PULSED OPERATION OF AN OPTOELECTRONIC FINLINE SWITCH

K. Uhde and J. Müller

Technische Universität Hamburg-Harburg,
Postfach 90 14 03, D-2100 Hamburg 90, West-Germany

ABSTRACT

Three finline structures on different semiconductor substrates are presented. By illuminating the slot region with a pulsed laser diode, the propagation properties of a mm-wave passing through the excited region are changed. The insertion loss without illumination and the attenuation caused by it are measured and experimental results are given.

INTRODUCTION

In the last years, a great deal of interest has been given to a general class of switching devices based on the photoconductivity effect. Using a planar millimetre-waveguide structure on semiconducting substrate the complex dielectric constant of the substrate is modified by an optically induced electron-hole plasma. This leads to a change in the propagation constant so that a mm-wave propagating through the plasma region is amplitude and/or phase modulated. Taking advantage of these properties several optically controlled devices have been realized: switches (1)-(3), phase shifters (3) and modulators (4), (5), which were either based on a stripline or on a dielectric waveguide configuration.

It looks very promising to generate an electron-hole plasma in the slot of a finline, since there is a high field concentration. Then, only a small region has to be illuminated but a strong effect can be expected.

In this paper, three finline structures on semiconducting substrate are presented. The first one is a finline on a lossless silicon oxide substrate with a thin film of polysilicon. The second structure is realized on a highly resistive silicon substrate and the third one is a finline on an intrinsic gallium arsenide substrate. The insertion loss of these finlines is measured over the full Ka-band. A pulsed laser diode is used to create an electron-hole plasma in the slot region and the effect on a mm-wave launched into the waveguide is investigated.

DEVICE CONFIGURATION

To ensure a suitable mounting of the finline in the hollow waveguide, a split block housing has been chosen. As shown in Fig. 1, the finline is fixed elastically between the metallic housing and a thin layer of rt-duroid™, which insulates the finline metallization from the housing. Using a choke structure with quarter wavelength metallic strips,

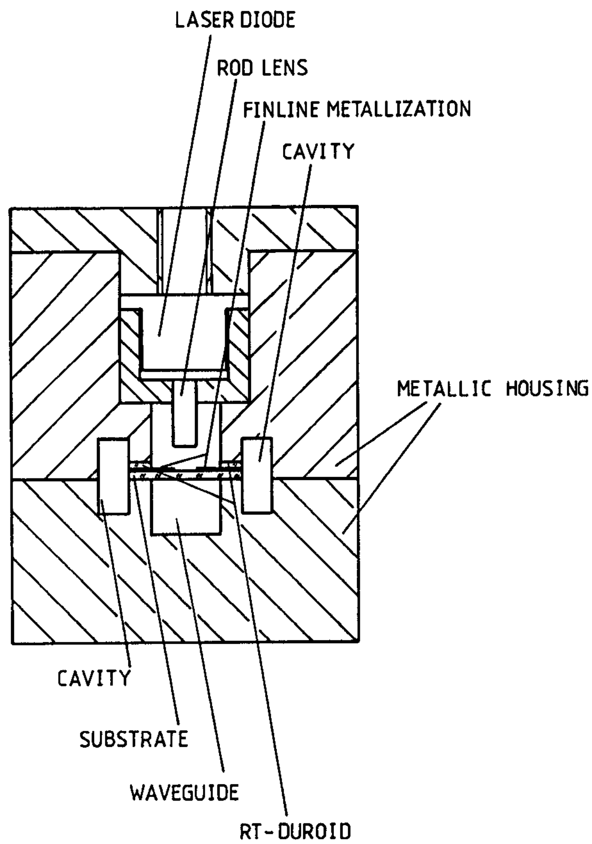

Fig.1 : Metallic waveguide housing

the open circuit at the end of the substrate is transformed into a short circuit at the waveguide walls. Three different length of the strips are corresponding to three frequencies with one in the centre of the frequency band and the others at the band edges. With its cathode having a thread the laser diode is screwed into the upper part of

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the waveguide housing. Thus, a heat sink as well as a solid mounting of the diode has been taken care of. Between laser diode and finline substrate, a gradient rod lens has been inserted to focus the laser beam. In Fig. 2, the finline structure is presented. It consists of an active finline section and a finline taper section at each side of the substrate.

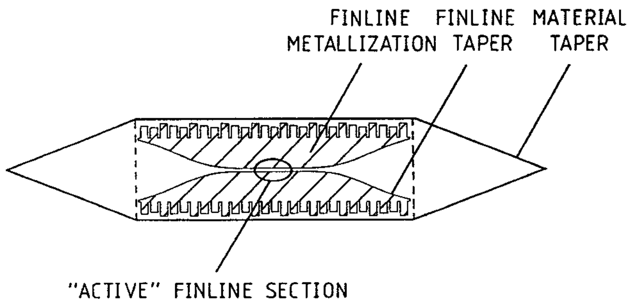

Fig.2 : Design of a finline structure on Si or GaAs substrate. The broken lines mark the shape of a structure on SiO_2 substrate.

The finline tapers are designed by the use of a taper synthesis. To minimize the input reflection of the finlines on high permittivity Si and GaAs substrate, also two wedge-shaped "material taper" sections have been symmetrically added.

The metallization consists of a thin titanium and a thin gold layer, which have been evaporated successively onto the different substrate materials. Then, the metallization has been photoetched.

EXPERIMENTAL SETUP

First, the insertion loss of the finline structures has been measured. This has been done in broadband operation using a sweep generator and a scalar network analyser.

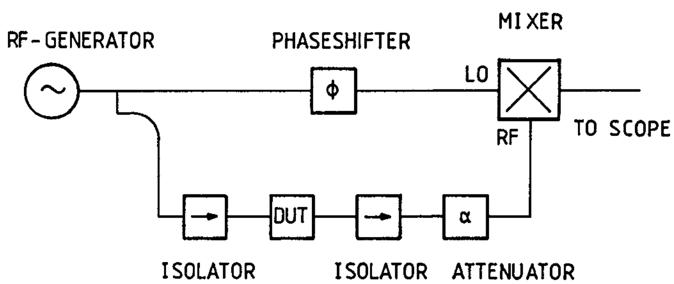

Fig.3 : Millimetre-wave bridge arrangement to measure the insertion loss in pulsed operation

When the slot region of a finline is illuminated with a pulsed laser diode, the propagation properties of a mm-wave passing through the excited region are directly changed. As the light pulses have a duration of the order of 50 ns, a measurement system with fast response is necessary. Therefore, a millimetre-wave bridge arrangement has been chosen which is shown in Fig. 3. A CW-signal is divided with one part connected to the local oscillator input of a mixer. The phase of this signal part is shifted to achieve a maximum output signal. The other arm of the bridge is connected to the signal input of the mixer. It consists of the device under test (DUT), i.e. the finline structure, which is enclosed by two isolators, and an attenuator to calibrate the output signal. By an oscilloscope the output impulse is displayed.

EXPERIMENTAL RESULTS

I. Silicon oxide substrate

Designing an optoelectronic finline switch, a lossless SiO_2 substrate with a thin polysilicon layer seems to have some advantages. As SiO_2 is an insulator, the losses should be minimized. The permittivity of SiO_2 ($\varepsilon_r = 4$) is much smaller than the permittivity of Si ($\varepsilon_r = 11.9$) and GaAs ($\varepsilon_r = 12.9$) which may avoid large reflections at the beginning and end of the structure. The electron-hole plasma is located in a thin layer next to the surface, and no diffusion of charge carriers into the substrate has to be considered. Last, polysilicon is a cheap semiconductor with high resistivity. Therefore, such a structure has been investigated first.

A 0.4 mm thick SiO_2 substrate has been taken, on which a thin film (0.5 μm) of polysilicon has been deposited. Focussing a CW laser beam onto the polysilicon, melting and recrystallization from the liquid phase into large grains has taken place, i.e. the polysilicon film has been annealed. Afterwards the metallization has been evaporated and a finline structure has been realized with a slot width of 0.2 mm and a length of 25.6 mm. No material tapers have been added. The measured insertion loss is about 1 dB (Fig. 4) and the input reflection varies between -12 dB and -20 dB.

Illuminating the polysilicon layer, no reaction could be detected. This can be explained by two facts: The used laser diode operates in the infrared region which involves a small absorption coefficient so that only little optical power is absorbed in the thin polysilicon layer. In addition, the grain boundaries act as recombination centres in the bandgap so that the carrier lifetime in polysilicon is very short. Hence, most of the laser-induced electron-hole pairs recombine before reacting with the millimetre wave.

II. Silicon substrate

As it is difficult to increase essentially the thickness of the polysilicon layer or the carrier lifetime, monocrystalline semiconductor substrates have been used in the following. To investigate the properties of materials with high permittivity, finline structures on rt-duroid™ with ε_r = 10.5 have been fabricated. Using the same device configuration as on SiO_2, large insertion loss and input reflection have been obtained. Adding material tapers, this can be improved. Good results have been achieved with symmetrical and wedge shaped material tapers. Another very important parameter is the resistivity of the substrate which has a strong influence on the insertion loss and should be high (6).

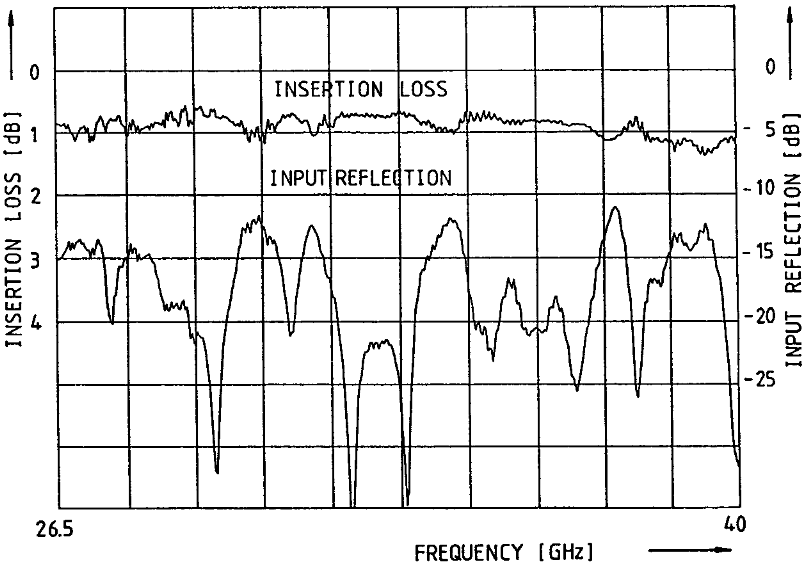

Fig.4 : Measured insertion loss and input reflection of a finline on SiO_2 substrate

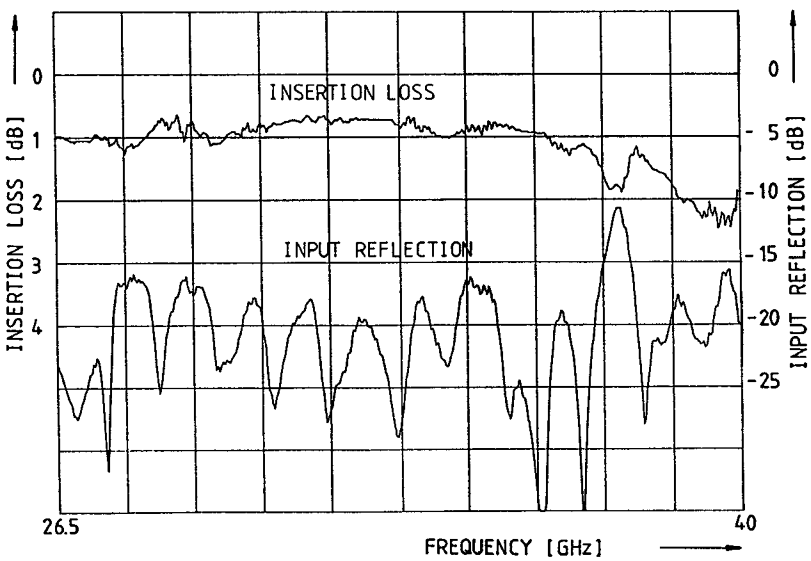

Fig.5 : Measured insertion loss and input reflection of a finline on high resistivity Si substrate

Taking a 0.38 mm thick Si substrate which is specified with a resistivity of 2000-4000 Ωcm, the second finline structure has been realized. Its shape is similar to the first one. Including the material tapers the structure has a length of 30 mm. The insertion loss without illumination is given in Fig. 5. A nearly constant value of 1 dB has been measured which increases up to 2.5 dB at the end of the frequency band. The input reflection is about -20 dB.

Next, the slot region has been illuminated by a pulsed laser diode which operates at 828 nm and provides 8 W optical power at a peak current of 25 A. As the current pulse width is smaller than the maximum width, the peak current has been increased up to 32 A. The attenuation has been measured at several frequency points within the Ka-band. Defining the light pulse width τ by the time during which the driving current of the laser diode exceeds its threshold current (I_{th} = 10 A), a light pulse width of τ = 46 ns leads to attenuations between 13 dB and 17 dB corresponding to different frequencies. The rise time of attenuation (0% - 100%) is about 35 ns. Between light pulse and "response pulse" a delay time of about 15 ns has been measured. Since the maximum attenuation occurs when the light pulse has just been switched off, the rise time and maximum value of attenuation depend on the pulse width. This is due to the long carrier lifetime in high resistivity silicon. This causes also a time of about 10 μs until the initial state is reached again. An additional phase shift due to the plasma region is negligible.

III. Gallium Arsenide Substrate

To achieve both small insertion loss and short response times, intrinsic GaAs is a promising substrate. Owing to its short carrier life times, fast switching can be expected. Using the same device configuration as on Si, a finline structure on 0.45 mm thick GaAs substrate has been fabricated. The substrate material is specified by a resistivity of 10^6 Ωcm. Fig. 6 presents the insertion loss. Again, values of about 1 dB have been obtained which increase with frequency. The input reflection varies between -15 dB and -20 dB.

Then, the slot region of the GaAs-finline has been illuminated by the same laser diode. The frequency of the CW signal has been varied. After a delay time of 15 ns, an attenuation has been detected. Its rise time corresponds to the rise time of the driving current of the laser diode which is 20 ns. Attenuations between 8 dB and 10 dB have been obtained. When the driving current begins to fall, the attenuation decreases without delay time too. Increasing the pulse width has no influence on attenuation and switching times.

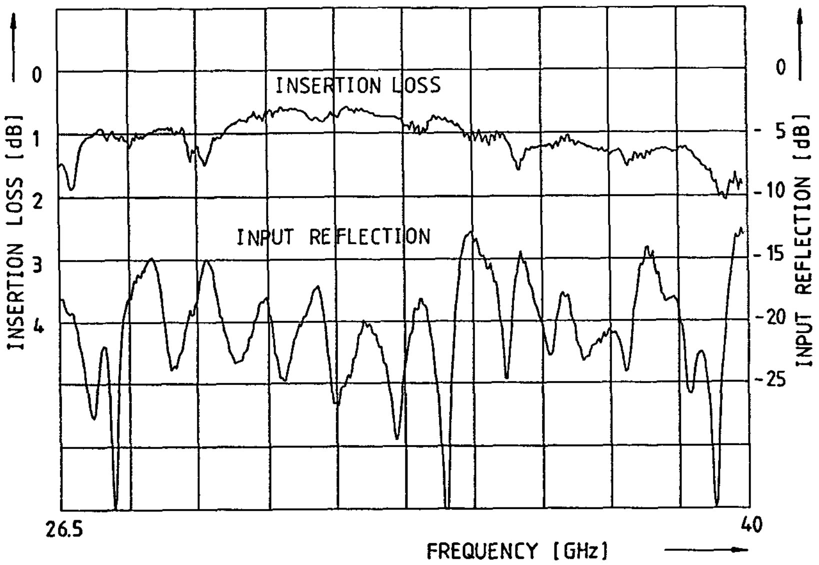

Fig.6 : Measured insertion loss and input reflection of a finline on intrinsic GaAs substrate

However, increasing the incident optical power increases the achieved attenuation. Again, the phase shift is negligible.

CONCLUSION

Three finline structures on different semiconductor materials have been presented. All structures show a relatively small insertion loss which may be further decreased by an improved choke structure and by material taper design.

Taking a finline on SiO_2 substrate with a thin polysilicon layer, no attenuation has been measured if the slot region is illuminated by a laser diode. To realize a very fast switch with this structure, further development and probably very high optical driving power are necessary. Using a high resistivity Si substrate, considerable attenuations have been achieved, but a fast mm-wave switch could not be built due to the long lifetime of the charge carriers. Compared to it, the finline on intrinsic GaAs substrate shows fairly good switching times but less attenuation has been obtained. However, attenuation can be increased by an optimized beam focussing system which e.g. contains a cylindrical lens. This can lead to a fast and well working optoelectronic finline switch with its attenuation controlled by the light power.

ACKNOWLEDGEMENT

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