Extraction of second harmonic from the $In_{0.57}Ga_{0.47}As$ planar Gunn diode using radial stub resonators

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Abstract— Planar Indium Gallium Arsenide (InGaAs) Gunn diodes with on chip matching circuits have been fabricated on a semi-insulating Indium Phosphide (InP) substrate to enable the extraction of the second harmonic in millimeter-wave and terahertz frequencies. The planar Gunn diodes were designed in coplanar waveguide (CPW) format with an active channel length of 4 µm and width 120 µm integrated to CPW matching circuit and radial stub resonator to suppress the fundamental and to extract the second harmonic. The initial experimental measurements have given a second harmonic signal at 118 GHz with an output power of -20 dBm and the fundamental signal at 59 GHz was suppressed to the noise level of the experimental set-up.

Keywords- Harmonics, Gallium Arsenide, Indium Phosphide, Gunn Devices, millimeter-wave source, Semiconductor heterojunctions

I. INTRODUCTION

The first millimeter-wave planar Gunn diodes on Gallium Arsenide (GaAs) were designed, fabricated and tested by Universities of Aberdeen & Glasgow in 2007 [1,2]. The devices were experimentally found to oscillate at 108 GHz with an RF output power of -43.5dBm. Later devices used $In_{0.53}Ga_{0.47}As$ which is lattice matched to the InP substrate providing improved properties over the GaAs based devices. In 2013 Khalid et al [3] designed, fabricated and tested an $In_{0.53}Ga_{0.47}As$ on an InP substrate planar Gunn diode with an active length of 1.3 µm and experimentally measured a fundamental oscillation frequency of 164 GHz with an RF output power of -10dBm.

The planar Gunn diode can be easily integrated into monolithic integrated circuit (MMIC) technology making the feasibility of including simple two terminal devices as frequency sources. The frequency of operation of these devices can be increased by reducing the active channel length and/or efficiently extracting the second or third harmonic frequency. In this paper we present a novel method to extract the second harmonic from the planar Gunn diode by using CPW matching elements and a radial stub resonator. The work was carried out using $In_{0.53}Ga_{0.47}As$ Gunn diode on an InP substrate. The diode was fabricated with a 4 µm active layer providing a fundamental frequency of oscillation around 60GHz. This geometry was chosen as the lower frequency made it easier to microwave characterize the device. The matching circuits and resonator structures were designed using Advanced Design System (ADS-2009) simulation package. The devices and on chip integrated circuits were fabricated and tested at the Nanotechnology Center at University of Glasgow. Preliminary experimental results gave a second harmonic signal at 118 GHz with an RF output power of -20 dBm (Figure 4) and the fundamental signal was in the noise floor of the measurement set-up.

II. Device fabrication

Figure 1 shows a schematic view of a cross section of the planar Gunn diode device. The device material layers were grown by molecular beam epitaxy (MBE) and consist of a highly doped $In_{0.53}Ga_{0.47}As$ layer ($8x10^{16}$ cm^{-3}) 300nm thick active channel, followed by 200-nm-thick cap of $In_{0.53}Ga_{0.47}As$ with a doping density of $2x10^{18}$ cm^{-3}. These layers were directly grown on top of a 600µm thick semi-insulating InP substrate. The nL_{ac} product of the device was greater than 10^{12} cm^{-2}, where n is the free carrier density and L_{ac} is the separation between the anode and cathode electrodes [4]. The anode and cathode ohmic contact layers were defined by electron beam lithography using polymethylmethacrylate (PMMA) resist and formed using Pd/Ge/Au/Pt/Au deposited by e-beam evaporation and annealed at 400ºC.

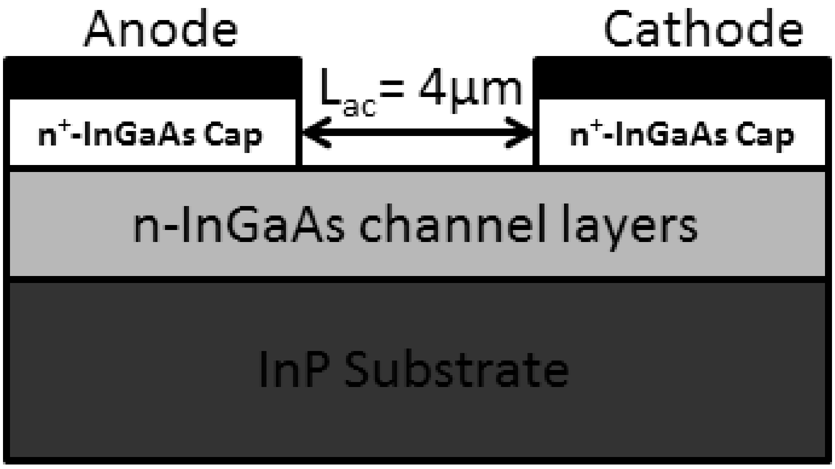

Fig-1 Schematic view of material layers

Figure 2 shows a SEM image of a 4 µm active channel length planar Gunn diode with an integrated CPW open circuit matching stub and radial stub resonator. The CPW open circuit stub line matches the reactive component of the Gunn diode at the fundamental frequency of 60 GHz and the radial stub resonator suppresses the fundamental component allowing the harmonics to pass to the load via a 50 Ohm CPW line with a pitch of 40-60-40 µm. The device and integrated circuit were passivated by depositing silicon nitride to suppress trapping and minimize surface oxidation.

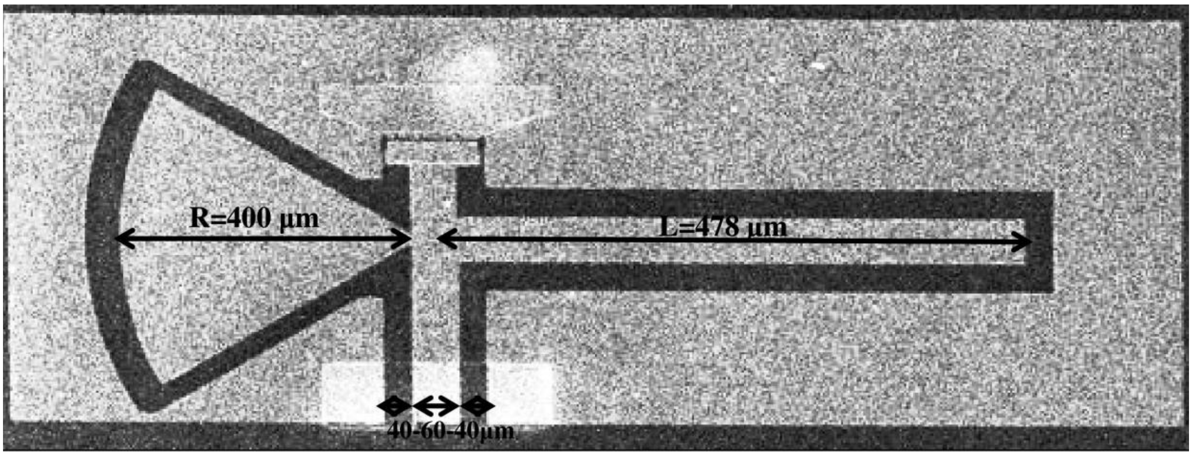

Fig-2 SEM image of a CPW planar Gunn diode with integrated matching and radial resonator to extract the second harmonic.

III. Experimental Results

The fabricated integrated InP based planar Gunn diode circuit was experimentally measured at the second harmonic and fundamental frequencies. The extended W band experimental set-up for measuring the second harmonic is shown in Figure 3. It consisted of a RF probe with a G-S-G pitch of 40-60-40 µm, the probe had an integrated bias-tee to enable biasing (2.91 V) the Gunn diode while coupling the RF signal to a Farran mixer with an internal local oscillator, the base-band frequency coupled directly to an Agilent E4448 spectrum analyser. The measured RF loss of the mixer was ≈ -50 dB over an extended W band to 125 GHz. Preliminary RF measurements identified a second harmonic signal at 118 GHz with an output power of -20 dBm (Figure 4). The fundamental response from the same circuit and bias conditions (2.91 V) was measured using a similar set-up working over V-band (50 to 75 GHz). The set-up briefly consisted of a V-band RF probe (GGB Technologies) with GSG pitch of 40-60-40 µm, bias tee, feeding a V-band mixer (Farran Technologies) and the down converted frequency was fed to the spectrum analyser (Agilent E4448). The measured RF loss of the mixer at 60 GHz was ≈ –50 dB. The measurement indicated the fundamental signal was in the noise floor of the measurement set-up. To verify the harmonic response of the above circuit, an identical planar Gunn diode with matching circuit and no radial resonator was tested with the same applied bias voltage of 2.91 V. A fundamental frequency of 59 GHz with an RF output power of approximatley -19 dBm was detected; the circuit gave no detectable second harmonic signal.

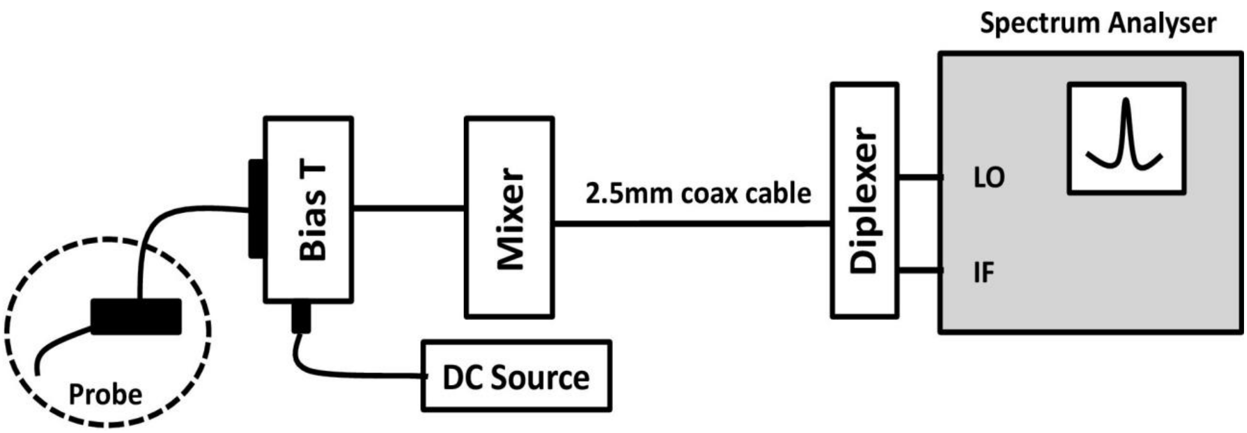

Fig-3 On-wafer Spectrum analyser measurment setup for W-band frequency

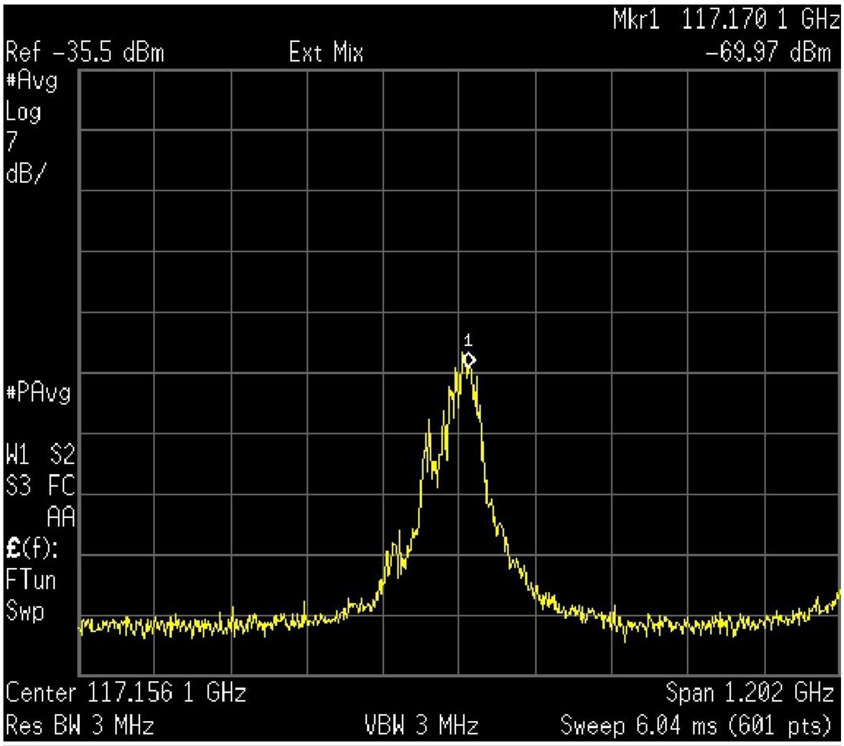

Fig-4 Spectrum Analyser Measurment Second harmonics frequency using W-band setup

V1. CONCLUSION

The paper describes an $In_{0.53}Ga_{0.47}As$ based planar Gunn diode fabricated on an InP semi-insulating substrate with an integrated matching circuit to extract the second harmonic. Preliminary RF measurements have been presented in which a device with a 4 µm active channel length oscillated with a second harmonic frequency of 118 GHz with a RF output power of -20 dBm and with good fundamental frequency suppression. When the radial resonator was removed from the circuit a fundamental frequency of 59 GHz was detected with an RF output power of approximatley -19 dBm.

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