A STUDY OF PLANE WAVE TRANSMISSION RESPONSE USING EQUIVALENT CIRCUITS OF GRIDDED SILICON WAFERS INCORPORATING SCHOTTKY DIODES

D.P. KORFIATIS1, K.A.T. THOMA1 and J.C. VARDAXOGLOU2
1Department of Physics                      2Department of Electrical & Electronic Engineering
University of Patras                            Loughborough University
26500 Rio Patras                                Loughborough, LE113 TU, Leicestershire
Greece                                                 U.K.

Abstract: A dynamic FSS incorporating Schottky diodes on high resistivity Si is proposed. Results from an equivalent circuit model prove the applied reverse bias on the Schottky diodes to be the controlling parameter.

Key-Words: Frequency Selective Surfaces, Active antennas, Schottky diodes.

1. Introduction
Tuning the electromagnetic properties of materials has been a distinct feature of many research and development fields. Optical control of the behaviour of the dielectric medium of an FSS, has been extensively reported by achieving changes in the dielectric material properties by means of an optical source of variable intensity. The underlying factor is the photo illumination of a semiconductor substrate generating electron-hole pairs and thus producing a plasma. In so doing results to an increase of the imaginary part of the refractive index of the substrate. If the optical source is used in conjunction with a negative image mask [1] planar arrays can be generated within a thin semiconductor substrate. In an attempt to enforce the formation of the array pattern formed by photo illumination, the experiments have been reported to be extended on Si wafers selectively doped, etched or micromachined with the array pattern of the optical mask [2].
Optical control of the dielectric medium as a result of plasma formation is limited by recombination mechanisms. In order to avoid this limitation together with the requirement of a compact setup, an alternative way of controlling the dielectric properties of the semiconductor is suggested. For this purpose a periodic array of a metal grid on the semiconductor surface provides the FSS. Schottky diodes are fabricated within the semiconductor substrate, providing a means to control the semiconductor dielectric properties by varying the biasing conditions of each diode. Ohmic contacts at the back of the wafers are ensured by depositing a metal grid on low resistivity areas at the back of the wafer following the same array pattern.

2. Device and equivalent circuit model
The proposed device is composed of metallic grids imposed on both surfaces of a p type high resistivity Si wafer of 10 cm diameter. The periodicity of the grids is 4 mm and the strips width is 2 mm.
At a first approach the problem is tackled through an equivalent circuit technique. The equivalent circuit of the device comprises of two parts. One is the generally accepted equivalent circuit of the Schottky diode as shown in Figure 1.

![Fig.1](image)

The second part follows the modelling equations applied to FSS as described originally by Marcuvitz [3]. In particular, the work of Evans [4] is used as a basis for the equivalent circuit of the gridded FSS.
(Figure 2), which in our case is extended to both semiconductor surfaces. Specifically for TE incidence the normalized immitance in the case of an inductive grid is given by:

$$X_{TE} = \omega L_{TE} = \frac{p}{\lambda} \cdot \cos \theta \left[ \ln \left( \cos ec \left( \frac{\pi w}{2p} \right) \right) + G(p, w, \lambda, \theta) \right]$$

and from Babinet's duality conditions, the normalized immitance for TM incidence in the capacitive case is given by:

$$B_{TM} = \omega C_{TM} = 4 \frac{p}{\lambda} \cdot \cos \phi \left[ \ln \left( \cos ec \left( \frac{\pi g}{2p} \right) \right) + G(p, g, \lambda, \phi) \right]$$

where p is the periodicity of the grid, w the width of the metallic strips, g the gap between the metallic strips, \(\lambda\) the wavelength and \(\theta, \phi\) the angles of incidence for TE and TM incidence respectively. The normalized immitance for TM incidence in the case of an inductance is given by:

$$X_{TM} = \omega L_{TM} = \frac{p}{\lambda} \cdot \sec \phi \left[ \ln \left( \cos ec \left( \frac{\pi w}{2p} \right) \right) + G(p, w, \lambda, \phi) \right]$$

and form Babinet's duality conditions, the normalized immitance for TE incidence in the case of a capacitance is given by:

$$X_{TE} = \omega C_{TE} = \frac{4p}{\lambda} \cdot \sec \theta \left[ \ln \left( \cos ec \left( \frac{\pi g}{2p} \right) \right) + G(p, g, \lambda, \theta) \right]$$

Results presented here are obtained for TE incidence, assuming the grid comprising of both inductive and capacitive components given as above. The incorporated Schottky diode is considered under reverse bias conditions with the depletion layer capacitance \(C_d\) being the dominant circuit component. In the overall equivalent circuit of Figure 3 the Schottky diode is modeled only through the dominant capacitance \(C_d\) and the resistance \(R_d\), which is a valid assumption under reverse bias conditions. The capacitance \(C_d\) is given by the well known relation:

$$C_d = A \sqrt{\frac{eN_p e}{2(V_{bi} - V)}}$$

and the dynamic resistance \(R_d\) is calculated through experimental I-V characteristics of the diodes according to

$$R_d = \frac{dV}{dI}$$

Finally, the complex admittance \(Y\) of the device (normalized to the impedance of free space) is derived and the transmission coefficient is calculated via the formula:

$$|\tau|^2 = \frac{4}{4 + |Y|^2}$$

![Fig. 2](image_url)

![Fig. 3](image_url)

3. Results

Results obtained for the transmission coefficient as a function of the applied reverse bias on the Schottky diodes are shown in Figure 4 for two different frequencies of the incident microwave beam.

![Fig. 4](image_url)
Figure 5 illustrates the device response in the microwave region for a 10 Volts applied reverse bias on the Schottky diodes.

![Graph showing transmission coefficient vs frequency](image)

Fig. 5 Microwave response of the device for an applied voltage of 10 Volts.

4. Conclusions

The derived preliminary results indicate that the proposed device could be successfully used as a dynamic FSS with the resonant frequency controlled by the applied voltage. Devices with the Schottky diode fabricated by metal evaporation on a high resistivity p-Si substrate under low pressure conditions are to be tested and results will be compared with those of the model.

References:


