Millimeterwave Integrated Circuits

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Abstract

This paper describes a compact, low cost 50 GHz-band integrated doppler radar module for an automobile ground speed sensor in which a copper embedded Fine Grained Alumina (FGA) substrate is successfully used for good heat-sinking and grounding. Results of an initial study on oscillator stabilization by a dielectric resonator in the millimeterwave region is also described.

1. Introduction

In 1979, the World Administrative Radio Conference adopted a frequency utilization plan for the millimeterwave spectrum beyond 40 GHz. This new plan opens the door for broad commercial applications of millimeter waves.

Millimeterwave integrated circuit technology will be the key to achieving reliable systems which are both compact and cost effective.

The fused quartz substrate, which has been used mainly in millimeterwave integrated circuits (ICs), has weak flexural strength and making it difficult to apply it to actual systems.

Fujitsu solved the problem by developing the Fine Grained Alumina (FGA)(1) substrate.

The FGA substrate is superior to quartz in flexural strength, and has the same surface roughness as sapphire.

Basic parameters of the microstrip line on the FGA were measured in the millimeterwave region and reported earlier (2).

Successful results of passive IC components fabricated on FGA substrates for the millimeterwave region were also reported.

This paper describes a 50 GHz band IC transmitter and receiver module for a doppler radar, fabricated on a new FGA substrate (copper rod embedded).

The new substrate construction employed provides good heat-sinking and grounding for the Gunn diode oscillator.

Results of a feasibility study on oscillator stabilization by dielectric resonator in the millimeterwave region are also given.

2. Fine Grained Alumina (FGA) Substrate

2.1 Basic parameters

FGA is an alumina of the Al_2O_3-MgO-Cr_2O_3 system, cast by the doctor-blading method. Not only is flexural strength (6500 kg/cm^2) superior to quartz (700), but FGA has a surface roughness (0.05 μm) similar to that of sapphire (0.03 μm). A disadvantage of sapphire substrates is their susceptibity to cracks. Other parameters such as dielectric constant, tan δ, and thermal conductivity are 9.8, 0.5 x 10^{-4} and 0.09 (cal/cm · sec · °C), respectively, similar to those of sapphire.

For use in millimeterwave integrated circuits, we chose a 0.2 mm thick substrate to avoid spurious higher modes and at the same time maintain sufficient flexural strength. The cut-off frequency calculated for this thickness is 127 GHz, which is sufficiently above the operating frequency range of 40 to 60 GHz.

Measured propagation loss and effective dielectric constant of the microstrip line fabricated on this substrate were 0.57 dB/cm (Z_0 =50 Ω) and 7.0 at 50 GHz, respectively. FGA performance is high, while it costs only a little more than conventional materials.

2.2 Waveguide to microstrip transition

An integrated front-end module in radio equipment must provide compact and broadband transition from the waveguide to the microstrip line.

Figure 1(a) shows configuration of a conventional transition and Fig. 1(b) shows newly developed one. In these transitions, a microstrip line is inserted into the waveguide perpendicular to the axis of the waveguide. The micrstrip line serves as an antenna.

To get broadband characteristics, the substrate in the waveguide must be as narrow as possible to reduce parasitic reactances produced at the junction. To machine a stepped shaped substrate to dimensions of a few millimeters is quite difficult, so the normal procedure is to prepare two substrates to form a conventional transition. The result is higher cost.

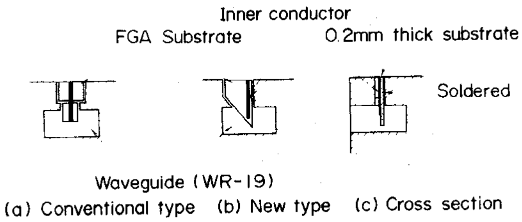

Fig. 1 Configurations of waveguide to microstrip line transition

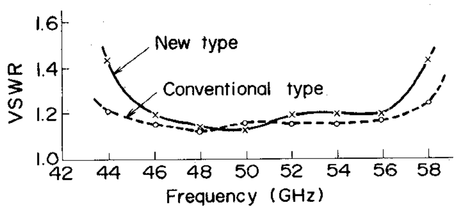

Fig. 2 Frequency responses of VSWR of waveguide to microstrip transition

To solve this problem, we developed a new transition with one substrate, as shown in Fig.1(b) and (c). One end of the substrate is obliqely cut and inserted into the waveguide through a window which has dimensions for cut-off the waveguide mode. This simple construction costs less because of the easy machining, and provides as good performance as conventional transition.

Figure 2 shows typical frequency responses of VSWR of these transitions. Both transitions had VSWR of less than 1.2 and insertion loss of 0.45 dB over a 20% bandwidth centered at 50 GHz.

3. Oscillator stabilization by dielectric resonator

3.1 New substrate configuration for active devices

In the design of an IC oscillator, good heat-sinking and grounding are the most important factors.

Figure 3 shows the new FGA substrate configuration ,which provides low thermal resistance and less series inductance to ground. Copper rods with a 0.3 mm diameter are embedded in holes of the 55 mm square FGA substrate. These holes are drilled before sintering the substrate. After sintering, copper wires are inserted into the holes and excess portions of the wires are cut away. After both surfaces are polished, the substrate is metalized with Ni-Cr, then gold plated on both sides.

Circuit patterns can be formed on the substrate by conventional photolithography. Active devices, such as a Gunn diode chip, can be directly bonded on the copper rod as shown in the figure. Thus, good heat-sinking and direct grounding with less series inductance between the diode and ground are obtained. Thermal resistance is negligible and series inductance is estimated at 0.05 nH.

3.2 Dielectric resonator characterization

Figure 4 shows measured frequency response of unloaded Q factors of dielectric resonators placed on the microstrip line with a quartz spacer disk.

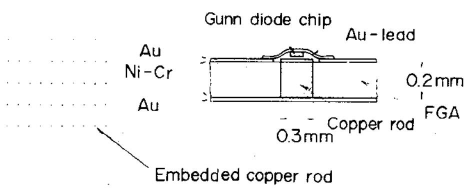

Fig. 3 Copper embedded FGA and circuit application

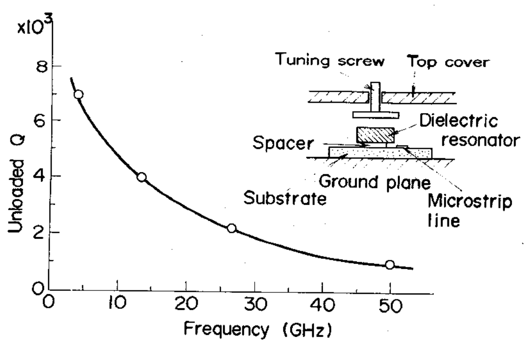

Fig. 4 Frequency response of unloaded Q of dielectric resonator

Dielectric resonators used in these experiments are made of a material system of SnO_2-TiO_2-ZrO and have a dielectric constant of about 40.

The disk shaped dielectric resonator has a temperature coefficient of around 2 ppm/°C at each resonant frequency. The unloaded Q decreased from 7000 at 4 GHz to 1200 at 50 GHz.

3.3 Oscillator performance

In our earlier development of GaAs FET feed-back oscillators stabilized by these resonators, we achieved frequency stabilities of 10 ppm at 4 GHz and 20 ppm at 13 GHz over a temperature range from 0 to 50 °C.

In the 27 GHz band Gunn oscillator stabilized by this new resonator, frequency stability of 100 ppm was achieved with slight mechanical compensation by an external metal screw.

Figure 5 shows the circuit pattern of a 50 GHz oscillator stabilized by a dielectric resonator. A Gunn diode chip is directly die-bonded on a copper rod embedded in the 0.2 mm thick FGA substrate.

External Q of the self-oscillating circuit including the Gunn diode is about 30. The dielectric resonator is placed on the inner-conductor of the strip line with a 0.05 mm thick quartz spacer. Diameter of the resonator is 1.2 mm, and thickness is 0.6 mm. Distance between the Gunn diode and dielectric resonator is almost three-quarters of a wavelength of the oscillating frequency. Measured external Q of this oscillator was about 400, and temperature characteristics are shown in the figure.

Frequency stability of 300 ppm over a temperature range from 0 to 50 °C was obtained with slight mechanical compensation by an external metal screw. Output power is about 13 dBm.

Frequency stability is sufficient for a local oscillator of a doppler radar in which instantenous stability is of greatest concern.

For use in communication systems, however, we must improve stability by one order. To do this, further improvement in the unloaded Q factor of the dielectric resonator is necessary.

4.Doppler radar front-end

An experimental model of a 50 GHz band CW doppler radar front-end was successfully fabricated on a copper embedded FGA substrate for an automobile ground speed sensor.

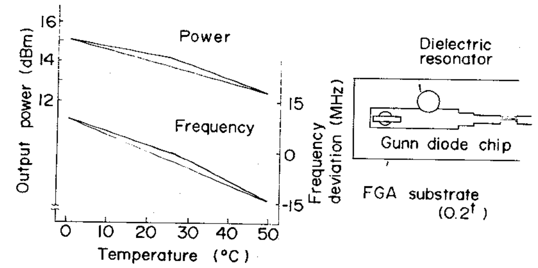

Fig. 5 Temperature characteristics of 50GHz Gunn oscillator

The interior of the front-end mounted in a waveguide flange is shown in Fig.6(a). A Gunn diode oscillator, a single-ended mixer, and a 10 dB directional coupler are integrated on a tiny substrate only 2.5 mm wide and 10.8 mm long. See Fig. 6(b).

To reduce cost, the 10 dB directional coupler is used for diplexing transmitting and receiving signals.

This front-end is a so called homodyne receiver and a doppler shift signal is extracted from the mixer. Minimum detectable signal level of the radar is mainly determined by the noise figure of the mixer in the doppler frequencies from 2 to 15 kHz. These doppler frequencies correspond to vehicle speeds ranging from 25 to 190 km/hour.

Measured noise figures at the doppler frequencies are shown in Fig.7.

As can be seen, Si-SBD is superior to GaAs-SBD in noise figure by as much as 5 dB at these frequencies, although the conversion loss from 50 GHz to 70 MHz is 7.5 dB for Si-SBD and 6 dB for GaAs-SBD.

Output power of the Gunn oscillator is 14.4 dBm at an operating bias of 3.1 volts at 760 mA.

Figure 8 is an exterior view of the doppler radar module with pyramidal horn antenna (22 dB gain) and integrated transmitter and receiver module. This doppler radar module is 40 mm wide 50 mm long, 35 mm high and weighs only 57 grams.

A photograph of the doppler radar installed on the front bumper of an automobile is shown in Fig.8. This photograph was taken just after running tests in heavy snow. Field tests were carried out under various driving conditions with no failures.

Over-all characteristics of the radar module are summarized in Table 1. A minimum detectable signal level of -105.7 dBm was obtained over the frequency range of 0.4 to 4 kHz.

The module showed excellent performance as an automobile ground speed sensor in tests exceeding 2000 km under various conditions.

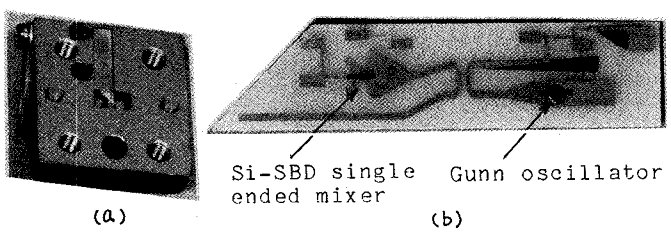

Fig. 6 Doppler radar front-end module

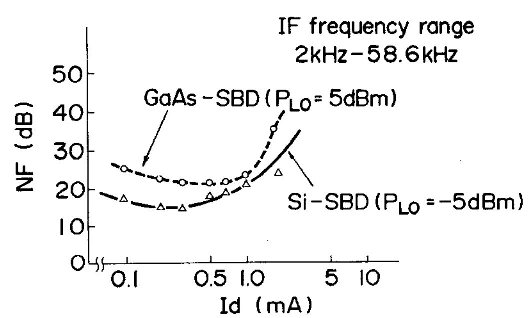

Fig. 7 Noise figure of Si-SBD and GaAs-SBD mixers in the low frequency range

5. Conclusion

A special automobile ground speed sensor has been developed in which a compact, low cost 50 GHz integrated doppler radar front-end was formed on a Fine Grained Alumina substrate. A new substrate configuration (copper rod embedded) was used which provided good heat-sinking and grounding of the Gunn oscillator. Oscillator stabilization by dielectric resonator is feasible at 50 GHz, although unloaded Q of the dielectric resonator must be improved for wide applications.

Acknowledgement

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References

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Fig. 8 50GHz-band doppler radar front-end

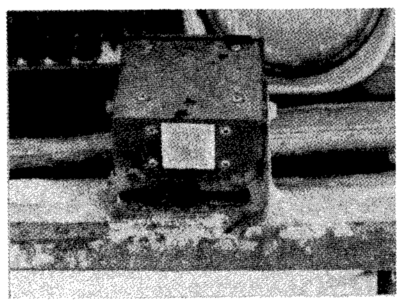

Fig. 9 Millimeterwave doppler radar for automobile ground speed sensor

Table 1 Summarized characteristics of the doppler radar module

Operating frequency	49.4 GHz
Output power (Gunn oscillator)	2.8 dBm (14.4 dBm)
Minimum detectable signal level	-105.7 dBm (IF : 0.4-4 kHz)
Doppler shift frequency	79.4 Hz/(km/H)
Antenna (Gain)	Pyramidal horn (22 dB)
Size	40 mm (W) x 50 mm (L) x35 mm (H)
Weight	57 gr.