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AL–SIO_2–AL SANDWICH MICROSTRIP LINES FOR ON–CHIP INTERCONNECTS UP TO 400 GHZ

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Abstract

We present a downscaled 2 μm wide microstrip line fabricated with both signal and ground conductors on top of the substrate. On this waveguide, a significantly reduced geometric dispersion for 400 GHz bandwidth pulses is measured by time–resolved electrooptic sampling technique.

Microstrip transmission lines with a narrow signal conductor on the wafer surface and an extended ground plane on the backside are the most commonly used interconnects in millimeter–wave integrated circuits. Usually, the thickness of the semiconductor wafer defines the separation h of the signal conductor and the ground plane. It is in the range from 100 μm to 500 μm. For frequencies of several GHz and above, this simple scheme limits the useful bandwidth of ultra-high-speed electronic circuits principially. Geometric dispersion distorts the electrical pulses propagating on the microstrip interconnects. Furthermore, crosstalk and substrate losses are detrimental for the circuit performence. The onset of geometric dispersion can be shifted to higher frequencies by reducing the separation h [1,2]. As shown in Fig. 1 where the calculated effective dielectric constant of a microstrip is plotted as a function of frequency for different values of h. With decreasing h, the onset of geometric dispersion shifts to higher frequency. For a signal conductor width of 10 μm and a conductor separation of 2 μm, dispersion remains negligible up to THz frequencies. Reducing the conductor separation has the additional advantage of a better mode confinement with less capacitive coupling between neighbouring lines.

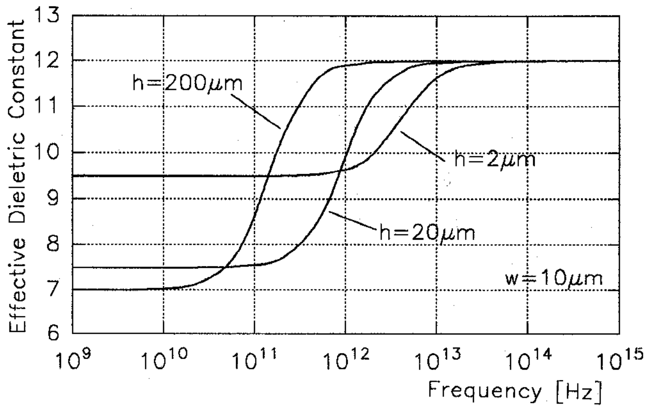

Fig.1: *Frequency dependence of the effective dielectric constant of a microstrip for a centre conductor width of $w = 10$ μm and different conductor separations h. The onset of dispersion is shifted to higher frequency as conductors are brought closer [2].*

Based on this principle we developed a downscaled 2 μm wide sandwich microstrip line with both the signal and ground conductors on top of the wafer surface, separated by a 800 nm thick SiO_2 insulating layer (Fig.2a). Such a waveguide configuration offers following further advantages: (i) Only a small part of the electromagnetic field leaks into the substrate resulting in reduced substrate losses. (ii) The replacement of a semiconductor dielectric by SiO_2 enhances the propagation velocity of electrical signals because of the lower dielectric constant ($\epsilon_r = 3$ compared to $\epsilon_r = 11 - 13$ of semiconductor substrates).

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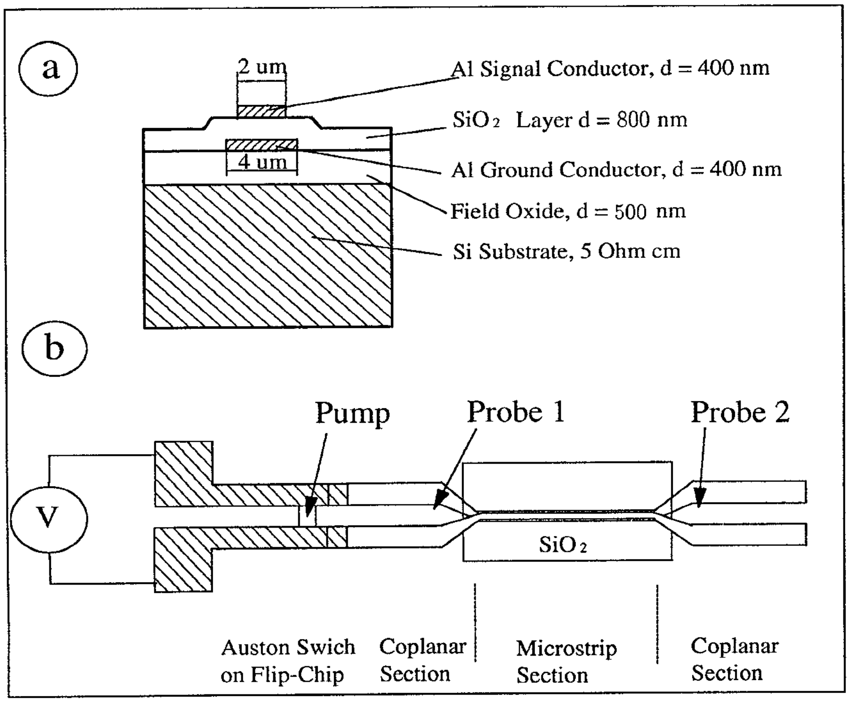

Fig.2 a): *Schematic of the cross–section through our surface–mounted microstrip line.* **b):** *Top view of the experimental arrangement. The arrows indicate the excitation spot on the flip–chip and the sampling spots in front of and behind the microstrip line.*

For the fabrication of our sandwich striplines we use standard processes compatible to silicon VLSI fabrication technology: A 500 nm thick field oxide is deposited onto a silicon substrate (p, (100), 5 Ωcm) by PECVD (Plasma Enhanced Chemical Vapour Deposition) followed by the evaporation of a 400 nm thick aluminum layer (Fig. 2). This first SiO_2 layer insulates the ground conductor from the semiconductor substrate. The Al ground conductor is structured by optical lithograpy and subsequent wet etching. A second 800 nm thick SiO_2 dielectric layer is deposited by PECVD and structured by RIE (Reactive Ion Etching). The RIE process allows a good etch depth control and does not attack the Al ground conductor in the contact regions. On top of the dielectric, the 400 nm thick Al layer for the signal conductor is evaporated and patterned by wet etching.

The microstrip line is integrated into an impedance–matched coplanar line, as shown in Fig. 2b. It is connected by flip–chip technique to a coplanar photoconductive Auston switch. Ultrashort laser pulses (100 fs, colliding–pulse–modelocked Rhodamine 6G laser) are used to generate 1.2 ps electrical pulses. Their propagation characteristics on the microstrip line are studied by electrooptic sampling with a $LiTaO_3$ crystal. The sampling points are indicated by arrows in Fig. 2b.

Before presenting time resolved data obtained with the sandwich microstrip, we would like to discuss briefly the pulse propagation on a conventional microstrip line. Fig. 3 displays the detected waveform of an electrical pulse on a such a line (width $w = 5\ \mu m$, $h = 500\ \mu m$) without coplanar couplers after propagation distances of 0.1, 1 and 2 mm (data taken from Ref. 3). The ratio of the peak amplitudes of the original data for distances of 0.1 mm and 2 mm is 1 : 0.32. In this measurement, the bandwidth of the pulses was limited to 100 GHz. Dispersion manifests itself as an increase of the risetime (10% to 90%) from initially 2.45

ps to 5.2 ps after 2 mm propagation distance, and a ringing in the trailing part of the pulse, not seen on the time scale of Fig. 2. Both result from the higher speed of the low-frequency components of the pulse.

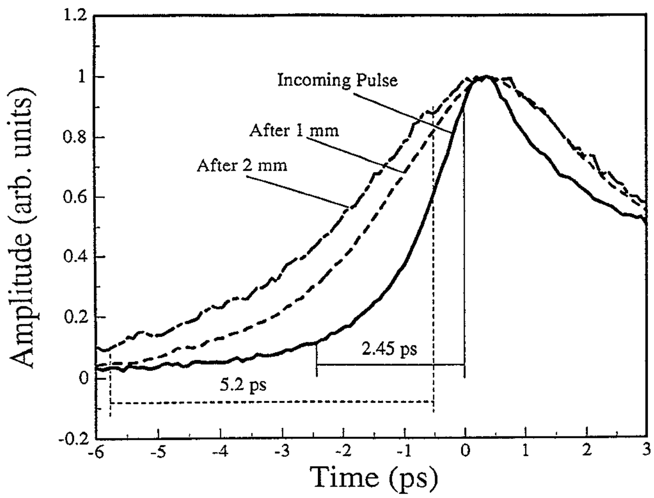

Fig.3: *Normalized detected electrical waveform on a standard microstrip line for the incoming pulse and after propagation distances of 1 and 2 mm. The time scale of each plot has been shifted so that the pulses are atop each other. The ratio of peak amplitudes of the original data for distances of 0.1 mm and 2 mm is 1 : 0.32.*

In Fig. 4, we show normalized pulse propagation data for our down-scaled (w = 2 μm, h = 800 nm) sandwich microstrip line for distances of 0.8 and 1.6 mm (the length of the 0.2 mm long coupling segments on each side must be added). The amplitude ratios of these pulses are 1 : 0.35 : 0.26 (40 mV : 14 mV : 10 mV). Because of the low amplitude of the incoming pulse of 40 mV the signal is fairly noisy. The pulses have a bandwidth of 400 GHz. Even with such a huge bandwith, they show little dispersion. The rise-time after 1.8 mm travelling increases from 0.8 ps to 1.1 ps only.

In the trailing part of the pulses a pedestal emerges. This change of the pulseform may result from frequency dependent losses. It is, however, likely that multiple longitudinal reflections at the micro-rough metal surfaces contribute significantly to the waveform change by a redistribution of energy from the center of the pulse to its trailing part. To check this, the surface qualitie of the sandwich striplines has to be improved.

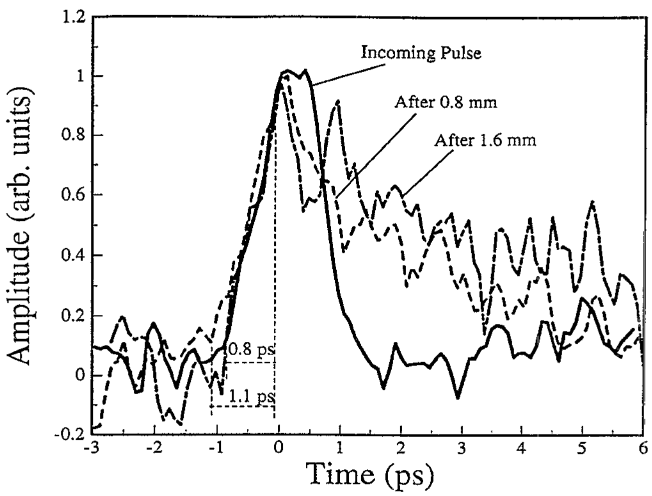

Fig.4: *Normalized detected waveform on an Al–SiO_2–Al sandwich microstrip line for the incoming pulse and after propagation distances of 1 and 1.8 mm. The amplitude ratios of the pulses are 1 : 0.35 : 0.26 (40 mV : 14 mV : 10 mV). The time scale of each plot has been shifted so that the pulses are atop each other.*

The losses seem to be slightly higher compared to the standard microstrip line. We attribute the decrease in pulse height from the incoming pulse to that detected after a distance of 0.8 mm (40 mV to 14 mV) mainly to leakage and reflections in the coplanar coupling segments in front and end of the sandwich stripline. The much smaller difference in peak amplitude between the pulses measured after 0.8 mm and 1.6 mm, respectively, (14 mV to 10 mV) is due to losses on a 0.8 mm long sandwich–stripline alone. These losses comprise conductor losses and to a smaller part substrate losses due to the magnetic field penetrating into the semiconductor substrate wich is not highly resistive. The attenuation of the sandwich stripline, as determined by the ratios of the peak amplitudes, has a value of 7.2 dB/mm (5.2 dB/mm for the standard microstrip line). Taking into account dispersion effects and therefore comparing the pulse energies instead of the peak amplitudes, the attenuation of 1.3 dB/mm is evaluated.

In future experiments, striplines on highly resistive silicon substrates have to be produced to reduce the substrate losses. Also the crosstalk behavior between neighbouring and crossing sandwich striplines will be tested.

In conclusion, we have demonstrated a very compact microstrip configuration usable even on doped substrates. Our Al–SiO_2–Al microstrip line has significantly less geometric dispersion for 400 GHz bandwidth pulses than standard microstrip configurations. The mode of the electromagnetic signal is strongly confined, promising reduced cross–talk between densely packed interconnects.

References

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