A NEW HYBRID TECHNOLOGY FOR MILLIMETER-WAVE INTEGRATED CIRCUITS

A. V. Chenakin[1], A. E. Martynyuk[1] and V. I. Skachko[2]

[1] Mexico National University
Centro de Instrumentos, Cd. Universitaria, A.P. 70-186, C.P. 04510, México, D.F.

[2] Kiev Polytechnic Institute
Pr. Pobedy-37, Kiev 252056, Ukraine

ABSTRACT

This paper presents an original hybrid technology for the production of millimeter-wave integrated circuits which does not require the use of a dielectric substrate as a principal element of the integrated circuit. We propose using a relatively thick perforated plate as a substrate. Thin metal-dielectric structure is deposited on the substrate surface to form effective wide-band bias circuits. This approach permits the realization of the high parameters of the modern solid state devices due both to the extremely low-loss in the matching and bias circuits as well as to the effective heat removal from the solid state devices. The advantages and application of this technology are also described.

INTRODUCTION

At the present time the main approach in the development of microwave integrated circuits is to use a relatively thick dielectric substrate with thin metal layers formed on its surfaces. This technique includes the monolithic technologies where GaAs substrates are used, as well as various hybrid technologies based on alumina, glass ceramic or other dielectric materials. Due to its adaptability this approach is intensively used for the development of various microwave components.

However, with this approach it is quite difficult to take advantage of the opportunities of modern solid state devices with millimeter waves because of the following disadvantages:

a) the relatively thick, imperfect, dielectric substrate concentrates the electromagnetic field resulting in an increase of insertion loss;

b) it is difficult to realize low-loss wide-band bias and choke circuits;

c) the dielectric substrate hinders effective heat removal from the solid state devices resulting in a decrease of their parameters;

d) not all dielectric materials can operate at deep cooling;

e) some dielectric materials have poor long-term stability.

This analysis indicates that an IC which does not use a dielectric substrate as a principal element would be very attractive. This approach was investigated by Konishi [1, 2] but only relatively simple structures were developed because of the absence of appropriate technology for the bias circuit fabrication.

This paper presents an original hybrid technology for millimeter-wave IC production. We propose to use a thick perforated metal plate as the IC substrate while thin film metal-dielectric structures fabricated on the substrate surfaces are used as low-loss wide-band bias and choke circuits. The advantages and application of this technology are described.

GENERAL DESCRIPTION

According to the proposed technology a relatively thick copper plate (0.3-5 mm) is used as a substrate (Fig. 1). Thin metal-dielectric structures (5-7 μm) are fabricated on the polished substrate surface with local film deposition. A special compound dielectric based on SiO is synthesized to decrease tgδ and to provide the necessary adhesion. The measured tgδ of the thin (3-4 μm) dielectric film was less than 0.001 at 20 GHz and the dielectric constant was close to 5.

The perforation of the high-conductive metal substrate was made to form a desired microwave structure: a slot transmission line, ridges of H-waveguide, a metal diaphragm in a waveguide cross section, etc. This structure resulted in a low insertion loss and excellent heat removal.

The thin metal-dielectric structure on the metal substrate permits the realization of extremely low impedance (3-5 Ohm) microstrip lines with the help of standard photolithography processes. DC filters based on such microstrip lines assure an excellent short circuit between the upper conductor and the metal substrate at high frequencies (Fig. 1, point A).

Therefore, at high frequencies the influence of the described metal-dielectric structure is negligible. The proposed integrated circuit may be thought of as a perfect high conductive perforated metal sheet with the biased solid state devices mounted on its surface. This permits the realization of the high parameters of modern millimeter-wave solid state devices.

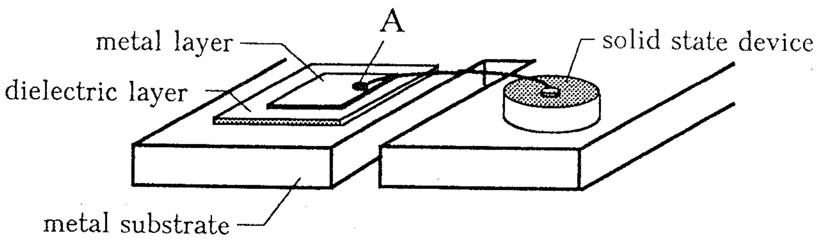

Figure 1: Hybrid integrated circuit based on metal-dielectric-metal structure

TECHNOLOGY DETAILS

Various thin dielectric composite materials were investigated to obtain necessary electrical, chemical and mechanical properties in a wide temperature range. The best result have been achieved with the dielectric material based on SiO. The special dopes were used to assure high dielectric parameters and chemical stability.

The proposed technology for the integrated circuit fabrication is realized as follows:

1. *Substrate preparation.* A copper plate is used as substrate. A mechanical polish followed by a chemical clearing is performed to obtain satisfactory adhesion.

2. *Deposition of dielectric layer.* A thin metal contact mask with special windows is made by the photolithography method. The local areas of the copper substrate are covered by the thin dielectric film using this mask.

3. *Deposition of metal layer.* A thin copper layer is deposited on dielectric film through the same contact metal mask.

4. *Photolithography.* The required topology of bias circuits is performed using the standard photolithography method.

5. *Cutting.* An electroerosion process is used to form the desired microwave structure.

6. *Coating.* The gold coating of the substrate is made to achieve necessary chemical stability and high conductive properties.

7. *Assembling.* Soldering is used for die attaching. Wires are bonded with a thermocompression or ultrasonic power method.

COMPONENT REALIZATION

The following components have been produced using the proposed technology described above:

1. *Waveguide transistor amplifiers.* The amplifier consists of a rectangular waveguide section with a metal substrate that forms H-waveguide ridges as shown in Fig. 2. On one side of the metal substrate the hybrid integrated circuit is fabricated. The described design has all of the above mentioned advantages. Also, due to the low values of the H-waveguide characteristic impedance it is possible to obtain more wide-band matching of millimeter-wave transistors as compared with well-known fin-line designs.

This technique permits the development of effective power amplifiers as well as low-noise amplifiers with an extremely low noise figure [3, 4, 5]. A photograph of amplifier hybrid integrated circuit is shown in Fig. 3. A one-stage low-noise amplifier demonstrated the noise figure of 1.7 dB at 36 GHz without cooling with the JS8910-AS HEMT by "Toshiba Co".

2. *Waveguide transistor mixers.* The amplifier construction may be easily transformed to a FET resistive mixer with the addition of IF filters. The mixer SSB noise figure was about 6 dB (RF - 36 GHz, IF - 1 GHz and the local oscillator power was 4 mW).

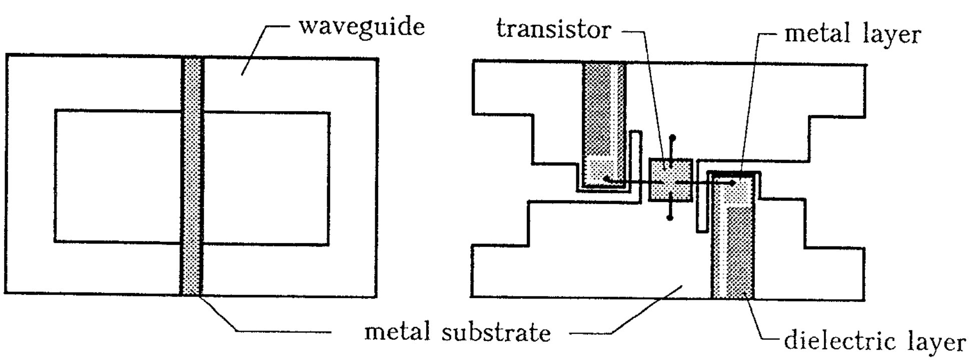

Figure 2: Transistor amplifier design

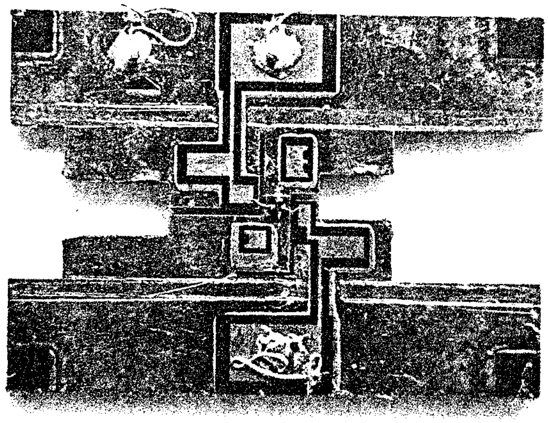

Figure 3: One-stage amplifier hybrid integrated circuit

3. *Waveguide oscillators.* Effective power oscillators as well as local oscillators may be realized in the presented technique. A photograph of a diode oscillator substrate is shown in Fig. 4.

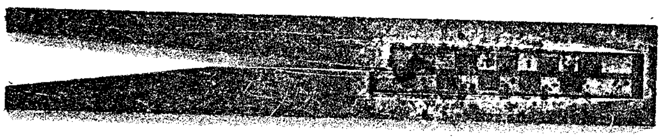

Figure 4: Diode oscillator substrate

The diode is installed on the metal substrate and is connected with the bias circuit as shown in Fig. 5. The

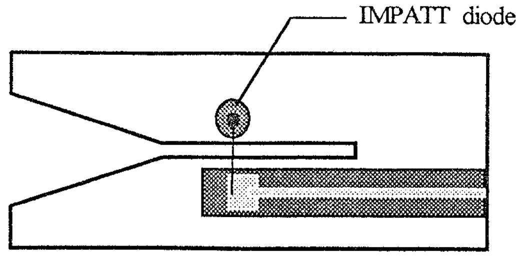

Figure 5: IMPATT diode oscillator design

assembled hybrid integrated circuit is placed into metal housing that forms the H-waveguide transmission line as described above. Such design provides high heat removal from the diode. An IMPATT diode oscillator with 1 mW output power at 107 GHz has been developed.

4. *Waveguide filters.* The advantages of E-plane waveguide filters are well known [6, 7]. Such filters may be easily integrated with the elements described above in a common production process. The single-resonator filter with unloaded Q of 1150 at 36 GHz has been fabricated for a waveguide diode oscillator on a common metal substrate.

5. *Eight-element module for passive phased array.* The module consists of eight reflective circular waveguide radiators which are situated at the nodes of a hexagonal grid (Fig. 6).

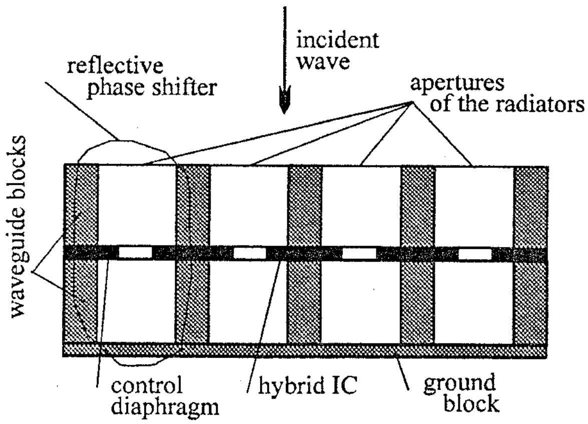

Figure 6: Module of reflective passive phased array

Each radiator contains a polarization reflect phase shifter [8] to change the phase of the incident circular polarized wave. The main element of the two-bit phase shifter is the control diaphragm with three switched on and one switched off p-i-n diodes mounted on its surface (Fig. 7). This control diaphragm is inserted at the cross section of the shorted circular waveguide to provide different reflection coefficients for the orthogonal linearly polarized components of the incident circularly polarized wave. The "dotted-line" linearly polarized component is reflected by the control diaphragm with a reflection coefficient that is approximately 1 due to the parallel resonant

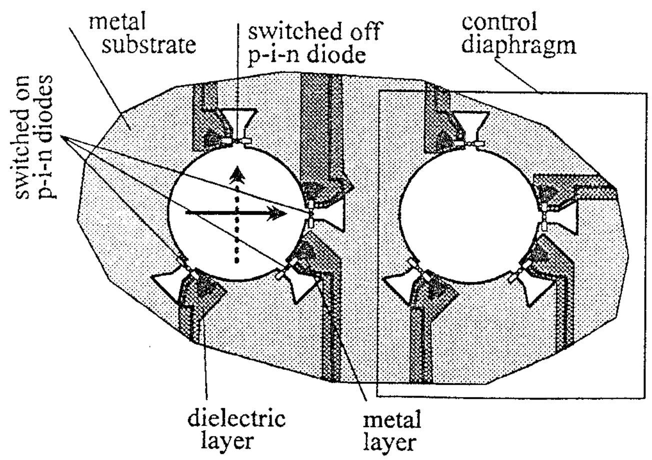

Figure 7: Hybrid integrated circuit containing control diaphragm

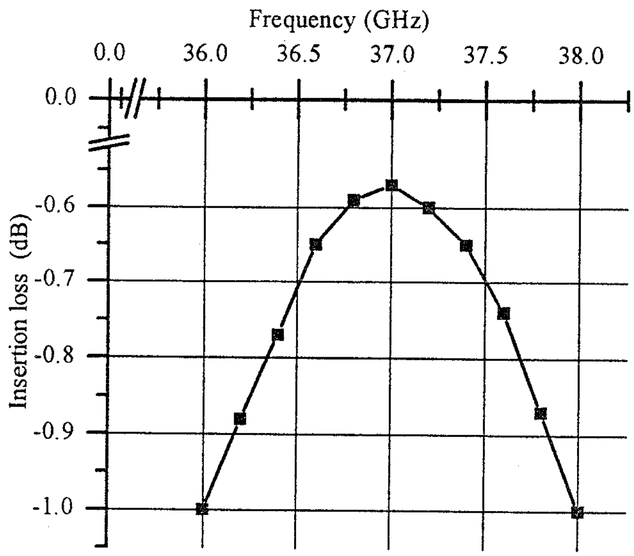

Figure 8: Measured insertion loss of the integrated phase shifter

of the inductive control diaphragm and the shorted waveguide section with capacitive input impedance. The "solid-line" linearly polarized component is reflected by the control diaphragm with a reflection coefficient that is approximately -1 due to the self resonant of the control diaphragm. Therefore, an additional differential phase shift of 180^0 appears between the linearly polarized components of the reflected wave. According to the famous Fox's result the mechanical rotation of such a diaphragm leads to the appearance of the additional phase shift in the reflected circularly polarized wave. With the change of the location of the switched off diode we can obtain a fast electronic simulation of the mechanical rotation at the angles a 0^0, 90^0, 135^0, 225^0. As a result, a 0^0, 180^0, 270^0 or 90^0 phase shift may be obtained in the reflected wave.

The technology mentioned above was used to fabricate the hybrid integrated circuit (Fig. 7) that contains all eight control diaphragms on the common substrate. The integrated phase shifters are characterized by good repeatability. Measured insertion loss of such phase shifter is shown in Fig. 8. Due to the reduction of insertion loss in the bias circuits, the minimal level of insertion loss was less than 0.6 dB and 0.9 dB in the 36-38 GHz frequency range for two- and three-bit phase shifters respectively. For both cases the maximum phase error did not exceed 15 degrees and the accompanying amplitude modulation was less than 0.3 dB.

CONCLUSIONS

A new hybrid technology for millimeter-wave IC production has been presented. The technology has special advantages at millimeter wavelengths due to the removal of the dielectric substrate as a principal element of the integrated circuit. This allows us to take advantage of the high parameters of modern millimeter-wave solid state devices. The proposed technology was applied to fabricate a wide variety of millimeter-wave components: low-noise and power amplifiers, mixers, oscillators, filters, phase shifters, modules of phased array. This approach has yielded good results and may be used for millimeter-wave system production.

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