Room Temperature Terahertz SubHarmonic Mixer Based on GaN Nanodiodes

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Abstract—GaN Unipolar Nanochannels is fabricated by etching in the AlGaN/GaN heterojunction. Adjusting the GaN nanochannel width results in a nonlinear, quadrantal symmetry, current voltage (I/V) characteristic. It means GaN nanochannel is quite suitable for subharmoinc mixing (fIF=|fRF-2fLO|). Here, we will present the DC and RF performance prediction of a novel terahertz sub-harmonically pumped mixer that uses the GaN Unipolar Nanochannels.

INTRODUCTION

Two dimensional Electron Gas (2-DEG) unipolar nanodiodes known as self-switching diode (SSD) is fabricated by etching two symmetrical L-shaped trenches in the semiconductor heterojunction [1]. Asymmetric nanodiode based on different semiconductor heterojunctions has been proposed to obtain planar devices with nonlinear current voltage (I-V) characteristic [2]. Devices using InGaAs/GaAs or AlSb/AlGaSb heterojunction have been demonstrated as room temperature direct detectors at millimeter[3] and terahertz frequencies already [2][4]. GaN nanodiodes is fabricated by etching in the AlGaN/GaN heterojunction. Firstly, the possibility of GaN nanodiodes as direct and heterodyne detectors in terahertz frequency range has been found in the numerical Monte Carlo (MC) simulations [5]. Then, GaN nanodiodes utilized as the direct detector and the fundamental mixer have been realized in the laboratory [6][7].

A rigorous device’s model which describes the physical mechanism or the electronic characteristic is very important for the circuit nonlinear simulation. Åberg et al. later modelled the I/V characteristic of silicon-based SSDs based on FET-equations, and their model is briefly reviewed in [9]. Schottky diode equation has also been used to describe the I/V characteristic of SSDs, however it is a challenge still to deal with the GaN nanodiodes quadrantal symmetry I/V characteristic. Here we introduced the phenomenological unified diode equation for GaN nanodiodes and the mixing conductivity $g$ of the device and the expression is as the following,

$$ g = \frac{dld}{dvd} = \left[\frac{1}{2}(e^{vd} + e^{-vd})\right]^{-2} \quad (1) $$

Then, Taylor series expansion to the diode’s mixing conductivity $g$ around its operating point $v_0$. Following the Taylor expansion, $v_d$ in the Eqn (1) was substituted by the local signal $v_{LO}e^{i\omega_{LO}t}$ and then the curves of each series expansion parameters depend of the operating point $v_0$ were plotted in @Mathematica and were shown in Fig1. If the operating point $v_0$ was set to zero, which means the device was zero biased, the linear, cubic and quantic terms are all zero at this case. And the constant and even order terms (quadratic and quartic) are at their peak position. With the RF signal $v_{RF}e^{i\omega_{RF}t}$ exciting, only the even order terms can be obtained, final result contains the $|2n\omega_{LO} - \omega_{RF}|$ terms after the low pass filtering ($n = 1, 2, 3 \cdots$).

DESIGN METHODOLOGY

Fig.2 depicts the basic mixer circuit, consisting of a mixer chip placed in a channel across the input waveguide. The mixer are using the silicon-on-insulator (SOI) substrate comprised of the antenna, filter and the SSDs, issuspended at the channel, plus a waveguide backshort which is the critical part for the optimization of a better LO/RF coupling.
SSDs model is implemented together with the ideal input and output matching networks to optimize the electrical parameters of the anode for certain input power using the Harmonic-balance simulator in ADS.

Figure 2. Configuration of mixer topology.

Passive networks around the diodes are simulated in HFSS to get the S-parameter matrices. These matrices were then utilized to determine initial dimensions of each section using the linear simulator and nonlinear simulator in ADS step by step. Iteration is required to run between the linear and the nonlinear steps until the emergence of the acceptable performance. Finally, the values of each part from the nonlinear step are feedback to reconstruct the mixer in HFSS, then the SSDs models and the S-parameter matrices of the whole mixer circuit are combined to check the performance using the nonlinear harmonic balance simulator in ADS.

SIMULATION RESULTS

The design is designed with the procedure mentioned in the last section and is optimized for available input pump power in practice. Lower conversion loss is obtained as a consequence of the wider bandwidth, for the mixer working at 300 GHz the relative bandwidth is higher than 12%. It is important to remark that the design owns the character with high port performance, as shown in Fig.3.

Figure 3. Predicted conversion loss as a sub-harmonical mixer.

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REFERENCES


