Advances of Terahertz Research and Terahertz Satellite Communications

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***Abstract*—Remarkable progress has been made of terahertz technologies such as the source and detector. Great advancement has also been achieved of terahertz systems. Such progress reviewed here presents a big impetus to terahertz satellite communications. For satellite-to-satellite communications terahertz link shows great advantages over either millimeter-wave link or optical link. The architecture of terahertz satellite communication systems is proposed.**

Keywords- terahertz technology; satellite communications; solid-state source; Schottky diode

I. Introduction

Although terahertz (THz) gap has been existed for long, THz wave science and technology is expected to become one of the key fields of the 21st century [1]. As more and more researches are being carried out all around the world, remarkable advancement has been achieved in this field. Many terahertz technologies have been broken through and many systems have been put forward, some of which even have been employed in space application.

The lack of good emission and detection techniques and devices has limited the development of terahertz technology. But still many prospective candidates are being explored [2-6]. With progress in terahertz technologies, terahertz systems will be developed for communication, remote sensing, environment control and homeland security, etc.

This paper is organized as follows. Progress in terahertz technologies around the world is introduced in section II. Recent typical terahertz systems are reviewed in section III. In section IV the impetus of above progress is addressed to terahertz satellite communications.

II. Recent Progress in Terahertz Technologies

Terahertz sources and detectors (receivers) are the most key devices in terahertz systems. Their advancements directly reflect progress of terahertz technologies.

A. Sources

A multitude of techniques are under development, including up-conversion of electronic RF sources, down-conversion of optical sources, lasers, and backward-wave oscillator (BWO) tubes. As for space applications, THz sources have to supply 0.1-10mW power for heterodyning and 10-1000mWfor radar. Their lifetime have to reach 2-15 years. Also they need 10-100kRad radiation hardness. Solid-state source may be a top-priority choice [7].

A solid-state source often employs a multiplier for frequency up-conversion. An active multiplier chain (AMC) typically uses a chain of GaAs Schottky diode multipliers with amplifiers at some certain frequencies. Virginia Diodes Inc. (VDI) and Rutherford Appleton Laboratory (RAL) keep ahead in terahertz Schottky diode design and fabrication, as shown in Fig. 1 and Fig. 2. VDI and RAL also take a lead in AMC assembly. Output power of such terahertz sources is depicted in Fig. 3 [8, 9].

Fig. 1 Terahertz Schottky diode of VDI.

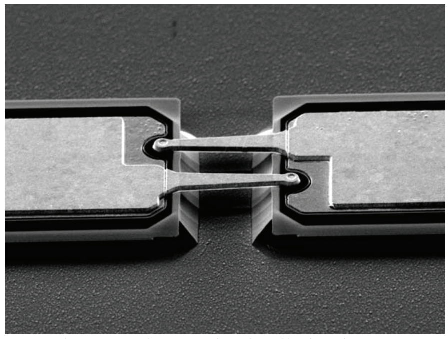

Fig. 2 Terahertz Schottky diode of RAL.

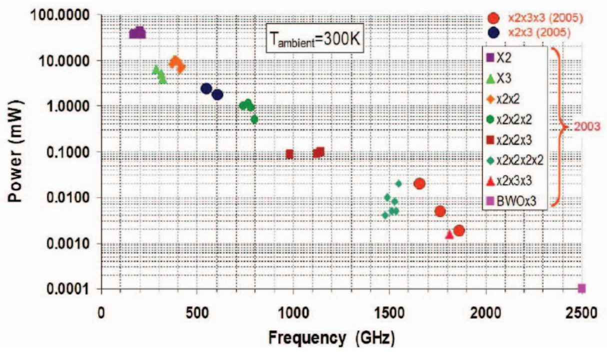

Fig. 3 Performance of terahertz Schottky sources.

B. Detectors

Many types of THz detectors have been developed, which fall into either semiconductor detectors or superconductor detectors. Here we will focus on heterodyne detectors. Double side-band (DSB) noise temperature is a specification to designate sensitivity of this kind of detectors (mixers).

Semiconductor detectors are also commonly implemented with Schottky diodes, which operate at both ambient and cryogenic temperatures. At ambient temperature, mixer noise temperature results are shown in Fig. 4 with RAL diodes. Recently it has been reported that 2600 K noise temperature was obtained at 848 GHz. Similar results can be got with VDI diodes.

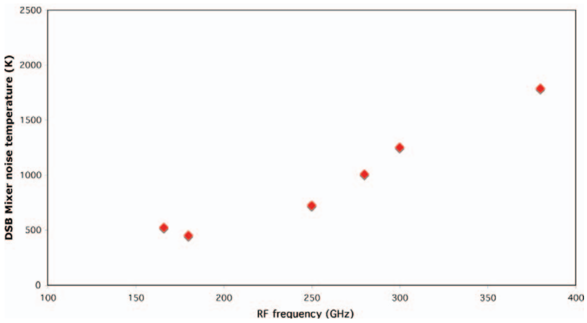

Fig. 4 Mixer noise temperature results with RAL diodes.

Superconductor detectors include superconductor–insulator–superconductor (SIS) mixers and hot electron bolometric (HEB) mixers. Most of them operate at liquid Helium temperature and have excellent noise performance. On board of Herschel, launched in 2009, the Heterodyne Instrument for the Far Infrared (HIFI) is one of the three instruments to be placed in the focal plane of the 3.5 meter telescope. The HIFI frequency bands, sensitivities and mixer elements are given in Table 1 [10].

To relax pressure on cryostat, NbN was used as superconductor to develop the SIS mixer incorporating tunnel junctions with larger energy gap. It has been demonstrated of high sensitivity for such a SIS mixers operated at temperatures even as high as 10 K [11]. Its noise temperature could be kept under 200 K, corresponding to 8 times the quantum limit. A 500 GHz mixer chip is shown in Fig. 5 with detailed image of the tunnel junctions.

TABLE I
HIFI DSB NOISE TEMPERATURES FOR DIFFERENT MIXER TYPES.

Band	Range (GHz)	T_{noise} (K)	Mixer Technology
1	480-640	70-110	Nb-SIS
2	640-800	110-150	NbTiN-SIS
3	800-960	150-190	NbTiN-SIS
4	960-1120	190-230	NbTiN-SIS
5	1120-1250	230-510	NbTiN-SIS
6Low	1410-1700	650-780	NbN-HEB
6High	1700-1920	790-870	Nb-HEB

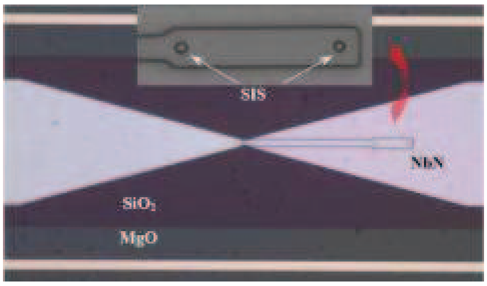

Fig. 5 500 GHz NbN SIS mixer chip.

III. RECENT PROGRESS IN TERAHERTZ SYSTEMS

As terahertz technologies develops, novel terahertz systems have come in to being.

A. VDI 340GHz Transceiver

Virginia Diodes Inc. has developed a 340GHz transceiver and demonstrated terahertz link in laboratory, as depicted in Fig. 6.

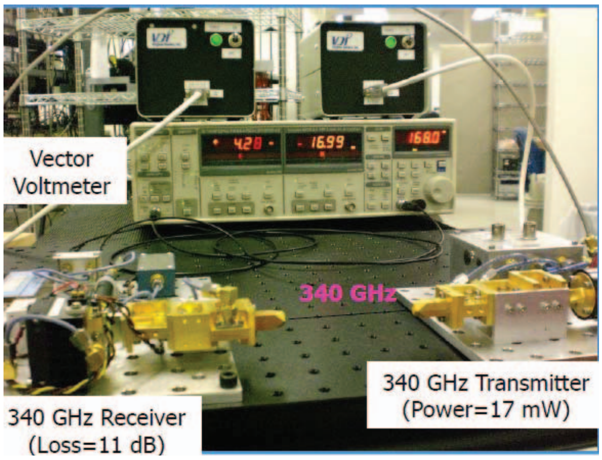

Fig. 6 VDI 340GHz transceiver.

The 340 GHz transceiver is a fully phase-locked system and its dynamic range is 94 dB. Transmitted power is 17 mW. As for the 340 GHz receiver, the first stage is a sub-harmonic mixer, whose conversion loss is 11 dB. With such a transceiver system terahertz signal can be transmitted and received without modulation.

B. 500GHz Heterodyne Detection System

Recently we demonstrated a 500GHz heterodyne detection system, as shown in Fig.7. Solid-state sources were employed for both simulant signal source and local oscillator source. A 500 GHz SIS mixer chip was used as the core of the detection system. A liquid helium (He) cryostat was used to create a 4.0-7.0 K low temperature circumstance for the high sensitive SIS detector.

In the demonstration the 500 GHz signal and local oscillator signal were directed to the SIS mixer, which is located at the center of the feeding waveguide. Then the IF signal was amplified by a low temperature and low noise amplifier in the cryostat. The IF signal was then sampled and processed in a digital Fourier Transformation Spectrometer (FTS). The spectrum was shown with a LCD screen.

In this demonstration the terahertz signal was not modulated either. What we were interested in was the frequency and the intensity of the signal.

Fig. 7 500GHz heterodyne detection system demonstration.

In both above systems, only carrier link were set up, but they still presented great impetus to terahertz communications and even terahertz satellite communications.

IV. TERAHERTZ SATELLITE COMMUNICATIONS

At present frequencies above 300 GHz are currently unallocated by the Federal Communications Commission (FCC).Therefore frequency resource is abundant for terahertz satellite communications

As terahertz covers sub-millimeter wave and far infrared, it owns advantages of both microwave and laser. Comparing with microwave communication satellites, terahertz ones can handle much higher transmission data rate. Terahertz beam is much narrower and the atmospheric loss much higher, which makes the communication link safer. At terahertz band, the transceiving systems get much more compact.

Comparing with laser communication satellites, terahertz ones have a higher energy efficacy because terahertz photonics is lower than laser. Terahertz beam can easily penetrate through dust and smog and so properly serve all-weather communication. What is more, capturing and aiming get easier for terahertz link. Terahertz communication satellites are appealing their development.

According to transmission performance of THz wave, inter-satellite link is one of the most promising applications for THz satellite communications. In such circumstances atmospheric absorption can be avoided.

In light of the state of the art, terahertz satellite communication systems may be constructed as in Fig. 8. For the absence of THz power amplifiers (PAs) and low noise amplifiers (LNAs), the transmission and reception antennas are directly connected with the modulator and mixer respectively.

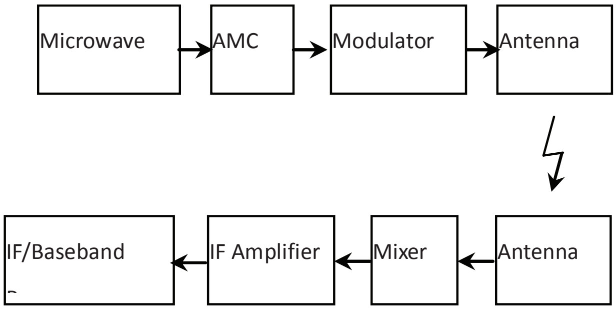

Fig. 8 Terahertz satellite communication systems.

V. CONCLUSION

Recently great progress has been made in both technologies and systems, which presents an impetus to THz communication. Although THz communication is in the very early stages of development, it has attracted some attention.

For satellite-to-satellite communications, atmospheric absorption can be overcome. Here the advantages of using THz technology are the larger bandwidth and therefore higher transmission rate, without having to switch to a different set of hardware such as lasers for optical communications.

The architecture of terahertz satellite communication systems is also proposed in this paper. Because of limits of terahertz amplifiers the architecture is different from that of conventional microwave communication systems.

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