

T-Ray's Terahertz Spectrometer and Imager System

About the System:

T-Ray Science's THz spectrometer and imager system is designed to address research community's need to a modular, compact, easy to use, versatile, and compatible THz table-top setup for daily measurements such as THz spectroscopy, THz imaging, THz device characterization, etc. The system is compatible with existing laser systems suitable for THz pulse or cw signal generation and detection.

Users have the option to use their own THz photoconductive source and detector modules, or alternatively use T-Ray Science's Mithra™ and T-Lux™ chips with a plurality of designs incorporated into the system to expand accuracy, precision, sensitivity, and selectivity of the system for generation of a wide range of frequencies and detection of THz signals reflecting from or transmitting through samples under test.

T-Ray Science's THz spectrometer and imager systems can be used to generate and detect both pulsed and continuous-wave THz signals with high signal-to-noise ratio and dynamic range. The optional sample holder and 2-D imaging translation stage modules can be incorporated into the system for THz spectroscopy and imaging applications.

Product Overview:

- Modular system attractive for research lab environment
- Easy transmitter and receiver module installation and exchange (see Mithra™ and T-Lux™ chip holder)
- Pulsed and continuous-wave mode operation
- Wide range of frequency (0.1-4 THz)
- Compatible to the existing laser systems in the market
- Fiber coupled or free beam laser excitation
- Small footprint
- Easy optical alignment

Application:

- THz Spectroscopy (Pulsed & CW)
- THz Imaging and Sensing (Pulsed & CW)
- THz Source and Detector Characterization
- THz Device Characterization



Product Schematic:

Figure 1 shows the basic schematic of T-Ray Science’s THz spectrometer and imager system with THz photoconductive antennas as transmitter and receiver elements and 4 off-axis parabolic mirrors to collimate and focus the THz beam. User can add sample holder units at the focus point of the THz beam between off-axis parabolic mirrors #2 and #3. One can also add two THz focusing lens between mirrors #1 and #2 to focus the THz beam at the input and output ports of a device under test.

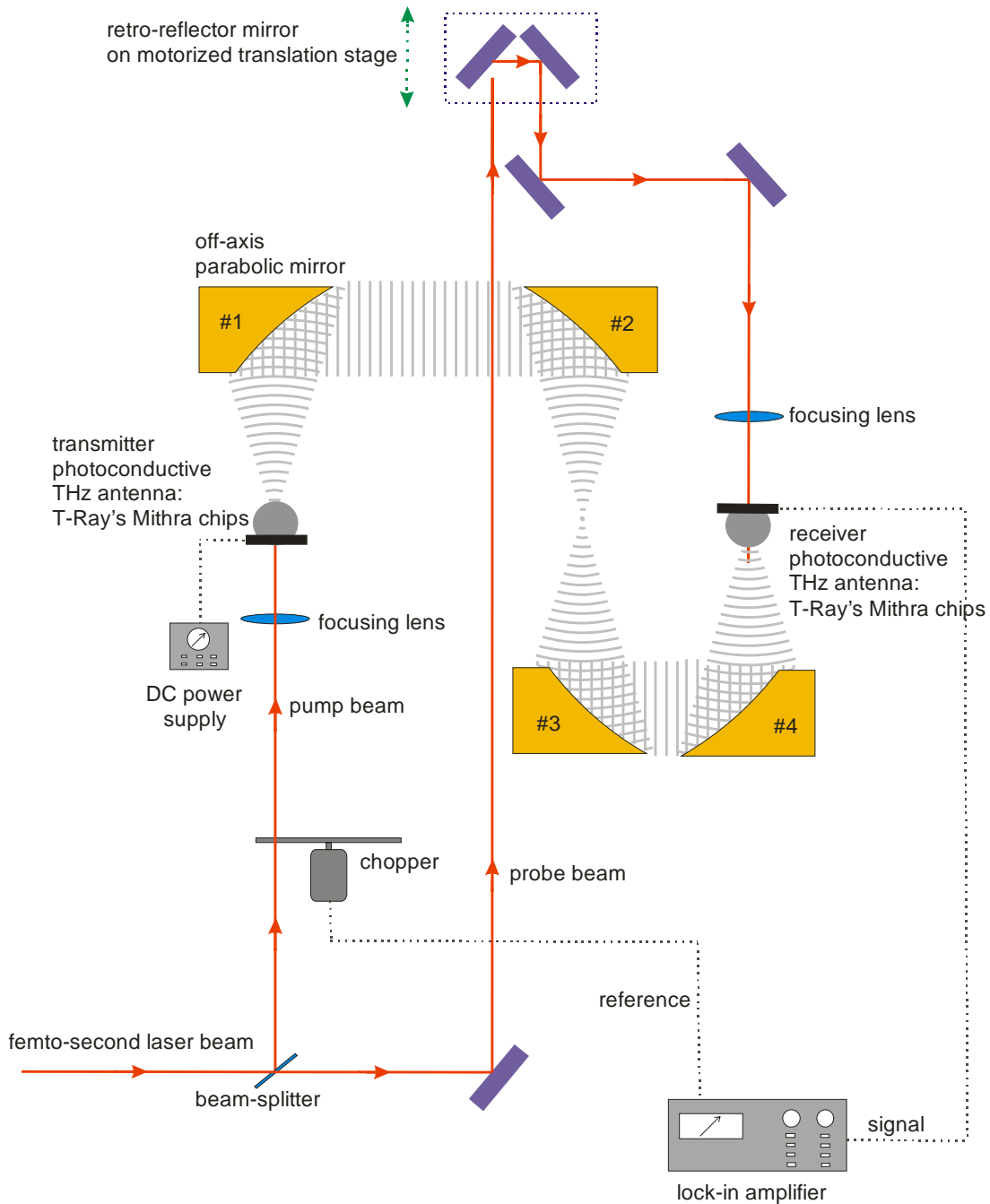


Fig.1 Schematic of T-Ray Science’s Terahertz Spectrometer and Imager System.

Performance Characteristics:

Fig. 2 and 3 show the generated and detected terahertz signal and its corresponding power spectrum in T-Ray Science's terahertz spectrometer and imager system using a pair of T-Lux™_AA series aperture array antennas as the transmitter and the receiver elements. The frequency content extends above 4 THz with 60 dB dynamic range. Terahertz pulses are generated by 100 fs optical pulses at 780 nm wavelength and 80 MHz repetition rate. The pump and probe powers are 100 mW and 90 mW, respectively, and the dc bias on the transmitter antenna is 30 V. The signal-to-noise ratio is 1650. Figure 4 shows the THz peak signal detected on the receiver antenna as a function of dc bias on transmitter antenna. The THz peak signal linearly increases by the applied dc bias and no saturation is observed for voltages up to 60 V. The maximum applicable average laser power can be as high as 1 W and the dc bias can be increased up to 100 V.

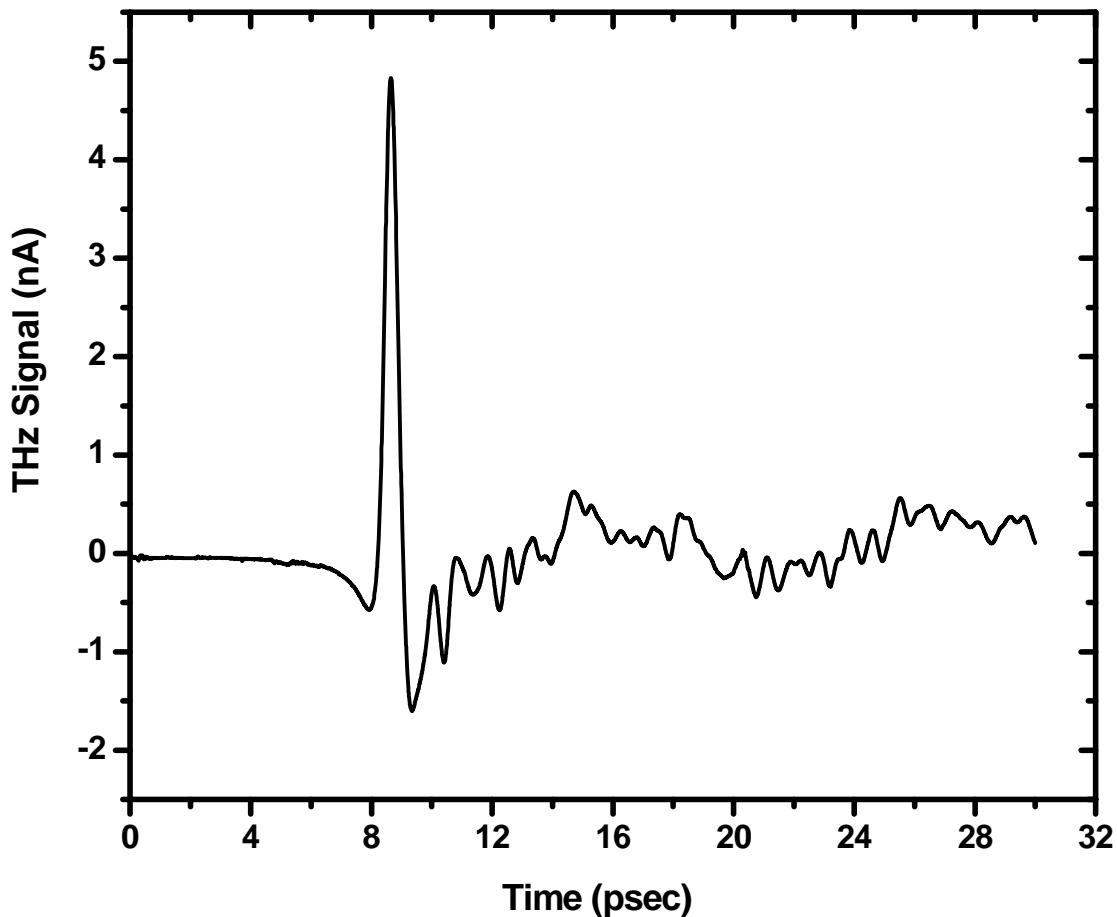


Fig.2 THz electric field as a function of time measured in ambient air.

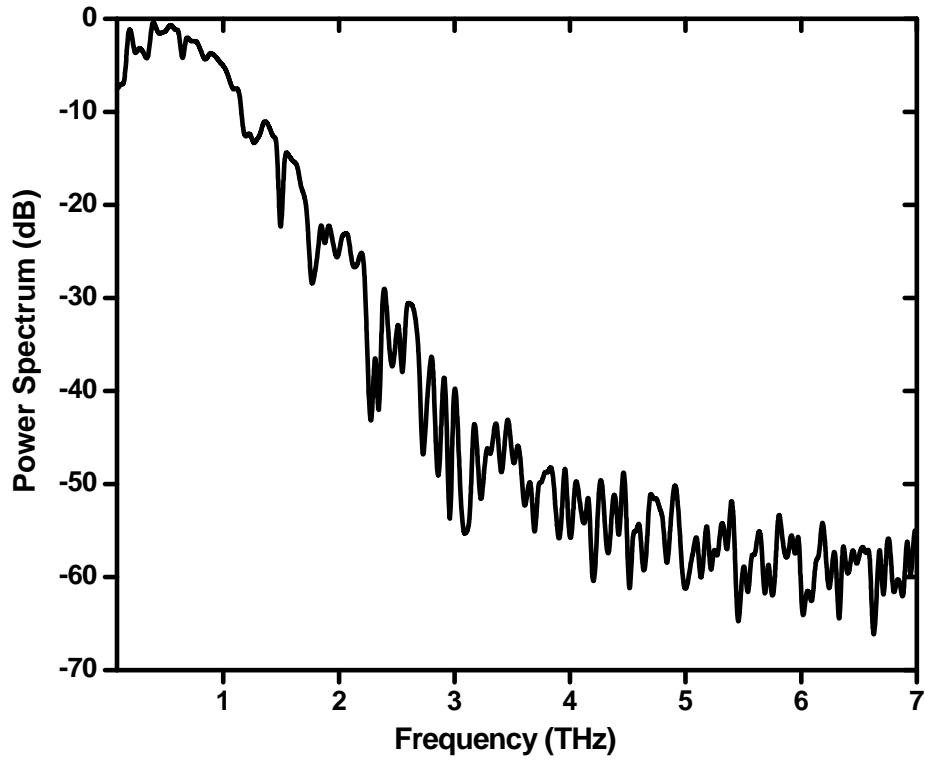


Fig.3 Power spectrum of the THz electric field shown in Fig. 2.

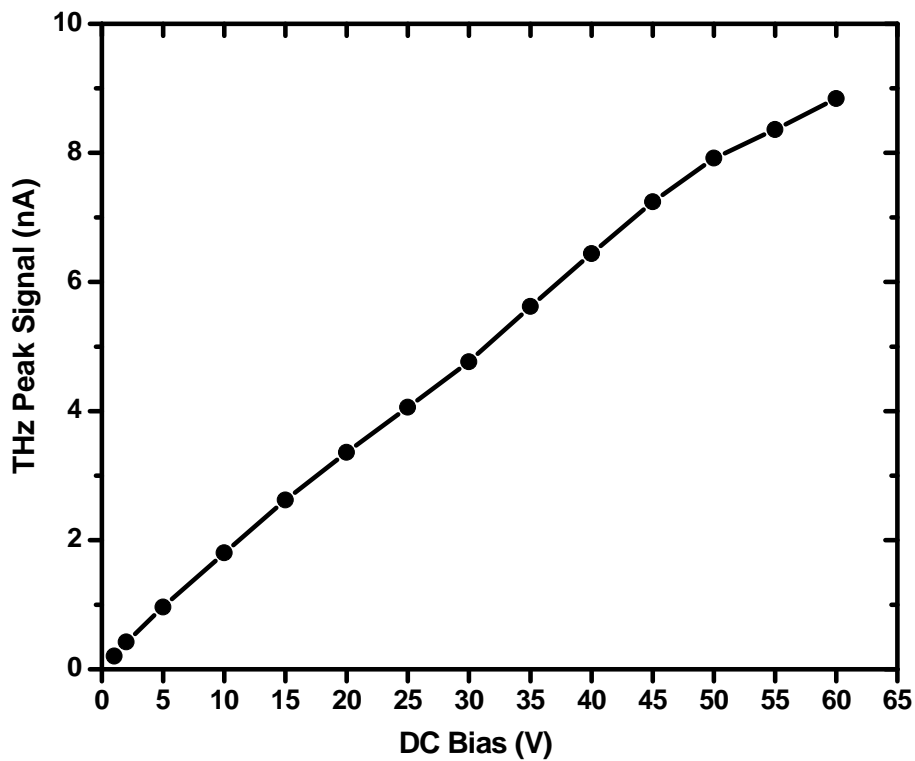


Fig.4 Terahertz peak signal versus dc bias detected by the aperture antenna array.

T-Lux™ AA Series Aperture Array Antenna

About T-Lux™ AA Series:

T-Ray Science’s T-Lux™ AA Series aperture array photoconductive antennas are made on epitaxially grown ultra-fast low-temperature (LT) GaAs thin films and are transferred on optically transparent silica substrates using advanced lift-off techniques. The transparent silica substrates are extremely low loss at THz frequencies. The two options of array antennas with and without optical micro-lens arrays are available (see Fig. 1). The T-Lux™ AA Series aperture array antennas are mounted and wire bonded to T-Ray Science’s proprietary designed chip carrier PCB boards with SMA connectors, and are attached to 1” adaptor units making them ready to be mounted on any standard optical stages and holder units.

T-Lux™ AA Series aperture array antennas can be easily incorporated into an existing THz time-domain spectroscopy and imaging setup to generate and detect sub-picosecond terahertz pulses with frequency content above 4 THz. T-Ray Science’s aperture array antennas are designed to address real-world applications requirements for the terahertz photoconductive antenna technology. T-Lux™ AA Series aperture array antennas are high power THz sources and wide band terahertz detectors, which are easy to use and reliable in the long-run, and are less sensitive to the environmental changes and to the transportation and vibration in work places. They can sustain more optical excitation power and dc bias voltages compared to the conventional photoconductive antennas, and can be used for a wide range of applications, including THz time-domain spectroscopy, THz imaging, and sensing, THz device characterization, etc.

With the T-Lux™ AA Series aperture array antennas there is no need to THz beam collimating silicon lenses, which makes the alignment process very simple and repeatable. Their large active area makes the optical beam alignment very easy and straight forward. The optical excitation can be applied either from the transparent silica substrate side or from the array side. The THz beam is radiated from and focused on the other side of the device in the transmitter and the receiver modes, respectively. In the case of micro-lens array coupled antennas, users only need to couple a collimated laser beam to the micro-lens array surface to make the device functional.

Product Specifications

Excitation wavelength	780 nm-850 nm
Optical power operation range	5 mW-1 W
DC bias operation range	2 V-100 V
THz bandwidth	4 THz
THz power dynamic range	55 dB
Active array area	1.1 mm×1.1 mm
Number of array elements	10

Product Overview:

- High power THz transmitter
- Wide band THz receiver
- Optical micro-lens array coupled option
- Wide range of frequency spectrum (0.1-4 THz) with 100 fs laser excitation
- Fiber coupled or free beam laser excitation
- Large active area: easy optical alignment, less sensitive to environmental changes, vibration, and transportation
- Reliable in the long-run and day-to-day use
- Transferred on optically transparent substrate: optical excitation from either side of the device is possible
- Destructive radiation is eliminated by removing unwanted active layer between every second bias fingers
- Unwanted carrier generation inside the native substrate is eliminated by transferring the photo-absorbing layer onto an optically transparent substrate
- Bias finger shadowing is eliminated by possibility to bring optical excitation from the transparent substrate side
- No need to THz beam collimating silicon lenses: easy and straight forward system alignment

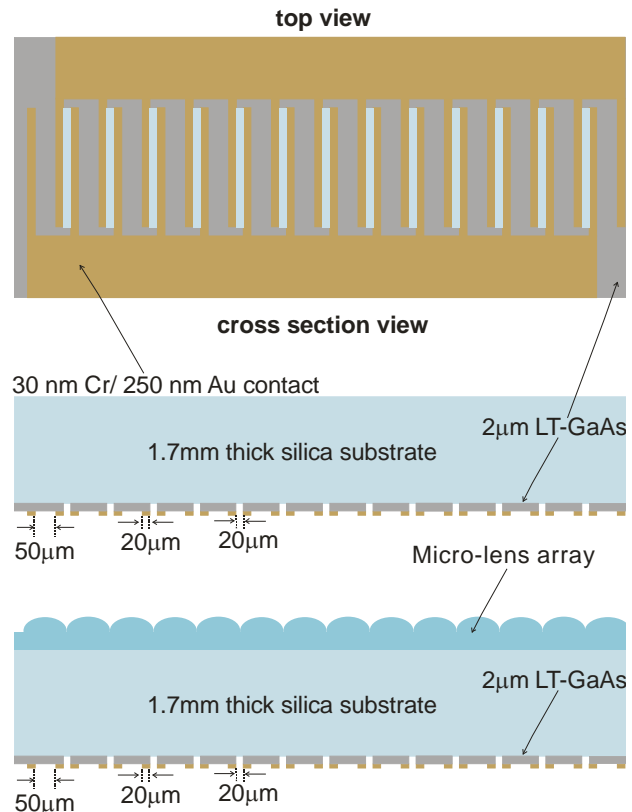


Fig.1 (a) T-Lux™ AA Series aperture array antennas mounted on a PCB carrier board and connected to a SMA connector (b) Drawing of the T-Lux™ AA Series aperture array antennas with and without micro-lens array.

Characterization Procedure:

1) Radiation Properties in Electro-Optic Detection Setup

A standard electro-optic detection scheme (see Fig. 1) is used to characterize THz radiation properties of the T-Lux™ AA Series aperture array antennas. In the setup shown in Fig. 1, an incoming infrared laser beam from a Ti:Sapphire short pulse laser with the central wavelength of 780 nm, the optical pulse duration of 100 fs, and the repetition rate of 80 MHz, is divided into a pump and a probe beam using a beam splitter. The pump beam impinges on the dc biased T-Lux™ AA Series aperture array antenna after passing through a focusing lens. A hyper-hemisphere high resistive silicon lens with 0.5 mm diameter and 0.84 mm setback is attached to the back side of the photoconductive antenna substrate to collimate the radiated THz beam. The radiated THz beam is collected by a series of off-axis parabolic mirrors and ultimately is focused on a 1mm thick (100) ZnTe crystal. After passing through a motorized delay line stage, the optical probe beam is also focused on the ZnTe crystal. The optical probe beam co-propagates with the THz beam inside the electro-optic crystal. A change in the polarization state of the optical probe beam due to the presence of the THz electric field is measured using a quarter wave-plate, a wollaston prism, and a balanced photodiode. The measured voltage at the output of the lock-in amplifier is proportional to the amplitude of the THz electric field. By changing the delay of the probe beam one can map the amplitude of the THz electric field in time-domain. Applying Fast Fourier Transform (FFT) to the measured THz electric field, one can extract the frequency spectrum of the generated THz field.

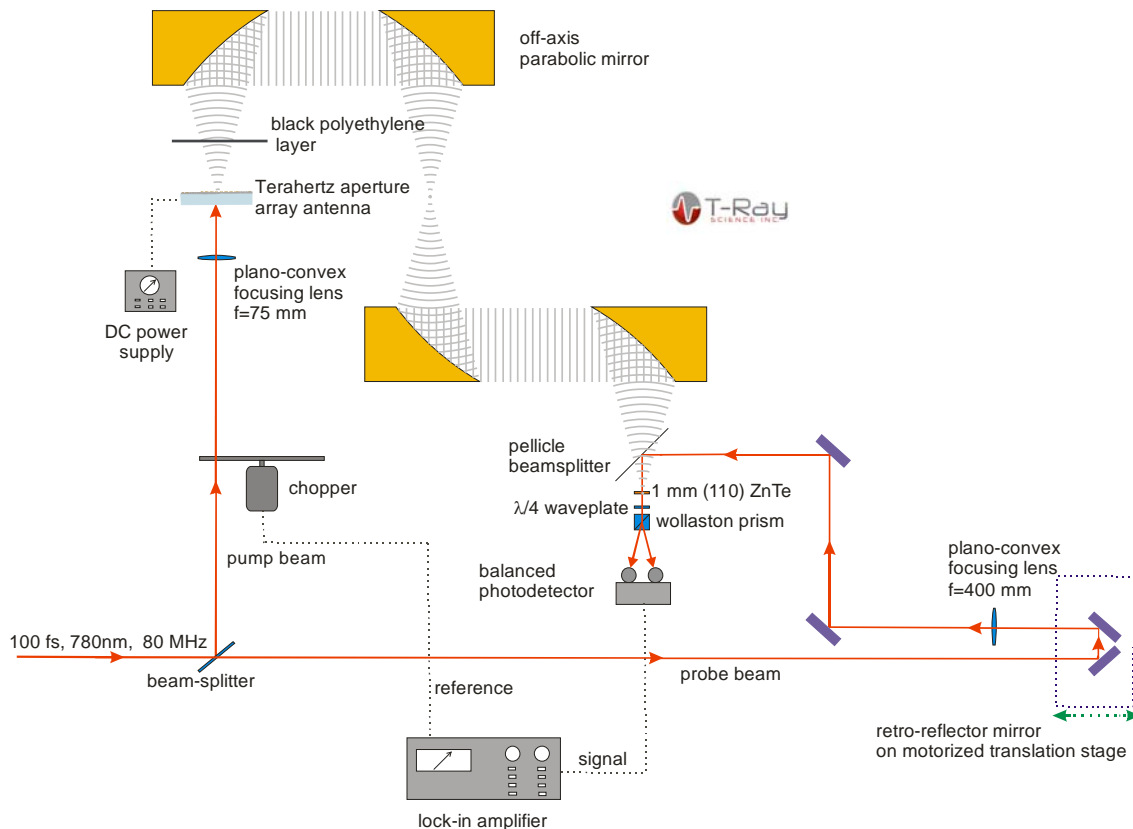


Fig.2 Schematic of the THz time-domain setup used to characterize T-Lux™ AA Series aperture array antenna.

Performance Characteristics:

Fig. 3 shows I-V characteristic of aperture array antenna measured at room ambient without infrared laser beam excitation. An ohmic behavior can be observed with a dark resistance about 3 MΩ. Fig. 4 shows DC photocurrent as a function of DC bias with 50 mW incident optical power. The measured peak of the THz electric field as a function of applied DC bias is shown in Fig. 5. The THz electric field as a function of time is shown in Fig. 6, and Fig. 7 shows the corresponding power spectrum. Figs. 8 and 9 show the THz electric field and the corresponding power spectrum when the THz path is purged by dry nitrogen for 20 minutes. The THz spectrum of the signal is extended up to 3.5 THz. Measurement parameters for Figs. 6-9 are given below:

Measurement Parameters

Excitation wavelength	780 nm
Transmitter Antenna	110 μm pitch aperture array on LT-GaAs (T-Lux AA Series)
Optical pump power	50 mW after chopper
DC bias on transmitter	30 V
Transmitter DC photocurrent	304 μA
Transmitter dark resistance	3 MΩ
Detector electro-optic crystal	1 mm thick (100) ZnTe
Optical probe power on each balanced photodiode	1 mW
Lock-in time constant	300 ms
Delay line stage speed	4 μm/s
THz peak signal (voltage on lock-in amplifier)	9.3 mV with the gain of 10 ⁵ for balance detector
Chopping frequency	1.28 KHz

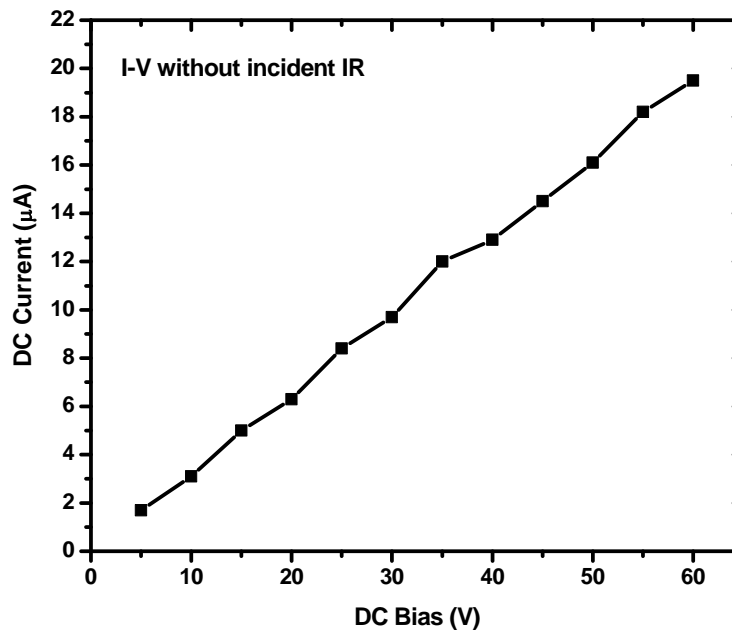


Fig.3 DC current for aperture array antenna as a function of DC bias measured at room light and with no incident infrared light.

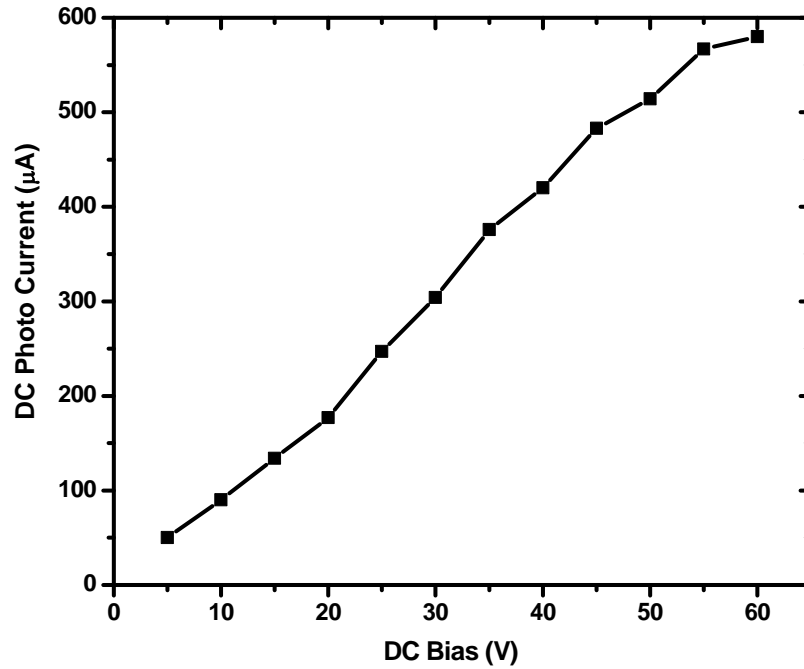


Fig.4 DC photocurrent for aperture array antenna as a function of DC bias with 50 mW optical pump power.

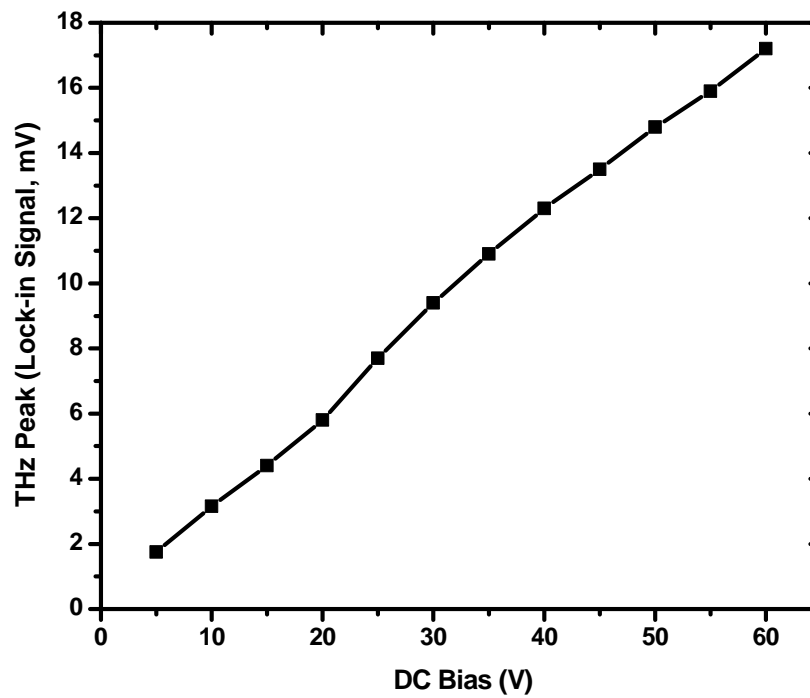


Fig.5 Terahertz peak signal for aperture array antenna as a function of DC bias with 50 mW incident optical power.

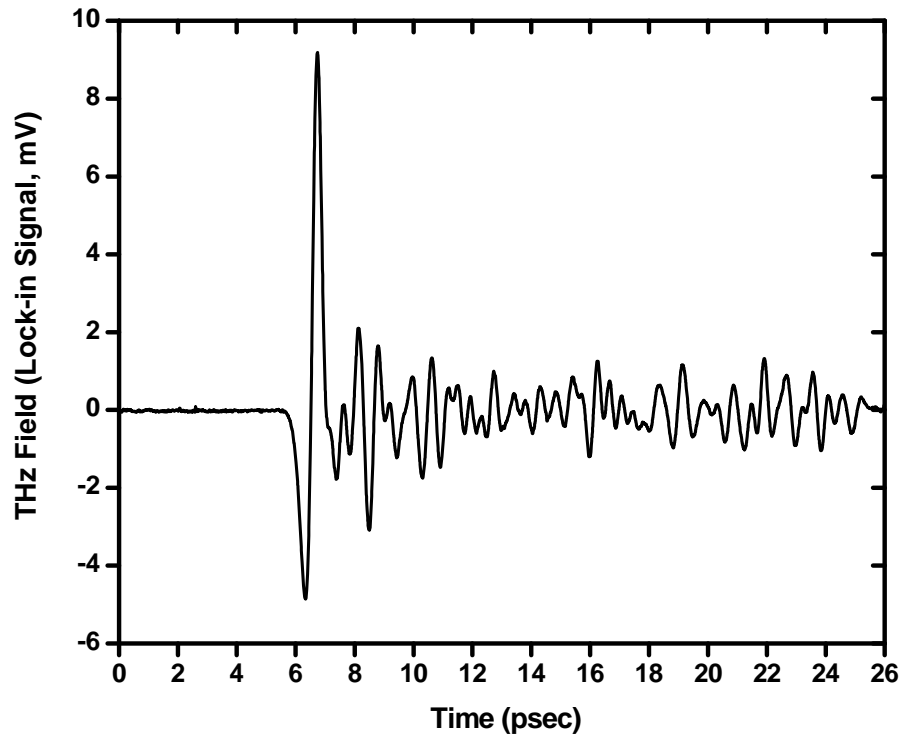


Fig.6 THz electric field as a function of time measured in ambient air.

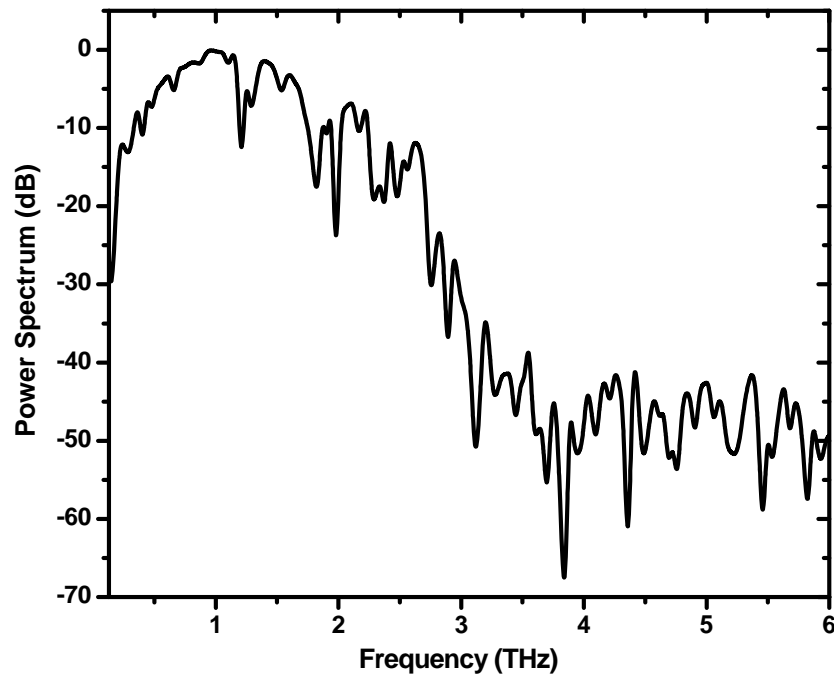


Fig.7 Power spectrum of the THz electric field shown in Fig. 6.

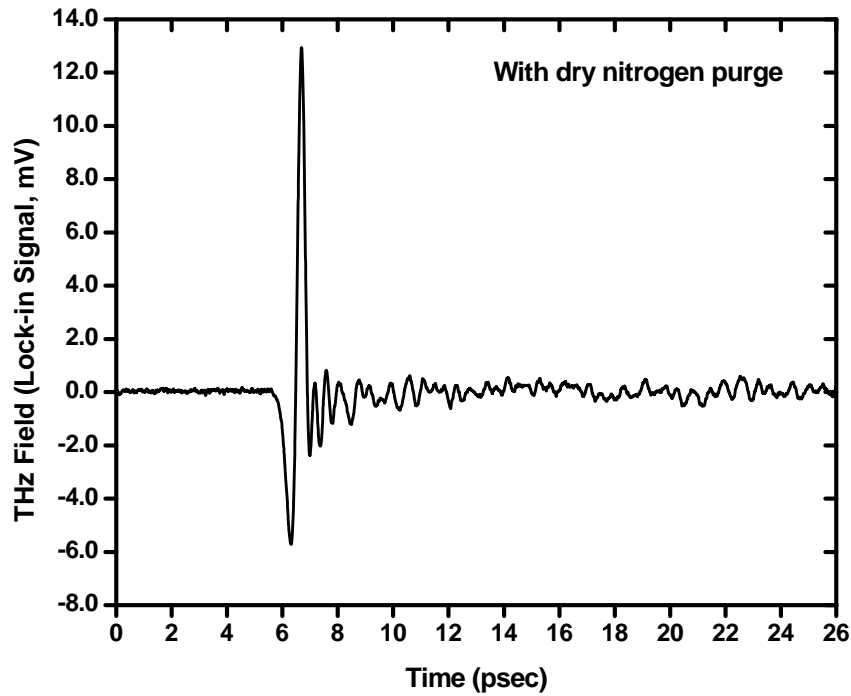


Fig.8 THz electric field as a function of time with THz path purged for 20 min by dry nitrogen.

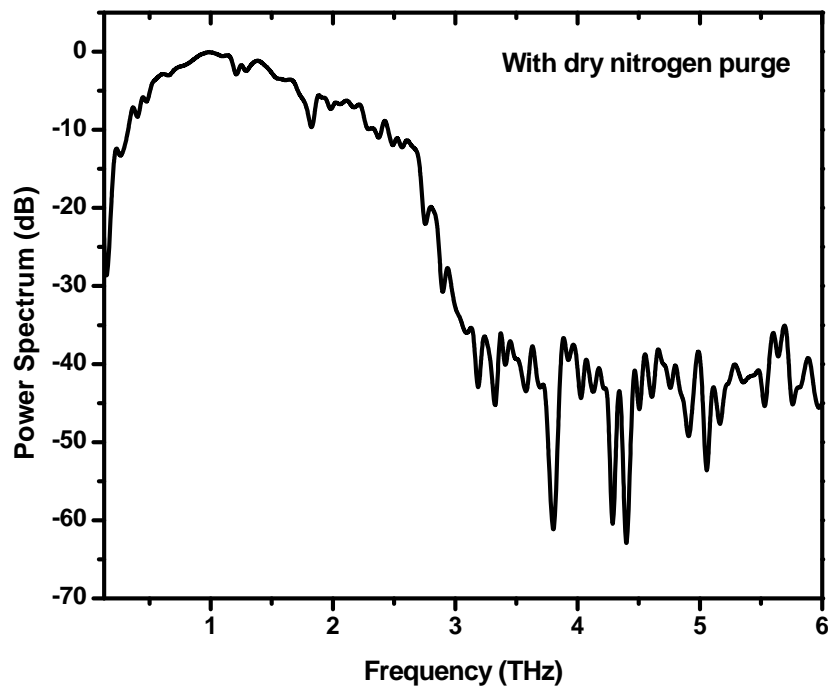


Fig.9 Power spectrum of the THz electric field shown in Fig. 8.

2) Radiation Properties in Terahertz Photoconductive Antenna Setup

A standard THz photoconductive antenna (PCA) setup (see Fig. 10) is used to characterize THz radiation properties of the T-Lux™ AA Series aperture array antennas in a THz PCA transmitter/receiver arrangement. In the setup shown in Fig. 10, an incoming infrared laser beam with the central wavelength of 780 nm, the optical pulse duration of 100 fs, and the repetition rate of 80 MHz, is divided into a pump and a probe beam using a beam splitter. The pump beam impinges on the dc biased T-Lux™ AA Series aperture array antenna after passing through a focusing lens. A hyper-hemisphere high resistive silicon lens with 0.5 mm diameter and 0.84 mm setback is attached to the back side of the photoconductive antenna substrate to collimate the radiated THz beam. The radiated THz beam is collected by a series of off-axis parabolic mirrors and ultimately is focused on the receiver T-Lux™ AA Series aperture array. No silicon lens is attached to the transmitter and the receiver antennas. After passing through a motorized delay line stage, the optical probe beam is also focused on the aperture array antenna. At the presence of the probe beam pulse, the incident THz signal on the receiver antenna induces a photocurrent which is proportional to the amplitude of the incident THz field. By changing the delay of the probe beam one can map the amplitude of the THz electric field in time-domain. Applying Fast Fourier Transform (FFT) to the measured THz electric field, one can extract the frequency spectrum of the generated THz field.

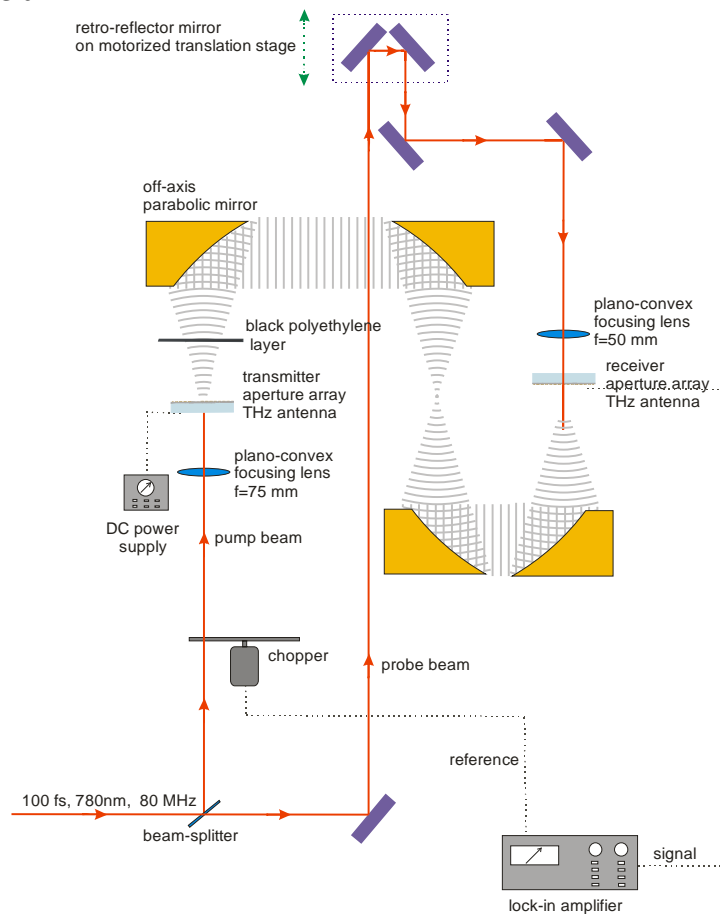


Fig.10 Schematic of the THz time-domain setup used to characterize T-Lux™ AA Series aperture array antenna.

Performance Characteristics:

The measured THz peak signal as a function of applied DC bias on transmitter antenna is shown in Fig. 11. The THz peak signal linearly increases for the dc bias voltages larger than 7 V. The THz electric field as a function of time is shown in Fig. 12, and Fig. 13 shows the corresponding power spectrum. The frequency spectrum of the signal extends up to 4 THz with 60 dB dynamic range for THz power spectrum. Measurement parameters for Figs. 12 and 13 are given in table below. Figure 14 shows the DC photocurrent as a function of incident optical pump power after optical chopper. The THz peak signal as a function of optical pump power is shown in Fig. 15. The top axis corresponds to optical probe power on the receiver antenna.

Measurement Parameters

Excitation wavelength	780 nm
Transmitter Antenna	110 μm pitch Aperture Array (T-Lux™ AA Series)
Receiver Antenna	110 μm pitch Aperture Array (T-Lux™ AA Series)
Optical pump power after optical chopper	50 mW
Optical probe power	90 mW
DC bias on transmitter	30 V
Transmitter DC photocurrent	286 μA
Transmitter dark resistance	3 M Ω
Lock-in time constant	100 ms
Delay line stage speed	5 $\mu\text{m/s}$
THz peak signal (voltage on lock-in amplifier)	4.8 nA on receiver antenna
Chopping frequency	520 Hz

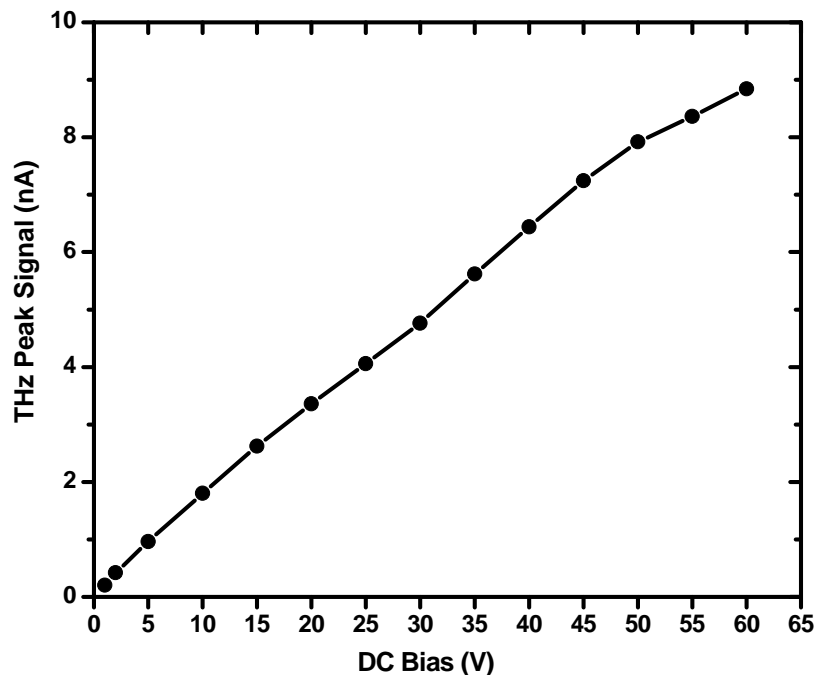


Fig.11 THz peak signal detected by the receiver aperture array antenna versus dc bias on the transmitter aperture array antenna with 50 mW optical pump power and 90 mW optical probe power.

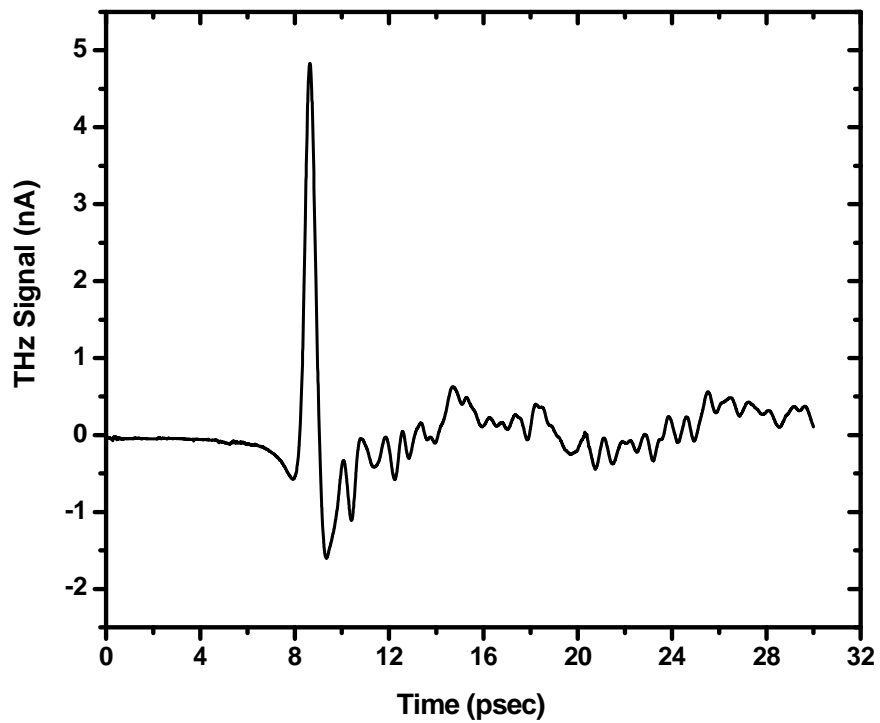


Fig.12 THz electric field as a function of time measured by the receiver aperture array antenna in ambient air.

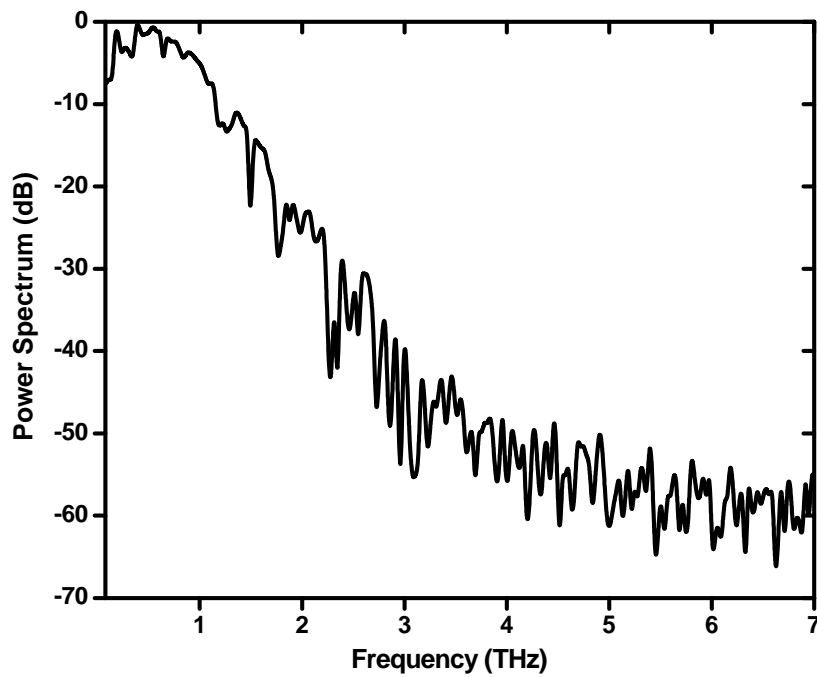


Fig.13 Power spectrum of the THz electric field shown in Fig. 12.

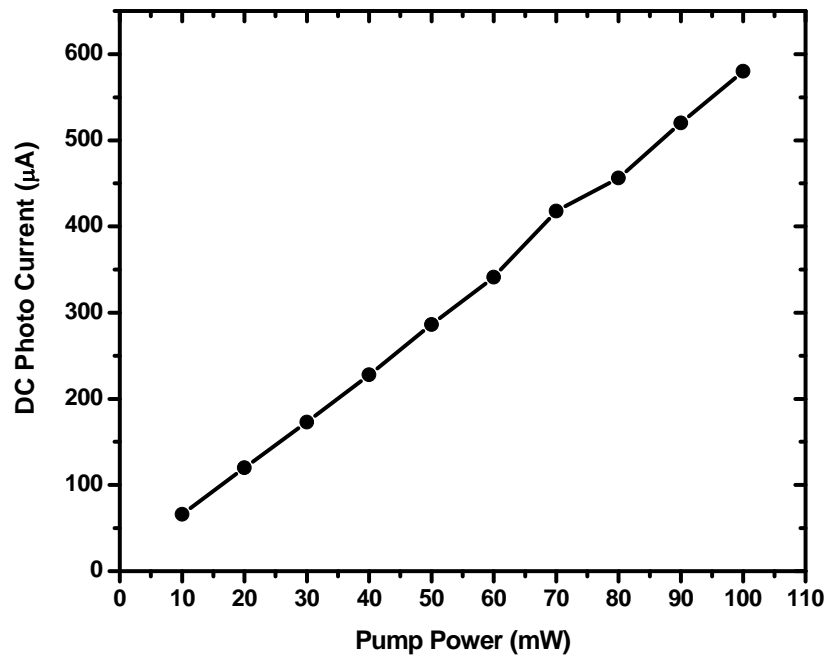


Fig.14 DC photocurrent on transmitter antenna as a function of incident optical power and for 30 V DC bias on the transmitter antenna.

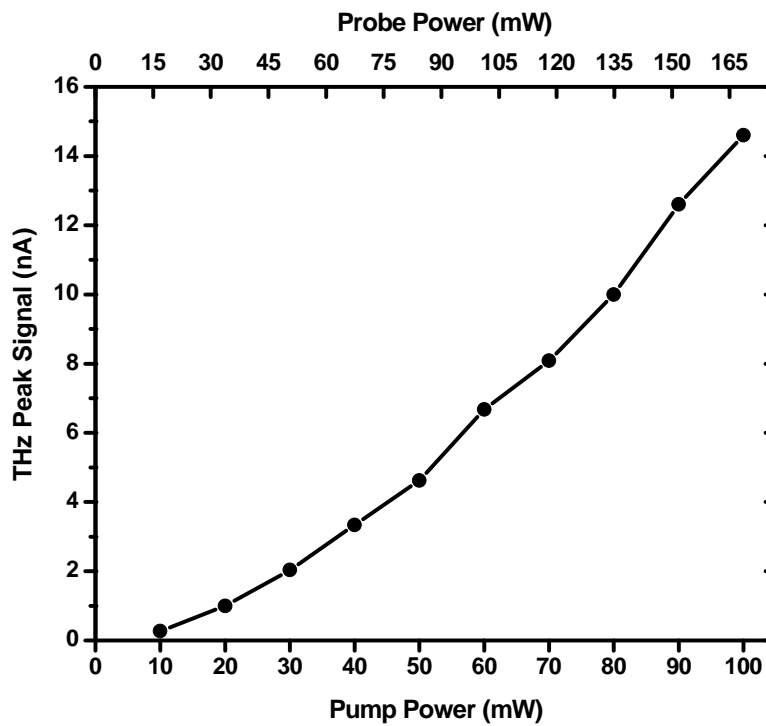


Fig.15 THz peak signal detected by aperture array antenna as a function of incident optical power and for 30 V DC bias on the transmitter antenna.

3) Terahertz Power Measurement Setup

Figure 16 shows the schematic of the setup used to measure the average THz power generated by T-Lux™ AA Series. An infrared filter in front of the Golay cell blocks the generated thermal infrared signal at the transmitter antenna. A black polyethylene layer blocks the infrared light passing through the slits between antenna array elements and the transparent substrate. The Golay cell is factory calibrated with responsivity of 4500 V/W at 10 Hz modulation frequency. Figures 17 and 18 show the average THz power versus DC bias voltage and optical pump power, respectively.

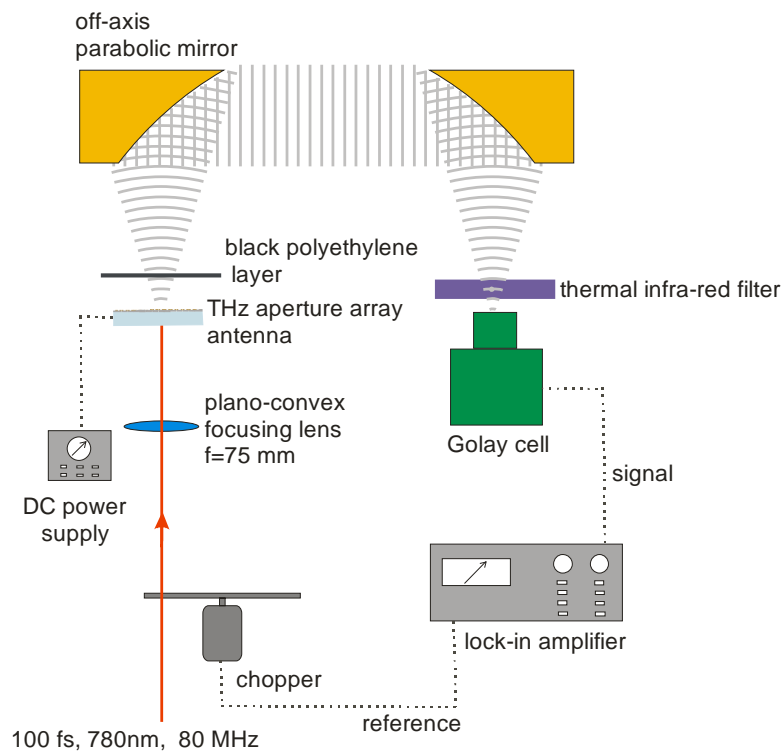


Fig.16 Schematic of the setup used to measure average THz power generated by T-Lux™ AA Series.

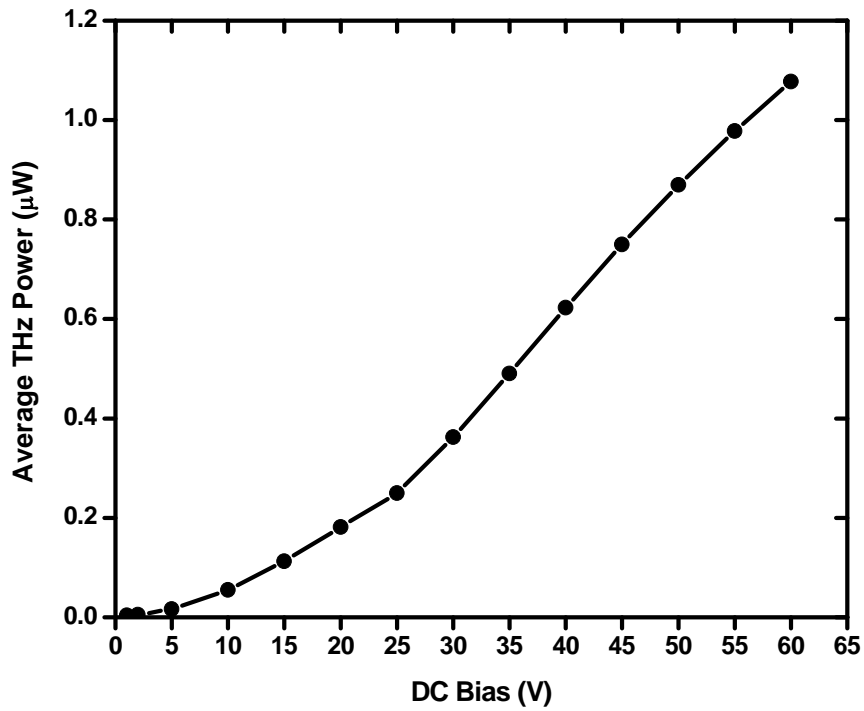


Fig. 17 Average THz power versus DC bias voltage generated by T-Lux™ AA Series for 50 mW incident optical power.

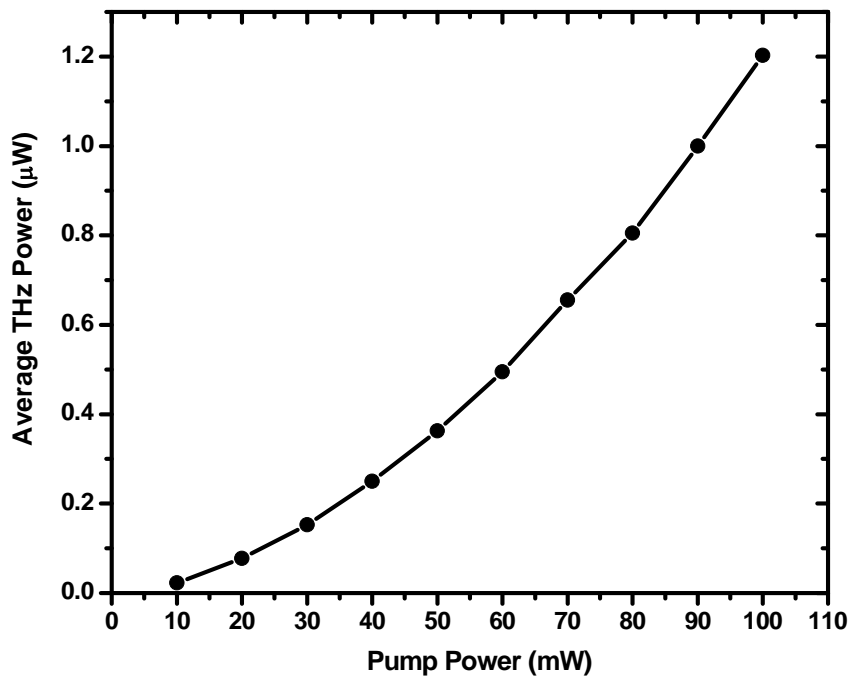


Fig. 18 Average THz power versus incident pump power (after optical chopper) generated by T-Lux™ AA Series for 30 V DC bias on the antenna.