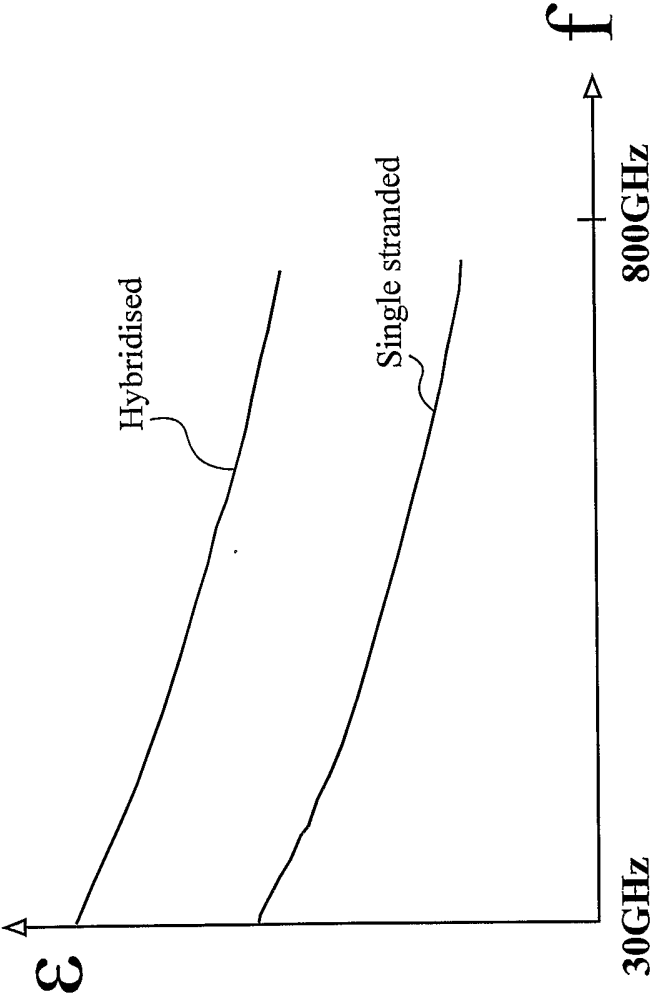


Fig. 9

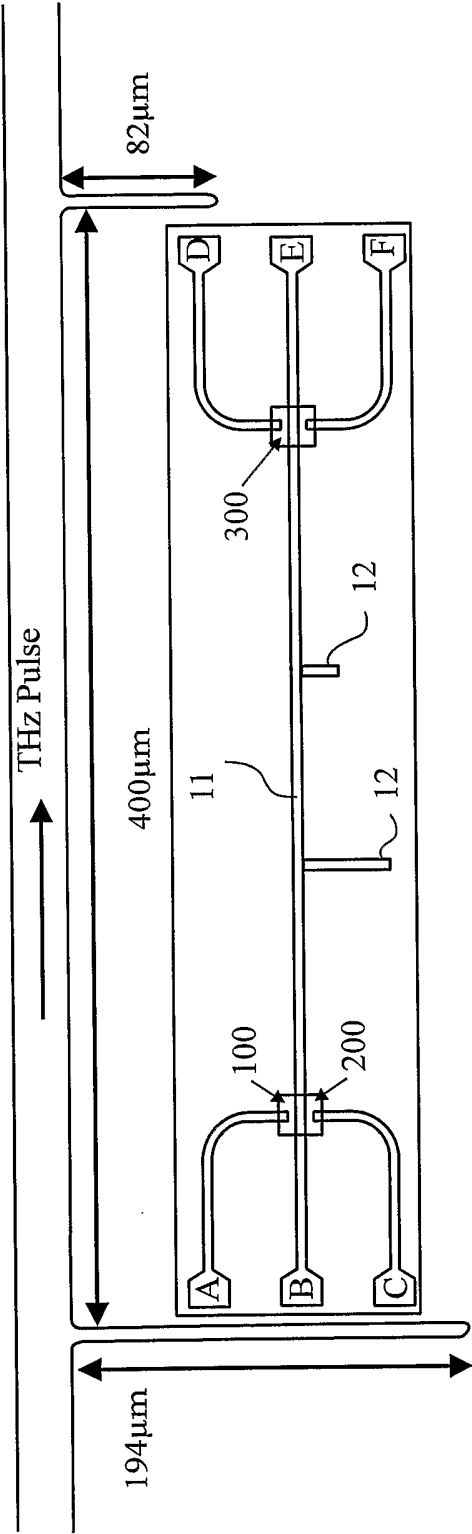


Fig. 10

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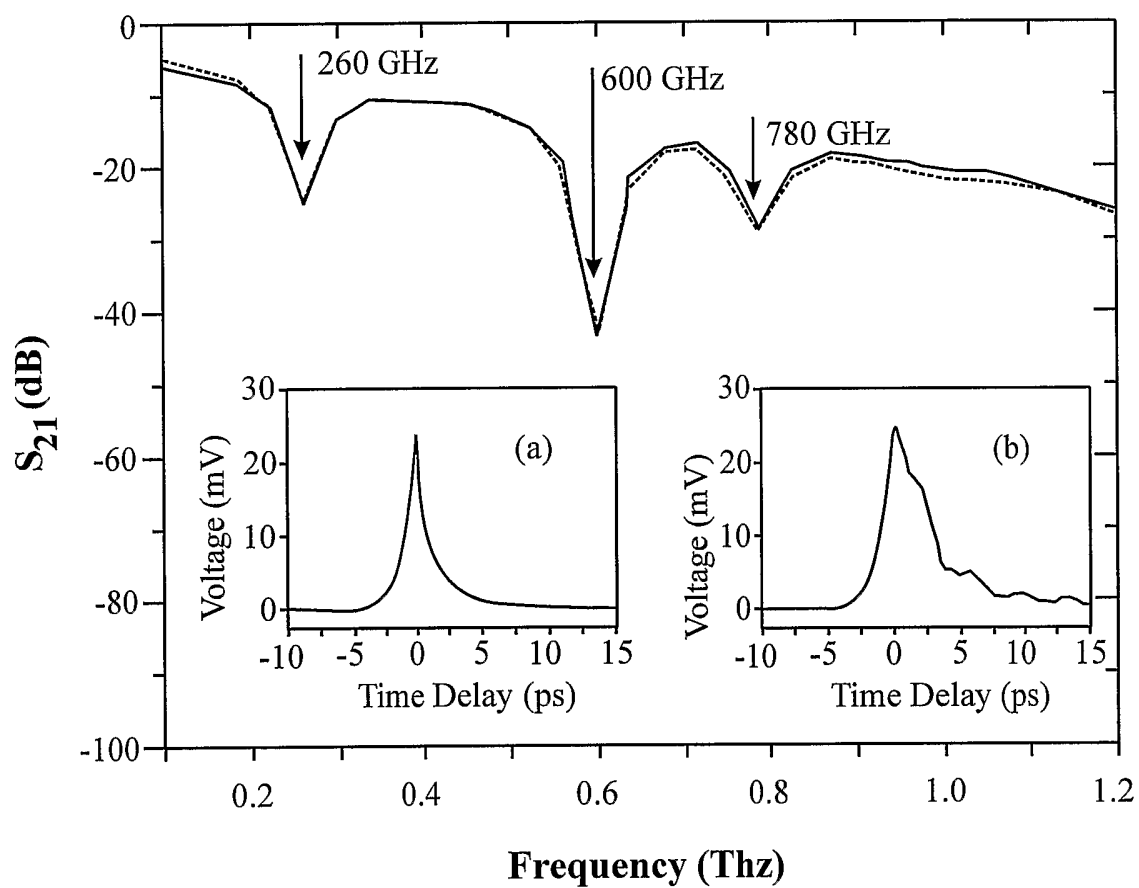


Fig. 11

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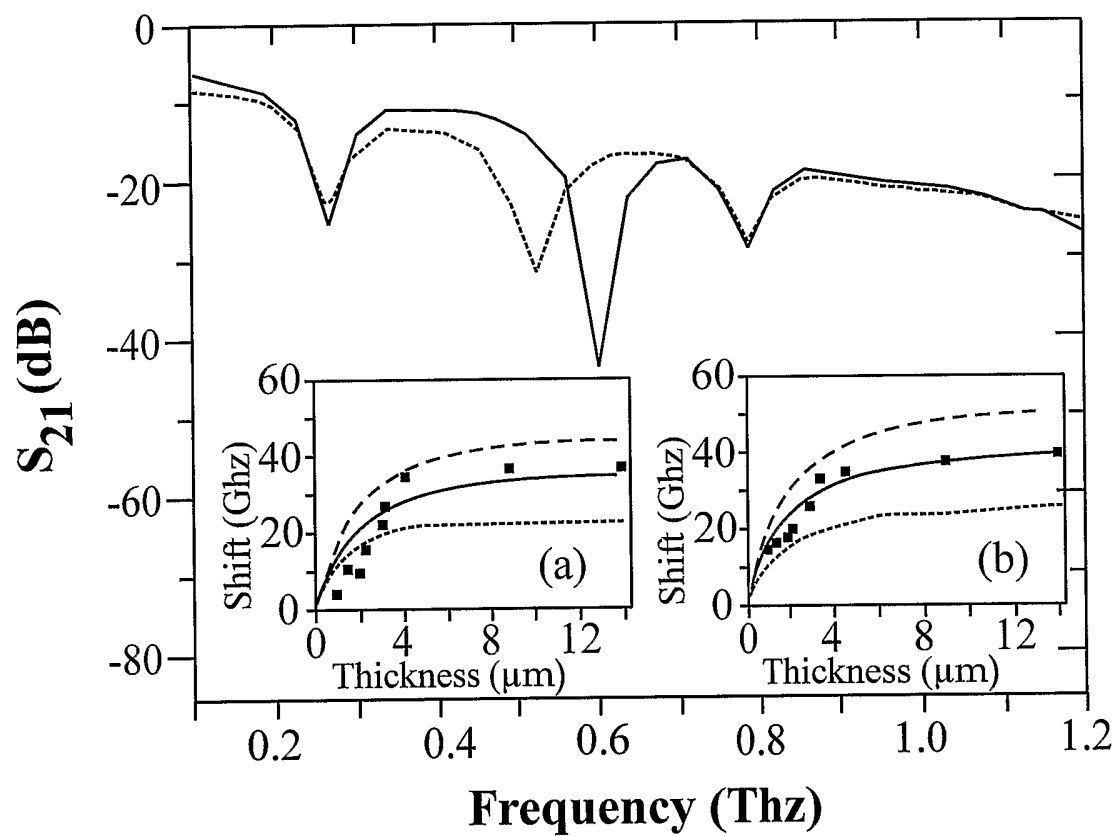


Fig. 12

INTERNATIONAL SEARCH REPORT

GB2005/004765

A. CLASSIFICATION OF SUBJECT MATTER
H01P1/203

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)
H01P

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BARAS T ET AL: "Design considerations for on-chip THz analysis of biomolecules" TERAHERTZ ELECTRONICS PROCEEDINGS, 2002. IEEE TENTH INTERNATIONAL CONFERENCE ON 9 - 10 SEP 2002, PISCATAWAY, NJ, USA, IEEE, 9 September 2002 (2002-09-09), pages 77-80, XP010605637 ISBN: 0-7803-7630-7 page 77, left-hand column, line 1 - page 78, left-hand column, line 13 page 79, right-hand column, line 13 - line 26; figure 3	1,3-20
Y		2
Y	EP 0 803 927 A (SHARP KABUSHIKI KAISHA) 29 October 1997 (1997-10-29) figure 7A	2

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

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
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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.
- *Z* document member of the same patent family

Date of the actual completion of the international search

6 March 2006

Date of mailing of the international search report

13/03/2006

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INTERNATIONAL SEARCH REPORT

GB2005/004765

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NAGEL M ET AL: "Optical second-harmonic probe for ultra-high frequency on-chip interconnects with benzocyclobutene" APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 72, no. 9, 2 March 1998 (1998-03-02), pages 1018-1020, XP012020789 ISSN: 0003-6951 page 1019, left-hand column, line 14 - line 27 -----	1-20
A	BRUCHERSEIFER M ET AL: "Label-free probing of the binding state of DNA by time-domain terahertz sensing" 11 December 2000 (2000-12-11), APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, PAGE(S) 4049-4051, XP012026916 ISSN: 0003-6951 the whole document -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

GB2005/004765

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			KR	261788 B1	15-07-2000
			US	6041224 A	21-03-2000