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(54) Slot coupled micromachined waveguide antenna

(57) The present invention relates to a device for emitting and/or receiving a signal in the millimetre wave range, characterised in that said device comprises a first metallic layer, a first insulating layer interposed between said first metallic layer and a substrate, said substrate comprising a cavity extending to said insulating layer, and having a second metallic layer at least covering the walls of said cavity and covering part of said insulating layer, said first metallic layer having a slot facing said cavity.

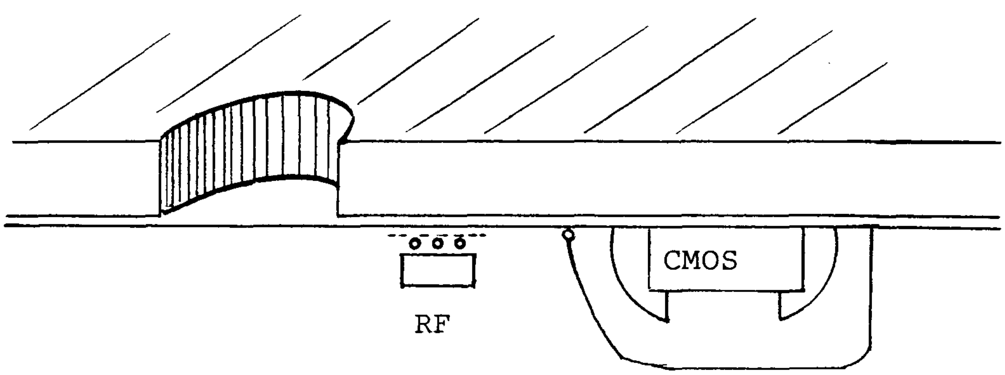

FIG. 1

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Description

Field of the invention

[0001] The present invention relates to a millimetre wave antenna, a device integrating such antenna and a method for manufacturing same.

State of the art

[0002] Microwave antennas are to emit radiation with a sufficient precision of directivity and are to be sufficiently small. State of the art millimetre wave antennas are, thanks to the antennas scaling laws, inherently small enough for being arrangeable in highly directive arrays. The larger the number of radiating elements in the array, the more directive the antenna can be. If the directivity of one element is already high, the number of elements required for reaching a target directivity will be smaller, and therefore the antenna itself can be smaller.

[0003] The state of the art directive antennas in the millimetre wave range are planar antennas, with patch antennas being the most widely used.

[0004] These planar antennas are very attractive for use within compact communication systems, (telecommunication, WLAN) owing to their simple integration with driving electronics and microwave circuits. However, they suffer from two serious disadvantages which are the limited bandwidth and the substrate losses.

[0005] Millimeter wave antennas furthermore find applications within the automotive market as a FLAR (Forward Looking Automobile Radar) or as automobile sensors.

[0006] Thus the millimetre wave portion of the spectrum is used for at least two important applications requiring small and directive antennas:

- Wireless data transmission (38 GHz).
- Automobile anticollision radar's (77 GHz).

[0007] Automotive applications are considered one of the two most important applications [H.H. Meinel, "Commercial Applications of Millimetre Waves. History, Present Status, and Future Trends", IEEE Transactions on Microwave Theory and Techniques. Vol.43. Nr 7, July 1995, pp 1639-1653.] in the millimetre wave communication range, the second being the short haul transmission links for PCN installations.

[0008] A FLAR is a radar used for measuring the relative velocity between two vehicles in a lane, and the distance between these vehicles, in order to issue warnings to the vehicle drivers. The FLAR consists of different parts:

- A set of antennas (Tx and Rx) for emitting a millimetre wave signal, and receiving the corresponding signal echoed by any obstacle on the lane.
- MMICs (Monolithic Microwave Integrated Circuit) called "transceiver", which comprises mixers, low noise amplifiers, power amplifiers, and an oscillator. The transceiver insures the generation of a millimetre wave oscillation, the mixing thereof with a signal of lower frequency (IF), and the amplification before emission. The transceiver also insures the recovery of the millimetre wave echoed signal and its downconverting to IF frequency range.
- Analogue and digital processing units.

[0009] The FLARs are to be designed for operation at different frequencies, depending on the geographic area:

- in Europe, at 76,5 GHz
- in Japan, at 60 GHz
- in the United States, there are several frequency bands allocated by the US Federal Communications Commission (F.C.C) for traffic radar's, including the 10.5 GHz and 24.1 GHz frequencies and the 33.4 to 36 GHz range. Radar's operating at 94 GHz are also under development.

[0010] Radar systems for the automobile have been studied since more than 20 years by major car companies in collaboration with RF companies and chips manufacturers.

[0011] Basically, there are two dominating factors that drive the technology for millimetre wave automotive radar's: cost and hardware size. Low cost is the key factor for consumers to accept the radar as a safety and affordable component in their vehicle. The size constraint is essential for easy integration of the radar on the vehicle without major impact on the vehicle design and performance.

[0012] An antenna for an Automobile anticollision radar (77 GHz) system needs to fulfil the requirements of scanning the road ahead. Thus, radar techniques are used requiring antennas which are:

- Directive : there should be no confusion between in line and adjacent lanes.
- Compact : The antenna size should not be detrimental to the car aesthetics. Furthermore, an easy and straightforward link between stearing electronics and the antenna should be feasible.

[0013] Most of the radar developments so far are built around GaAs (or other III-V) MMIC's, but also other developments have been going on. Daimler Benz is active in developing SIMMWIC and has reported mid 1995 the successful fabrication of

- schottky diodes for mixers
- PJN diodes for switches
- low noise oscillators using SiGe HBT's
- IMPATT diodes for mmwave power generation on high resistivity Si (> 10k.cm). [J F. Luy et al, 'Si/SiGe MMIC's". IEEE Transactions on Microwave Theory and Techniques. Vol.43. N04, April 1995, pp 706-719 and A. Stiller et al, A Monolithic Integrated Millimetre Wave Transmitter for Automotive Applications. IEEE Transactions on Microwave Theory and Techniques. Vol.43. Nr 7, July 1995, pp 1654-1657.]

[0014] Another approach followed by Hughes Research Labs is the flip-chip mounting of GaAs MMIC chips on low cost duroid substrates. Successful realization of a mixer for the 77 GHz by flip-chip mounting GaAs schottky diodes was reported [R.S. Virk et al, "A Low Cost W-Band MIC Mixer Using Flip-Chip Technology", IEEE Microwave and Guided Wave Letters. Vol. 7, Nr 9, September 1997, pp 294-296.]

[0015] Therefore, the cost of devices fabricated in a III-V process technology remains higher than silicon-based devices.

[0016] Furthermore, it is known that the radar size can be reduced by the following measures

- By higher degrees of integration i.e. regrouping the different functional blocks of the communication system. This is not straightforward in practise: trade-offs are imposed on the performance of the different elements brought together;
- By stacking several chips; ([M. Stotz et al, "Planar Millimetre Wave Antennas Using SiNx Membranes on GaAs", IEEE Transactions on Microwave Theory and Techniques, Vol.44. Nr 9, September 1996. Pp 1593-1595.].
- By suitable antenna design. The radar size however cannot be reduced to less than the area occupied by the antenna. In practise, the antenna size is fixed by the radar specification of directivity.

[0017] Thus, there is a need for the development of a millimeter wave communication device that includes an antenna

- which can be fabricated at low cost but at the same time with sufficient precision;
- which has a sufficient directivity;
- that is compact and can be integrated with other electronic components of the device;
- that has a sufficiently large band width and is sufficiently efficient.

<u>Aims of the invention</u>

[0018] A first aim of the present invention is to provide a suitable antenna for millimeter wave communication device applications. The antennas according to the present invention are millimetre wave antennas having high directivity and high efficiency. The antennas can be used for instance for telecommunications and for automotive radars.

[0019] Another aim is that the antenna can be integrated with other parts of a device for communication applications. Specifically the applications of wireless data communication and automotive radar devices are aimed for. It is an aspect of such application that a reasonably compact antenna is needed. The compactness of the antenna allows for a dense integration with other components enhancing its use in automotive applications requiring portable devices.

[0020] Yet, another aim is to provide millimetre wave antennas that are

- of comparable or same size as "patch antennas",
- at least as directive as the "patch antenna",
- if possible made on a similar technological platforms,
- having as additional features a larger bandwidth, and
- being more efficient (with less or no substrate losses) than patch antennas

Summary of the invention

[0021] The present invention relates to a device for emitting and/or receiving a signal in the millimetre wave range, characterised in that said device comprises a first metallic layer, a first insulating layer or a membrane interposed between said first metallic layer and a substrate, said substrate comprising a cavity extending to said insulating layer, and having a second metallic layer at least covering the walls of said cavity and covering part of said insulating layer, said first metallic layer having a slot adjacent to said cavity. The structure of a first metallic layer, a first insulating layer or membrane interposed between said first metallic layer and a substrate, said substrate comprising a cavity extending to said insulating layer, and having a second metallic layer at least covering the walls of said cavity and covering part of said insulating layer, said first metallic layer having a slot adjacent to said cavity, can form an antenna on its own.

[0022] The substrate can be made of any material that allows for manufacturing with a reasonable precision and adequate dimensions. Examples of such substrates are semiconductor materials such as silicon wafers: silicon allows for the use of established micromachining techniques in order to fabricate the proper device structure.

[0023] The substrate can also consist of III-V semiconductors, a ceramic (Al_2O_3, AlN), a glass, a plastic, a polymer material or any combination thereof or such materials in a matrix of another material or vice-versa. Fabrication techniques of the proper device structure can include laser cutting, ultrasonic dilling, injection moulding or similar techniques known in the art.

[0024] The substrate can also be a metallic substrate, in which case the second metallic layer is the outer layer of said substrate. A second substrate having a dielectric insulating layer and the first metallic layer can then be attached by any means known in the art to the metallic substrate with a membrane therebetween, in order to achieve the device structure of the invention. This fabrication technique of working with two separated substrates that are connected can also be applied to any other of the above-referenced substrates.

[0025] Another way to produce the device of the invention with a specific geometry is using a moulding process. The production is then done by injection moulding or any other way of making replicates. The mould can then be made with LIGA using X-ray or photolithography, for instance deep UV lithography, which allows to achieve very small dimensions. Plastics such as PMMA, PEEK, PVE and PEI can be used as a substrate. The use of plastics for making microstructures in plastic is known in the art.

[0026] The mould fabricated by means of the above-defined methods can be used again as a tool for further replication processes, e.g. as mould inserts for micromoulding or reaction injection moulding. Materials to be used for the replication processes are usually melted polymers and casting resins. After hardening in the metallic forms, the mould materials have reached a sufficient strength and the separation of mould and mould insert can take place. For the realisation of micromoulding and micro-reaction injection moulding the extremely low roughness of the walls of LIGA fabricated mould inserts is most important.

[0027] Materials that have been used for microreplication include low viscosity thermoplastic polymers like polymethyl methacrylate (PMMA), polyoxymethylene (POM), polyamide (PA) or polycarbonate, as well as reaction resins based on methacrylates, silicones and caprolactames. However, many more materials could be used. Except for filled moulding materials, almost any material suitable for macroscopic moulding can be used for micromoulding.

[0028] Ceramic microstructures can be fabricated by slurry casting, by using sol-gel processes or by means of electrophoretic and other processes. It is e.g. possible to fill the gaps of a LIGA fabricated polymer structure with a slurry of microcrystalline ceramic powder. After drying and firing, the polymer degrades, evaporates or is oxidised, which results in a ceramic microstructure. The characteristic dimensions of the ceramic structures are smaller than the polymer form, due to shrinkage during the firing process. Mechanically very stable and temperature persistent materials can thus be microstructured by means of the LIGA process.

[0029] In an embodiment of the invention, the substrate can essentially consists of Si with the first insulating layer consisting essentially of a Si-oxide material.

[0030] The device can also comprise a polymer layer or said first insulating layer that is interposed between the first metallic layer and said substrate. The polymer layer for instance can be PCB or PBO (polybenzo-xyzazole). In fact, for a number of applications, the first insulating layer is to have high-quality dielectric properties. The applications requesting such properties are those wherein a transmission line is made in the first metallic layer. With the high-quality dielectric material, substrate losses during signal transmission in the transmission line are avoided. The device can further comprise means for generating an electrical signal in the first metallic layer. The high-quality dielectric properties can also be important in order to achieve a good coupling between the feeding network of the device generating a signal in the first metallic layer and the antenna of the invention, without major losses in the first insulating layer. The coupling to be achieved depends on the frequency aimed for in a particular application.

[0031] The cavity can be filled with a low-loss polymer material, preferably comprising BCB, to increase the electrical length of the cavity. Yet another material can be PBO.

[0032] The substrate can also be an MCM-D substrate. Suitable materials for the first metallic layer can include low-resistive metals such as Cu, Ag, Al, Au and alloys thereof.

[0033] Another device for emitting and/or receiving a signal in the millimetre wave range according to the invention is characterised in that it comprises an array of any of the precited devices.

[0034] Another device for emitting and/or receiving a signal in the millimetre wave range according to the present invention is characterised in that it is made and configured as a flipchip of any of the precited devices and a CMOS substrate with integrated circuits having a functionality therein.

[0035] In the method of operating the device of the invention, the signal is generated in the first metallic layer, said signal being transmitted to said second metallic layer and being emitted in the form of radiation therefrom.

[0036] The present invention furthermore relates to a method for manufacturing a device for emitting and/or receiving a signal in the millimetre wave range, characterised in that it comprises the following steps:

- depositing a first insulating layer on a first side of a substrate,
- depositing a first metallic layer on said first insulating layer,
- defining, for instance etching, a cavity with predetermined dimensions in said substrate at a second side thereof,
- depositing a second metallic layer at said second side of said substrate, and
- removing a part of said second metallic layer located at the bottom of said cavity.

[0037] The method can further comprise the steps of:

- depositing a second insulating layer on said second side of said substrate and
- creating an opening in said second insulating layer, the cavity being etched through said opening.

[0038] This method can further comprise the step of filling said cavity with a polymer, preferably BCB, the substrate being an MCM-D wafer.

[0039] In an embodiment of the method of the invention, the substrate can comprise Si and the first insulating layer can comprise a Si-oxide layer and a polymer layer, said polymer preferably comprising BCB.

Short description of the drawings

[0040] Figure 1 shows a radar device according to the present invention.

[0041] Figures 2a to 2d are representing two distinct embodiments of the cavity of the antenna according to the present invention are shown. Parameter values are given in Table 1 and Table 2.

[0042] Figure 3a to 3f illustrate a method of fabricating the device according to the present invention.

Detailed description of several embodiments of the invention

[0043] The invention of a new millimetre wave antenna for emitting and/or receiving and a method for the fabrication of such millimetre wave waveguide antennas according to the invention is disclosed. The use of the antenna and the integration within a device and a system for communication applications is disclosed as well. The invention will be explained hereinafter with non-limiting examples and figures.

[0044] One of the set of conditions defining a specific embodiment of the invention is the combination of process tolerance and the frequency of the radiation that is to be emitted.

[0045] For a large wavelength of emission, the substrate is to be thick enough. In such a case (large wavelength of emission), the process tolerances are less demanding, and the corresponding fabrication technique can be less expensive. For instance, the substrate can than be a metallic substrate, in which case the second metallic layer is the outer layer of said substrate. A second substrate having a dielectric insulating layer and the first metallic layer can then be attached by any means known in the art to the metallic substrate with a membrane therebetween, in order to achieve the device structure of the invention. This fabrication technique of working with two separated substrates that are connected can also be applied to other substrates.

[0046] On the other hand, for a high frequency application, the tolerances on the process of fabrication are demanding and a high precision in the definition of the device structure is requested. Such applications request high precision techniques such as silicon micromachining or LIGA.

[0047] Another way to produce the device of the invention with a specific geometry is using a moulding process. The production is then done by injection moulding or any other way of making replicates. The mould can then be made with LIGA using X-ray or photolithography, more preferably deep UV lithography, which allows to achieve very small dimensions. Plastics such as PMMA, PEEK, PVE and PEI can be used as a substrate. The use of plastics for making microstructures in plastic is known in the art.

[0048] The mould fabricated by means of the above-defined methods can be used again as a tool for further replication processes, e.g. as mould inserts for micromoulding or reaction injection moulding. Materials to be used for the replication processes are usually melted polymers and casting resins. After hardening in the metallic forms, the mould materials have reached a sufficient strength and the separation of mould and mould insert can take place. For the realisation of micromoulding and micro-reaction injection moulding the extremely low roughness of the walls of LIGA fabricated mould inserts is most important.

[0049] Materials that have been used for microreplication include low viscosity thermoplastic polymers like polymethyl methacrylate (PMMA), polyoxymethylene (POM), polyamide (PA) or polycarbonate, as well as reaction resins based on methacrylates, silicones and caprolactames. However, many more materials could be used. Except for filled moulding materials, almost any material suitable for macroscopic moulding can be used for micromoulding.

[0050] In an embodiment of the invention, the antenna consists of a metallized cavity etched into the bulk of a silicon substrate, and extending from the substrate backside, to the substrate front side. Said substrate is preferably an MCM-D wafer.

[0051] The waveguide is excited by a feed line of coplanar type located on the wafer front side. The feed line is in a metal layer separated by a dielectric layer from the substrate.

[0052] Excitation is done by coupling the cavity to the feed line through a feed slot in the bottom of the metallized cavity.

[0053] On the MCM-D wafer, other circuits for system integration with the antenna can be assembled. Thus, the device of the invention has the following features:

- Advanced micromachining (deep dry etch), microelectronics (SiGe/Si HBTs) and assembly techniques (flip-chip) are combined with CMOS processing, to make a self packaged, low cost, small size transmitter/receiver device. The high precision of Silicon manufacturing techniques allows for making a device with high precision.
- The transmitter/receiver antenna can be designed for minimised size and maximal directivity.
- The device can be used in the automotive market (FLAR), but it can easily be adapted for other automobile sensors (Doppler radar) and to other areas of applications (namely millimetre wave communications, such as in WLANs).

[0054] In this embodiment of the present invention, it is preferred:

- To use highly resistive Si as the substrate. The RF functions can be integrated in the Si substrate or can be defined in other components, for instance in CMOS technology, CMOS-SiGe, bipolar technology or III-V technology, that are mounted on the first metallic layer. This mounting step can be achieved for instance by flip-chip mounting, ball-grid array technology and other techniques known in the art (see Fig. 1). It is nowadays practical to define the high frequency (>5 GHz) RF function in another substrate material than Si.
- To adopt a directive antenna element design for the antenna, and to machine this element (alone, or arranged in arrays) into the bulk of the resistive silicon backside.

[0055] Because the active element chips in a millimetre wave transceiver device are made in a variety of technologies, an attractive direction for its fabrication is the bonding of these multiple chips on one platform, which might support passives as well. Such a platform is available in the multilayer thin film technology as used in the MCM-D, technology which is well known in the art.

[0056] Thus a preferred embodiment of the present invention is a millimetre wave antenna micromachined on an MCM-D silicon platform. It is designed for radiating above 20 GHz. The radiating aperture of this antenna is a micromachined waveguide. The aperture is etched in the bulk of the silicon substrate. The cross section of the micromachined waveguide can take a rectangular (Figs. 2a and 2b) or a circular (Figs. 2c and 2d) cross section or a cross section of any geometry. The cavity may be filled with a low loss dielectric, material such as a polymer material (BCB), to shrink the antenna dimensions.

[0057] The proposed antenna is fed by a coplanar waveguide (CPW) realised on the MCM-D side of the substrate but separated therefrom by a dielectric material. The electromagnetic coupling from the feeding CPW to the antenna is achieved through a slot etched in the metal base of the aperture waveguide. The coupling slot has the same shape as the waveguide cross section. Fig 4 a and b show a rectangular slot (41) in the base of a micromachined rectangular waveguide (42). The feeding CPW (43) is also shown on this figure. Several radiating ends of the feeding CPW are used, such as open, short, capacitive, and inductive ends.

[0058] The frequency of the signal radiated by the antenna is the frequency of the signal propagating in the CPW waveguide, and fed to the antenna by electromagnetic coupling through the slot. In other words, the radiated wavelength is basically not set by the waveguide dimensions. The waveguide dimensions actually define the cut-off frequency of the respective modes which could be excited by a fed signal of given frequency.

Description of a preferred embodiment of the invention

1. Production of an antenna according to the invention

[0059]

Step	Operation
1	Thermal growth SiO_2 (both sides)
	Deposit LPCVD Si_3N_4 (both sides)
2	RIE etch LPCVD nidtride on backside, deposit 3µm AMT oxide on backside
3	Pattern AMT + oxide
4	Spin BCB 4028 on frontside (2 layers of ~20µm each)
5	Microroughening BCB in Argon plasma
6	Sputter or electroplate Top electrode on frontside (~2µm Cu on 0.05µm Ti typically)
7	Pattern Top electrode
8	Etch through Si wafer (in STS system) with AMT as an etch mask, and stop on BCB.
9	Dry etch of the oxide mask overhangs
10	Sputter or electroplate bottom electrode (~2µm Cu on 0.05µm Ti typically)
11	Electroplate PEPR 2400 using Cu as a seed layer, UV resist exposure, develop the resist
12	Pattern bottom electrode (etch Cu/Ti)
13	Strip resist in acetone
14	(optional) Fill cavity with BCB

[0060] As represented in Fig. 1, the process of fabrication starts with a double side polished low resistivity silicon wafer, wherein the following steps are performed:

- For DRIE dry etching through the silicon wafer (31), a thick oxide layer (21) is CVD deposited on the wafer backside, and further patterned into an oxide hard mask (see Fig. 3a).
- The MCM-D circuit can be made on the front side of a silicon wafer using either spin-on dielectric (thick BCB or polyimide), and metal deposition/patterning as described in J F. Luy et al, 'Si/SiGe MMIC's". IEEE Transactions on Microwave Theory and Techniques. Vol.43. N04, April 1995, pp 706-719.
- The hard mask is aligned with the MCM-D patterns on the wafer front side, in order to align the tip (23) of the coupling CPW (25), the etched slot (29), and the waveguide. Double side alignment is performed on an Electronic Vision dedicated equipment (see Fig. 3b).
- At this point, a resist protective layer is coated on the MCM-D circuit.
- A cavity (27) with desired cross section is etched vertically through the bulk of the silicon wafer (see Fig. 3 c), using an STS recipe applied on wafer backside. The etch stops as soon as the interface between the silicon and the dielectric layer is reached, thanks to etch selectivity.
- The residual masking oxide is removed using dry etching. The backside is then metallized with a blanket layer of sputtered metal (33) (see Fig. 3 d).
- Copper is then sputtered on the wafer backside. Copper is used as a seed layer for coating electrodeposable resist of type PEPR 2400 by Shipley.
- Next, resist is exposed through a photolithographic mask, then developed. The unprotected copper is etched away. This completes the opening of the feed slot in the bottom of the metallized cavity. Resist is then stripped.
- A layer of electrophoretic PEPR 2400 photolithographic resist (35) from Shipley is electroplated and baked. The resist is further exposed (see Fig. 3 d), and developed, this leaves an opening (37) in the resist in the bottom of the metallized cavity (27). The exposed metal is wet etched (see Fig. 3e).
- The PEPR 2400 resist and the protective layer are stripped in a compatible solvent (e.g., acetone or hot resist stripper).
- Finally (optional), BCB (41) can be dispensed in the cavity (27) (see Fig. 3f).

2. Detailed analysis of aperture form

[0061] A cylindrical aperture antenna is described on Fig 2b. The walls of the cylinder are sputter coated with TiW/Au. An opening is made in this metal in the bottom of the cylinder, in order to feed (excite) the antenna located on chip's backside through a microstrip tine leaving the oscillator, and located on the frontside of the substrate.
[0062] In order to cancel the high order resonating modes of the antenna, the hole is either

- filled with a low loss dielectric
- or half wavelength deep.

[0063] In order to make the antenna a resonator, the following is done:

- The cylinder is etched in Si, using a deep dry etch recipe from STS.
- A photolithographic resist layer Shiplev PEPR 2400 [S. Linder et al. "Photolithography in anisotropically etched grooves", Proc. IEEE MEMS Worskhop San Diego. CA, pp 38-43.] based on combined planar and non planar technology (the term "non planar technology" refers in this case to the metallic waveguide) will be electroplated on MMIC chip's backside. An opening in resist is performed, and the slot etched (the front side being resist protected).
- BCB can be dispensed in the cavity (or if not possible, the depth of this cavity will equal half wavelength).

[0064] A rectangular aperture antenna can be manufactured similarly.
[0065] The directivity of the integrated antenna was evaluated analytically. An empty waveguide was assumed for these first calculations (no BCB filling).
[0066] Results show that:

- the circular aperture antenna compares in size with the micropatch, but is more directive (7.4dB against 5.4dB for the micropatch) and obviously more robust. The BCB filling is expected to further improve the directivity of the circular aperture antenna.
- the rectangular aperture antenna is even more directive (9.8 dB against 5.4 dB for the micropatch), it is observed however that the rectangular aperture antenna features a larger size than the circular one (there is room in a rectangular aperture for two rectangular micropatch. And a 2 elements array factor should therefore be considered).

3. Manufacturing of a low cost, robust and small size radar

[0067] One can envisage to process two silicon chips separately, one highly resistive supporting all the RF functions plus the antenna (as e.g. in example 1), the second supporting all the CMOS and IF functions. These can to flipchip assemble the 2 chips, connecting the RF and IF circuits where necessary.
[0068] The result will be a low cost fully integrated, compact self packaged and robust radar as shown on Fig. 1.
[0069] The method for manufacturing a device for emitting and/or receiving a signal in the millimetre wave range according to the present invention comprises the following steps:

- depositing a first insulating layer on a first side of said substrate,
- depositing a first metallic layer on said first insulating layer,
- etching a cavity with predetermined dimensions in said substrate at a second side thereof,
- depositing a second metallic layer at said second side of said substrate, and
- removing a part of said second metallic layer located at the bottom of said cavity.

Table 1

	Rectangular Aperture	Circular Aperture
Design Parameters	• $f_o = 77$ GHz $\Rightarrow$ $\lambda_o = 3.9$ mm • $f_c)_{TE_{01}} = \frac{c}{2b} = 78$ GHz $\Rightarrow$ $b = 1.92$ mm $= 0.49\ \lambda_o$ • $a = 2\lambda_o = 7.79$ mm $\Rightarrow$ $f_c)_{TE_{01}} = 19.26$ GHz $< f_o$ • $a' = a/10 = 0.779$ mm, $b' = b/10 = 0.779$ mm • $d_1 = 2$ mm $\cong \lambda_o/2$ • $d_2 =$ • $w =$ • $\varepsilon_1 = 12.8$ (Si)	• $f_o = 77$ GHz $\Rightarrow$ $\lambda_o = 3.9$ mm • $f_c)_{TM_{01}} = \frac{2.4c}{2\pi R} = 78$ GHz $\Rightarrow$ $R = 1.47$ mm $= 0.377\ \lambda_o$ • $f_c)_{TE_{11}} = \frac{1.841c}{2\pi R} = 60$ GHz $< f_o$ • $R' = R/10 = 0.147$ mm • $d_1 = 2$ mm $\cong \lambda_o/2$ • $d_2 =$ • $w =$ • $\varepsilon_1 = 12.8$ (Si)

Radiation Paterns		Rectangular Aperture		Rectangular Patch		Circular Aperture	
		E-Plane	H-Plane	E-Plane	H-Plane	E-Plane	H-Plane
	HPBW	110°	30°	85°	110°	85°	70°
	FNBW	$>180^\circ$	95°	$>180^\circ$	$>180^\circ$	$>180^\circ$	$>180^\circ$
	SLL	—	< -30 dB	—	—	—	—
	D	9.8 dB		5.4 dB		7.4 dB	

Notations:

HPBW: Half Power Beam Width
FNBW: First Null Beam Width
SLL: Side Lobe Level
D : Directivity=32400/(HPBW $|_{E\text{-Plane}}$ * HPBW $|_{E\text{-Plane}}$)

Table 2

Important Figures

	Rectangular Aperture	Circular Aperture
Design Keys	• $f_o = 30\ \text{GHz} \Rightarrow \lambda_o = 10\ \text{mm} \Rightarrow a = 1.3\ \lambda_o,\ b = 0.32\ \lambda_o$ • $f_c)_{TE_{01}} = \frac{c}{2b} = 47\ \text{GHz}$ • $f_c)_{TE_{10}} = \frac{c}{2a} = 11.24\ \text{GHz}$ • $f_c)_{TE_{20}} = \frac{c}{a} = 22.48\ \text{GHz}$ (can not be excited) • $f_c)_{TE_{30}} = \frac{3c}{2a} = 33.72\ \text{GHz}$ (the first higher order mode) • $\lambda_p = \lambda_o / \sqrt{1-(f_c/f_o)^2} = 10.79\ \text{mm} \Rightarrow d_1 = 0.7\ \text{mm} = 0.065\ \lambda_p$	• $f_o = 45\text{GHz} \Rightarrow \lambda_o = 6.67\text{mm}$ • $f_c)_{TM_{01}} = \frac{2.4c}{2\pi R} = 47\text{GHz} \Rightarrow R = 2.44\text{mm} = 0.366\lambda_o$ • $f_c)_{TE_{11}} = \frac{1.841c}{2\pi R} = 36.03\text{GHz} < f_o$ • $\lambda_p = \lambda_o / \sqrt{1-(f_c/f_o)^2} = 11.13\text{mm} \Rightarrow d_1 = 0.7\text{mm} = 0.06\lambda_p$

		Rectangular Aperture		*Rectangular Patch*		Circular Aperture	
		E-Plane	*H*-Plane	*E*-Plane	*H*-Plane	*E*-Plane	*H*-Plane
Radiation Patterns	HPBW	110°	40°	85°	110°	85°	70°
	FNBW	$>180^\circ$	130°	$>180^\circ$	$>180^\circ$	$>180^\circ$	$>180^\circ$
	SLL	——	< -30 dB	——	——	——	——
	D	8.67 dB (13.34 mm x 3.19 mm)		5.4 dB (5 x 5 mm)		7.4 dB (*R* = 2.44 mm)	
		30 GHz		30 GHz		45 GHz	
Effciency		High (very small SW loss)		Small (high SW loss)		High (very small SW loss)	

Notations:

HPBW: Half Power Beam Width

FNBW: First Null Beam Width

SLL: Side Lobe Level

D : Directivity=32400/(HPBW $|_{E\text{-Plane}}$ * HPBW $|_{H\text{-Plane}}$)

Claims

1. Device for emitting and/or receiving a signal in the millimetre wave range, characterised in that said device comprises a first metallic layer, a first insulating layer interposed between said first metallic layer and a substrate, said substrate comprising a cavity extending to said insulating layer, and having a second metallic layer at least covering the walls of said cavity and covering part of said insulating layer, said first metallic layer having a slot adjacent to said cavity.

2. Device as in claim 1, wherein said first metallic layer has a slot facing said cavity.

3. Device as in claim 1 or 2, wherein said substrate is selected from the group consisting of semiconductors, plastic, polymers or ceramic materials.

4. Device as in any of the preceding claims 1 to 3, characterised in that the substrate essentially consists of Si and the first insulating layer comprises a Si oxide layer.

5. Device as in any of the claims 1 to 4, characterised in that said first insulating layer includes a polymer material preferably comprising BCB.

6. Device as in any of the claims 1 to 5, characterised in that the cavity is filled with a polymer material, preferably comprising BCB, to increase the electrical length of the cavity.

7. Device as in any of the preceding claims 1 to 6, characterised in that the device further comprises means for generating an electrical signal in the first metallic layer.

8. Device as in any of the preceding claims 1 to 7, characterised in that the semiconductor substrate is an MCM-D substrate.

9. Device for emitting and/or receiving a signal in the millimetre wave range, characterised in that it comprises an array of devices as in any of the preceding claims 1 to 8.

10. Device for emitting and/or receiving a signal in the millimetre wave range, characterised in that it comprises a flipchip of a device as in any of the preceding claims 1 to 9 and a CMOS substrate.

11. Method for manufacturing a device for emitting and/or receiving a signal in the millimetre wave range, characterised in that it comprises the following steps:

    - depositing a first insulating layer on a first side of a substrate,
    - depositing a first metallic layer on said first insulating layer,
    - defining a cavity with predetermined dimensions in said substrate at a second side thereof,
    - depositing a second metallic layer at said second side of said substrate, and
    - removing a part of said second metallic layer located at the bottom of said cavity.

12. The method as in claim 11, further comprising the steps of depositing a second insulating layer on said second side of said substrate and creating an opening in said second insulating layer, the cavity being etched through said opening.

13. The method as in claim 11 or 12, further comprising the step of filling said cavity with a polymer, preferably BCB.

14. The method as in any of the claims 11 to 13, characterised in that the substrate is an MCM-D wafer.

15. The method as in any of the preceding claims 11 to 14, characterised in that the substrate comprises Si and the first insulating layer comprises a Si oxide layer and a polymer layer, said polymer preferably comprising BCB.

16. A method of operating the device of claim 1, characterised in that a signal is generated in the first metallic layer, said signal being transmitted to said second metallic layer and being emitted in the form of radiation therefrom.

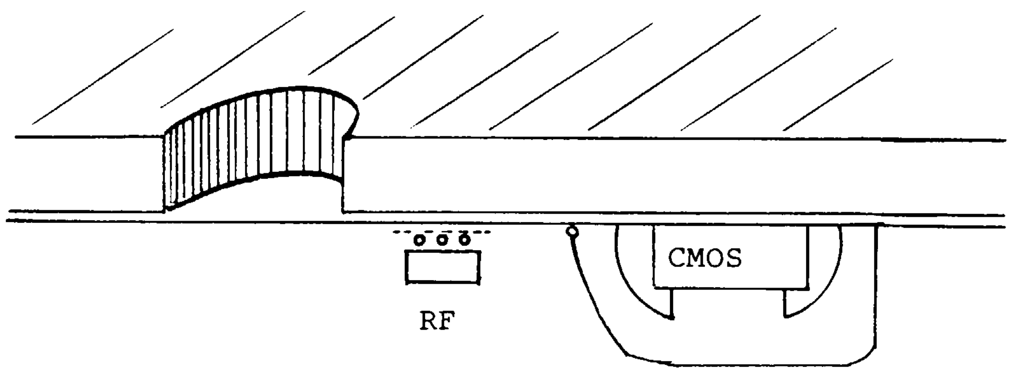

FIG. 1

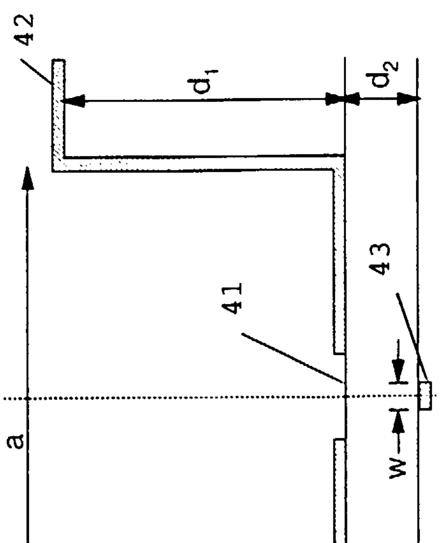

FIG. 2a

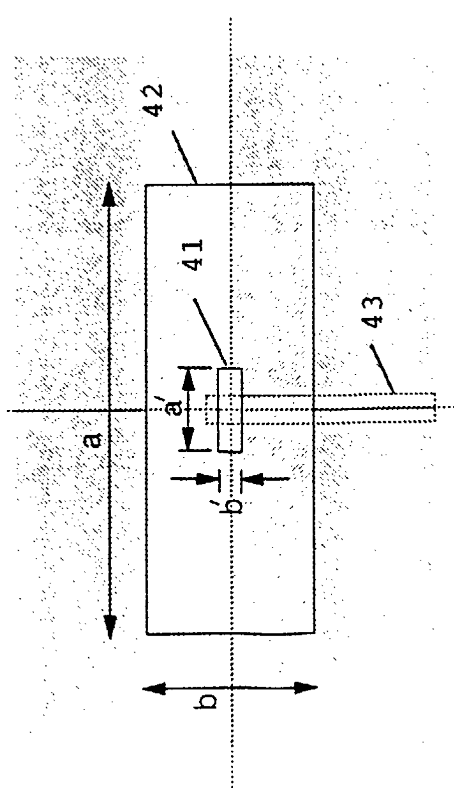

FIG. 2b

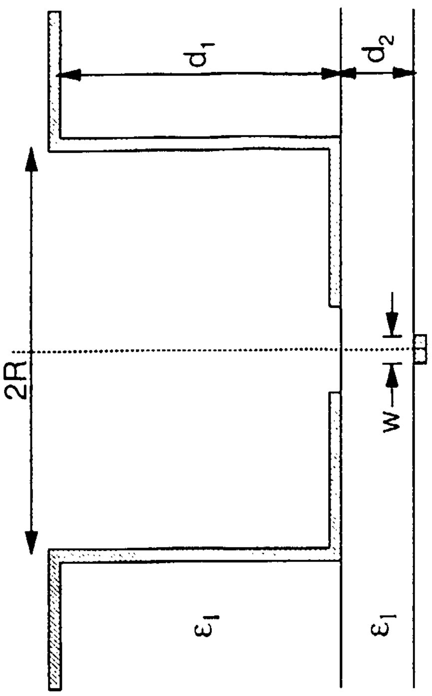

FIG. 2c

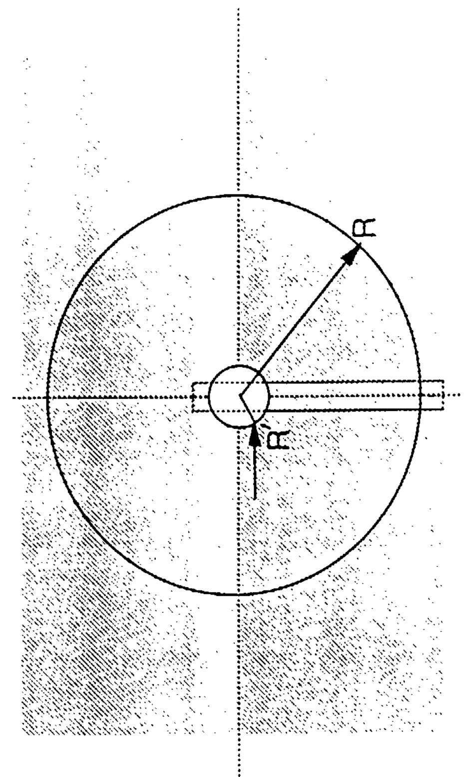

FIG. 2d

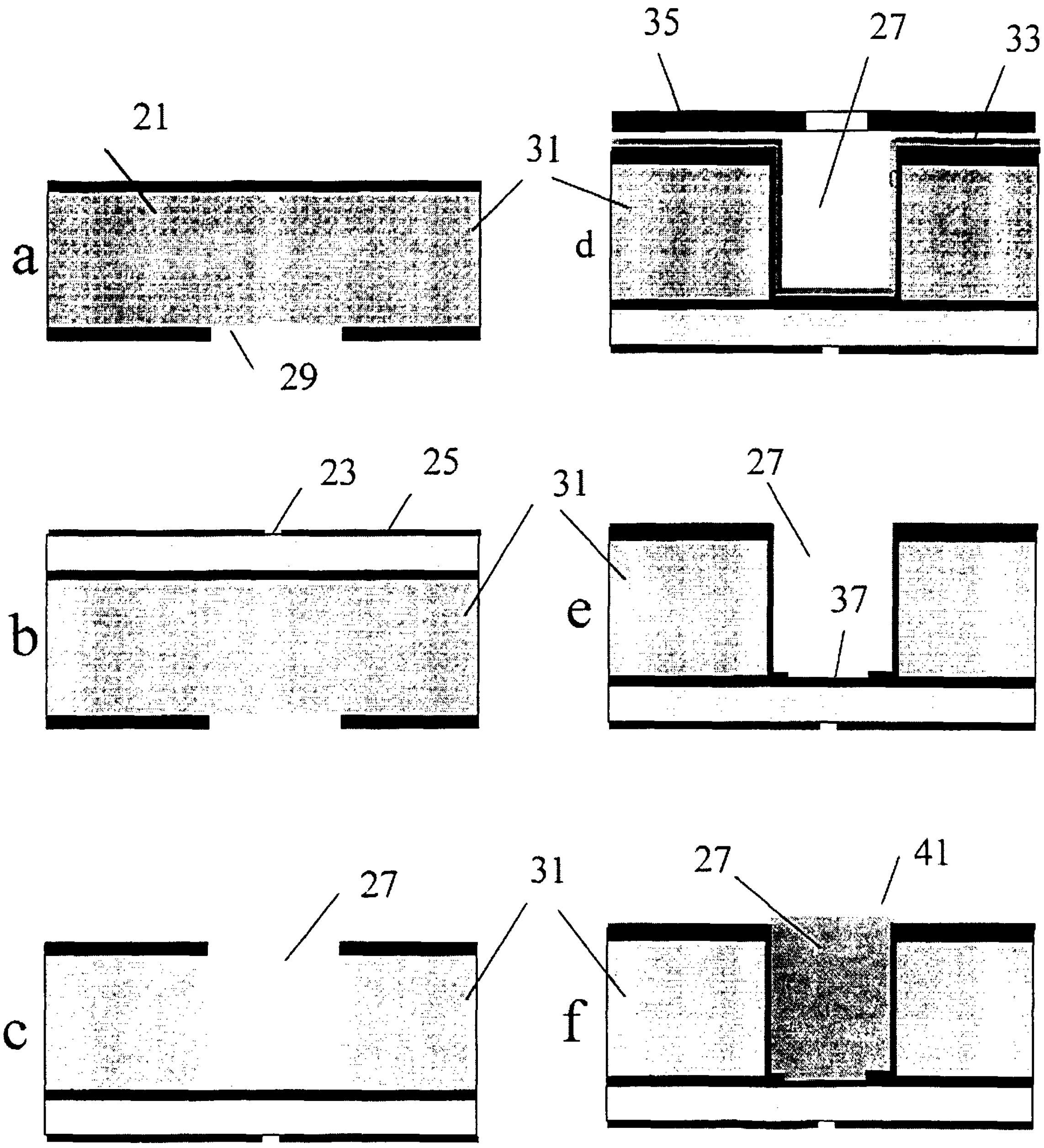

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 99 87 0129

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 November 1999	Van Dooren, G

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EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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