A Terahertz Ring Hybrid Coupler Based on Parallel Plate Dielectric Waveguide with Signal Line for a Ballistic Deflection Transistor Travelling Wave Amplifier

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Abstract — **In this paper, a new design of Terahertz (THz) Ring Hybrid Coupler Based on Parallel Plate Dielectric Waveguide with Signal Line inserted (PPDWS) is proposed. The PPDWS is a simple transmission line, easy to fabricate, with a low average loss of 0.45dB/mm at 1-1.4THz, and designed to be implemented into the THz Ring Hybrid Coupler Design. We employ (3N+1.5)λ for the circumference of the Ring Hybrid Coupler for a fundamental mode of TE10. ANSYS HFSS simulations show S21=S41=-4.5dB, S31< -20dB, S11<-20dB at 1.022THz. We obtain an excellent isolation between split ports for signal transmission, and a very good signal cancellation on port3. The coupler and PPDWS line are planned for use in the Terahertz Ballistic Deflection Transistor Travelling Wave Amplifier; however, the design is also capable of being applied to other very high frequency applications.**

Index Terms — **Terahertz, PPDWS, Ring Hybrid Coupler, transmission line, BDT**

I. Introduction

In recent years, there is a growing interest in the research and development of Terahertz (THz) devices and applications. Within the last two decades, THz applications have become more and more important in various areas such as imaging [1], telecommunication [2], biomedical [3], astronomy [4], radar system [5] and so on. For this purpose, different kinds of semiconductor devices were developed to operate in the THz region.

Our group had introduced one of these devices called Ballistic Deflection Transistor (BDT) [6]. It is based on an InGaAs/InAlAs heterojunction, which provides a two-dimension electron gas (2DEG) where electrons are able to travel at 10^8 cm/s without scattering. Fig-1 shows a three-dimensional view of the BDT device. It is composed of a source, a top drain which pulls electrons, two opposite drains and two lateral gates in push pull configuration. The concept is to steer electrons to one or the other drain thanks to channel depletion generated by the negative gate and a strategically placed triangular deflector. More details can be found in [7]. Due to its relative low transconductance (g_m=200μA/V) [8], it would require at least ten stages, each stage comprising 15BDTs in parallel

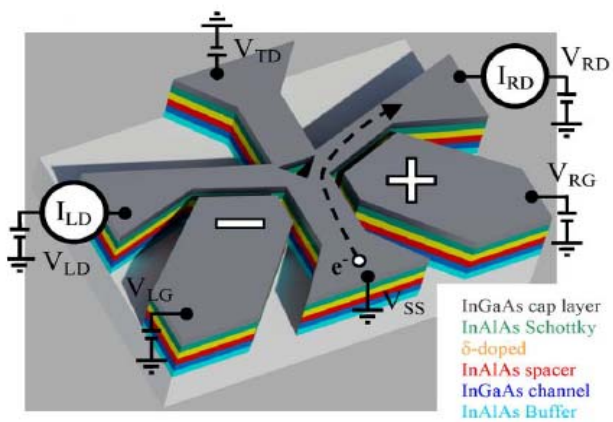

Fig-1 3D "Artistic" Model of BDT [9]

with a gain of 3 mA/V. The total length of the transmission line and ten BDT stages would be on the order of 400μm, providing a total gain of 30 mA/V. A new design of Terahertz (THz) Ring Hybrid Coupler Based on Parallel Plate Dielectric Waveguide with Signal Line inserted (PPDWS) [10] has been developed for this purpose.

The unique symmetrical design of the BDT means the input and output signals are differential. As a result, we need to have an input splitter to obtain the differential inputs to the left and right gates, and a combiner to combine the differential signals to create a single-ended output. However, with the high frequency in THz, we will need extremely small capacitance and inductance to design a suitable THz balun by exploiting the simple lumped 180º splitter/combiner structure [11]. Therefore, scaling the circumference of the Ring Hybrid (or rat-race) structure [11] by an appropriate ratio will be a practical way for a THz balun design.

Besides the application of the amplifier design, the Ring Hybrid coupler is a major component used in numerous RF and Microwave systems, such as RF switches [12], mixers [13], and antenna systems [14] etc. As mentioned above, when the frequency reaches the THz regime, the traditional design of a Ring Hybrid structure will become very lossy, and due to its size, will be very difficult to fabricate. Under this circumstance, this new Ring Hybrid design based on the PPDWS seems very promising.

II. Parallel Plate Dielectric Waveguide with Signal Line inserted (PPDWS)

Fig-2 shows a 3D model of the PPDWS design in HFSS. The design consists of two metal plates, a dielectric strip and a signal line positioned in the center of the dielectric strip. The two metal plates and signal line are made of gold, because of its high conductivity ($\sigma=4.42\times10^{7}$S/m), high melting point and high resistance to oxidation. The center strip is built with silicon nitride, outside the center strip all the gaps will be filled with silicon dioxide. The material selection has been proposed in our previous study [10]. In order to avoid energy leakage, we need higher dielectric constant material for the center strip and lower dielectric constant material for gap filler. On account of this, silicon nitride (ε_r = 7.5, $\tan\delta=2\times10\text{-}5$) was chosen for center strip and silicon dioxide (ε_r = 3.9, $\tan\delta=0.001$) is utilized to fill in the gap to support the upper metal plane.

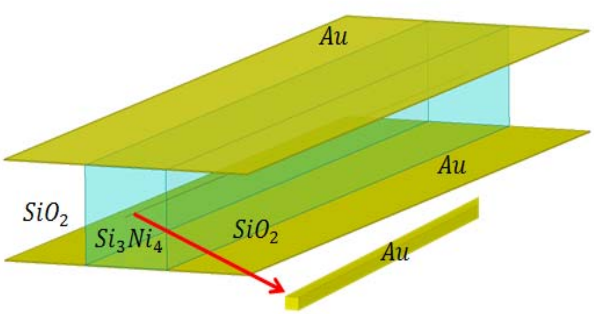

Fig-2 3D model of the PPDWS design in HFSS

The width of the signal line is equal to the transistor channel width 300nm and the thickness of the signal line is 3 times the skin depth. The idea to insert a signal line in the center of the dielectric comes from the Coplanar Waveguide Structure (CPW). By using the signal line structure the device is able to be connected to the transistor directly.

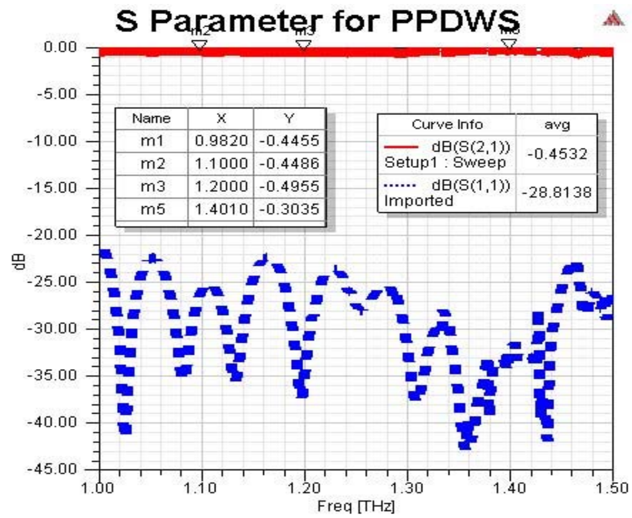

Fig-3 Reflection and transmission parameters of 100μm thick PPDWS

Fig-3 shows a plot of the results of a HFSS simulation of the return loss and total transmission loss in a 1mm length of PPDWS transmission line. The average total transmission loss for PPDWS is 0.45dB/mm at frequency 1-1.5THz. And the return loss is below -20dB for the entire frequency band at 1-1.5THz. The size of the dielectric strip will have a great influence on the performance of the PPDWS; the detailed study is presented in [10]. Here we select 100μm×100μm×1000μm for the dimension for the dielectric strip.

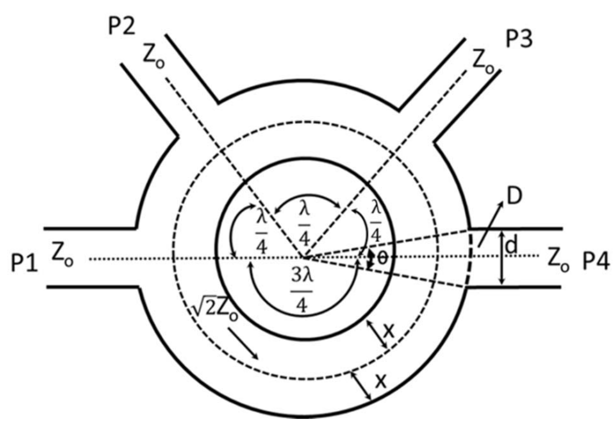

Fig-4 Ring Hybrid Circuit Topology

III. Ring Hybrid Coupler Design

A. Ring Hybrid Circuit Topology

Fig-4 presents the Ring Hybrid Coupler circuit topology. The standard Ring Hybrid consists of a closed