Coplanar Striplines for THz Frequencies: Design, Fabrication and Measurements

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We investigate the feasibility of coplanar striplines (CPS) in conjunction with infrared (IR) detectors. Since attenuation and dispersion issues dominate at IR, the analytical formulas for transmission line parameters valid below few hundred GHz are not applicable at IR. Therefore, we perform numerical modeling to determine these parameters at 28.3 THz. Comparison of modeling with measured voltage response is presented.

Introduction

Frequency range above few hundreds of GHz well exceed the range of validity of the quasi-static approximations that are often made in modeling the propagation of electrical signals on transmission line interconnects [1]. Also, the measurements of the transmission line propagation properties have been applied to more fundamental studies such as the extraction of material parameters for high temperature superconducting films in subterahertz frequency regions [2]. The requirement for transmission line interconnects modeling as well as the application of the propagation measurements to material characterization necessitates a precise knowledge of transmission line dispersion and attenuation characteristics.

The propagation factor of a transmission line, in general, is given by

$$\gamma(f) = \alpha(f) + j\beta(f) \qquad (1)$$

where α and β are attenuation constant and phase constant, respectively. The former mainly arises from the radiation, conductor, and dielectric losses while the latter term determines the degree of dispersion a signal experiences. Experiments conducted in past to study the attenuation and dispersion characteristics below 1 THz show that the radiative losses are dominant at frequencies over ~ 200 GHz for coplanar transmission line dimensions of the order of few tens of microns [3]. Discrepancies were found between the radiative attenuation derived based on quasi-static approximation and the one measured at frequencies ranging from 100GHz-1THz [1], [4]. The transmission line parameters also depends on the substrate type, e.g. strong attenuation for lossy semiconductor substrates [5] while virtually no attenuation and much lower dispersion for less permittivity mismatch between substrate and air [6].

In order to study the characteristics and behavior of CPS at IR, we perform modeling, fabrication and testing of dipole connected to CPS of different lengths. Numerical modeling of CPS is done using Ansoft HFSS. Numerical results of port current as a function of CPS length are compared with the measured IR voltage response.

Numerical Characterization of CPS

We model Au-CPS on quarter-wave thick SiO_2 (1.19-μm at 10.6-μm wavelength) on top of Si wafer. One end of CPS is connected to load impedance Z_L, while the other end is connected to the port. We estimate the CPS parameters in two steps: (1) compute the impedance at the port as a function of CPS length, keeping the CPS width and separation constant, and, (2) fit the impedance versus CPS length curve thus obtained to the impedance transformation equation,

$$Z_{in} := Zo \cdot \left(\frac{Z_L \cdot \cosh(\gamma \cdot l) + Zo \cdot \sinh(\gamma \cdot l)}{Zo \cdot \cosh(\gamma \cdot l) + Z_L \cdot \sinh(\gamma \cdot l)} \right) \qquad (2)$$

where γ is given by (1),

$$\beta := \frac{2 \cdot \pi}{\lambda_{eff}}, \qquad \lambda_{eff} := \frac{\lambda_0}{n_{eff}}$$

where, Z_o is characteristic impedance of CPS, Z_{in} is input impedance at port, λ_0 is freespace wavelength, λ_{eff} and n_{eff} ($n_{eff} = 1.7$) are the effective wavelength and refractive index, respectively, in the substrate (200-nm SiO2 on Si). Z_o and α are found by fitting the impedance transformation equation to the data obtained from HFSS by simultaneously varying these two unknowns. Each unknown has a particular effect on the Z_{in} versus CPS length curve; e.g., the value of Z_o defines the peak of the curve while α defines the damping of curve. Figure 1 shows the curve fitting and extracted parameters for CPS widths of 0.2-µm and 0.4-µm. We find that as we increase the CPS width keeping the separation constant, the characteristic impedance decreases and the attenuation constant increases, as shown in figure 2.

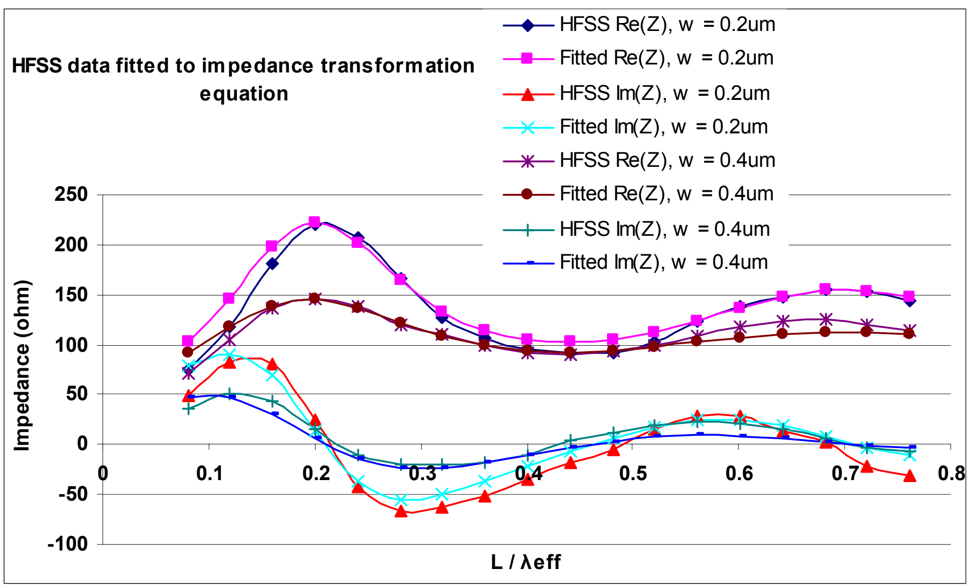

Figure 1 Curve fitting of HFSS data to eq. (2) for *w* = 0.2-µm and 0.4-µm

Next, we replace the load impedance Z_L by a dipole resonating at 28.3 THz (λ_0 = 10.6-µm) in our model to calculate the current at the port (response) as a function of CPS length "*L*". Calculated normalized response is shown in figure 4.

Fabrication and Measurements

We fabricated dipole antenna resonating at 28.3 THz connected to CPS of different lengths ranging from 0-µm to 5.75-µm in steps of 0.25-µm (Figure 3) on quarter-wave thick SiO2 isolation layer on top of Si wafer. The dipole antenna and the CPS were made

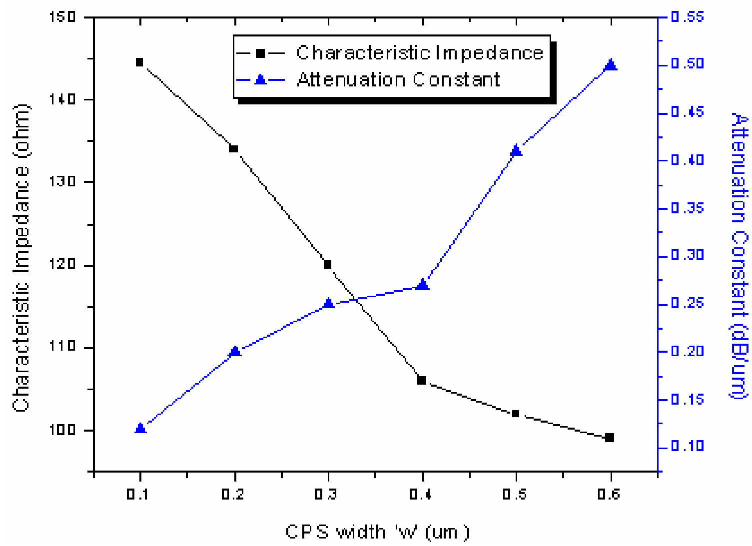

Figure 2 Zo and α for CPS separation of 0.4-µm

of 100-nm thick gold (Au). The width of dipole arms and CPS is 0.6-µm and are separated 400-nm apart. Nickel (Ni) bolometer, 1.2-µm x 0.5-µm and 125-nm thick, was fabricated at the other end of CPS. Approximately 25-µm long dc lead lines connect the CPS to the bondpads for DC biasing of bolometer.

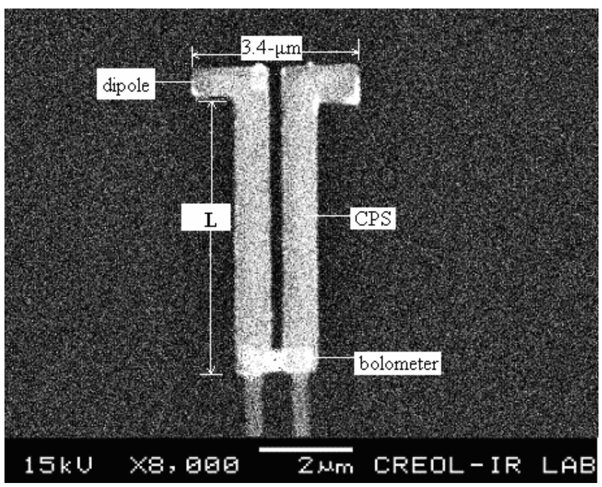

Figure 3 Dipole antenna connected to CPS

The device measurement was carried out using CO2-laser emission at 10.6-µm. The laser beam was focused by an F/8 optical train, resulting in spot with a $1/e^2$ diameter of 200-µm at focus. The bolometer under test was biased at 100 mV and placed at the focus of the laser beam. The laser beam was modulated with a chopper at a frequency of 2.5 kHz and the modulated signal produced by the bolometer was read with a lock-in amplifier after a 1000 x preamplifcation. We measured at normal incidence the voltage response polarized along the dipole arm. Measured voltage response can be related to the characteristic impedance, input impedance and port current obtained from modeling; since, the voltage response depends on the impedance transformation at the sensor which in turn is related to Z_o and α of CPS. Thus our response measurement can be related to the modeled parameters and their validity can be confirmed. We measured the device voltage response and compared them to the modeled port current. Both these quantities are comparable since the current couple thermally in the bolometer and change in resistance of sensor material produces measurable change in an external bias voltage. Figure 4 shows modeled and measured quantities are in good agreement. Measurements will be performed for the remaining range of CPS lengths.

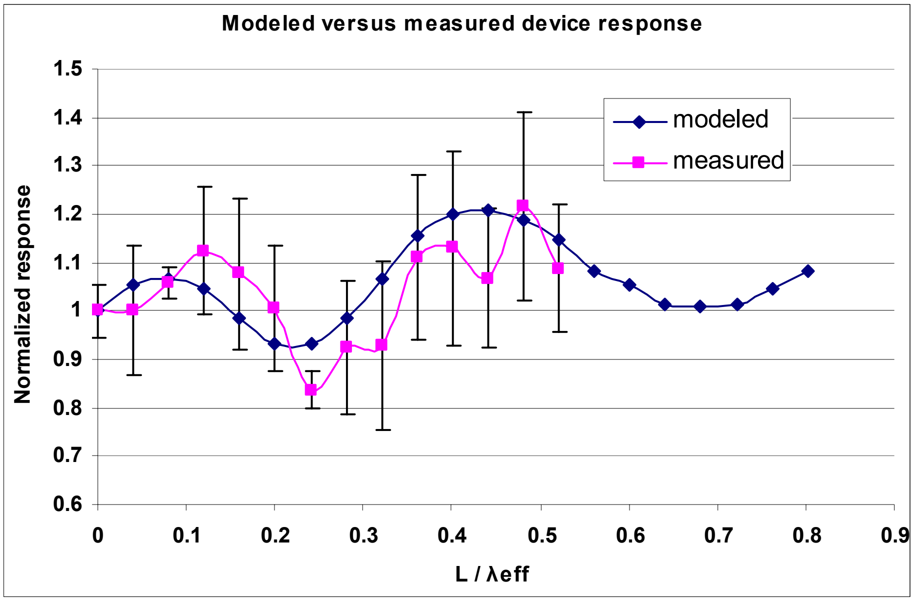

Figure 4 Device response (Average and standard deviation for 4 devices at each point)

Conclusion

The CPS interconnection for antenna at IR frequencies is studied. Transmission line parameters like Z_o and α are computed using HFSS. Current response is computed as a function of CPS length to relate to the transmission line parameters. Comparison of modeled and measured response as a function of CPS length is presented.

References:

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