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DISCONTINUITIES IN FIN-LINE ON SEMICONDUCTOR SUBSTRATE

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ABSTRACT

Discontinuities in both slot width and substrate complex dielectric constant are investigated theoretically. The fin-line slot pattern is defined on a double-layer substrate with finite conductivity. Numerical results are presented showing that a step in the permittivity can almost be compensated for by a step in the slotwidth.

INTRODUCTION

A lot of interesting applications are imaginable for finlines on semiconductor substrate. Using an insulator-semiconductor substrate, slow wave modes can be obtained /1/ which may be utilized to build delay lines or phase shifters. Interchanging the sequence of the layers yields a slot pattern on a semiconductor active layer with insulating dielectric substrate. It can be utilized for realizing an opto-electronic switch or phase shifter, if the slot region is illuminated by a laser beam. Due to the high field concentration in the slot, this structure seems to be superior to others using alternative transmission media /2/.

As a first step towards the design of an opto-electronic fin-line switch, this paper deals with analysing discontinuities in slot width and substrate complex dielectric constants. Two different cross sections have been investigated: a sandwich structure (Fig. 1), where the metal fins are located between two layers, and a structure with the fins located at one side of a double-layer substrate (Fig. 2). The discontinuities to be dealt with are shown in Fig. 3 for an abrupt change in the slot width and in Fig. 4 where the complex dielectric constants are assumed to change abruptly in a certain transverse plane. Finally, both discontinuities are treated together in order to demonstrate that an input matching can thus be obtained. These superposed discontinuities may serve as a simple narrow-band transformer between generator or load and the "active" fin-line section.

THEORY

Dispersion in fin-lines is usually studied using the spectral domain technique /3/-/5/. Recently it has been shwon that the singular integral equation (SIE) technique is numerically more efficient if also higher-order modes are to be analysed /6/, /7/. Matching the transverse electromagnetic fields in the plane of the discontinuities mentioned above may require some ten eigenmodes. Hence we have chosen the SIE technique for their determination.

Step discontinuities in the slot width of a fin-line have already been analysed (see e.g. /8/-/10/). We have adopted the procedure outlined in /9/ and generalized it to include the double discontinuity for a fin-line on a layered semiconductor substrate. The dielectric constant is replaced by a complex permittivity

$$\varepsilon^*_{ri} = \varepsilon_{ri} - j\,\frac{\sigma_i}{\omega\varepsilon_0}\,, \quad i = 1,\ 2.$$

ε_{ri} means the relative dielectric constant, and σ_i the conductivity of the corresponding layer. The hybrid field is constructed by superposing an LSE with an LSM term which are each described by 4 scalar potentials satisfying the Helmholtz equation in their respective region. The solution is obtained by generalizing the procedure outlined in /7/. This results in a linear set of homogeneous equations from which the complex propagation constant and the field expansion coefficients of the different eigenmodes must be determined.

The transverse electric and magnetic field components of each waveguide are written in terms of the amplitude vectors of the incident and scattered modes. Establishing continuity relations as in /9/ then leads to a system of linear equations containing these amplitudes as variables. They can be arranged so that the discontinuity is described in a scattering matrix representation. In the following results will be given for both the reflection and the transmission coefficients of the dominant mode.

RESULTS

The fin-line structures which have been analysed consist of a substrate with a silicon layer (ε_r = 12.0) and a silicon oxide layer (ε_r = 4.0). The latter is assumed lossless. First, a step discontinuity in the slotwidth has been studied. Figures 5 and 6 show the magnitude of the reflection and the transmission coefficients ($|S_{11}|$ and $|S_{21}|$) of the dominant modes versus slotwidth w_1 of waveguide "a". Then, an abrupt change in the complex permittivities has been calculated. In Figs. 7 and 8, $|S_{11}|$ and $|S_{21}|$ are presented versus conductivity $\sigma_2^{(a)}$ of waveguide "a". Finally, both discontinuities are analysed together. At fixed conductivity $\sigma_2^{(a)}$, the influence of the slotwidth w_1 on $|S_{11}|$ and $|S_{21}|$ is computed. As shown in Figs. 9 and 10, a minimum of $|S_{11}|$ is obtained. Therefore, a reflection occurring at the intersection between two regions with different material constants can be compensated for by a proper step in the slotwidth.

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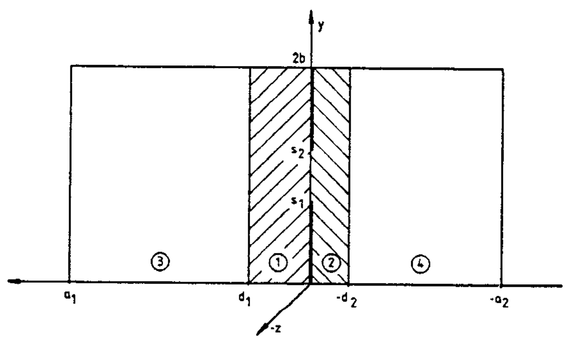

Fig. 1: Fin-line on a double layer substrate with the fins located between the two layers

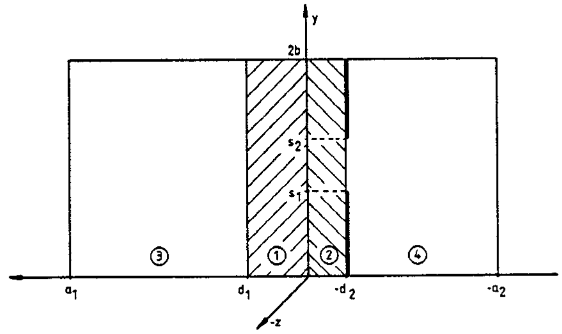

Fig. 2: Fin-line on a double layer substrate with the fins located at one side of the substrate

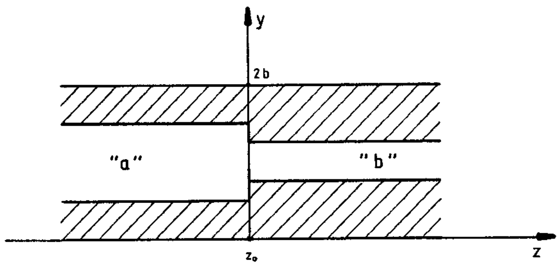

Fig. 3: Step discontinuity in the slot width

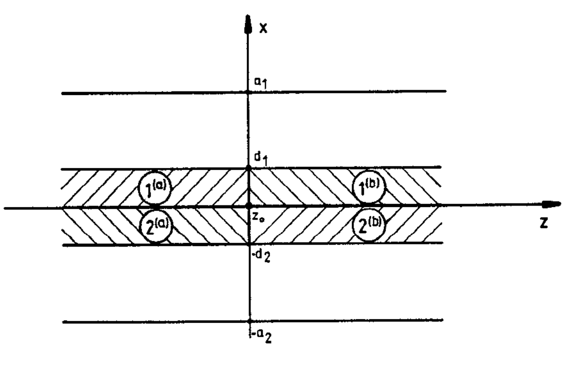

Fig. 4: Abrupt change in the dielectric constants

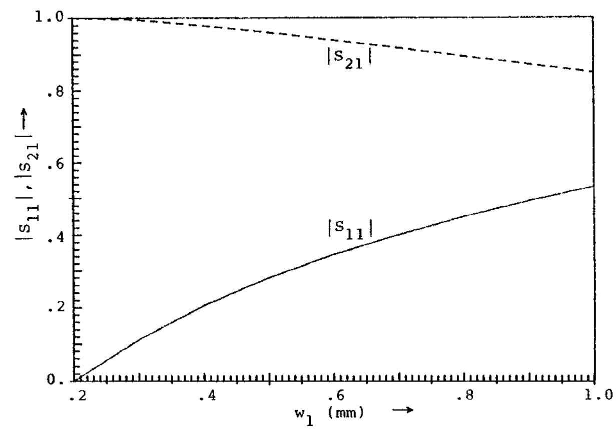

Fig. 5: Slot width dependence of $|S_{11}|$ and $|S_{21}|$ for the structure shown in Fig. 1, d_2 = 0.1 mm, $\varepsilon_{r2}^{(b)}$ = 12.0, $\sigma_2^{(a)} = \sigma_2^{(b)}$ = 1.0 $(\Omega m)^{-1}$. Identical quantities for Fig. 5 - Fig. 10: f = 33 GHz, w_2 = 0.2 mm, $a_1 + a_2$ = 7.112 mm, a_1 = 2b = 3.556 mm, d_1 = 0.3 mm, $\varepsilon_{r1}^{(a)} = \varepsilon_{r1}^{(b)}$ = 4.0, $\varepsilon_{r2}^{(a)}$ = 12.0 , $\sigma_1^{(a)} = \sigma_1^{(b)}$ = 0.

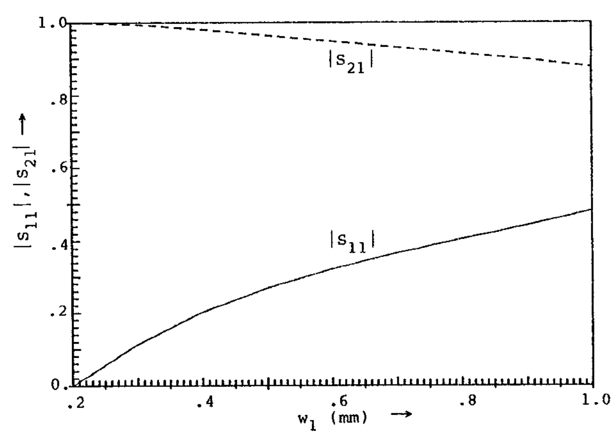

Fig. 6: Slot width dependence of $|S_{11}|$ and $|S_{21}|$ for the structure shown in Fig. 2, d_2 = 0.001 mm, $\varepsilon_{r2}^{(b)}$ = 12.0, $\sigma_2^{(a)} = \sigma_2^{(b)}$ = 1.0 $(\Omega m)^{-1}$.

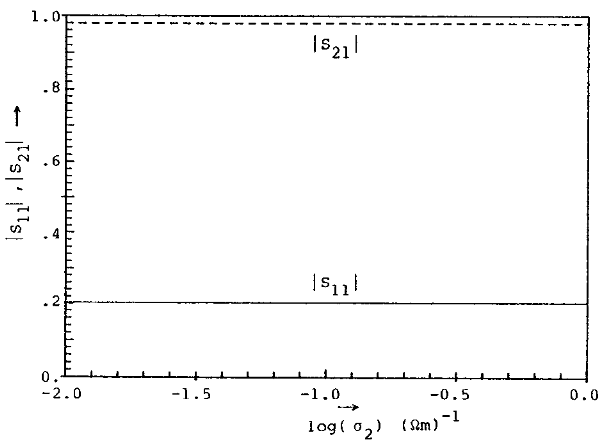

Fig. 7: $|S_{11}|$ and $|S_{21}|$ versus conductivity $\sigma_2^{(a)}$ (structure of Fig. 1), w_1 = 0.2 mm, d_2 = 0.1 mm, $\varepsilon_{r2}^{(b)}$ = 1.0, $\sigma_2^{(b)}$ = 0.

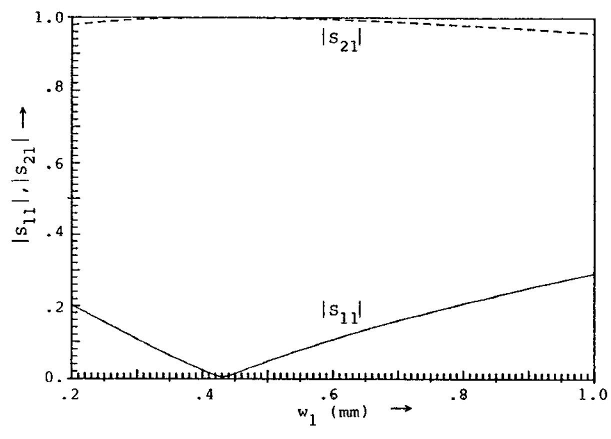

Fig. 9: $|S_{11}|$ and $|S_{21}|$ versus slot width w_1 (structure of Fig. 1), d_2 = 0.1 mm, $\varepsilon_{r2}^{(b)}$ = 1.0, $\sigma_2^{(a)}$ = 1.0 $(\Omega m)^{-1}$, $\sigma_2^{(b)}$ = 0.

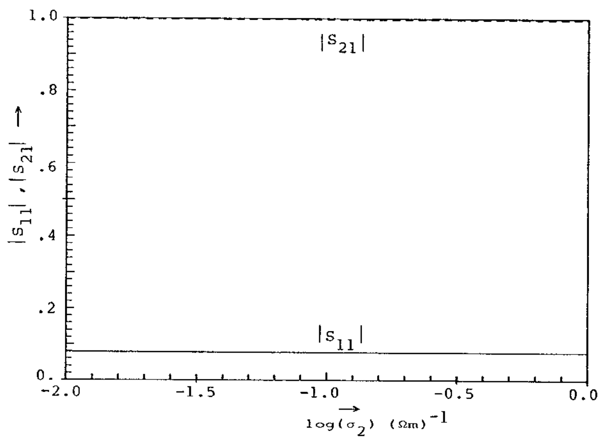

Fig. 8: $|S_{11}|$ and $|S_{21}|$ versus conductivity σ_2(a) (structure of Fig. 2), w_1 = 0.2 mm, d_2 = 0.001 mm, $\varepsilon_{r2}^{(b)}$ = 4.0, $\sigma_2^{(b)}$ = 0.

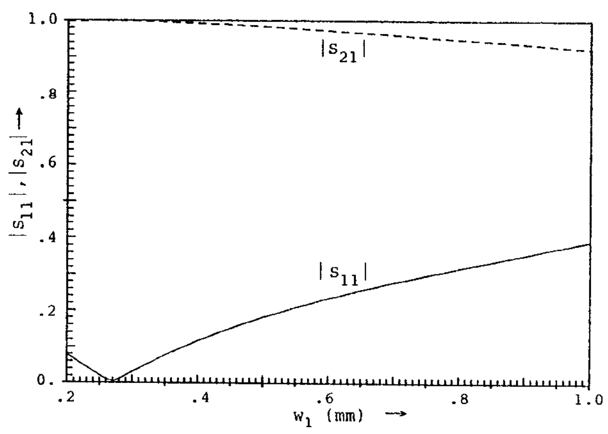

Fig. 10: $|S_{11}|$ and $|S_{21}|$ versus slot width w_1 (structure of Fig. 2), d_2 = 0.001 mm, $\varepsilon_{r2}^{(b)}$ = 4.0, $\sigma_2^{(a)}$ = 1.0 $(\Omega m)^{-1}$, $\sigma_2^{(b)}$ = 0.