Improved microwave test fixture for brittle substrate materials

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(Received 7 December 1987; accepted for publication 28 November 1988)

A microwave test fixture has been designed and built to hold brittle substrate materials, such as GaAs, without inducing damage. The substrate pressure is adjustable and easily controlled by the use of compression springs. Tests have shown that the holder does not damage GaAs substrates, and produces repeatable and reliable measurements.

INTRODUCTION

Current research involves the fabrication of optically driven millimeter-wave circuits on GaAs substrates. Optical techniques for millimeter-wave applications have not been used in the past because of the difficulty of modulating an optical carrier signal at high frequencies (above 30 GHz). Recently, a spectrally pure signal was produced at 35 GHz using an injection-locked laser diode.[1] In that experiment, two longitudinal modes of a long-cavity slave laser were locked to the FM sidebands of a master laser modulated at a frequency near 6 GHz. GaAs was chosen as the substrate for these devices because it can be obtained in semi-insulating substrates that have generally good photoconductive properties. This allows for the fabrication of microwave circuits and photodetectors on the same substrate. The first generation devices detected a beat signal from an injection-locked laser with a simple photoconductor that supplied the signal for a ring-resonator microwave circuit. It is necessary to use a high-Q, low-loss circuit to efficiently extract the millimeter-wave beat signal from the injection-locked laser. A ring-resonator design was chosen because of its generally high-Q value and the fact that it does not suffer from end effects. The GaAs substrates must be approximately 15 mil thick to maximize the Q value at 10 GHz and approximately 10 mil to achieve the best possible Q value at 35 GHz.[2] Unfortunately, GaAs is very brittle, and making connection to a circuit fabricated on a thin substrate often results in its destruction. For this reason, it was necessary to design and construct a test holder that would not destroy the delicate circuits. An optical signal is used to generate the microwave output; thus, the holder was designed for easy attachment to an optical *x-y-z* micropositioner in an upright position. Since several dozen circuits are to be tested, it was also necessary to design a holder that could be easily loaded and unloaded for reuse. This article describes a mounting assembly to accommodate delicate substrate materials and to provide a straightforward means of handling, interchanging, and connecting microwave circuits undergoing characterization.

I. CIRCUIT HOLDER DESIGN

Commercially available mounting structures proved to be inadequate because they did not allow for small increments of pressure to be added without the risk of destroying the circuit. A design published recently[3] offered some ideas of how to eliminate of few problems encountered with GaAs substrates. In this particular design, conductive rubber was used to moderate some of the pressure applied to the circuit, thus decreasing the risk of destroying the substrate. The substrate was bonded to a metal base and brought slowly into contact with the tab terminals by a screw beneath the base. Unfortunately, this design does not allow for the circuit to be adjusted under the tabs, and too much pressure added to the circuit will cause the tabs to bend. Thus, it was necessary to design a circuit to alleviate these problems in addition to meeting the above criteria.

Several fixture designs were constructed and tested before arriving at the one described in this text. Early models of substrate mounting assemblies proved to be inadequate because the substrate was brought into contact with the microwave connectors with clamps or screws. For this reason, it was difficult to make small increments in the applied pressure to the substrate, which resulted quite often in the destruction of the circuit. Other problems encountered were difficulty with loading and unloading, poor grounding of the microstrip ground plane, and flexure of the tab terminal connectors. The following mounting assembly was designed to address the above problems.

Figure 1 shows the mounting fixture with a ring-resonator circuit on a GaAs substrate installed. The structure is composed mainly of brass because of its high conductivity and its machining ease. The GaAs substrate can be bonded to a sliding substrate plate to allow for lateral alignment with

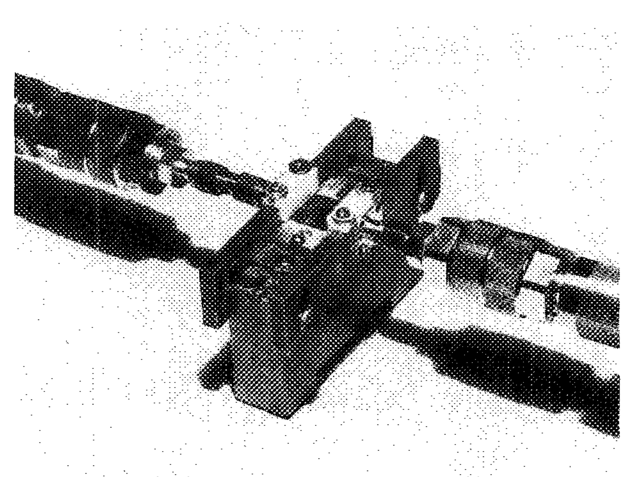

FIG. 1. Spring-loaded test fixture showing a ring-resonator circuit on a GaAs substrate installed for testing.

the microstrip jack receptacles and increase the durability of the substrate. This substrate plate is fastened to an adjustable pressure plate. To eliminate the problem of destroying delicate circuits, the substrate pressure is applied by four adjustable compression springs (unseen) that push on the pressure plate. Teflon stops are fastened above the tabs to prevent flexure from the applied pressure. The side panels attached to the main body can be adjusted vertically for different substrate thicknesses.

The main body for the fixture was designed such that all pieces could be installed separately (Fig. 2). The width of the main body is large enough to allow a laser focusing lens to be brought very close to the substrate. The block design allows the holder to be stood upright on any side. The gap through the top center allows the pressure plate to be recessed for substrate loading. Four holes were drilled at the corners in the top gap for the springs. The bottom half of the holes were threaded, and the top half were redrilled with an oversize bit to enlarge the holes and ensure that the springs would move easily. Nubs were machined at the end of four round-head machine screws so that the springs could be easily attached. This allows the height of the springs to be changed by simply turning the screws in or out. The springs with the screws could then be inserted into the bottom of the structure and fastened into place. A large gap was milled through the bottom center such that the compression spring screws would be recessed, thus allowing the fixture to be stood upright without interference from the screws. Two side panels were machined to the exact thickness of the feed through extension of the subminiature type A(SMA) jack receptacles to be used so that they would be flush with the inside. Adjustment slots were milled at each end for attachment to the main body, and holes were drilled at the upper center for the jack receptacles. A Teflon stop was installed on each side panel above the tab terminal to prevent the tab from flexing upward when pressure is applied. Holes were drilled and tapped on each side of the main body for the side panels. The pressure plate is 100 mil thick and was machined

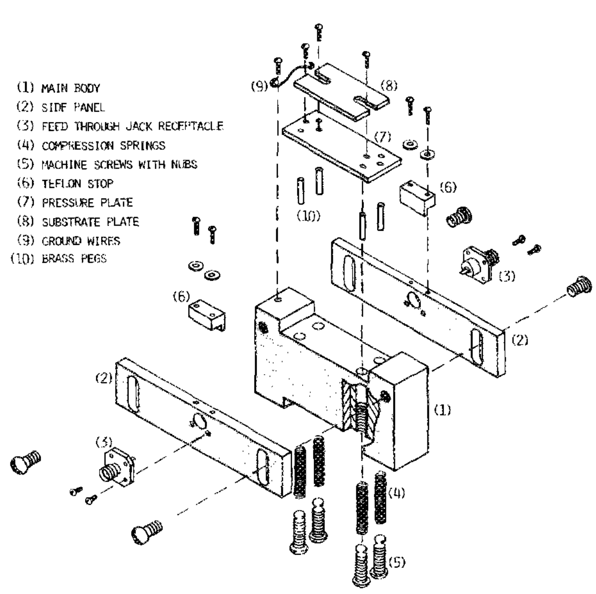

FIG. 2. Exploded view of the spring-loaded microwave test fixture.

to fit exactly inside the top gap of the main body with enough tolerance to allow for easy movement. Four holes were drilled in the pressure plate to exactly align with the compression spring holes in the main body. Four brass pegs were then press fit into the holes in the pressure plate. It is important to use pegs that easily slide into the compression springs since it is these pegs that align the pressure plate and allow for rotation adjustments of the springs. Two small holes were then drilled and tapped into the pressure plate to allow attachment of the substrate plates. These substrate plates are also 100 mil thick, but are at least 500 mil shorter than the pressure plate. This allows for removal and insertion when the holder is fully assembled. The substrate plates have slots milled at each end for lateral adjustments. Another hole is drilled and tapped at one end of the pressure plate to attach ground wires to the main body.

Since the compression springs allow for very small increments of pressure, the force on the substrate can be easily controlled and it is not necessary to bond most substrates to substrate plates before insertion. Substrates that are silver epoxied to the substrate plates are inserted into the fully assembled mounting structure and fastened with a second screw that is inserted after the plate is positioned. These screws help to ensure proper grounding. Additional adjustments can be made if necessary by simply loosening the two substrate plate screws and sliding the plate to the proper position. Adjustments are made to level the pressure at each corner of the pressure plate until the desired force on the substrate is reached. It is important that the pressure be evenly distributed to avoid tilting.

II. SAMPLE PREPARATION

The following procedures were used to prepare the samples made of Duroid and also of GaAs which were tested in the substrate holder. In preparing the Duroid sample, a copper stripline is fabricated by first drafting an oversized illustration of the desired microstrip. This is photographed and reduced to produce a properly proportioned negative. Negative photoresist is then spun onto a copper-plated sheet of Duroid and exposed with the photographic negative as a mask. The resist is developed and hard baked to produce an image of the stripline. The copper-plated Duroid is then chemically etched, and the remaining photoresist is removed.

Gold striplines are fabricated on a GaAs substrate as follows. The GaAs substrate is cleaned and placed in a dc sputtering system where 400 Å of Ni followed by 1000 Å of Au are deposited for the grounding plane. The Ni layer helps to bond the Au to the substrate. The ground plane is then increased to at least four skin depths for the desired frequency with gold electroplating. Afterwards, the substrate is turned over and 400 Å of Ni are sputtered onto the front. A plate-through process[4] is used for the metallization where Shipley S1400-37 positive resist is spun onto the substrate, and the strip pattern is exposed and developed in the resist. The result is an insulating positive trench pattern of the microstrip that serves as a guide for the microstrip during the plating process. Photoresist is brushed onto the back of the substrate to insulate the ground plane from the electroplating bath. After a hard bake, the substrate is lowered into a

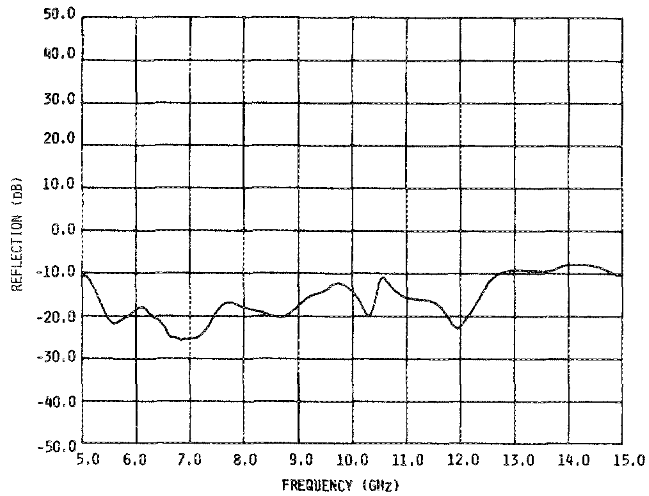

FIG. 3. Reflection (S_{11}) characteristics of a microstrip fabricated on Duroid 5870 ($\epsilon_r = 2.33$) and tested in the test fixture for frequencies ranging from 5 to 15 GHz.

gold-plating bath and 3–4 μm of Au are plated on the exposed surface. The substrate is then lowered into Nophenol 922 at 95 °C, which removes the photoresist and the underlying Ni layer. Any residual resist is removed with an O_2 plasma. The substrate is then trimmed to the proper proportions using a laser trimming system.

GaAs microstrip circuits to be permanently mounted are prepared for testing as follows. A thin film of silver epoxy is spread onto a clean substrate plate, and the substrate is gently pressed into place. This requires extreme care in order to not fracture the brittle substrate. The substrate and brass substrate plate are then baked at 90 °C for 1 h. The brass plate provides a thick ground plane for the circuit and a strong back support that aids in the handling of the circuit. It should be noted that a much thicker ground plane (at least four skin depths) must be sputtered or plated on the back of the microstrip substrate if the experimenter does not wish to permanently mount it to a substrate plate.

III. TESTING PROCEDURE AND RESULTS

A 50-Ω microstrip was etched on a Duroid 5870 substrate with ϵ_r equal to 2.33. This microstrip was loaded into the holder and revealed a maximum reflection loss (S_{11}) of -11 dB in the range between 5 and 12 GHz with an increasing reflection loss at frequencies above 13 GHz. The transmission losses (S_{12}) on this microstrip ranged from -1 to -3 dB between 5 and 12 GHz with increasing losses above 13 GHz. The S_{11} and S_{12} characteristics of the stripline fabricated on Duroid 5870 can be seen in Figs. 3 and 4, respectively. The higher losses above 13 GHz can be attributed to the losses from the connectors and the losses in the microstrip at higher frequencies.

A 50-Ω gold microstrip line on GaAs was also fabricated to test the reliability of the holder. This microstrip was loaded into the holder without being bonded to a substrate plate and revealed a maximum reflection loss (S_{11}) of -9 dB in the range between 5 and 12 GHz. The average value of S_{11} was much lower than -9 dB between 5 and 12 GHz with an increasing loss above 12 GHz. The S_{12} characteristic revealed losses ranging from -1 to -7 dB between 5 and 15 GHz. The S_{11} and S_{12} characteristics can be seen in Figs. 5 and 6, respectively. Much of the loss seen can be attributed to the connectors and some impedance mismatch of the microstrip. This substrate was inserted and removed from the circuit several times, resulting in no breakage, and showed the same microwave characteristics upon every test.

IV. DISCUSSION

The holder was designed to circumvent the problem of destroying brittle substrate materials. After over a year use and over 100 insertions, no GaAs substrates have been destroyed to date with the use of this mounting structure, with or without being bonded to a substrate plate. The holder has been used repeatedly, and is easy to load and unload. Tests reveal that the ground connection is adequate and stable, and that the output results are repeatable on every substrate thus far. The holder can also be easily attached to an optical

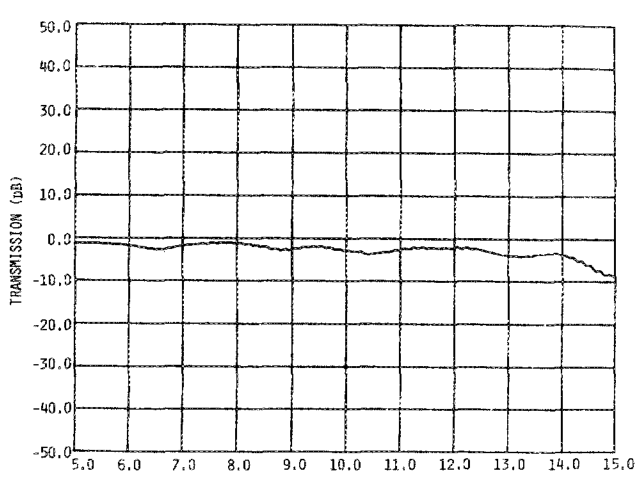

FIG. 4. Transmission (S_{12}) characteristics of a microstrip fabricated on Duroid 5870 ($\epsilon_r = 2.33$) and tested in the test fixture for frequencies ranging from 5 to 15 GHz.

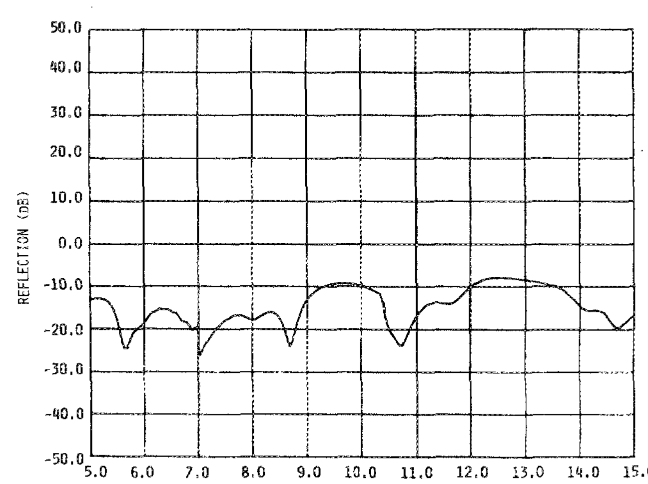

FIG. 5. Reflection (S_{11}) characteristics of a microstrip fabricated on GaAs (from the text) and tested in the test fixture for frequencies ranging from 5 to 15 GHz.

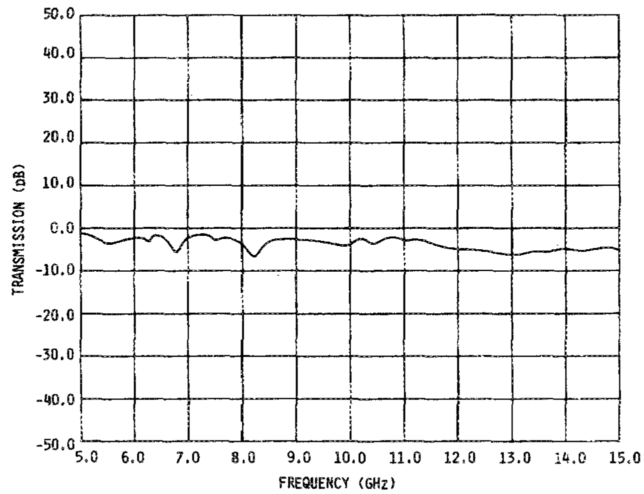

FIG. 6. Transmission (S_{12}) characteristics of the microstrip fabricated on GaAs (from the text) and tested in the test fixture for frequencies ranging from 5 to 15 GHz.

x-y-z micropositioner in an upright position for optical signal insertion. The tabs do not flex when force is added to the pressure plate, indicating that the Teflon stops have helped to minimize the problem. The S_{11} measurements revealed a maximum reflection loss of -11 dB for a microstrip on Duroid 5870 and -9 dB for a microstrip on GaAs at frequencies below 12 GHz. The S_{12} measurements showed a maximum transmission loss of -3 dB for a microstrip on Duroid 5870 and -7 dB for a microstrip on GaAs at frequencies below 12 GHz. Jarring the fixture did not affect the output of the microstrips tested, and repeated removal and reinsertion of the substrates yielded the same results, showing that the holder is reliable.

ACKNOWLEDGMENT

This work was supported in part by the Office of Naval Research under Contract No. N00014-86-K-0348.

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