Generation and Detection of Picosecond Electric Pulses with Freely Positionable Photoconductive Probes

Torsten Pfeifer, Hanns-Michael Heiliger, Hartmut G. Roskos, and Heinrich Kurz

***Abstract*—Two different kinds of external photoconductive probes are investigated in detail. Their dual character in application as generators or detectors of picosecond electric transients is demonstrated. The probes are manufactured on transparent silicon-on-sapphire substrates suitable for on-wafer testing of integrated circuits. A detailed analysis of the freely positionable probes is performed in time domain with respect to linearity, sensitivity, time resolution and invasiveness.**

I. Introduction

THE FREQUENCY limit of novel electronic and optoelectronic devices has been pushed up to cut-off frequencies of several hundreds of GHz. The design of such ultrahigh-frequency components requires appropriate optoelectronic measurement techniques, because standard electronic measurement equipment such as network analyzers or sampling oscilloscopes are limited in bandwidth to less than 100 GHz.

Among optoelectronic measurement techniques capable of ultrahigh frequency analysis, the recently developed photoconductive (PC) sampling with freely positionable probes allows on-chip characterization of devices and circuits [1]–[4]. A sensitivity of 1 μV has been reported for freely positionable PC probes based on LT-GaAs employing a low-noise laser source [1]. The application of this type of probe manufactured on opaque GaAs substrate is limited to the characterization of devices or circuits fabricated on optically transparent substrates. Alternatively, PC probes based on silicon-on-sapphire (SOS) technology are optically transparent. Thus, backside illumination of the switch and optically controlled positioning to nearly any point of interest even in complex circuits on opaque substrates are possible [2]–[4]. Additionally, SOS probes are inexpensive and easy to manufacture.

In this contribution, we describe in detail the fabrication of flexible PC probes based on SOS technology. We introduce a new and simple conductive-epoxy-based manufacturing scheme for fabrication of the tip on the probe that facilitates contacting of the PC probes to a device under test (DUT). A detailed characterization of freely positionable PC SOS probes acting both as *detectors* and *generators* for ultrafast electric signals is given.

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The authors are with the Institut für Halbleitertechnik II, Rheinisch-Westfälische Technische Hochschule Aachen, Sommerfeldstr. 24, D-52056 Aachen, Germany.

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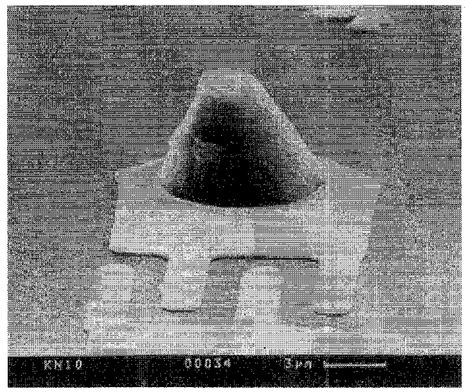

Fig. 1. SEM micrograph of a four-finger MSM-photoconductive sampling probe with a 5-μm Ti tip.

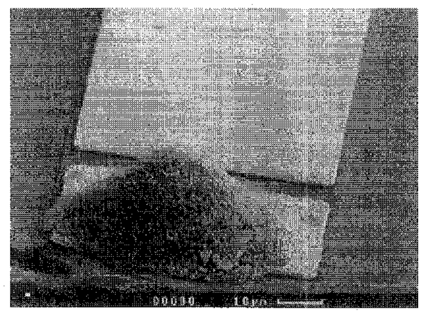

Fig. 2. SEM micrograph of a photoconductive sampling probe with a tip fabricated from conductive epoxy. The PC probe is realized on ion-implanted SOS substrate and utilizes a 60-μm-wide Au strip as electrode structure. The gap width is 5 μm. The probe is shown prior to its use in measurements.

II. Fabrication of Freely Positionable PC Probes and Experimental Set-Up

The freely positionable PC probes presented here utilize a metal-semiconductor-metal electrode structure as PC switch as shown in the scanning electron micrographs in Figs. 1 and 2. To contact an electrically accessible point on a DUT, a tip is fabricated with a height of several μm at the end of the short electrode.

The electrode structure of the PC probes is defined by optical lithography and a standard lift-off process for pat-

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terning of the 20-nm-Cr/200-nm-Au metallization. Subsequent implantation of high-energy Si^+ and Ne^+ ions at a dose of approximately 9×10^{14} cm^{-2} reduces the carrier lifetime in the Si layer [5] and ensures good ohmic contact between the electrodes and the Si. After a second lithography step, the Si is etched off by reactive-ion etching except for a mesa at the PC gap in order to enable optical transparency of the back-side-polished SOS substrate needed for easy adjustment of the PC probe in experiments. With an additional electrode on the PC probe, separate biasing of the PC switch and the DUT by the freely positionable probe can be accomplished alternatively [6], [7].

For fabrication of the contact tip located at the short electrode of the PC probe, we have developed two process schemes: (i) In one approach, a 5-μm-high Ti tip (see Fig. 1) is fabricated in a way similar to that described in [1] and [2], but with a special lift-off process based on a several-μm-thick photoresist layer [4]. Holes with a diameter of 8 μm are opened into the resist and a 5-μm-thick Ti layer is deposited by e-beam evaporation. Before lift-off, the tip is coated with a 20-nm-thick Pt and a 40-nm Au layer to prevent oxidation. (ii) In a second approach of much simpler technology, the contact tip is formed by a drop of electrically conductive adhesive placed onto the short electrode structure (see Fig. 2).

We use a two-component epoxy (Epo-Tek H 20 E-PFC) consisting of one part of resin and one part of hardener. A high electric conductivity of the adhesive is guaranteed by a high density of silver particles in the epoxy. For fabrication of tips with small base area, a glass fiber, sharpened by pulling the fiber apart in a flame, is dipped into the adhesive. A small drop of conductive epoxy at the fiber tip is subsequently brought into contact with the electrode employing a mechanical three-axis-micropositioning system. When the fiber is slowly removed from the electrode, the drop sticking to the electrode is drawn into conical shape. Finally, the adhesive is hardened at 80°C for five hours. Typical tip base diameters on the order of 40 μm and top diameters of 10 μm are achieved. The height of the tips ranges between 10 and 30 μm depending on the quantity and the viscosity of the adhesive [8]. When the tip is brought into contact with the DUT for the first time, the tip is flattened somewhat under the applied pressure. This does not impose a limitation on the number of times the tips can actually be used as the tip shape does not change any more after the first few applications. The relative softness of the tip has the important advantage that it prevents damaging the DUT by the probe tip itself.

Time-resolved optoelectronic characterization is performed with a 100-fs ring dye laser or alternatively with a Ti:sapphire laser in a pump-probe set-up. The laser beam is split into two parts by a polarizing beam splitter. The stronger pump beam is focused onto the biased PC switch for electric-pulse generation. Probe laser pulses, time-delayed relative to the pump pulses via a stepper-driven translation stage, are focused onto the detector. A lock-in detection scheme is used to reduce the signal noise.

The PC probes are adjusted to the measurement point by optical control. The quality of the electric contact between the PC probe and the DUT is checked by photocurrent (I_{il}) and

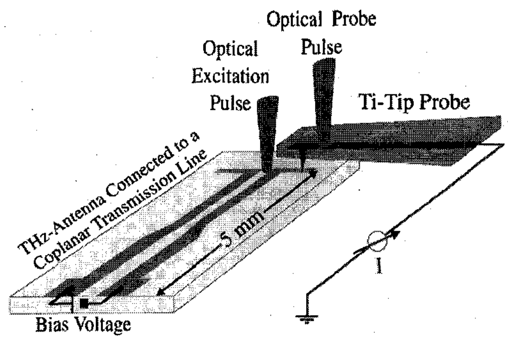

Fig. 3. Schematic of the THz-dipole antenna contacted by the freely positionable PC probe on the antenna dipole.

dark-current (I_d) measurements at 1.5 V bias voltage between PC probe and DUT. The laser-pulse-illuminated PC probe is conductive only within a time window set by the lifetime of the charge carriers of 600 fs in appropriately ion-implanted Si [5]. The difference in electric potential between the DUT and the probe drives a small amount of charge from one electrode of the gap to the other electrode each time the optical pulse strikes the gap coincidently with the electric signal on the DUT. The amount of charge is proportional to the signal voltage (for 2 mW optical power and 1.5 V bias voltage, typically 2000–5000 electrons per pulse are transfered). The time-averaged dc current through the PC probe as a measure for the electric voltage optically induced by the pump pulse on the DUT is traced as a function of the optical delay between the pump and probe pulse. The dark resistance of the PC switch is 30 MΩ. During optical excitation, the resistance drops to 1 kΩ. Freely positionable PC probes can be used as detectors for electric transients, but also for electric pulse generation. This is demonstrated with the help of coplanar waveguides (CPW) where the waveform of electric pulses launched by the PC probes is analyzed precisely by external electro-optic (EO) sampling [9].

III. Experimental Results and Discussion

A. Metal-Tip Probes

In a first experiment, the temporal optoelectronic response of flexible Ti-tiped PC probes is investigated. Electric pulses of 40 mV peak amplitude and 1.3 ps duration are generated on a THz-dipole antenna [10] whose principal structure is sketched in Fig. 3. The antenna, fabricated on ion-implanted SOS substrate, consists of a Hertzian dipole, realized as a 50-μm-long and 10-μm-wide Au strip with a 5-μm slot in the center. The two dipole arms are connected to a coplanar strip transmission line consisting of two 5-μm wide Au lines separated by 10 μm. At a distance of 3.15 mm, the transmission line is expanded to 25-μm width and 50-μm spacing. The Si is removed except for a mesa with the Hertzian dipole on top of it. The gap in the dipole together with the Si underneath forms the switch for electric pulse generation. The electric pulses launched onto the antenna are sampled with the PC probe in full contact with one of the arms of the Hertzian dipole.

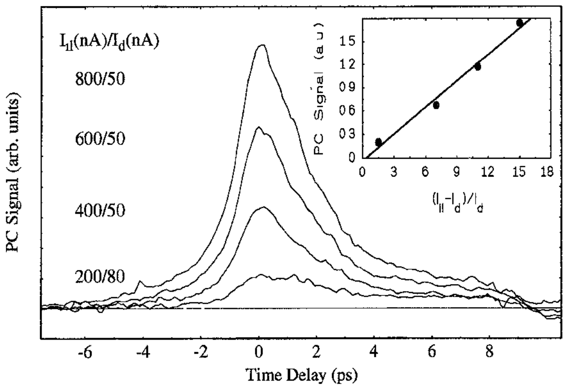

Fig. 4. Time-resolved PC signals of electric pulses of constant amlitude (40 mV). The laser fluence on the PC probe is varied. The response of the PC probe scales linearly with the photocurrent (I_{ll}/nA) induced by the optical probe pulse (see inset).

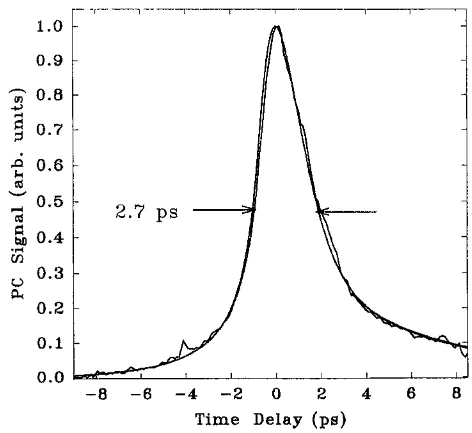

Fig. 5. Time-resolved PC signal from Fig. 4 for $I_{ll} = 800$ nA. The smooth curve is a fit to the measured data and is calculated by Austons's theory for a correlation measurement with a pair of closely spaced photoconductors.

The experiments are performed with a dye laser system. The fluence of the beam illuminating the flexible PC probe is varied, while the fluence of the pump beam on the antenna is kept constant. A typical set of time-domain data is shown in Fig. 4. As a quantity proportional to the probe laser fluence, the photocurrent I_{ll} through the PC switch under a bias of 1.5 V is measured prior to the time-resolved experiments. The peak amplitude of the detected signal rises linearly with the probe fluence as demonstrated in the inset of Fig. 4. No distortion in signal shape is observed when the probe fluence is increased. The PC signal lasts for 2.7 ps (FWHM), twice as long as the electric pulse width of 1.3 ps (FWHM) measured via EO sampling technique.

The temporal shape of the detected signal is analyzed following Auston's theory for a correlation measurement involving a pair of closely spaced photoconductors [11]. The observed linear dependence of the PC signals on the fluence of the probe beam confirms that the sensitivity of a PC detector is determined by its photoconductance, given by the product of mobility and density of photoexcited carriers. The rise time of the correlation function is mainly determined by the photoconductance of the detector PC switch (flexible PC probe) [4]. The decay depends on the photoconductances and the capacitances of both the generator (THz antenna) and the detector switch, as well as on the impedance of the interconnecting transmission line (for a detailed analysis see [4]). We fit our measured PC data with Austons's formula assuming a biexponential time dependence of the photoconductance of the generating and detecting gap (see Fig. 5). The capacitance of the sampling gap and the transmission-line impedance are calculated to be 1.7 fF and 120 Ω, respectively. The best fit to the measured data is obtained with a generator capacitance of 5 fF. In both the antenna as well as the PC probe response, a fast component with a time constant of 600 fs is observed in the biexponential decay. The slower decay component is characterized by time constants of 6 and 2.2 ps for the generator and the detector, respectively. The amplitude of the slow component relative to the total initial photoconductance is 8.5% for the antenna and 14% for the flexible PC probe. The time resolution of the PC probe is mainly limited by the conductance lifetime of 2.2 ps in the Si layer. With further reduction of the carrier lifetime to 600 fs by optimized ion implantation, a time resolution of 1.3 ps should be achievable [4].

PC probes exhibit a linear response to electric signals of different voltage amplitude. For flexible LT-GaAs PC probes, this linearity has been proven by varying the external voltage applied to the DUT and the probe over four orders of magnitude [1]. An approach to adjust the amplitude of ps electric pulses is to vary the optical pump power at fixed bias voltage at the generator gap. In a recent publication, we demonstrated that the optoelectronic response of our SOS PC probes follows linearly the illumination strength on the stimulus switch over at least two orders of magnitude [4]. The noise floor can be estimated from the data depicted in Fig. 4 to be 400 μV for a single scan with a lock-in time constant of one second. To increase the sensitivity of SOS PC probes, higher excitation levels of the probe, and laser sources with low noise characteristics instead of dye lasers are necessary (a quantitative discussion of the sensitivity and an explicit comparison to LT-GaAs probes by Kim *et al.* are given in [4]).

To investigate the invasiveness of the PC probes with Ti tip on microwave signals, electric pulses are detected on a CPW behind a point where the probe is in full contact with the signal conductor. The measurement geometry is illustrated in Fig. 6. The CPW (signal conductor width 60 μm, spacing 30 μm, length 10 mm) is fabricated on SOS substrate with an integrated PC switch for electric pulse generation. The switch is realized as a 5-μm gap in the signal conductor with ion-implanted Si as photoactive material. The gap is located 50 μm away from one of the open ends of the CPW and is biased via a needle prober in contact with the short arm of the signal conductor. EO measurements indicate that electric pulses of approximately 1 ps duration are excited on the CPW when the switch is illuminated by fs optical pump pulses. For this and all following experiments, a Ti:sapphire laser system is employed.

Waveforms are sampled at a distance of 1.92 mm from the excitation gap behind a point where the flexible PC probe is in full contact with the signal conductor of the CPW (see Fig. 6). EO sampling instead of external PC sampling is chosen for

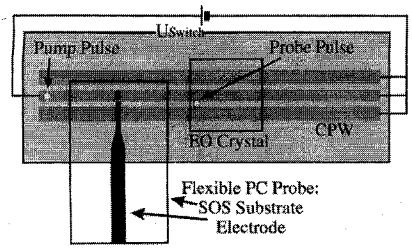

Fig. 6. Schematic of the experimental arrangement for testing of the invasiveness of a flexible PC probe on a CPW.

detection because of the better time resolution of EO sampling (300 fs (EO) versus 2.7 ps (PC)). Thus, no deconvolution of the electro-optically detected signals is required to obtain the exact electric waveform in time domain on the CPW. The PC probe is oriented with the electrodes perpendicular to the conductors of the CPW. With this arrangement, excitation of parasitic microstrip modes between the electrode of the PC probe and the signal conductor is avoided. The contact point is 0.73 mm away from the excitation gap. In a control measurement, the flexible PC probe is completely removed from the experimental set-up and the electric pulse on the CPW is sampled at the same position and for the same excitation conditions (pump power and bias of the stimulation switch) as before.

Fig. 7 depicts waveforms detected with and without the Ti-tip PC probe in contact with the CPW. The electric pulse appears slightly modified in shape and amplitude when the PC probe is in full contact with the signal conductor. A temporal shift of the signal peak by 1.6 ps towards longer time delays is observed when the PC probe is in contact with the CPW compared to the case when the probe is removed. This shift is explained by an increase of the effective refractive index of the CPW induced by the sapphire substate of the flexible PC probe. With a substrate width of 1.33 mm, a 15% increase of the effective refractive index can be estimated from the time delay. Less than 7% of the incident electric field (<1% of the incident power) is reflected at the frontface of the probe substrate. From these considerations, one would expect a reduction in the amplitude of the transmitted pulse for the probe being in contact with the CPW of about 14% caused by reflection losses at the front- and endface of the sapphire substrate. This is not supported by the measured data as both the amplitude and the spectral power of the transmitted electric pulse are found to be slightly higher for the PC probe in contact with the CPW compared to the case where the probe is completely removed. In addition, the pulse sharpens and the ringing in the trailing part is less pronounced in the contact case. These features are also a result of the dielectric influence of the probe substrate on the microwave propagation. When the CPW is covered by a superstrate with a permittivity comparable to the CPW substrate, the additional reflection losses introduced by the probe substrate are compensated by the reduction of modal dispersion and high-frequency radiation losses. Both, reduced attenuation and dispersion lead to an enhanced peak amplitude and a decrease in pulse duration. In our specific case, the width of the probe substrate covering the CPW is so large,

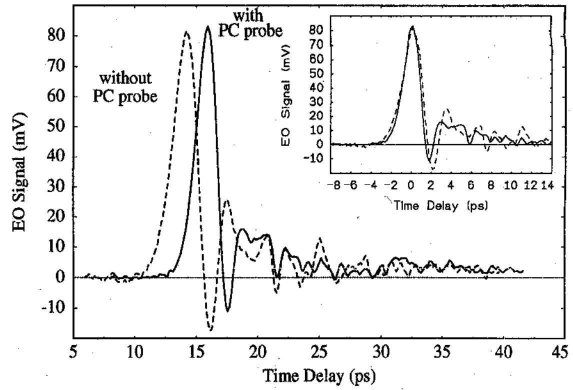

Fig. 7. Electro-optically detected electric pulses on a CPW with (solid line) and without (dashed line) a PC probe in contact with the CPW. In the inset, the peak amplitude of the pulses is shifted to zero time delay for better comparison of the waveforms.

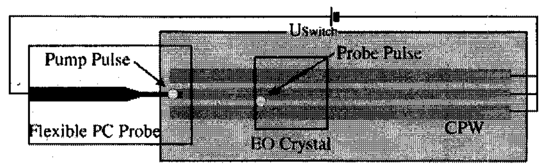

Fig. 8. Schematic of the experimental arrangement for electric-pulse injection with a flexible PC probe.

that reflection losses are overbalanced. The slight increase in amplitude of the transmitted pulse, the reduced pulse width, and the enhanced pulse delay time for the probe being in contact are perfectly reproduced by model calculations taking into account the dimensions and electric properties of the CPW and the PC probe in the experimental arrangement as specified above [12]. The dielectric invasiveness can be further minimized by increasing the height of the tip, using probe substrates with smaller width, and by choosing a substrate with a lower refractive index. The fact, that the modifications of the electric pulse transmitted through the probe-contacted region are entirely explained by the invasiveness by the probe substrate, allows the conclusion that the Ti tip itself does not cause a significant reflection of the pulse. Hence, the inductive load by the metal tip is below the detection limit.

As pointed out above, a satisfying agreement between Auston's theory for correlation measurements with closely spaced photoconductors, and our experimental data is obtained when electric pulses are detected with a flexible PC probe (see Fig. 5). As Auston's theory allows to interchange generators and detectors, one is led to utilize the freely positionable PC probes also as generators of ps electric transients. To demonstrate that flexible PC probes are not only capable to detect but also to generate ps electric pulses, we contact a Ti-tip PC probe to the signal conductor at the open end of a 10-mm-long CPW on a GaAs substrate (signal conductor width: 52 μm, spacing: 40 μm. The probe electrodes are oriented parallel to the CPW conductors (see Fig. 8). In contrast to the experiments presented above, the gap of the flexible PC probe is biased and is excited by the pump laser pulse instead of the probe pulse. The electric transients injected into the CPW are

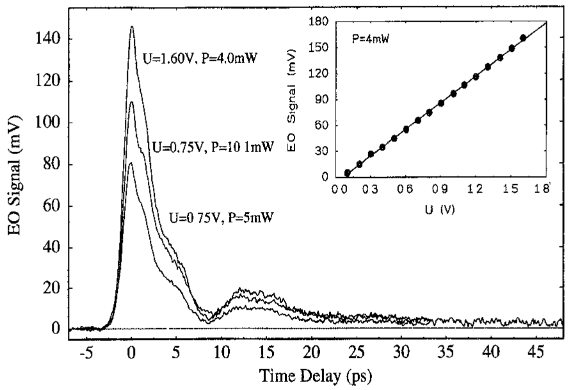

Fig. 9. Electro-optically detected electric transients generated by a Ti-tipped probe on a CPW. The pump-beam fluence and the bias voltage of the PC switch are varied. In the inset: Peak amplitude of the electric signals for various bias voltages applied to the PC probe. The average power of the pump beam is 4 mW.

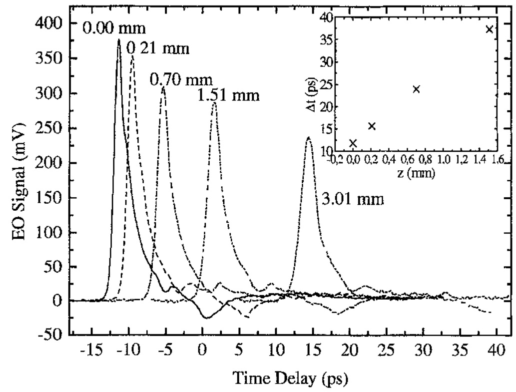

Fig. 10. Picosecond electric transients generated by a flexible PC probe with a tip fabricated from conductive adhesive. The pulses are detected electro-optically on the CPW at various distances away from the open end of the CPW. In the inset: The time delay between the initial electric pulse and the negative-going dip (Δt) is shown for different measurement positions z.

detected electro-optically with a free-standing $LiTaO_3$ crystal at a position approximately 400 μm away from the flexible PC switch. EO sampling is chosen for detection because of the superior time resolution compared to PC sampling.

Fig. 9 depicts electric transients launched onto the CPW for various bias voltages (U) and average pump powers (P). The amplitude of the generated pulses rises linearly with increasing bias voltage (see inset of Fig. 9) and an electric pulse duration of 3.3 ps (FWHM) is obtained in all measurements. The 20-ps-long tail results in part from the long photoconductance lifetime in the Si layer due to an insufficient ion-implantation dose which has been found also in the experiments presented above (see Figs. 4 and 5), where PC probes of the same fabrication run have been used. However, to fully explain the 20-ps duration of the trailing pedestal, multiple reflections in the contact region have to be taken into account. The dip at approximately 9 ps delay is due to a reflection of the electric pulse at the $LiTaO_3$ crystal (for explanation see below).

B. Probes with Conductive-Epoxy Tips

In a final experiment, we demonstrate the application of freely positionable PC probes with conductive-epoxy tips for the generation of ps-duration electric pulses. As a DUT, we utilize a 20-nm-Cr/400-nm-Au CPW (signal conductor width 20 μm, spacing 15 μm, length 20 mm) fabricated by standard lift-off technique on high-resistivity (>2000 Ωcm) Si substrate. The signal conductor of the CPW is connected to a contact pad of 40 μm width and 70 μm length. The spacing between the signal conductor and the ground conductor pads is expanded to 30 μm keeping the impedance constant. In the experiment, the tip of the PC probe is placed onto the contact pad of the signal conductor of the CPW and oriented in the same way as described above (see Fig. 8). The PC switch is biased with 5 V and excited by pump pulses derived from the 150-fs Ti:sapphire laser. The bias voltage and the optical fluence are kept constant. The injected electric pulses are traced electro-optically at various positions along the CPW. Fig. 10 depicts the measured waveforms. The first measurement point is approximately 600 μm away from the center of the contact pad of the signal conductor. This measurement point is taken as the origin of the sampling position ($z = 0$ mm). An electric pulse of 2.1 ps duration (FWHM) and 377 mV amplitude is obtained at $z = 0$ mm. Again the injected electric pulse reveals an asymmetric shape with a decay that is slower than the rise of the pulse. The asymmetry does not originate from an enlarged carrier lifetime in the Si layer of the PC switch. This has been confirmed experimentally by measuring electric pulses on CPWs with integrated switches manufactured on the same wafer as the flexible PC probe. In this case, the asymmetry is likely to result from multiple reflections of the electric pulses at the boundaries of the CPW contact pad and the photoconductive gap of the flexible PC probe. The distance between these points is approximately 50 μm translating into a signal round-trip time on the order of 1 ps, if a typical effective permittivity of 6 is assumed. The superposition of the multiple reflections can not be separated into single pulses and appears as the observed slow decay. However, the waveform of the launched pulses is reproducible from measurement to measurement for a fixed PC probe position. For device characterization, the enlarged electric pulse width means a slight reduction in maximum bandwidth of about 600 GHz [13], [14]. It has no impact on the extraction of device parameters as we have found in the spectral analysis of various other waveguides on Si substrates [13], [14]. A way to shorten the injected electric pulses would be to fabricate flexible PC probes in a CPW geometry with three contact tips and to enlarge the distance between the switch and the tips.

For larger propagation distances, the influence of attenuation and dispersion can be clearly observed in the drop in amplitude and temporal broadening of the pulse [13], [14]. In all measurements, a negative-going dip is observed in the trailing part of the pulse. The time delay between the initial peak of the electric pulse and this dip increases linearly with larger propagation distance (see inset of Fig. 10). Evidently, this dip originates from a reflection of the incident electric pulse at the $LiTaO_3$ crystal front face. The inverted reflected pulse hits the open end of the CPW and returns to the EO crystal where it is detected.

Concerning the temporal response, the PC probes with conductive-epoxy tips behave similar to the PC probes with Ti tip. In addition, they reveal linearity with respect to detection and generation of ps electric pulses as described for the Ti-tiped probes (data not shown). We have not investigated the inductive invasiveness of the probes with conductive-epoxy tip. It should be higher compared to the Ti-tip PC probes because of the enlarged diameter of the conductive-epoxy tip. As for the larger tip height, on the other hand, the dielectric load by the probe substrate is expected to be lower.

An important parameter for the transmisson of the generated ps transients from the flexible PC probe onto the DUT is the resistance of the interconnecting elements, in particular the short electrode and the contact tip. The specific resistivity of the epoxy adhesive of 2×10^{-4} Ωcm is clearly higher than the specific resistivity of Ti (4.8×10^{-5} Ωcm) and Au (4×10^{-6} Ωcm). The resistance of the tips, however, is not very different. For both types of tips investigated here, we estimate a resistance on the order of 1 Ω taking into account typical dimensions of the tips as shown in Figs. 1 and 2. The low specific resistivity of the epoxy is nearly compensated by the larger cross-section of the epoxy tips. Indeed, in the high-frequency experiments, we find that the amplitude of the ps-electric pulses injected into the DUTs is comparable for both types of flexible probes and is mainly defined by the properties of the PC switch and the applied bias voltage.

IV. Conclusion

In conclusion, we have described in detail two different ways to fabricate freely positionable PC probes and have investigated characteristics such as linearity, sensitivity, time resolution, and invasiveness. We have shown that such PC switches can serve in a dual purpose as efficient generators and detectors of ps-electric signals. This opens the way for high-frequency PC testing at any electrically accessible point on a circuit without the need for integration of switches into the chip. It is worth mentioning that PC probes with conductive-epoxy tips are now routinely employed in our laboratory as efficient ps-signal injectors into standard devices and circuits, which are commonly supplied without integrated switches [13], [14]. The epoxy-tip probes are simple to manufacture and can be employed in all cases provided the lateral dimensions of the DUTs are not too small [13], [14].

Acknowledgment

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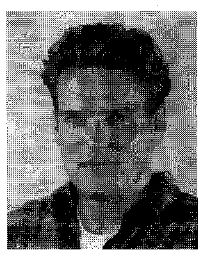
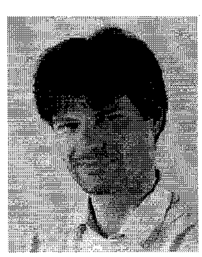
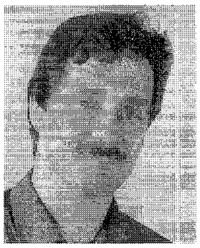


Torsten Pfeifer was born in Kamen, Germany, in 1967. He received the diploma degree in physics from the RWTH Aachen in 1993.

His thesis concentrated on optical investigations of ultrafast dynamics of surface fields and phase relaxation mechanisms of coherent optical phonons in III-V semiconductors. Since 1993 he has been a graduate student at the Institut für Halbleitertechnik II (RWTH Aachen), working on optoelectronic characterization of high-frequency devices and circuits.

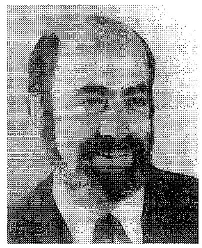


Hanns-Michael Heiliger studied pharmaceutics at the University of Bonn and electrical engineering at the RWTH Aachen, both in Germany. Since 1994 he has been a graduate student at the Institut für Halbleitertechnik II, RWTH Aachen, dealing with electrooptic and photoconductive sampling.



Hartmut G. Roskos studied physics at the Technical Universities of Karlsruhe and Munich, Germany. He received the diploma degree in 1985 and the Ph.D. degree in 1989, both from the Technical University of Munich.

From 1989 to 1991, he worked as a Postdoctoral Fellow at AT&T Bell Laboratories, Holmdel, NJ. In 1991, he joined the Institut für Halbleitertechnik II, RWTH Aachen, where he worked first as a Research Assistant and, since 1993, as Oberingenieur. The main research activities in his group focus on the spectroscopy of ultrafast phenomena in semiconductors and superconductors in the optical and terahertz frequency range, and on high-speed device development and characterization.



Heinrich Kurz was born in Pennewang, Austria. He received the Ph.D. degree in experimental physics from University Vienna, Austria in 1971.

He joined the Phillips Research Laboratories, Hamburg, Germany, from 1971 to 1981. From 1981 to 1984 he was with Harvard University, Cambridge, MA. He has been a Professor of Electrical Engineering at RWTH Aachen since that time. His current research interests cover ultrafast solid-state phenomena, application of femtosecond laser technology, and high-speed device characterization. He is also involved in research on Si-based nanostructures and novel materials for microelectronics such as SiC and high-T_C superconductors. Recently, he has founded an extra-University Center for Applied Micro- and Optoelectronics (AMO GmbH) that will go into operation at the beginning of 1996.