Transient Response of Optically-Controlled Microwave Pulse through an Open-Ended Microstrip Lines

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Abstract

In this paper we analyze the reflection characteristics of a dielectric microstrip line with an open-end termination containing optically induced plasma region, which are analyzed by the assumption that the plasma is distributed homogeneously in the laser illumination. The characteristics impedances resulting from the presence of plasma are evaluated the transmission line model. To estimate theoretically the characteristic response of same systems in the time domain, the Fourier transformation method is evaluated. The reflection characteristics of time response in microwave systems have been calculated.

Keywords: microwave, opto-electronics, microstrip lines, optical control

1. Introduction

Research in the past, and in recent years there has been increasing interest in the applications of lightwave technology for control, generation and measurement of microwave[1-3]. At higher frequencies, either microstrip or dielectric waveguide structures become more attractive. Especially stripline configurations are very important for the integration of electro-optic and microwave components

Now, there are many literatures of optically-controlled microwave circuits using microstrip lines or coplanar waveguides[1-5]. Most of their analyses and experiments concentrated upon the time and frequency characteristics for the purpose of high speed performance. Here we analyzed the reflection characteristics in the dielectric microstrip line optically induced plasma region.

In this paper we treat a microstrip line on a semiconductor substrate, one end of which is open terminated and illuminated for optical injection of carriers. The microwave reflection characteristics of this line are investigated with respect to the illuminating light theoretically.

2. Dielectric Properties of Plasma

When a semiconductor material is illuminated with laser photon energy greater than the bandgap energy of the semiconductor, photons are absorbed, creating electron/ hole pairs and resulting in a thin layer of plasma near the surface of the material. The presence of electron-hole plasma in the semiconductor yields in the modification of the conductive as well as the dielectric properties of the semiconductor material. The dielectric constant in the plasma-induced semiconductor material can be analyzed by the equation of motion of charge carriers in the semiconductor by considering classical electron-hole plasma theory as predicted by Drude Lorentz equation [3]. One end of the strip is connected to an input / output port and the other end are open terminated as shown in Figure 1.

The plasma region Δz is assumed to have a uniform density of free carriers. The relative permittivity of plasma induced in a semiconductor is given by [1]

$$\varepsilon_p = \varepsilon_s - \sum_{i=e,h} \frac{\omega_{pi}^2}{w^2 + \gamma_i^2}(1 + j\frac{\omega_i}{\omega})$$

$$= \varepsilon_{pr} - j\varepsilon_{pi} \qquad (1)$$

$$\omega_{pi}^2 = \frac{N_p \times q^2}{\varepsilon_0 \times m^*} \qquad (i = e, h)$$

where the subscripts e and h indicate the electron and hole. Also γ_i is collision frequency, w_{pi} is the plasma angular frequency, q is the electron charge, and m^* is the effective mass. In addition, N_p is the plasma density.

The frequency and plasma dependence of the real part of the dielectric constant of Eq. (1) is fairly weak, whereas the imaginary part of the dielectric constant shows a strong variation with frequency and density of plasma.

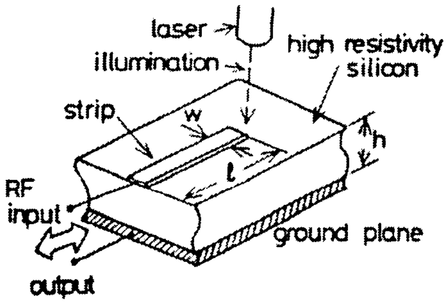

Fig. 1. A microstrip line with an open-end termination to be illuminated.

3. Optical Control of Reflection Characteristics

The optical control of microwaves through discontinuities of microstrip lines have been actively studied, specially in reflection characteristics of waves in microstrip line [4]. In most analyses of this type of devices, which microwave switches having gaps of strips to be illuminated, only the conductance in the discontinuity of the line has been taken consideration in the neglecting capacitance in *ON* state (large carrier density), while the conductance is neglected in *OFF* state (no carrier induced). In here we take both the capacitance and the conductance into consideration. We numerically evaluate the characteristics impedance and reflection characteristics of waves in this line with transmission line model.

The equivalent terminal impedance at the open end is represented as Z_L, a transmission line model can be expressed as referencel with Z_L and the characteristics impedance Z_o of the line. The input impedance to a transmission line varies with the distance progressed along the line. The characteristics impedance Z_o is given generally

$$z_0 = \sqrt{\frac{R + jWL}{G + jWL}} \qquad (2)$$

at high radio frequencies.

In most microstrip configuration transmission loss is neglected due to the compactness of an entire circuit. The total attenuation of the line is insignificant due to the short line length. If the attenuation is primarily due to the dielectric loss, the dielectric constant ε becomes a complex quantity. Then, from Eq(1)

$$\varepsilon_p = \varepsilon_0(\varepsilon_{pr} - \varepsilon_{pi}) \qquad (3)$$

We can derived the related equation with Maxwell's equation

$$\nabla \times \vec{H} = \vec{J} + jw\varepsilon\vec{E}$$

$$= \vec{E}(\sigma + jw\varepsilon)$$

$$= \vec{E}[jw(\varepsilon - j\frac{\sigma}{\omega})] \qquad (4)$$

The imaginary parts of the permittivity in Eq(1), which are related to the conductivities, yield the conductance.

The reflection coefficient in input termination is given by

$$\rho_{in}(w) = \frac{z_{in}(w) - z_0(w)}{z_{in}(w) + z_0(w)} \qquad (5)$$

The Figure 2 shows the reflection coefficient in $1GHz$ and $128GHz$ when the input signal has the unit impulse function. The microwave signal is input to the port and reflected signal is calculated through a directional coupler connected tothe same port. The input microwave is almost totally reflected in the dark state, and increasing the frequency reduces the amplitude of the reflection.

To estimate theoretically the characteristics response of some systems in time domain, the Fourier transformation method is evaluated. The Fourier transformation is defined as [6]

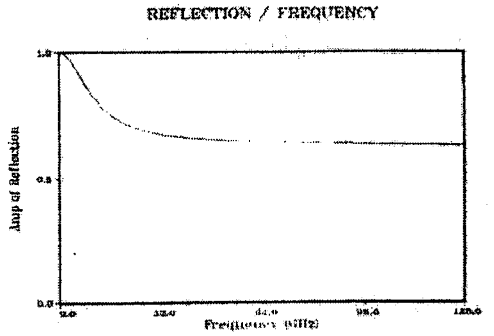

Fig. 2 Reflection coefficient vs. Frequency

$$F(w) = \int_{-\infty}^{\infty} f(t)e^{-jwt}\,dt \qquad (6)$$

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(w)e^{jwt}\,dw \qquad (7)$$

These two relations couple the time and frequency dependent responses for liner microwave circuits. Consider the pulse-modulated sinusoid when an amplitude modulating carrier ω_0 shifts angular frequency w to $(\omega - \omega_0)$ that is, if

$$F_0(w) = \int_{-\infty}^{\infty} \rho_{in}(t)e^{j(w0-w)t}\,dt \qquad (8)$$

$$\int_{-\infty}^{\infty} \rho_{in}(t)e^{j(w0-w)t} = F_0(w - w_0)$$

The frequency dependence of reflection coefficient is evaluated the carrier frequency and the plasma density as parameters and the characteristics response is

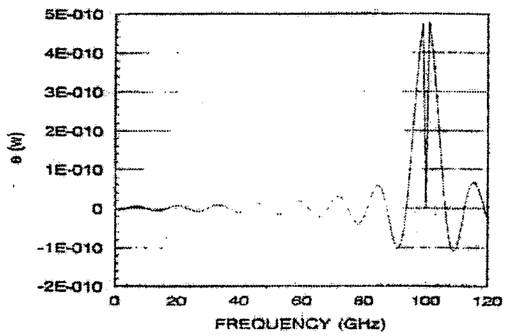

Fig. 3. Characteristics response in the frequency reflection coefficient

$$O(w) = \rho_{in}(w)e(w) \qquad (9)$$

The Figure 3 shows the characteristics response in frequency-domain when the input signal is the pulse modulated sinusoid signal. This results are shown the maximum peak of frequency in $e(w)$ at about 16 GHz. In here, we used the input signal at 1 GHz and 128 GHz with variable carrier frequency ranging from $1GHz$ to 100 GHz. Figure 4 shows the characteristics in time domain to the input signal is shifted to the angular frequency.

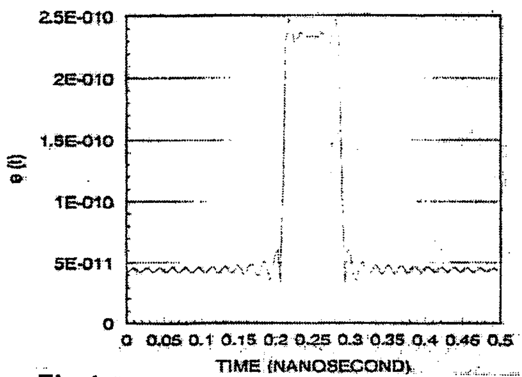

Fig.4 Transient response in time domain of optically-controlled microwave pulse

In compared with the unit impulse signal in reflection characteristics, the effect of shifted sinusoid signal is shown in Figure 5 which are the real and imaginary parts of the input termination reflected coefficient at the open end of the line.

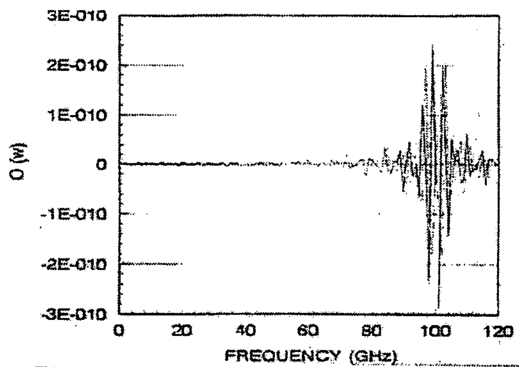

Fig.5 Characteristics response to optically - controlled microwave pulse with shifted signal

In the evaluated amplitude and characteristics of the reflected microwave, Figure 6 shows the reflection characteristics when the input signal has shifted sinusoid signal. *vs.* frequency domain. It represents the frequency characteristics with carrier density (N_p) at the open end of the line. The frequency used in this paper are used from 1 GHz to 128GHz and carrier frequency ω_0 is used 100 GHz. the central frequency of the pulse modulated signal in this figure, $f_0(w)$, shifts about 16 GHz towards higher frequency. The Fig. 6 shows the characteristics of time domain.

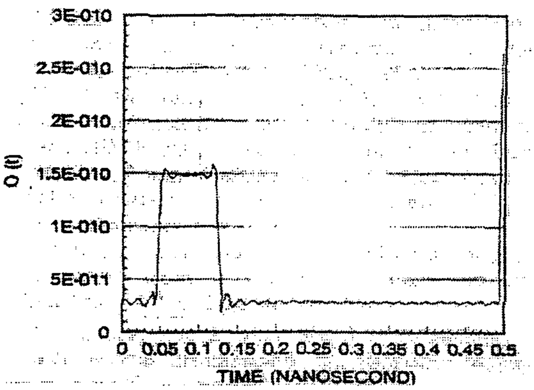

Fig.6 Transient response in time domain of optically-controlled microwave pulse by shifted signal

4.Conclusion

The reflection characteristics of microwaves in a microstrip line with one end open-terminated have been studied with respect to light illumination that open end of the strip. We have emphasized the frequency and time characteristics in the presence of electron-hole plasma region. The calculation of the characteristics was carried out for the transmission line model taking account of both the conductance and capacitance of the open end of the line.

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