

Terahertz Electronics

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Abstract

Applications of terahertz technology include detection of biological and chemical hazardous agents, explosive detection, applications in building and airport security, radio astronomy and space research, and in biology and medicine, for example, in cancer diagnostics. These applications have stimulated a lot of interest in terahertz electronics technologies that have potential to replace or augment more traditional terahertz photonics techniques, such as Time Domain Spectroscopy, Fourier Transform Infrared Spectroscopy and THz dielectric spectroscopy. In addition to THz electronics technologies relying on the frequency multiplication using mostly Schottky diodes, THz transistor technology has emerged, since the device feature sizes have shrunk to the point, where ballistic mode of electron transport becomes important or even dominant. Both Heterostructure Bipolar Transistors (HBTs) and High Electron Mobility Transistors (HEMTs) have reached cutoff frequencies approaching 1 THz. Recently, THz emitters based on the excitation of two-dimensional electron gas (2DEG) plasmons at semiconductor heterointerfaces have been demonstrated opening up a new paradigm in the terahertz electronics. These sources are tunable and can be used together with THz plasmonic resonant and non-resonant detectors using the same technology. The challenge here is to increase efficiency and output power by orders of magnitude.

Applications of terahertz technology [1-4] include detection of biological and chemical hazardous agents, explosive detection, applications in building and airport security [5], earth and ozone hole [6,7] monitoring, radio astronomy and space research [8,9], in biology and medicine [10], for example, in cancer diagnostics. These applications have stimulated a lot of interest in terahertz electronics technologies [11] that have potential to replace or augment more traditional terahertz photonics techniques, such as Time Domain Spectroscopy [12], Fourier Transform Infrared Spectroscopy [13] and THz dielectric spectroscopy [14].

In addition to THz electronics technologies relying on the frequency multiplication mostly using Schottky diodes [15], Gunn diodes, and IMPATT diodes (see Figures 1 and 2), THz transistor technology has emerged, since the device feature sizes have shrunk to the point, where ballistic mode of electron transport [16] becomes important or even dominant. Heterostructure Bipolar Transistors (HBTs) and High Electron Mobility Transistors (HEMTs) are capable of

operation in the sub-terahertz region [17], and recently have reached cutoff frequencies approaching 1 THz. University of Illinois group has recently reported on Type-II GaAsSb/InP HBTs with Record $f_T = 670$ GHz and Simultaneous $f_T, f_{max} > 400$ GHz (see Fig. 3) [18]. In these devices, the compositional grading was used to enhance the electron velocity, hence, increase speed.

The Northrop Grumman group reported on Sub a 50 nm InP HEMT Device with f_{max} greater than 1 THz (see Figure 4). [19] They also demonstrated an amplifier with a 15 dB gain at 340 GHz and predicted that their technology will allow building MMIC amplifiers operating up to 600-700 GHz. The Seoul National University group reported on 610 GHz InAlAs/In_{0.75}GaAs Metamorphic HEMTs with an Ultra-Short 15-nm-Gate and extracted ballistic velocity of 4.3×10^7 cm/s. [20]

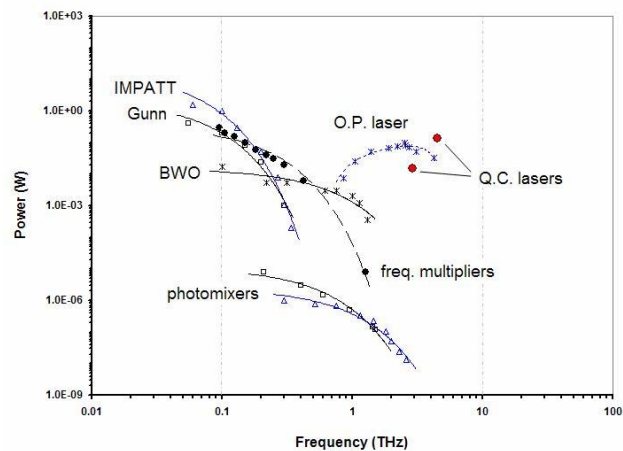


Figure 1: Power output versus frequency of available Continuous Wave (CW) Terahertz and Sub-terahertz sources. (From [21]). References: IMPATT, Gunn oscillators [22], BWO [23], frequency multipliers [24], photomixers [25,26], OP laser [27] and QC lasers [28,29]

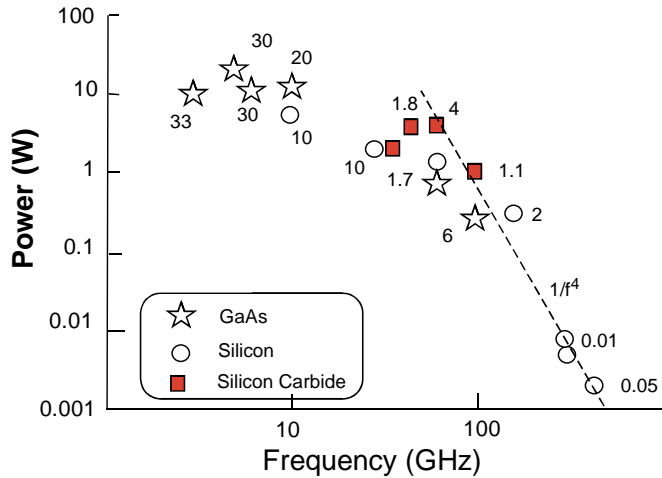


Figure 2: IMPATT power versus frequency. Data points from R. J. Trew, Transit time microwave devices, p. 7-32. In The RF and Microwave Handbook, M. Golio, Editor, CRC Press (2001)

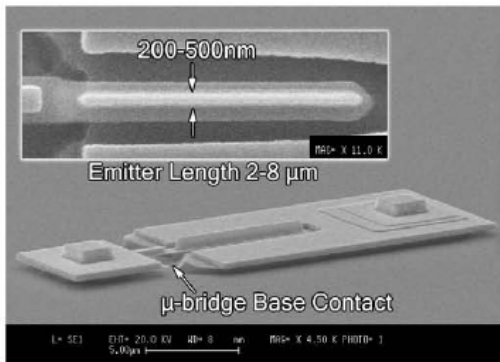


Figure 3: SEM image ultra-high frequency HBT from UIUC.[18] © IEEE 2007

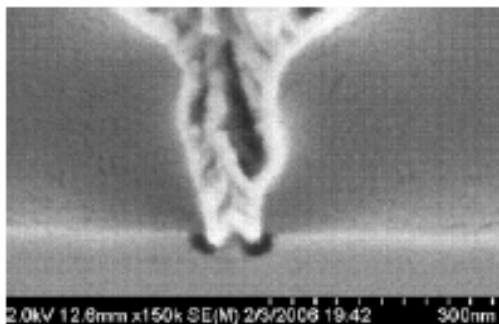


Figure 4: Cross section of 35 nm InP HEMT T-gate from Northrop Grumman.[19] . © IEEE 2007

In 2007, IBM demonstrated record RF performance of silicon SOI achieving the cutoff frequency 485GHz with a 45nm NMOS transistor. Using a notched body contact reduced the parasitic capacitance. Even the IBM PMOS transistors reached the cutoff frequency of 345GHz (see Fig. 5).

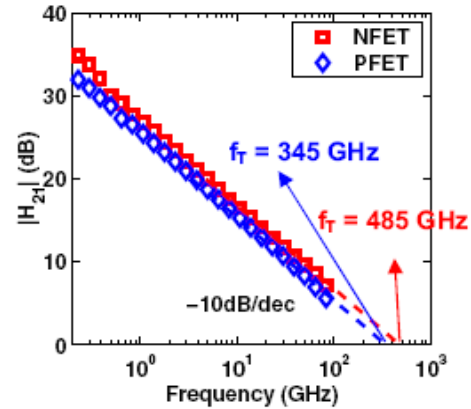


Figure 5: Current gain $|H_{21}|$ for 30 μ m wide SOI NFET ($L_{poly}=29$ nm) and SOI PFET ($L_{poly}=31$ nm) with relaxed poly pitch at $V_{GS}=0.6$ (-0.6) V, $V_{DS}=1.0$ (-1.0) V. From [30] ©IEEE (2007)

A new and different approach to THz electronics relies on using wave of electron density (called plasma oscillations) for detection and generation of THz radiation. This approach (first proposed in [31,32]) was recently used to demonstrate THz detection by Si CMOS [33-36], (see Fig. 6). THz emitters based on the excitation of two-dimensional electron gas (2DEG) plasmons at semiconductor heterointerfaces have been also demonstrated. These sources are tunable and can be used together with THz plasmonic resonant and non-resonant detectors using the same technology. The challenge here is to increase efficiency and output power by orders of magnitude, and we discuss the design approaches for achieving this goal.

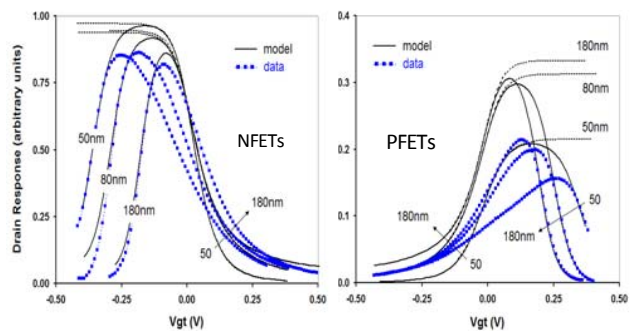


Figure 6: Sub-THz response of CMOS Si detectors (from [37]) ©IEEE 2007

ACRONYMS

FET's: Field Effect Transistor
HBT's: Heterostructure Bipolar Transistors
HEMT's: High Electron Mobility Transistors
SOI: Silicon on Insulator
IMPATT: Impact Avalanche Transit Time
THz: Terahertz
MMIC: Monolithic Microwave Integrated Circuit
SEM: Scanning Electron Microscope
RF: Radio Frequency
NMOS: N-Type Metal Oxide Semiconductor
PMOS: P-Type Metal Oxide Semiconductor
CMOS: Complimentary Metal Oxide Semiconductor

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