ANALYSIS OF PROPAGATION ON MODFET-TYPE COPLANAR WAVEGUIDE

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ABSTRACT

An analysis of propagation on Coplanar Waveguide loaded with extrinsic semiconductor material – in MODFET-like structure - is proposed. The model takes into account both semiconductor and conductor losses, as well as the finite conductor thickness.

INTRODUCTION

Planar waveguides printed on semiconducting substrates feature some peculiar properties, as compared to conventional ones. For instance, when a thin lossless dielectric layer is sandwiched between a metal strip and a doped semiconductor, it often shows slow-wave phenomena, supporting waves propagating at a phase velocity that is much lower than that of light in the denser dielectric. This kind of structure is known as a Metal-Insulator-Semiconductor (MIS) structure, and its modelling attracted attention since the early 70's (1), as it is very common in semiconductor circuitry: any Schottky contact provides an MIS structure, thanks to its depletion layer. On the other hand, in the last decade MODFET devices have proved to be the state-of-the-art high frequency transistors.

The purpose of the present paper is to investigate propagation in coplanar waveguides printed on MODFET structures for MMIC applications.

MODELLING

Various analysis techniques were applied to the study of MIS structures such as Finite Elements (2,3), mode matching (4) and Transverse Resonance (4).

All the above methods neglect conductor losses, apart from a few authors who approached the problem by the way of some approximations such as quasi- TEM (5), or a modified SDA (6). This last approach provided in fact a reasonable trade-off between complexity and reliability of results.

One of the few rigorous techniques that were successfully employed is the FDTD method (7); its computational effort, however, is considerable, particularly when dealing with MMIC's, because of the fine meshes required.

In this contribution we have used a technique proposed by us in (8), and already successfully used for MIS microstrips.

As a first step, we calculate the dyadic Green function $\tilde{\mathbf{Z}}$ of the composite dielectric substrate, without the conducting strips. In order to simplify this step, the whole structure is enclosed in a metallic box: hence radiated fields are not considered. This box allows to model rigorously just shielded structures; anyway we believe that this assumption works as a satisfactory approximation for open CPW grown on extrinsic semiconductor, as the semiconducting substrate guarantees better field confinement, as compared to standard CPW. Assuming complex permittivities accounts for the lossy nature of the semiconducting layers. The second step is to impose that the fields satisfy Ohm's law in the metal strips: this way we obtain the integral equation

$$\iint_{Strips} dx'dy'\tilde{\mathbf{Z}}(x,y,x',y',\gamma)\cdot\mathbf{J}(x',y') = \rho\ \mathbf{J}(x,y) \qquad (1)$$

to be solved in the conducting strips. The z-dependence of all quantities does not appear explicitly in (1) as it is assumed to be of the usual form $\exp(-\gamma z)$ for both the fields and the sources. The solution of equation (1) for non-trivial sources **J**, yields the complex propagation constant γ, the electric sources and, by means of the function $\tilde{\mathbf{Z}}$, the fields of the structure.

Further details of this approach and its practical advantages and problems can be found in (8).

RESULTS

The first simulation refers to an MODFET-type CPW, whose experimental data were reported in (6). The structure is depicted in figure 1, and comparison between the computed data and the experimental ones for both attenuation and propagation constants are reported in figure 2, showing good agreement. The conductivity of the doped AlGaAs layer is 32000 S/m, whereas the two-dimensional electron gas (2DEG) constitutes a layer 100Å thick, having a conductivity of 67200 S/m. In this example (as in (6)) the doped contact GaAs layer is assumed to be completely depleted, corresponding to an applied bias of 0V. The depletion region has been modelled as an insulating layer extending in the horizontal direction up to the box walls, in spite of its physical localisation beneath the central conductor. As pointed out in (3), this approximation does not substantially affect the modelling of the fundamental mode of CPW. On the other hand, it has to be noted that, if one is concerned with a characterisation of the well-known parasitic mode (the odd mode), this approximation becomes unacceptable, as the semiconducting layer beneath the lateral fins supplies a load to such a mode.

Figure 2 clearly indicates that slow-wave phenomena in this structure are accompanied by relevant losses. Moreover, if the biasing voltage applied to the central electrode is increased to -1V, the propagation characteristics of the fundamental mode do not change appreciably (not shown), in spite of the consistent variation of the depletion depth (from 0.024 to 0.036 μm). This kind of situation usually occurs when slow-wave phenomena are more controlled by ohmic losses than by an effective spatial dislocation between electric and magnetic fields. Under these conditions slow-waves can neither be used to build voltage controlled phase shifters, or filters, nor to reduce the transmission lines length in MMIC devices.

The picture basically changes if the biasing voltage is varied in order to extend the depletion region all over the AlGaAs substrate: now the electric fields "sees" the 2DEG, and its density is responsible for the slow-wave phenomena. Figure 3 depicts this case, where we have considered the 2DEG as dense as before, but leaving the AlGaAs layer completely depleted: slow-wave phenomena do appear, showing reduced losses and a marked sensitivity on the carrier sheet density of the 2DEG. Nonetheless losses are still very high: in fact the primary sources of losses are the relatively thin strips. For strip thickness of 1 μm results becomes more interesting (Figure 4). It has to be pointed out that for the higher frequency range we expect losses in figure 4 to be somewhat underestimated, for the conductor skin effect requires a higher number of expanding functions to solve equation (1). On the other hand, enlarging the expanding set of the integral equation usually also produces spurious (non-physical) solutions: hence, we kept the number of expanding functions small in order to keep a (qualitatively) reliable investigation. Hence, with some care, we can state that a MODFET-type structure with the geometry assumed to obtain results of figure 4 could be used as a slow-wave device. Figure 5 depicts the behaviour of such a structure for a varying 2DEG density, at 5 GHz. Consequently, it could be argued that, e.g., some resonator or filter electrically tuneable may be realised, based on this structure. In fact figure 5 shows that varying the 2DEG conductivity from 120000 to 20000 S/m, the structure wavelength may be varied nearly by 100%.

For both figure 4 and figure 5 we have assumed the AlGaAs layer as depleted: this operating condition is quite a standard one for MODFET amplifier devices, where parasitic paths in the semiconducting layer for the channel currents are to be avoided.

These considerations are emphasised for the case of pseudomorphic MODFET, where the larger bandgap of the alloys guarantees higher 2DEG densities.

CONCLUSIONS

We have applied a technique previously introduced by ourselves in the modelling of real planar structures to the characterisation of coplanar waveguides printed on MODFET-type structures. A comparison with experimental data shows good agreement. It has been found that a CPW printed on an MODFET-type structure can be used as a slow-wave line, provided that an appropriate bias is applied: by modulating the density of the 2DEG, the propagation properties of the structure can be modified. Electrically tuneable filters, resonators or phase shifter exploiting these structures may be envisaged.

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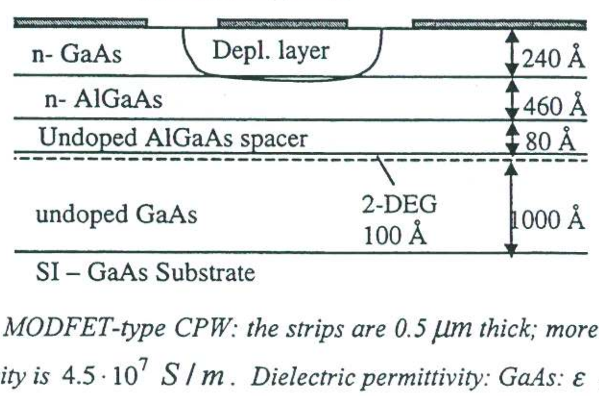

Figure 1: Cross-section of a MODFET-type CPW: the strips are 0.5 μm thick; moreover W=5 μm, G=1.25 μm. The strip conductivity is $4.5 \cdot 10^7$ S/m. Dielectric permittivity: GaAs: ε_r=12.9, AlGaAs: ε_r=12.26.

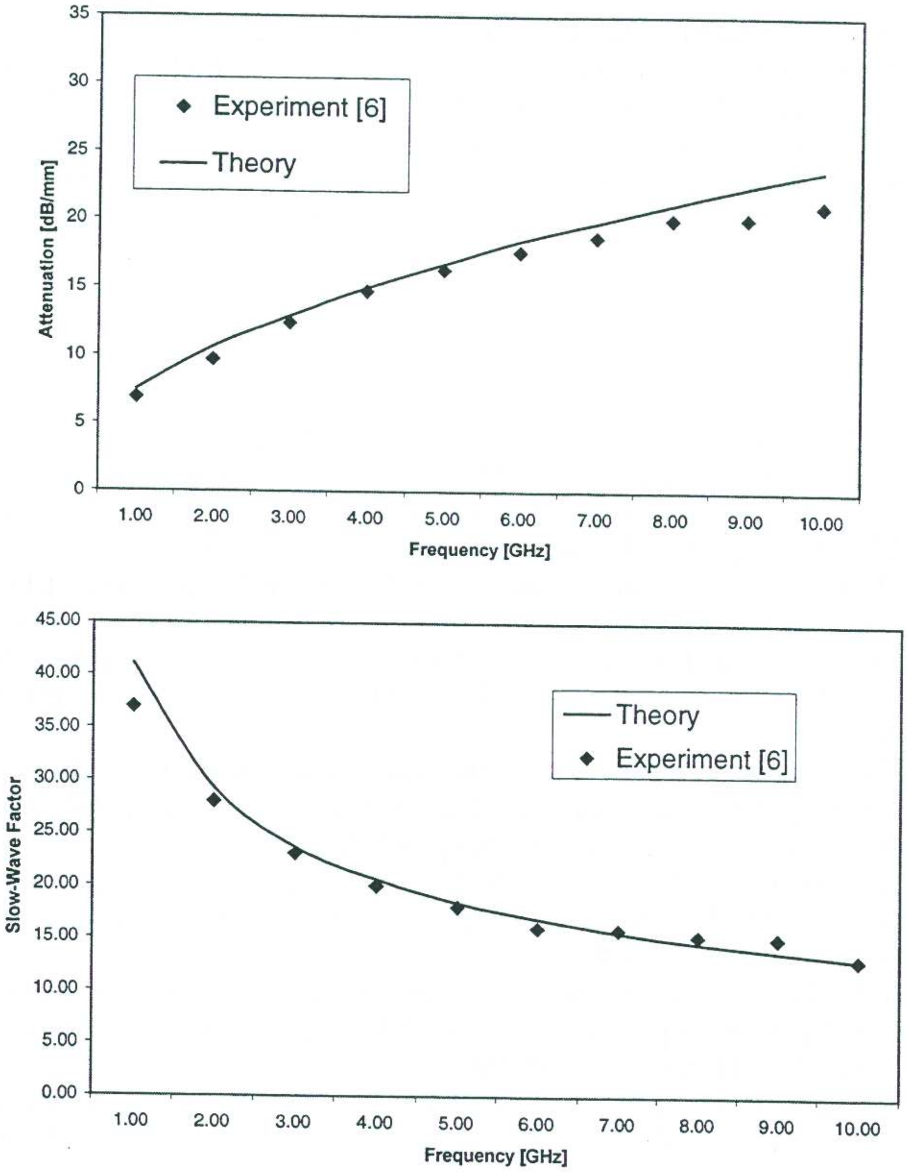

Figure 2: Attenuation and propagation constants for the structure in fig.1: comparison between theoretical and experimental data.

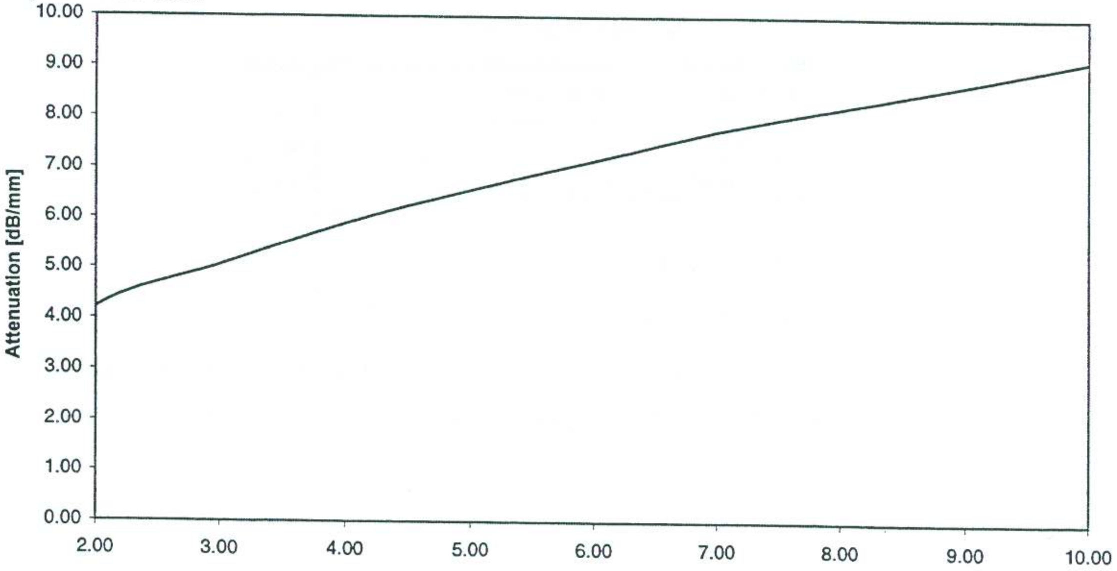

Figure 3a: Attenuation constant computed when the AlGaAs layer is completely depleted.

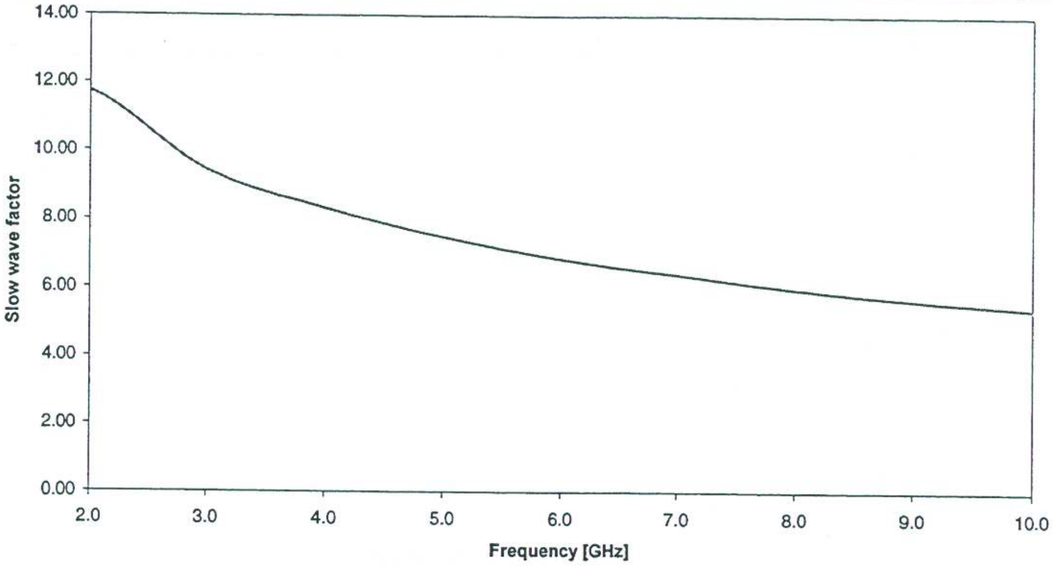

Figure 3b: *Propagation constant computed when the AlGaAs layer is completely depleted.*

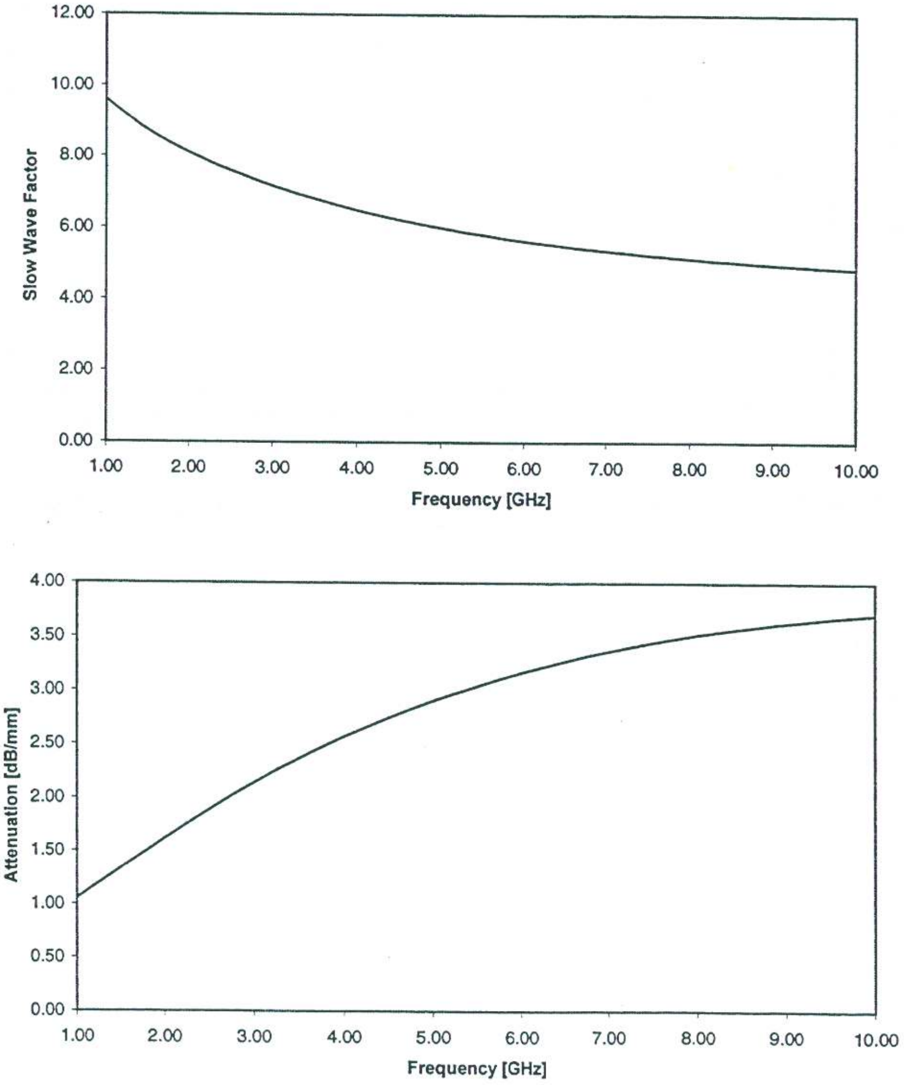

Figure 4: *Attenuation and propagation constants for one micrometer thick strips.*

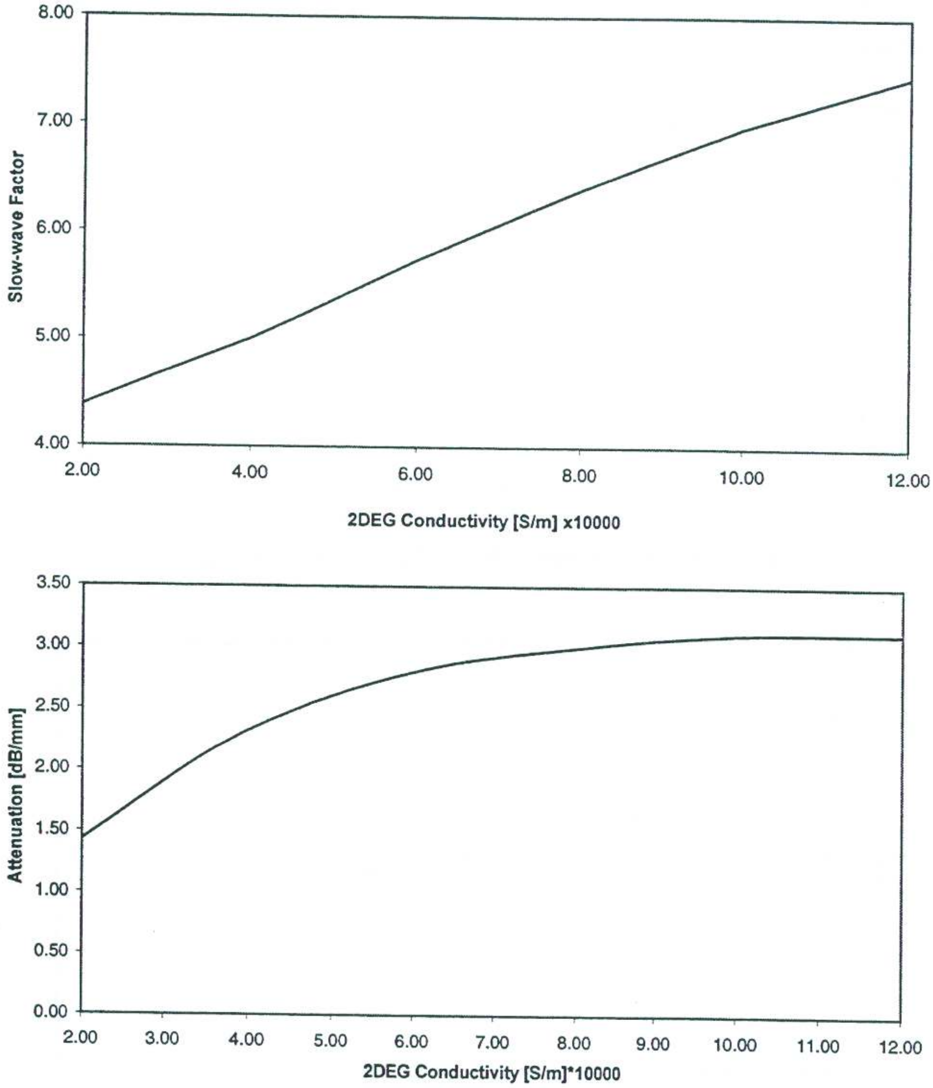

Figure 5: *Computed Slow-Wave factor and attenuation versus 2DEG conductivity for structure of figure 4.*