Integrated Terahertz Sources and Receivers

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Abstract

Terahertz sources and receivers with exceptional bandwidth, power and efficiency have been demonstrated. These components use integrated diode circuits (no whiskeres or mechanical tuners) and are therfore very compact and reliable, thus facilitating a host of new applications in science, medicine and defense.

INTRODUCTION & BACKGROUND:

Nonlinear diode circuits based on compound semiconductors are used to translate the functionality of traditional microwave electronics into the terahertz band. Examples include harmonic generators, frequency multipliers and mixers. Schottky diodes are useful primarily because of their inherent simplicity, which yields a very high 'electronic' cut-off frequency. Above about 100 GHz it is more efficient to take the power available from a lower frequency oscillator, say a Gunn diode or amplifier, and frequency multiply, than it is to create a higher frequency oscillator. However, as the frequency of operation is increased the performance of the diodes gradually degrades. This is due to a variety of both fundamental and practical limitations. All electronic devices are limited by parasitic circuit elements such as series resistance and shunt capacitance. As the operating frequency increases terahertz diodes must be made smaller to reduce junction capacitance, but this increases series resistance, thereby resulting in a fundamental design trade-off. Electron transport is also subject to a variety of transit-time and scattering time limitations, as well as the limitations imposed by the finite maximum velocity of the electrons in the crystal. Eventually, even the impedance of a passive element of semiconductor becomes complex as dielectric relaxation (capacitive) and charge carrier inertia (inductive) effects become significant. In fact, these phenomena cause a well known plasma resonance that falls in the terahertz band. Fortunately, through clever design most of these effects can be minimized, resulting in a gradual degradation of device performance as frequency increases, rather than a dramatic cut-off. Today diode mixers and detectors are available to 5 THz and useful multipliers are available to well over 1 THz.

TERAHERTZ CIRCUITS

The goals of the terahertz circuit designer are to couple the terahertz power efficiently into and out of the nonlinear diodes, to reduce any noise added to the signal and to ensure that unwanted signals (harmonics or mixing products) are suppressed. Two recent technological advances have greatly improved the performance of terahertz circuits. The first is the advent of fast and accurate circuit simulation tools that model the linear three dimensional electromagnetic structure of the diode embedding environment and solve the nonlinear circuit. The second has been the development of integrated diode circuits that greatly reduce parasitic losses and allow micron level precision of the circuit structure. Fig. 1 shows a microscopic view of a 640 GHz integrated GaAs Schottky mixer circuit. The metal features form waveguide probes, impedance matching elements, and quasi-coaxial lines. The background (substrate) material is quartz and the GaAs material exists as only small mesas, 3 microns thick and 30 um x 30 um in area. These mesas support the Schottky anodes and ohmic contacts (2 of each). Two airbridged metal fingers contact the anodes. The GaAs mesas are attached to the low-loss substrate at the wafer level by a bonding process. After dicing the circuits are simply placed in an appropriate waveguide housing to complete the mixer assembly. Virginia Diodes has developed mixers and multipliers to about 1 THz using integration technologies and these are now successful commercial products. The subharmonic mixer shown in the figure has a mixer noise temperature as low as 1,500K and conversion loss of 8 dB (DSB).

TERAHERTZ COMPONENTS AND SYSTEMS

Figure 2 shows the output power of several very broadband frequency multipliers. These results are remarkable because the multipliers achieve full waveguide band performance yet require no mechanical tuning as the frequency is swept. Other components presently available include very high power varactor doublers, mixers, sideband generators and direct detectors. Such components are revolutionizing the design of terahertz systems and are allowing scientists to realize much bolder and more complex terahertz measurements and experiments.

Given the exceptional performance of the integrated terahertz circuits and components, we are now developing practical and affordable terahertz systems, such as sources, receivers and transmit / receive modules, as well as complete terahertz spectrometers. One example is a terahertz transmitter developed for Compact Range Radar applications. It generates of order 0.5 mW of power and can be swept electronically across the 480 - 540 GHz frequency band to simulate a chirped radar. The entire unit is about eight inches long and ongoing research promises to greatly reduce the system size through further integration of the primary components.

CONCLUSION

Recent efforts by terahertz researchers have led to a great expansion in the availability of practical sources and detectors. These components are greatly expanding the realm of potential applications of the terahertz frequency band. Although there are fundamental limitations to using either electronic or optical devices in this critical frequency band, through the continued efforts of terahertz researchers the level of performance of terahertz components and systems will continue to improve. Thus, it is expected that the terahertz frequency band will eventually become just as useful for scientific, military and commercial applications as the microwave and infrared bands are today.

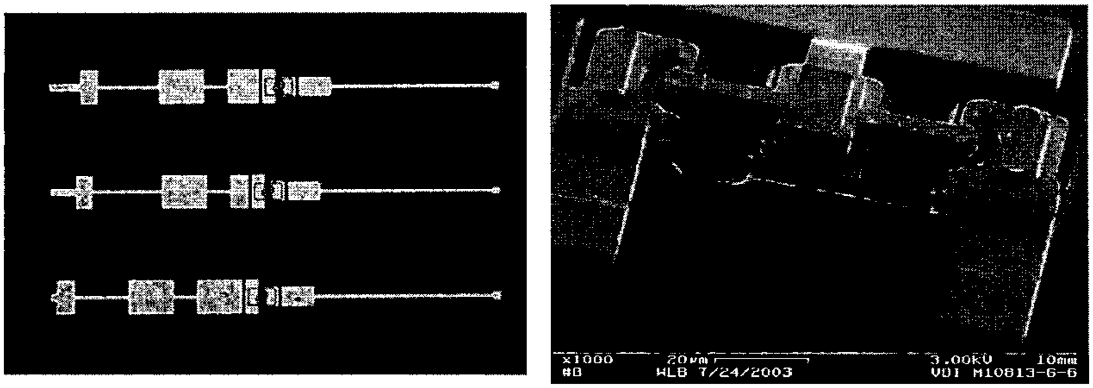

Fig. 1: Left: An integrated GaAs mixer circuit. The background material is the quartz substrate used to reduce parasitic capacitance. The GaAs mesas are only 3 um thick and exist only in the central region where the diodes are formed. Right: An SEM view of the diode region of an integrated multiplier circuit. The background areas are the quartz substrate, the lightest areas are metallization and the dark mesas (in between) are the micron thick GaAs mesas.

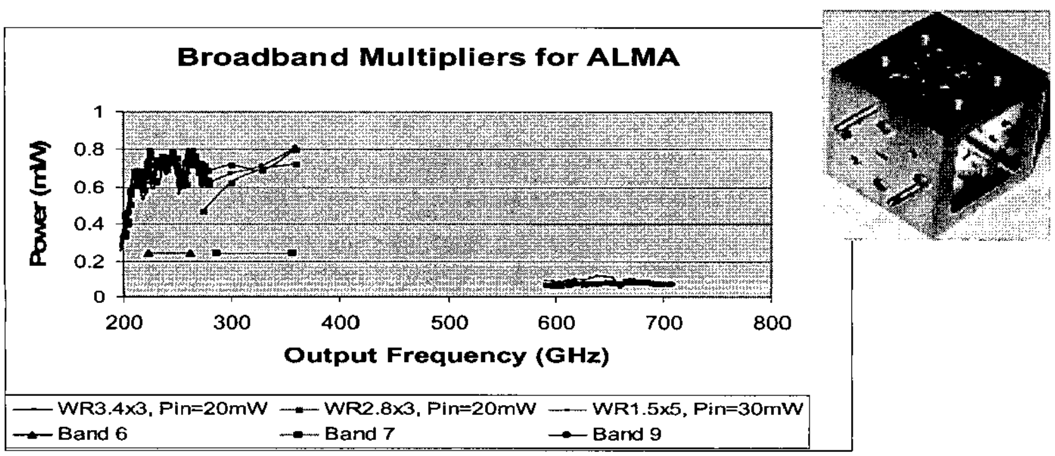

Fig. 2: The output power of broadband multipliers with integrated diode circuits. The multipliers require no mechanical tuners and achieve full waveguide band performance.

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