TERAHERTZ SOURCES AND DETECTORS BASED ON NONLINEAR DIODES

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The terahertz frequency band, spanning from roughly 100 GHz through 10 THz, is often sited as the most scientifically rich, yet unexplored region of the electromagnetic spectrum. Applications include radio astronomy, chemical spectroscopy, plasma diagnostics, compact range radar, atmospheric remote sensing and electron paramagnetic resonance studies of organic molecules. Recent studies have also shown that biological samples, such as RNA, DNA and bacterial spores, have unique spectral features that may open a new range of applications [1]. However, when one compares the wealth of technology available in the microwave and infrared frequency bands with the relatively immature state of terahertz technology, it is clear that much work remains before the terahertz frequency band can be fully exploited.

At microwave frequencies transistors and oscillators are relatively easy to build. Also, circuits and systems are simple to design because most components can be considered as discrete electronic devices. That is, we consider voltages and currents and their effect on the electrons in the device. Similarly, at IR and optical frequencies, diode lasers and photodetectors are readily available and we talk about photons and electron energy transitions. However, the terahertz frequency band lies at the transition from classical electronics to quantum photonics and many of the simplifying approximations used at either higher or lower frequencies are not useful. For example, the critical dimensions of most devices are on the same order as the wavelength, so that certain simplifying assumptions to Maxwell's equations cannot be used. Add to these factors the large atmospheric absorption that occurs in most parts of the terahertz band and it is not difficult to understand why this spectral band has not yet been fully exploited.

Despite these difficult challenges, significant progress is being made. For example, transistors operating above 100 GHz with reasonable gain, power and bandwidth are now becoming available [2]. Also, quantum cascade lasers have been extended down to a few terahertz [3]. Perhaps more importantly in the short term, microwave engineers and scientists have found clever methods to build sources and detectors that span the entire terahertz technology gap. This has primarily been achieved through the use of nonlinear diodes to extend microwave functionality to higher frequencies. For example, a chain of frequency multipliers can be used to multiply a 100 GHz source to, for example, 600 GHz, where it can be used as a probe of a particular molecule that resonates in this band. Likewise a frequency mixer can be used to convert a signal collected by a radio telescope at 900 GHz to a convenient microwave frequency, say 10 GHz, where it is easily amplified and analyzed.

Our goal is to make the terahertz frequency band just as useful for scientific, military and commercial applications as the microwave and far-infrared bands are today. A recent advance has been the development of integrated diode circuits manufactured by a GaAs-on-quartz integration process [4,5,6]. GaAs is the material of choice for the nonlinear diodes because of its high electron mobility, whereas quartz is a more ideal supporting structure because of its low dielectric constant and high resistivity. Figure 1 shows an optical view of a GaAs-on-quartz process wafer before dicing. Each circuit is a complete 600 GHz mixer with integrated GaAs diodes, frequency filters, impedance matching structures and waveguide probes. Because of the reduced circuit parasitics, the lithographic alignment of the circuit features, and the careful circuit design aided by the use of modern computer aided design tools this circuit has achieved record conversion efficiency and bandwidth. A wide range of other integrated circuits have now been achieved and

are being used in a variety of scientific measurements. The range of the circuits and the potential for future advances will be discussed in greater detail at the meeting.

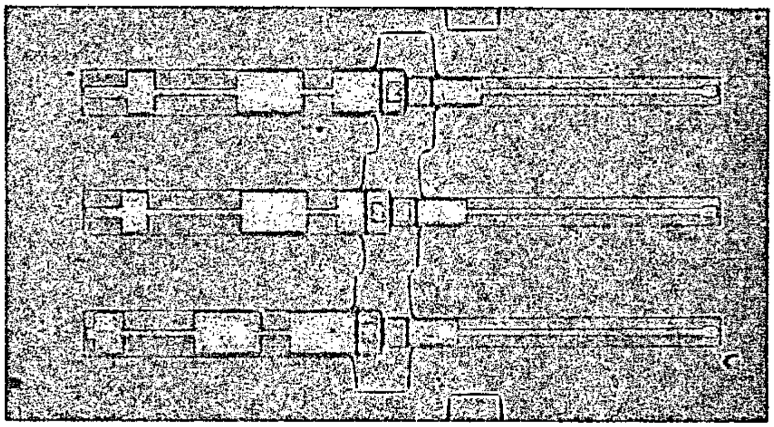

Fig. 1: An optical view of a GaAs-on-quartz process wafer containing an array of 600 GHz mixer circuits. The background material is the quartz substrate, the gold structures form frequency filters, tuning elements and waveguide probes and the only remaining GaAs material is a pair of micron-thickness mesas that support the ohmic contacts and Schottky diodes in the center of each circuit.

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