A NOVEL TYPE OF CONSTANT IMPEDANCE TRAVELING WAVE PHASE SHIFTER FOR InP-BASED MMICs

R. Kremer, S. Redlich, L. Brings, and D. Jäger

FG Optoelektronik, Sonderforschungsbereich 254,
Gerhard-Mercator-Universität GH Duisburg

ABSTRACT

The paper presents a novel type of externally controllable phase shifter based on periodic coplanar transmission lines consisting of Schottky contact (SCCPL) and coplanar sections on passive substrate. The modeling of the devices is carried out by utilizing a four-pole representation of the underlying π-sections. An optimized InP/InGaAs/InAlAs layer structure for the SCCPL is developed providing an external electronic control. Measured phase shifts up to 60°/mm at 20GHz with a line impedance of 48 ± 1.2Ω agree well with theoretical calculations.

INTRODUCTION

As an example phased array antennas as well as adaptive filters for microwave signal processing require a large number of elements and channels, respectively. In particular, for space programs where very large arrays of greater than 10.000 elements are needed, the development of beamforming systems with high performance, low weight, high efficiency, and low cost are essential [1]. Monolithically integrated coplanar phase shifters are promising candidates for these applications. Previously reported coplanar microwave variable phase shifters, however, suffer from inherent impedance mismatch and high microwave attenuation [2-5]. In this paper, we present a novel type of impedance matched coplanar phase shifters to overcome these problems.

DEVICE STRUCTURE

In Fig.1. a schematic sketch of a periodic transmission line consisting of sections on passive (length L_1) and active (length L_2) substrate is shown. The InGaAs and InAlAs

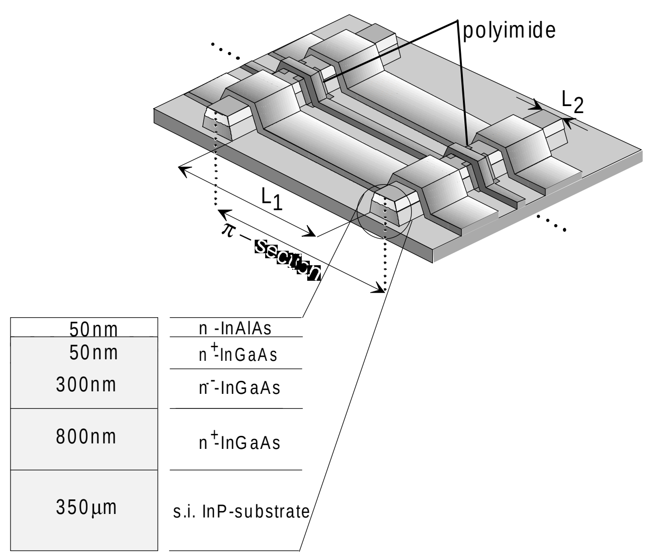

Fig. 1. Schematic device structure of a periodic transmission line with alternating passive coplanar- (length L_1) and Schottky contact coplanar transmission lines (length L_2).

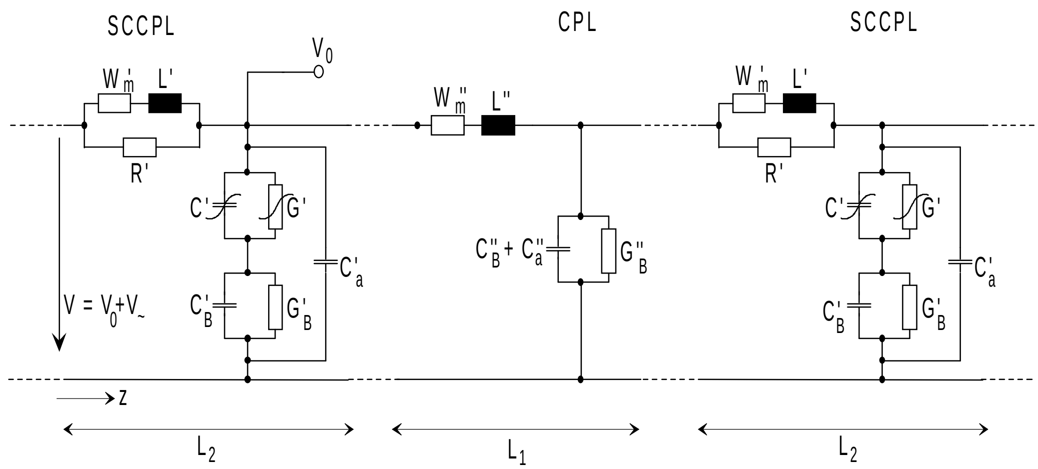

Fig. 2. Equivalent circuit of a periodic transmission line with alternating coplanar (CPL) - and Schottky contact coplanar transmission lines (SCCPL).

layers are grown by usual MBE, lattice matched to the substrate. The thin InAlAs film is used to provide a high Schottky barrier at the metal semiconductor contact using Ti/Pt/Au metallisation in the present case. The 50nm n^+-InGaAs layer provides both a high value of capacitance as well as a pronounced slope in C-V characteristic. A 800nm n^+-InGaAs layer has been introduced for sufficient high values of the bulk conductance. The diode mesas are formed by selective wet chemical etching where the edges are coated with nonconducting polyimide. The realized lengths L_1 and L_2 are 415µm and 22µm, respectively. We fabricated phase shifters with one, two and three π-sections according to Fig. 1. Results presented in this paper will focus on the electronic control of the one section device with an overall length of 460µm.

PERIODIC TRANSMISSION LINES

Coplanar microwave transmission lines used as traveling wave devices capable of changing the phase of a microwave signal propagating along the line have been presented by several groups [2,4]. In this case, the basic mechanism of phase shifting is the variation of the capacitance per unit length by varying the depletion layer thickness beneath the center conductor. The drawback of these devices is (i) the corresponding change of the characteristic impedance of the line which leads to reflections at the interconnections and (ii) the inherent microwave attenuation. Both problems can be solved utilizing periodic transmission lines, as shown in the following.

In Fig. 2. the equivalent circuit of a periodic transmission line with alternating coplanar (CPL) - and Schottky contact coplanar transmission lines (SCCPL) is shown [6]. The basic idea to control periodic transmission lines is as follows. In the slow mode region of this structure, the phase is shifted via a control of the capacitance of the SCCPL. However, because a decrease, for example, of the capacitance enhances the low frequency characteristic impedance, but increases also the cut-off frequency of the Bragg structure, there is a frequency range where the phase is shifted while the characteristic impedance is constant. Note, that a π-structure is necessary performing the function of this device (cf. Fig. 1) [6].

An easy way to analyze the structure in terms of characteristic impedance and propagating coefficient is to utilize a four pole formulation. Each transmission line of the phase shifter can be described by its complex chain transfer matrix $\underline{T}$. If $\underline{T}_S$ refers to the SCCPL and $\underline{T}_C$ to the CPL the device chain matrix $\underline{T}_D$ can be written as

$$\underline{T}_D = \underline{T}_S \, \underline{T}_C \, \underline{T}_S$$

Conversion between $\underline{T}$, $\underline{S}$ and $\underline{ABCD}$ parameters yields the desired characteristics. Optimization of the devices was carried out applying additionally a genetic algorithm as described in [7].

EXPERIMENTAL AND THEORETICAL RESULTS

Experimental and theoretical results to be discussed in this paper will focus on the one section device corresponding to Fig. 1. Experimentally, the phase shifter is reverse biased for electronic control. Results of optically controlled phase shifters will be presented in a forthcoming paper. In Fig. 3(a) the measured capacitance of a SCCPL is shown. The maximum slope of $\partial C'/\partial V_0 = 14.7\,pF/V$ can be observed at 1.7V. A capacitance ratio of $C_{max}/C_{min} \approx 5$ is a large value for SCCPLs resulting from an optimized layer structure (cf. Fig. 1). Measurements and calculations of the resulting phase coefficient are shown in Fig. 3(b). As can be seen, up to 25GHz the experimental results agree well with the numerical calculations. For frequencies above 25GHz the quasi-TM model does not hold due to the influence of additional circuit elements. For a bias variation from 1.5V to 3.0Volts a phase shift of 60°/mm has been measured at 20GHz while the impedance is 48Ω with a variation of merely 1.2Ω (Fig. 4(a)). The measured and simulated absorption coefficients are shown in Fig. 4(b). In the above mentioned voltage range the absorption coefficient varies between 0.26/mm at $V_0 = 3V$ and 0.52/mm at $V_0 = 1.5V$.

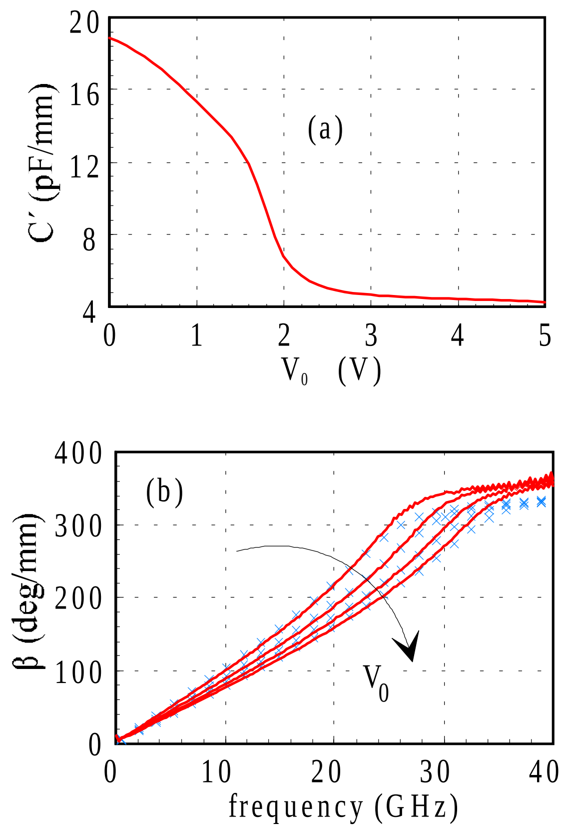

Fig. 3. Measured capacitance per unit length versus reverse dc bias voltage for a frequency of 1MHz (a). Measured (-) and calculated (×) phase coefficients with V_0 = 1.5V, 1.7V, 2V and 3V dc bias (b).

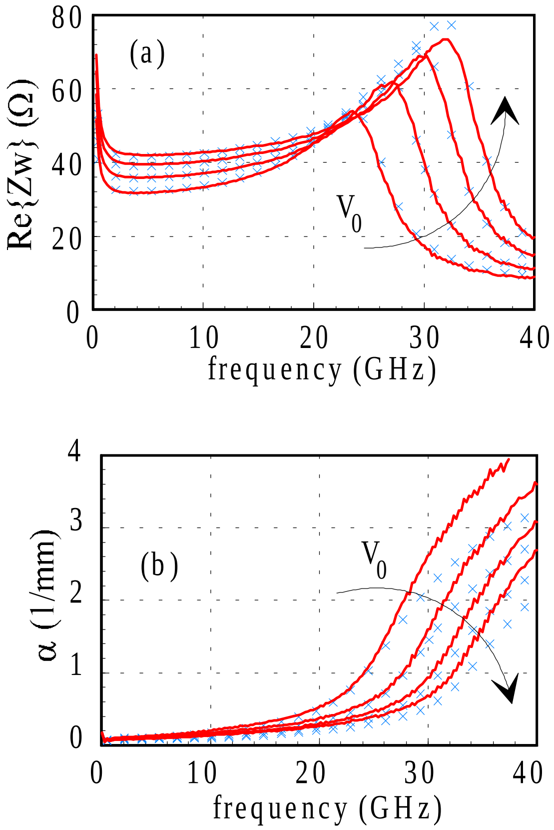

Fig. 4. Measured (-) and calculated (×) characteristic impedance (a) and attenuation coefficient (b) for V_0 = 1.5V, 1.7V, 2V and 3V.

CONCLUSIONS

We have designed, fabricated and measured a novel type of constant impedance traveling wave phase shifter for a frequency of 20GHz. The underlying periodic structure of the device was realized using an optimized InP-based layer configuration leading to a phase coefficient variation of 60°/mm at a line impedance of 48 ± 1.2Ω. The corresponding overall attenuation was measured to be 1.6 ± 0.5dB. The devices are promising candidates for phased array antennas as well as adaptive filters where a large number of elements is required. A forthcoming paper will also discuss the ability of optical control of the devices. It should finally be noted that the experimental results as shown in Fig. 4. can also be obtained by an external optical control.

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