ANALYSIS OF PRINTED FINLINES ON SEMICONDUCTOR SUBSTRATES

THESIS SUBMITTED BY
AYMAN ABDELAZEIM MOSTAFA
Assistant of Electronics and Computer Department
Ain Shams University

For the Fullfilment
of the Degree of
MASTER OF SICENCE

Electronics and Computer Department
Faculty of Engineering
Ain Shams University

1 9 8 4

SUPERVISORS

Prof. Dr. SAFOUAT MAHROUS MAHMOUD
HEAD OF
ELECTRONICS AND COMPUTER DEPARTMENT

Dr. HADIA MOHAMED SAID EL HENNAWY
ASSISTANT PROFESSOR OF
ELECTRONICS AND COMPUTER DEPARTMENT

بسم الله الرحمن الرحيم

ACKNOWLEDGEMENTS

*I'd like to express my sincere thanks and gratitude to **Prof.Safouat Mahrous,** Head of Electronics and Computer Eng. Eept., Faculty of Engineering, Ain Shams Univrsity, for his supervision, encouragement, invaluable advice and powerful support.*

*I'd like also, in this respect, to express my indebtness and sincere thanks to **Dr: Hadia El-Hennawy,** Electronics and Computer Dept., Faculty of Engineering, Ain Shams University for her valuable assistance, close supervision, encourgragment and unfailing help during all the stages of my research.*

*Sincere thanks and gratitudes to **Prof. Klaus Schünemann**, Technishe Universität Hamburg-Harburg, West Germany, for providing me both the materials for experimental work and the computer facilities.*

ABSTRACT

This thesis presents an attempt to analyze the behaviour of MIS finline laid on a semiconductor substrate . It is a new type of transmission line which has been suggested due to the resent developments in the monolithic microwave integrated circuits . The method presented can be applied to any planar structure laid over a semiconductor substrate.

A complete survey of the technology and development of both hybrid and monolithic integrated circuits applied in the microwave region is given. Computer programs based on the full wave analysis were built to examine the behaviour of the propagation constant for MIS finline structures, under the influence of the frequency , line parameters (insulator thickness , substrate thickness , ... etc) and the substrate conductivity . The programs were first examined for the special case when the semiconductor thickness tends to zero which represents the case of a unilateral finline and the results were compared with these published and showed excellent agreement. The problem of relative convergence and number of basis function is studied. A family of curves was generated relating the slow wave factor and attenuation constant to the frequency , conductivity and all line parameters. This family of curves helps the finline designer to choose the proper parameters of the circuits to obtain the optimum performance. The variation of the slow wave factor with the resistivity shows the existance of three fundamental regions of operation which are known as lossy dielectric mode, slow wave mode, skin effect mode. The slow wave mode region obtained is of great importance in the MIC design , In this region the wave propagates with a very low phase velocity accompanied by a relatively low attenuation.

./..

A slow wave factor of 15.5 and an attenuation of 8.6 dB/mm are obtained at 10 GHz which are superior to those obtained using shielded coplanar line or coplanar waveguide.

The obtained results were tested experimentally using a specially designed housing and the comparison showed good agreement.

Partical applications of the MIS structure in this region were suggested and discussed.

ABBREVIATIONS

MIC	Microwave Inetegrated Circuits.
MMIC	Monolithic Microwave Integrated Circuits.
SDA	Spectral Domain Approach
MIS	Metal Insulator Semiconductor.
S.W.F.	Slow Wave Factor.
CAD	Computer Aided Design
MBC	Miniature Beryllium oxide Circuit
VPE	Vapour Phase Epitaxy.
LPE	Liquid Phase Epitaxy
MBE	Molecular Beam Epitaxy
SEBL	Scanning Electron Beam Lithography.
PTL	Planar Transsimion Line.
LSE, LSM	Lonitudinal section Electric and Magnetic field respectively.
SSCPW	Semiconductor Slow wave Co-Planar Waveguide
CTCPW	Cross Tee Co-Planar Waveguide.
FEM	Finite Element Method.

LIST OF SYMBOLS

ϵ', ϵ''	real and imaginary parts of complex dielectric constant respectively.
μ^*	Complex scalar magnetic permeability.
ϵ^*	Complex scalar electric permittivity.
α, β	real and imaginary part of the complex propagating constant.
σ	Conductivity of the semi-conductor layer.
γ	Complex longitudinal propagating constant.
$\hat{a}_x, \hat{a}_y, \hat{a}_z$	Cartezian unit vectors.
$\bar{\alpha}, \hat{\alpha}, \tilde{\alpha}$	Transverse propagating constants.
ω	Angular frequency
$\psi^{e,h}$	Scalar electric or magnetic potential functions.
$\underline{\pi}^{e,h}$	Hertz electric or magnetic vectors.
$\nabla, \nabla\cdot, \nabla\times$	Vector operators, viz:grad., div and curl.
∇_t^2	Transvers laplacian operator.
J_z, E_z	Current and field components in the space domain.
$\tilde{J}_z, \tilde{E}_z$	Current and field components in the transform domain.
$J_m(x)$	Bessel function of first kind and order 'm'.
$T_n(x), U_n(x)$	Chebyshev polynomial of first or secand kind, respectively, and order n.

CONTENTS

INTRODUCTION

Recently an intensive revival has been witnessed in the field of analog monolithic microwave integrated circuits **(MMICs)**, that is, microwave circuits deposited on a semiconductor, or an insulating substrate with a semiconductor layer over it. On a planar substrate, four basic configurations for the monolithic circuits are available which are: microstrip with a bottom side ground metalization, its inverse slot line, coplanar waveguide which consist of central "hot" conductor separated by a slot from two adjacent ground planes and its inverse coplanar strip line in which one of the two conductor is used normally as a ground plane. Up till now most of the analysis that have been carried were concerned with the microstrip and coplanar line as suitable candidate of the monolithic circuits at low microwave frequencies. However, as it is well known, the contribution of the conductor losses becomes significante, and may even dominate, above 20 GHz which is considred as the maximum useful operating frequency for such line. The finline structure which is currently used at millimeter wave length, or above, is an alternative for such lines at high frequencies.

The aim of this thesis is to analyze the finline over a semiconductor substrate. The **analysis** is based on the spectral domain approach **SDA** which is a powerful method to analyze not only lossless planar transmission line but also for lines which contain highly dissipative material.

This thesis contains four chapters. It can be divided into two parts: part I contains a presentation for the hybrid integrated ciruits and monolithic microwave integrated circuits **(MMICs)**. A survey for the work that has been done in planar metal-insulator semiconductor **(MIS)** structures is also included in chapter 1 and 2. Part II deals with the finline **MIS** as a new candidate for **MMICs** . Its applications accompanied with practical measurments are discussed in chapter 3 and 4.

Chapter 1 describes **MMIC** as an alternative approach to the hybrid technology for the fabrication of microwave components. It covers, in some detail, the design consideration that must be applied to the **MMICs** in general and **Ga As** in particular with numerous examples of practical circuits and components that have been recently developed. The future prospects of **MMIc** is also considered. A survey of the hybrid rigorous approachs for analyzing **MIS** structures is given at the end of this chapter.

In chapter 2, A complete survey for the **MIS** microstrip and coplanar waveguide has been given starting from the approximate theory till the recent full wave analysis. The three fundamental modes of propagation in such structures are discussed and the conditions for appearance of each mode and its equivalent circuit is clarified. The physical mechanism of energy transfer in each mode is also explained.

Chapter 3 presents an extensive full wave analysis based on **SDA** for unilateral multilayer **MIS** lines with two different formulations. The problem of solving complex equations is discussed beside some numerical and computational consideration. Various curves of slow wave factor (S.W.F) and attenuation constant as a function of the conductivity and frequency for different line parameters (Slot width, substrate thickness, insulator thicknes.....etc) were calculated. The problem of relative convergence has been checked by increasing the resulting size matrix and the results showed excellent agrement when it is checked with other authors.

Chapter 4 Contains the practical measurments with special designed housing to measure the S.W.F. and attenuation constant. A comparison of the obtained results with theoretical values calculated by the programs mentioned in chapter 3 is also included.

Chapter 5 offers practical applications and many devices for the **MIS** and some ideas for minimizing the attenuation beside suggestions for future work.

CHAPTER 1

AN OVERVIEW ON MICROWAVE INTEGRATED CIRCUITS

1.1 Introduction:-

Before 1965, waveguides , coaxial or stripline circuits have been used for the utilization of nearly all microwave components. Recently. the technology of integrated cireuits has been introduced for use at the microwave frequencies. Microwave integrated circuits , like conventional integrated circuit, can be fabricated in monolithic or hybrid form. The difference between M I C S and converntional I C S is that the latter contains very high packing densities. M I C S offer the following advantages over discrete circuits:

1- Low Cost (due to the large quantities processed).

2- Small Size .

3- Light Weight.

4- High Reliability.

5- Improved Reproducibility.

6- Improved Performance.

Conventional ICS are combinations of active and passive elements that are manufactured by successive diffusion processes on a semiconductor substrate. The active elements are in most cases silicon or gallium arsenide planar chips, while the passive are either thin or thick film compononents. Nowadays, There are two competing technologies of building MICS : monolithic microwave circuits and conventional hybrid. Each method has its advantages and disadvantages over the other. In the next section we will present a survy for both technologies and their developments accompained with real practical circuits.

1.2 Development and Technology of MMICS and conventional hybrid

1.2.a MMIC Technology

The rapid development of MMICS has been recently extended to the microwave frequency range . MMICS are microwave circuits deposited on semi-conductor or substrate with a semi- conductor layer over it. By Mono- lithic, we mean an approach where-in all active and passive circuit elements or components are formed into the bulk or into the surface of a semi-insulating substrate by some deposition scheme. Due to the fast development of the technology circuit design, many devices and components have existed up to 100 GHz .Ga As MESFET is one of these components which perform variety of functions like : amplification, oscillation , phase shifting , switching , frequency conversion ...... etc. Schottky barrier diodes are only used as DC level shifting or at millimeter wave frequencies as mixers. Recently , varactor diodes have also been incorporated into MMICS for tuning purposes [1] .

In 1968 Mehal and Wacker [2] tried to fabricate a 94 GHz receiver front end by using Semi-insulating Ga As , as the base material, schottky barrier diodes and Gun devices. However , the first successful MMIC was produced by Plessey and it was an x-band amplifier based on shottky-gate-effect transistor (MESFET).This element was the key active element that started the present MMIC activities.

In fact, the reapid development of Ga As material technology which led to high-frequency semiconductor device performance previously unattained was the main reason for this successful trial. By producing successful MMICS based on Ga As, the interest in silicon MMICS has increased for two reasons: First, the losses accompained during silicon fabrication due to the thermal process could be eleminated by using silicon on sapphire approach. Second , the silicon technology is extremely well developed compared to Ga As technology.

From application point of view, there are many systems based on a large number of identical components such as space-borne, phase-array radars,transimitter -receiver modules and computer systems.... etc. These systems require light weight, reliable, low cost and large number of identical circuits.. The reliable performance of MMICS arised from the fact that wire bonding is eleminated through the chip. Wire bonds have always been a serious factor in reliability and reproducibility beside being labor intesive .
The reproduibility of MMICS is a result of high resolution capabality of lithograghy used to define the active devices and circuit geometries. Small size and volume and consequently light weight are intrinsic properties of the monolithic approch. The elemination of wire bonding and fabricating the components within a printed circuit eliminate many undersired parastics which limit the broad band performance of microwave circuits. The small circuit size of the monolithic approach enables circuit integration on a chip. This integration may start from the lowest degree of complexity, such as oscillators, mixers, power amplifiers and switchs to the higher level ' functional block' such as a phase shifter, modulator and demodulator to even higher level of complexity such as transmit- receive module which is one of the most important features of MMICS . We have mentioned breifly the advantages of Monolithic approach , The disadvantages of this approach are:

1) Unfavorable device per chip area ratio.
2) Circuit tuning.
3) Trouble- shooting difficulty.