On-Wafer Testing of MMIC with Monolithically Integrated Photoconductive Switches

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Abstract

This is the first report that photoconductive (PC) test structures have been fabricated monolithically with MMIC amplifiers for microwave characterization using a optical technique. Good agreement has been obtained between the measured results and those obtained from a conventional network analyzer.

I. Introduction

Photoconductive (PC) sampling has been demonstrated as a useful technique for the characterization of microwave/millimeter wave integrated circuits [1]. One of the main advantages of this measurement technique is that the electrical pulse signal containing the microwave spectrum is generated on-wafer, alleviating the need for high-frequency probe contacts. Only low-frequency sampled signals need to be extracted from the device under test (DUT). In addition, this technique allows broadband characterization from a single measurement.

To apply the PC sampling technique to on-wafer characterization of a GaAs monolithic microwave integrated circuit (MMIC), two requirements must be met. First, PC switch fabrication must be compatible with the GaAs MMIC production process. In a hybrid case, we have previously demonstrated that PC sampling can be preformed with switches fabricated to these specifications [2]. This compatibility allows monolithic integration of the PC switches with the MMIC. Second, only DC probes should be used to generate and extract the signal from the wafer, hence avoiding the need for high-frequency contact. Monolithically integrated on-wafer sampling of a MMIC has been achieved. Additionally, it has been demostrated that PC sampling can be used to measure the S_{21} of a nonlinear transmission line.

II. Experiment

Photoconductive sampling of a 12 GHz 2-stage MMIC amplifier was performed using ~ 3 - 5 ps 0.527-μm mode-locked laser pulses with an average power of 50 mW at a 76 MHz repetition rate. To facilitate on-wafer testing, a DC tungsten probe station was developed. These probes were used to bias the MMIC and the generation gap switch, and to extract the cross-correlated signal from the sampling ports. A high-resistivity probe is required to bias the generation switch gap. The DC probes provide the only electrical contacts to the MMIC. With the exception of this probe station, the standard optical generating and sampling method was used for the measurement [1].

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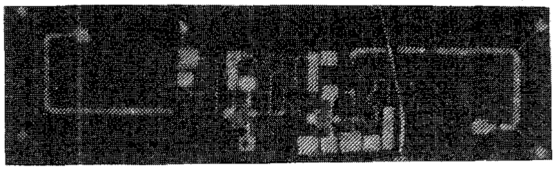
One important consideration limiting the commercial viability of on-wafer optical measurement techniques is the size of the GaAs real estate required for the built-in optical test structure. Two different methods were used in an attempt to reduce the size of these structures. One utilized a bent microstrip line, while the other used a test structure whose size is comparable to that used in a conventional coplanar waveguide (CPW) probe, referred to here as the de-embedding structure. De-embedding is a computational procedure devised to extract S-parameters from a DUT in the presence of other scattering sites.

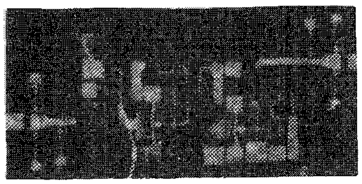
The various test structures are shown in Figure 1. Figure 1a shows the bent microstrip with generating and sampling gates monolithically fabricated with the DUT. In this configuration, chamfered corners for the microstrip line are used. Figure 1b depicts the DUT measured using the second method. Data obtained from measurements of this device were compared to reference through-line measurements to compute the true input signal to the MMIC. Figure 1c, which shows the test structure required for the CPW probe, is included as a comparision of the wafer sizes required for the various methods. All these MMIC chips are mounted on gold-plated kovar slabs and attached to a small metal block having a tapped hole on the bottom.

Accurate characterization of the MMIC using the PC sampling technique requires careful calibration of the PC switches. A DC signal is usually applied to the microstrip and the on-state and off-state resistances are measured. In the case of the monolithic test structure, the microstrip is terminated in a 50 Ω integrated resistor. This prevents application of a large DC signal on the line to calibrate the switch sensitivity. Instead, a needle probe is used to deliver 4-V, 80-μs electrical pulses with a 1.2-kHz repetition rate on the line. This signal, detected by a lock-in amplifier, serves as the reference for cabibration.

Finally, we investigated the case of photoconductive sampling as a tool to characterize nonlinear devices. Due to its broadband nature, PC sampling allows characterization of S-parameters of nonlinear devices which can not be characterized by the conventional network analyzer. The conventional network analyzer can extract only the harmonic frequencies due to the nonlinear response from the device. It this paper, we will demonstrate S-parameter characterization of a nonlinear device, particularly, a nonlinear transmission line.



(a)



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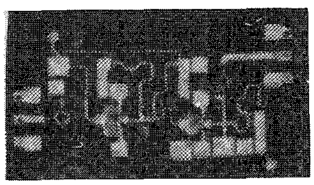

(c)

Fig. 1 MMIC broadband amplifiers with (a) bent structure (b) de-embeding structure (c) CPW test structure.

III. Results

The typical input and output waveforms from the built-in optical test structure configurations are shown in Figures 2 and 3. The multiple peaks of the input waveforms are a result of reflections from the end of the biasing side line, which is a shunt microstrip line designed to minimize the discontinuity seen by the electric pulse on the main microstrip line. Both methods give reasonable results compared to the conventional network analyzer measurement, as shown in Figure 4. Some discrepancies can be attributed to the nonuniform performance of the specific circuits tested.

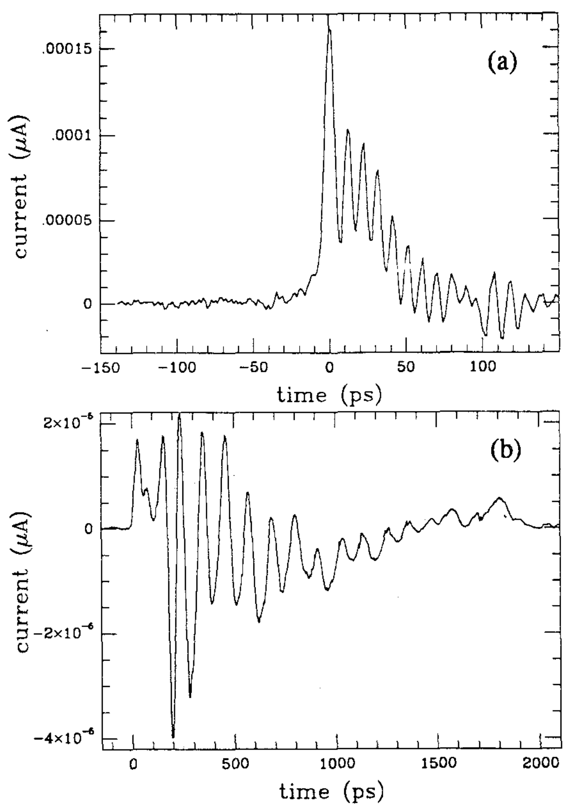

Fig. 2 (a) Input and (b) output waveforms for the bent structure.

Since the reflection at the end of biasing side line depends on the exact position of the probe on the contact pad, different probe positioning can slightly alter the shape and timing of the reflection. This effect is more pronounced in the case of a de-embedding structure because the needle probe may not be at the corresponding position when measuring the responses of the MMIC and the through-line calibration structure. The exact position of the generation gap biasing probe can not be duplicated from device to device or from measurement to measurement. With the implementation of a DC probe, which has a built-in chip resistor, the mechanical constraints in positioning the probes on the contact is not critical. We found that a ~ 50 - 100 Ω chip resistor gives the best attenuation. Larger resistance may cause more radiation coupling across the chip resistor resulting in less attenuation. This also suggests that it is possible to use a lossy biasing side line to reduce the reflection from probe/side line contact.

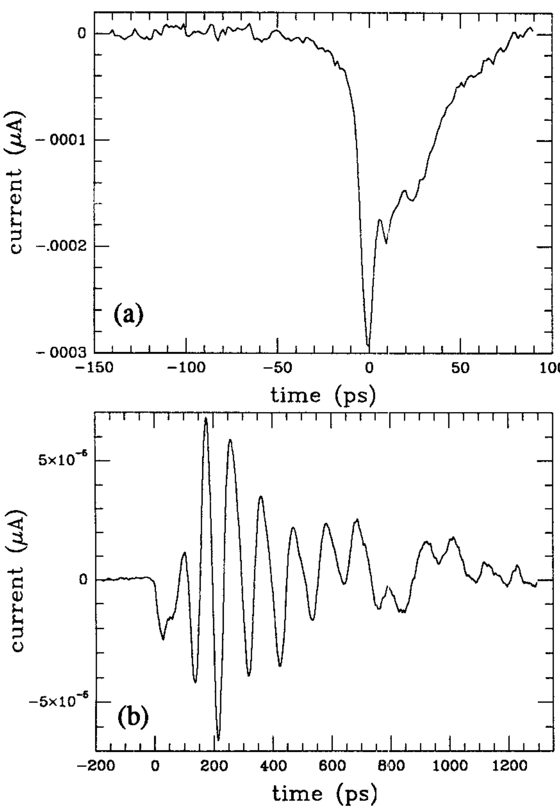

Fig. 3 (a) Input and (b) output waveforms for the de-embeding structure.

Using the same built-in structures, we are able to characterize nonlinear circuits. Figure 5a shows the input and output waveforms measured from a nonlinear transmission line. The pulses become narrower after propagating along the line. Due to this nonlinearity, new frequencies are generated; therefore, some frequencies experience gain. The magnitude of S_{21} of this nonlinear transmission line is shown in Figure 5b. Figure 6 shows the dependence of the magnitude of S_{21} on the input signal amplitude. With a larger signal on the line, the loss due to voltage-dependent capacitance between the microstrip line and the wafer becomes larger, increasing the loss assoicated with the structure.

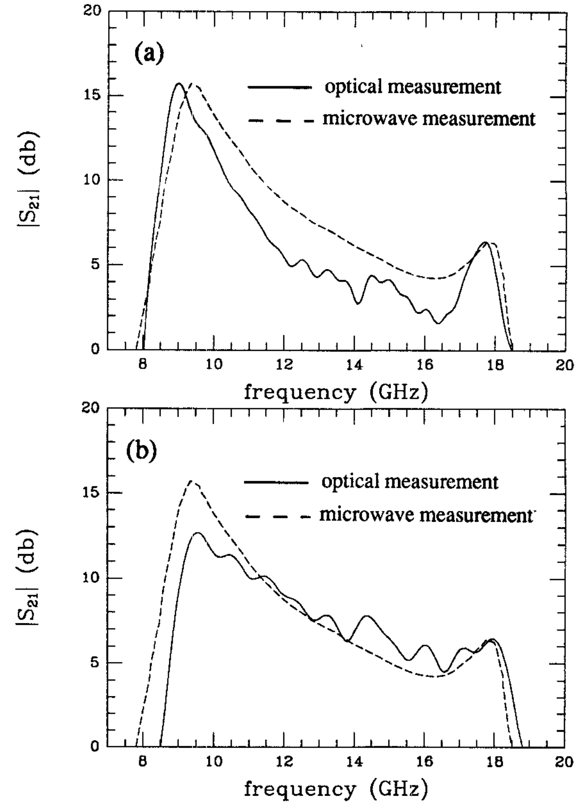

Fig. 4 Comparison of $|S_{21}|$ of the microwave network analyzer to those obtained by (a) bent structure and (b) de-embedding structure.

IV. Conclusion

For the first time, this paper presents on-wafer photoconductive sampling and characterization of a MMIC with a monolithically integrated optical test structure. Reasonable agreement has been achieved between the conventional network analyzer measurement and two optical test results. This shows that a test structure designed to reduce the overall size can be used. Better measurement accuracy can be obtained by designing the biasing side line to suppress the unwanted reflections. The S-parameter characterization of a nonlinear transmission line has also been demonstrated.

This work was supported by the DARPA MIMIC Phase III Program, monitored by the U.S. Army Labcom.

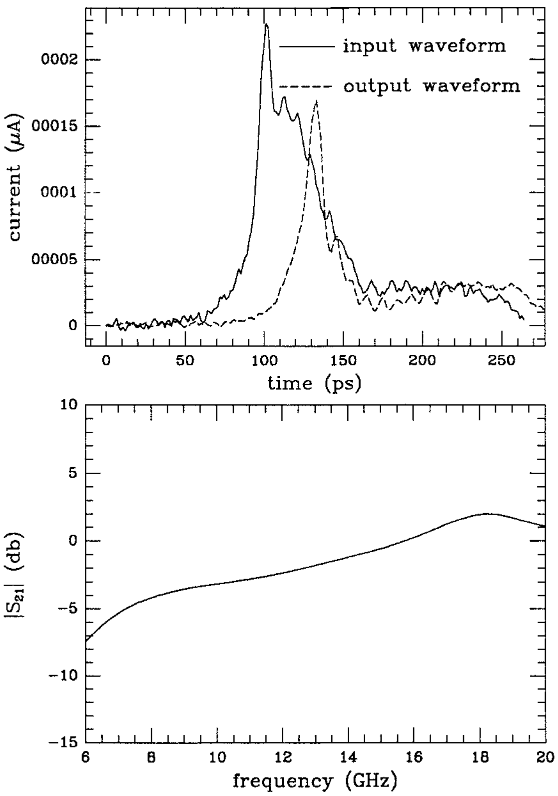

Fig. 5 (a) Input and output waveforms and (b) $|S_{21}|$ of the nonlinear transmission line.

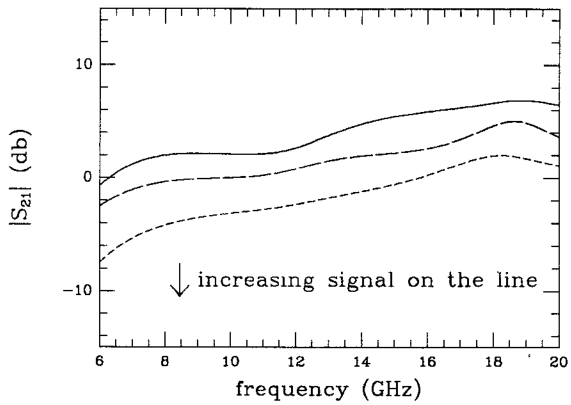

Fig. 6 Signal dependence of the $|S_{21}|$ of the nonlinear transmission line.

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[2] S. L. Huang, E. A. Chauchard, C. H. Lee, T. Smith, T. T. Lee, T. R. Joseph,"Comparison of oxygen ion and proton implanted GaAs photoconductive switches," in *OSA Proceedings on Picosecond Electronics & Optoelectronics* **9**, p. 248-252, Mar. 1991.