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PROBE TIP INVASIVENESS AT INDIRECT ELECTRO-OPTIC SAMPLING OF MMIC

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Abstract

For the first time, a systematic experimental investigation up to 40 GHz of the invasiveness of an electro-optic probe tip at indirect electro-optic sampling of MMICs is made. The direct electro-optic sampling technique is used to measure the influence on the transmission characteristic of a coplanar waveguide. As far as possible the results are compared with network analyzer measurements.

INTRODUCTION

The progress in the development of modern MMICs requires a powerful test technique for circuit internal function and failure analysis. For future MMIC generations conventional electric test systems such as sampling oszilloscopes or network analyzers (NWA) are limited in their applicability. For any internal test they suffer from their need to use special probes featuring large size and significant parasitic impedances [1].

Promising circuit internal test techniques offering high sensitivity and, additionally, high spatial and high temporal resp. frequency resolution are the direct [2-5] and the indirect [6-9] electro-optic (e-o) sampling techniques. Both techniques are based on the electric field-induced birefringence of an e-o material. In case of the direct e-o sampling the substrate of the MMIC is used as an e-o modulator and the electric stray field of the test point inside this substrate can be tested. In case of the indirect e-o sampling an e-o probe tip (e. g. KD*P) is immersed into the electric stray field above the test point. Therefore, the electric stray field above the circuit inside the e-o probe tip can be tested.

To increase the sensitivity of an indirect e-o sampling system the working distance between the test point and the probe tip has to be decreased [7]. On the other hand, several authors [7, 9-12] have shown that due to the close placement of the probe tip to the test point and its high permittivity the pertubation of a propagating electric waveform increases with decreasing working distance. This has two consequences: 1. It may lead to a malfunction of the circuit [11], i. e., this test technique may no longer be noninvasive. 2. The measurement may be influenced, i. e., the probe tip may lead to measurement errors [11]. A compromise between working distance and invasiveness has to be found. Therefore, it is of crucial importance to know how large the perturbations are.

Most of the papers dealing with the influence of the e-o probe tip on electric waveforms have presented results based only on simulations [7, 10, 11]. To our knowledge there are only few papers presenting experimental results. [6, 9] show only an example of an electric waveform perturbation. Moreover, the distorted electric pulse has been measured with an e-o probe tip. In [12] the investigation about the invasiveness is based on the evaluation of standing waves measured with the direct e-o sampling technique but without variing the working distance.

In this paper we present a more systematic experimental investigation of the invasiveness of an e-o probe tip for different geometries and working distances up to 40 GHz by using the direct e-o sampling technique. As far as possible the results are compared with measurements made with a network analyzer.

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INDIRECT AND DIRECT ELECTRO-OPTIC SAMPLING GEOMETRIES

Fig. 1 shows the indirect and the direct e-o sampling geometries for measuring the electric waveform on a coplanar waveguide (CPW) above the circuit and inside the substrate. In case of the indirect e-o sampling geometry (a) an e-o probe tip is immersed into the electric stray field with a working distance *d* above the test point. The laser beam is focussed through this tip and is reflected either from the center electrode or the ground electrodes. In case of the back side geometry of direct e-o sampling (b) the laser beam enters the MMIC from the back side

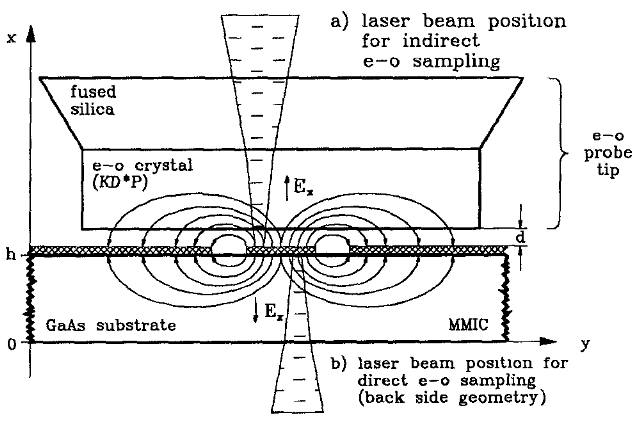

Fig. 1: Sampling geometries used for probing MMICs based on CPW technology. a) Probe tip geometry for indirect e-o-sampling of the electric fields above the circuit. b) Back side geometry for direct e-o sampling of the electric fields within the circuit substrate.

and is reflected from the electrodes. The polarization of the laser beams is changed either by the electric stray field inside the e-o crystal above the circuit or by the stray field inside the e-o substrate. This change in polarization which can be converted into a change of the detected laser intensity by a Pockels-cell is proportional to the test point signal.

EXPERIMENTAL SET-UP AND TEST STRUCTURE

The measurements are carried out with the experimental set-up as shown in Fig. 2. A mode-locked cw Nd:YAG-laser system driven at a repetition frequency of 76 MHz produces optical pulses of 1.064 μm wavelength and 90 ps duration. A fiber-grating pulse compressor reduces the pulse duration to less than 5 ps. Due to the use of a timing stabilizer the temporal jitter is less than 1 ps. The circularly polarized laser beam is focussed by a 20x microscope objective from the back side of the MMIC onto the test point with a beam diameter of less than 5 μm and with an accuracy of ±0.1 μm within the MMIC. The reflected elliptically polarized laser beam is separated into its two orthogonal polarization components by a polarizing beamsplitter and is detected by two photodiodes. A lock-in amplifier measures the difference signal and gives values representing the amplitude of the component E_x of the tested electric field integrated over the laser beam path within the substrate. The sensitivity of the measurement system is 0.1 $mV/\sqrt{Hz}$.

The circuit under test is driven by a microwave synthesizer tuned to exactly the N-th harmonic of the laser pulse repetition frequency with an offset Δf of 3 kHz. By using the harmonic mixing technique [2], the frequency spectrum of the laser beam pulse is mixed with the spectrum of the microwave signal resulting in a transformation of the microwave signal frequency f down to the frequency Δf which can easily be processed furtheron. The frequency characteristic of the test point can be measured by variing N. An electric network analyzer has been connected to the test structure for performing the electric measurement of the transmission coefficient $|S_{21}|$.

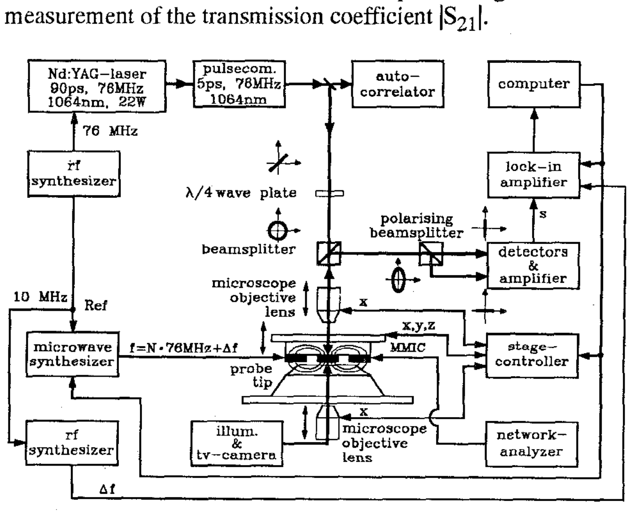

Fig. 2: Experimental set-up.

We have used a 500 μm x 500 μm x 200 μm piece of KD*P glued to a pyramid-support made of fused silica as e-o probe tip. The working distance d has been varied between 0 μm and 50 μm for measuring the invasiveness of the probe tip.

The test structure used for the measurements is built up on a 2 x 3 mm^2 wide and 410 μm thick semi-insulating GaAs-chip (Fig. 3). It consists of a set of 50 Ω CPW. For the measurements only CPW 3 within the test structure has been used.

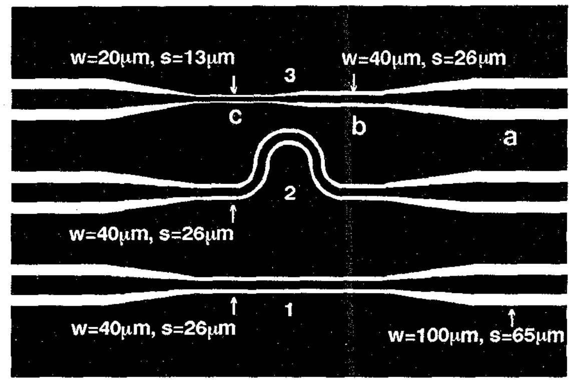

Fig. 3: Layout of the test structure based on a 410 μm s. i. GaAs substrate with different coplanar waveguides (1, 2, 3) and test points (a, b, c).

The test structure is mounted on a carrier made of Al_2O_3 having two 50 Ω CPW. Electric interconnections to the GaAs-chip are made by bondwires. Finally, at the outer end of the carrier there are transitions from CPW to coaxial transmission lines.

EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 4 shows an example of the influence of an e-o probe tip on the distribution of the electric field component E_x within the subtrate below CPW 3 between test point a and b measured with the direct e-o field mapping technique [4, 13-15] at 5.5 GHz and 37.7 GHz. In these gray-level images bright areas represent high signal levels and dark areas represent low signal levels. The signal on the center electrode can be clearly seen in all images. Additionally, a standing wave pattern is obvious in c) and d). No significant differences between the images without (a) and with (b) an e-o probe tip can be seen for the frequency of 5.5 GHz. However, the images for 37.7 GHz (c and d) become noisy due to the attached e-o probe tip.

In order to find out the impact of this influence on a MMIC and due to the fact that the test points inside the MMICs are normally waveguides, first experiments with respect to the transmission characteristic of a CPW have been made. In Fig. 5 the transmission characteristics of the CPW 3 for two different working distances measured with the direct e-o sampling system at test point b are plotted. In the region between 0 GHz and 10 GHz no remarkable discrepancy between both characteristics is

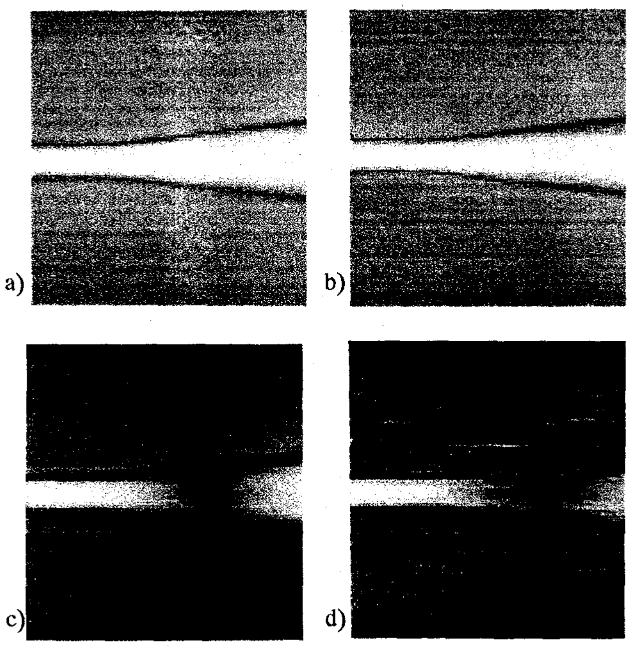

Fig. 4: Gray-level images of the field distribution on CPW 3 between test point a and b. a) and c) Without an e-o probe tip for 5.5 GHz resp. 37.7 GHz. b) and d) E-o probe tip directly attached to the waveguide (5.5 GHz resp. 37.7 GHz).The scanned area is 650 μm x 700 μm.

observable. Above this frequency the signal for d = 0 μm becomes noisy and a little bit different from the signal for d = 50 μm. Between 18 GHz and 33 GHz the amplitude of the electric signal decreases drastically and lies below the sensitivity limit of the test system. Therefore, the measured signal is very noisy and no statements can be made. Above 33 GHz the electric signal increases again and the CPW shows a 'band pass characteristic'. In this region a remarkable change in the characteristic of both

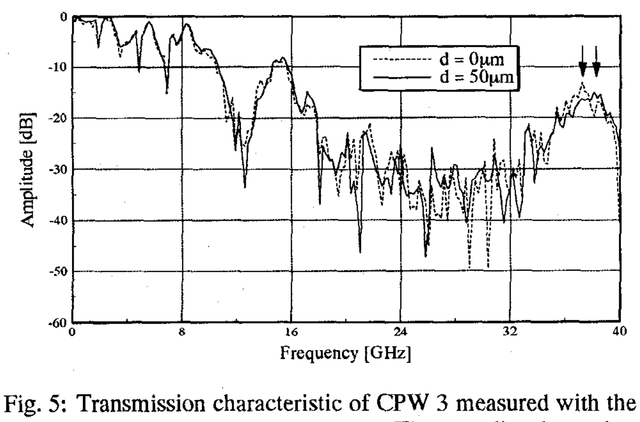

Fig. 5: Transmission characteristic of CPW 3 measured with the direct e-o sampling technique. The sampling beam has been positioned at test point b. The probe tip has two different working distances d. The center frequency shift is marked with arrows.

signals is reproducible. The impact of the influence of the e-o probe tip is that it shifts the center frequency of the 'band pass'. When the probe tip comes closer to the test point the center frequency is shifted towards lower frequencies. This frequency shift has been observed for the investigated test points b and c. Additionally, this observation is consistent with theoretical predictions that an observable influence of probe tips occurs only at higher frequencies [11].

Further measurements at different line geometries and working distances in the reduced frequency range of 33 GHz to 40 GHz at test point b and c have been made in order to make quantitative statements about the impact of the influence. In Fig. 6 the center frequency shift f normalized to the center frequency f_0 without any probe tip vs. the relative working distance d is plotted. For the discussion of the results it has to be taken into account that the probe tip cannot be fabricated with its bottom side being absolutely flat and parallel to the tested waveguide. Therefore, four regions have to be distinguished. Region I^b, I^c: Most of the part of the bottom side area of the probe tip is still attached to the CPW. A constant frequency shift is observable. This region is approximately equal for both test points. Region II^b, II^c: The probe tip begins to remove from the CPW and the impact decreases slowly. Region III^b, III^c: The whole probe tip removes further from the CPW and a significant reduction of the impact is observable. Region IV^b, IV^c: The probe tip is that far from the CPW that an impact is no longer observable. We have found that the last three regions depend on the tested geometry. Due to the discussed geometry dependency the plotted working distance is a relative measure. The working distance of interest starts at the beginning of region III^b, III^c.

It can be seen from Fig. 6 that for test point b the region $III^b \approx 19$ μm is bigger than for test point c ($III^c \approx 11$ μm). This has been expected because the slot of the CPW at test point b is bigger than that of the CPW at test point c. Therefore, the spatial extension of the electric stray field of test point b is bigger than that of test point c, i. e., the influence of the stray field of test point b is spatially more extended than that of test point c. These results are in a good agreement with theoretical predictions [10, 11].

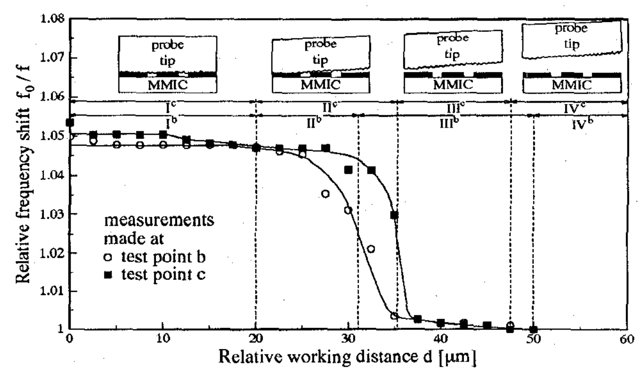

Fig. 6: Relative frequency shift vs. relative working distance at test points b and c.

Measurements of $|S_{21}|$ have been made for working distances of 0 and 50 μm in order to examine the possibility of verifiing the impact of an e-o probe tip by a NWA. When comparing Fig. 5 and 7 it can be seen that up to 33 GHz principally the same transmission characteristic has been measured. In contrast to the measurements made with the direct e-o sampling technique the tendency of the transmission characteristic remains constant above 33 GHz. This may occur because the network analyzer measures the characteristic of the whole CPW 3, while at e-o sampling the characteristic of exactly the test point b is measured. We interpret this result as a local distortion of the electric field which cannot be observed with a NWA. This distortion cannot be neglected when, e. g., an integrated filter is tested with the external e-o sampling technique, because, as demonstrated, the specific transmission characteristic could be changed due to the influence of the probe tip.

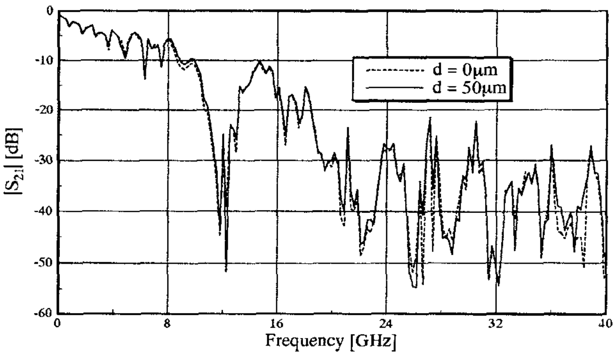

Fig. 7: Measurement of $|S_{21}|$ of CPW 3 with a network analyzer.

CONCLUSIONS

Electric field disturbances induced by an e-o probe tip have been experimentally investigated up to 40 GHz by means of direct electro-optic sampling. The results have been compared with conventional network analyzer measurements. A field distortion depending on the working distance between the e-o probe tip and the tested circuit has been shown which has to be taken into account when using this technique for MMIC characterization above 30 GHz.

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