Resonant Tunneling and Planar Gunn Diodes: A Comparison of Two Solid State Sources for Terahertz Technology

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Abstract: The demand for higher frequency applications is growing and a solid-state source for THz frequencies is needed. We compare experimetally demosntarted results of resonant tunnleing diode and planar Gunn diodes for terahertz technology. The highest power demonstrated for W-band RTD oscillators at 75.2 GHz with -0.2 dBm (0.96 mW) and at 300GHz for submicron planar Gunn with -16dBm (28µW) are compared as the potential solid-state source for Terahertz applications.

Keywords: Terahertz soli-state source; Resonnant Tunneling Diode; Planar Gunn Diode

Introduction

The terahertz (THz) range (0.1 THz to 3 THz) has been considered as the very useful yet least explored spectrum region. The THz applications include ultrahigh-speed wireless communication systems, low visibility imaging systems, and chemical spectroscopy analysis, etc [1]. Resonant tunneling diode (RTD) is one of the most promising candidate to realize the compact, room-temperature, coherent solid-state terahertz (THz) sources [2]. However, the output power of RTD based oscillators tended to be low due to parasitic bias oscillations and small device dimensions. Todate, the output power of the single RTD (0.35 μm^2) oscillator operating at the record 1.3 THz is only 10 µW [3].

In recent years, planar Gunn diodes (PGD) have also shown consistent improvements in frequency towards the THz region of electromagnetic spectrum [4-6]. The first hetero-structure AlGaAs/GaAs based planar Gunn diode operation above 100 GHz was demonstrated in 2007 [4]. Higher frequency of operation is limited by the saturation velocity in GaAs [7]. In order to achieve higher frequencies, a new material system possessing high electron saturation velocity is needed. $In_{0.47}Ga_{0.53}As$ lattice-matched to InP is one possible material system and recently the first $In_{0.47}Ga_{0.53}As$ based planar Gunn diode has shown oscillations at 164 GHz in fundamental mode [5]. So far, the minimum channel length of any planar Gunn diodes reported in the literature has been greater than one micrometre and it is the channel length and saturation electron velocity that determines the oscillation frequency. Semiconductor materials such as, $In_{0.47}Ga_{0.53}As$, InN, InSb GaN and InP have sufficiently large electron velocity, compared to GaAs and are therefore suitable choices [7]. A submicron planar Gunn diode is expected to oscillate at higher frequencies using such semiconductor materials [7]. In recently reported simulation results, a 300 nm long Gunn diode in InN was predicted to reach 0.8 THz [8]. The first experimentally demonstrated submicron planar Gunn diode using $In_{0.47}Ga_{0.53}As$ as channel material has been reported to oscillate above 300GHz in fundamental mode [6].

In this paper we compare the results of experimentally demonstrated RTDs and PGDs as solid state terahertz radiation source as the potential candidate for terahertz technology.

Experiemental Results & Discussion

Fabrication details of RTD [9] and submicron PGD have already been reported elsewhere [6]. Figure 1 show a completed 4×4 μm^2 RTD and Figure 2 shows a fabricated 600nm long submicron PGD. The RTD is a vertical device compared to PGD which is a lateral in terms of current flow, therefore their device layout is different from each other. In case of RTD, it's the device mesa area that is important factor while it is Anod-Cathode separation in case of PGDs. Table I and II compare the performance of RTD and PGD for various size geometry and channel lengths respectively. A brief description of two technologies can be summarise as follows:

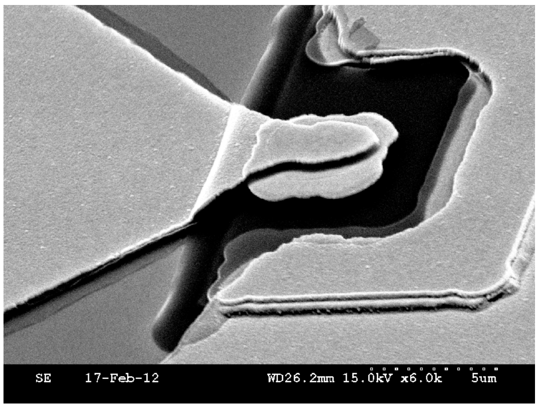

Figure 1. Fabricated single InGaAs/AlAs RTD device. Polyimide PI-2545 is used as insulation and passivation layer

Resonnent Tunneling Diode

– InGaAs/AlAs based RTD has been developed
–86GHz Oscillations measured experimentally

–0.98mW of RF power recorded up to 39GHz
–Poor phase noise (determined by external circuit)

Planar Gunn Diode

–GaAs and InGaAs based PGD has been developed
–300GHz Oscillations measured experimentally
–28 μW of RF power recorded up to 300GHz
–Low phase noise (determined by device physics)

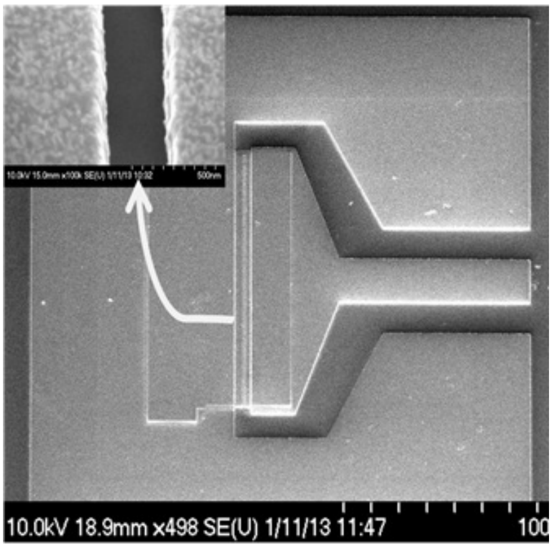

Figure 1. Fabricated 600nm long x 120nm wide InGaAs PGD. Inset show a close-up of the channel.

RTDs have already shown working devices above 1THz and there is great potential for these sources to increase its radiation power at terahertz frequencies.

Table 1. A performance comparison of fabricated InGaAs/AlAs RTD for vaious device

Mesa Area (μm^2)	Length of CPW (μm)	Frequency (GHz)	Output power (dBm)
4×4	620	33.7	-5.5
4×4	320	39.6	-0.1
4×4	120	75.2	-0.2
5×5	60	86.5	-4.6

Table 2. A performance comparison of fabricated PGD using various anode-cathode separation and channel materials

Anode-Cathode Distance Lac	Device Width (μm)	Material	Frequency (GHz)	Output power (dBm)
1.3 μm	120	InGaAs	164	-10
1.1 μm	120	GaAs	115	-28
600nm	120	InGaAs	307	-16

PGDs are, on the other hand have shown highest fundamental mode oscillation up to 300GHz. The prediction for PGD in new materials like InN are promising. However, Nitride based materials failed so far in demonstrating Gunn oscillations. Therefore, potential for a PGD based solid-state terahertz source depends on successful demonstration of Nitride based Gunn diode.

In conclusions, RTDs and PGD are two emerging solid-state terahertz technologies for emerging terahertz applications. RTDs have shown terahertz operation while PGD have reached 0.3THz mark, promising potential solid-state terahertz source technology for terahertz applications

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