

HASSP-THz

High-resolution THz spectrometer



Overview

HASSP-THz is a time-domain THz transmission spectroscopy system with 1 GHz spectral resolution and a spectral coverage of more than 6 THz for scientific applications. The purged system has a peak dynamic range of greater than 60dB within only 1 minute of acquisition time. Video-rate spectroscopy (28 spectra per second) is performed at approximately 30 dB peak dynamic range.

Applications

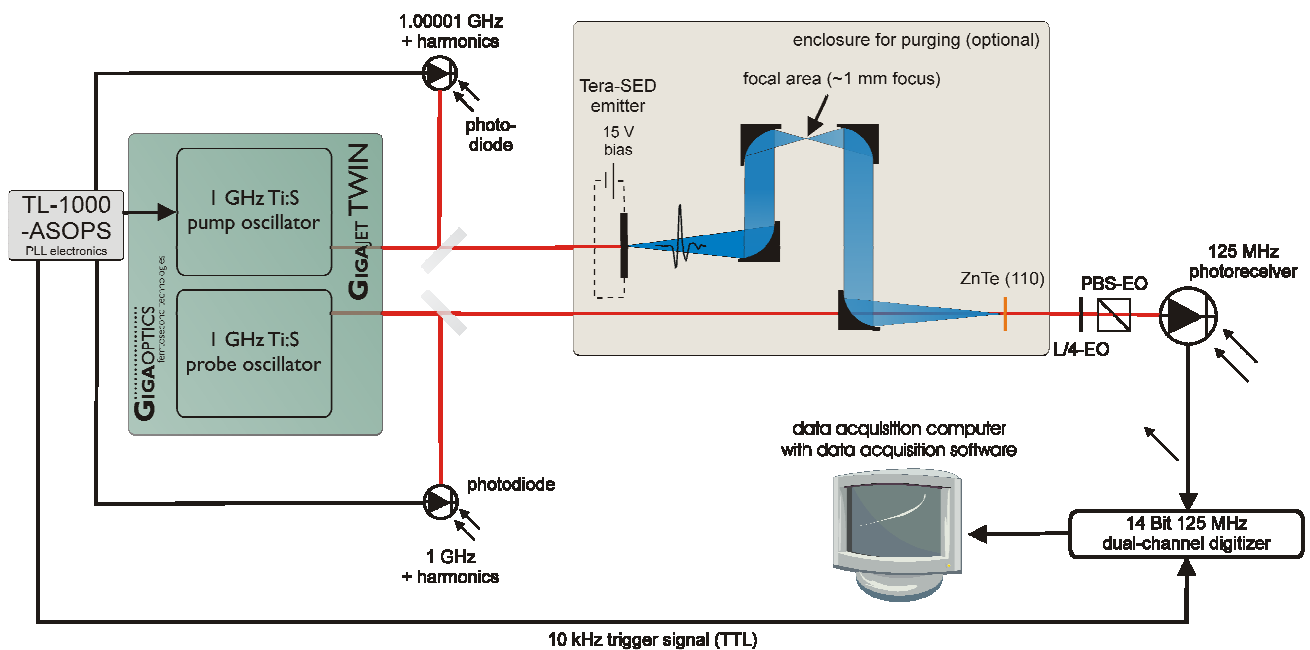
THz transmission spectroscopy - HASSP-THz is used for THz transmission spectroscopy in scientific applications where ease of use, high precision and high spectral resolution are required. The ASOPS principle makes mechanical delay stages obsolete, there is no need to find a time-zero point. The absence of residual alignment errors and the long time-delay guarantee high precision and resolution.

THz studies of dynamic processes - HASSP-THz rapid data acquisition capability (up to 10,000 spectra per second at 1 GHz resolution) permit the investigation of dynamic processes and studies under rapidly varying environmental conditions.

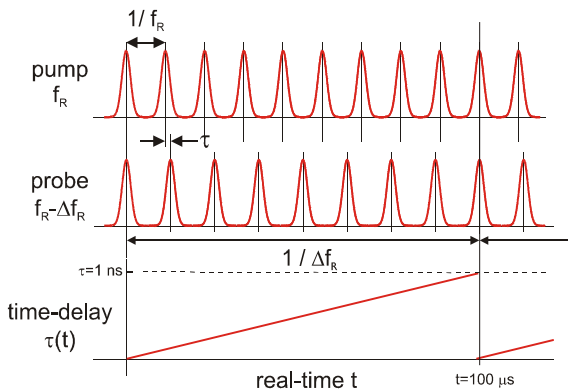
THz imaging applications - The rapid data acquisition capability of HASSP-THz makes very short pixel dwell times in spectroscopic THz imaging applications possible. Images can thus be acquired in a matter of a few seconds.

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Schematic of HASSP-THz. Optical beam paths are green (532 nm pump laser) and red (femtosecond pulse trains), electrical paths are black. Pump laser for Gigajet TWIN is not shown. Optical triggering optics and path is not shown.



High-speed ASOPS scheme. The time delay between pump and probe pulses is scanned by slightly differing repetition rates ($f_R \sim 1$ GHz). The difference Δf_R determines the scan rate, while the measurement window is given by the inverse of the repetition rate $1/f_R = 1$ ns. Here, Δf_R is 10 kHz, i.e. the time-delay is repetitively ramped with a 100 μ s period.

HASSP-THz technology

As enabling technology, HASSP-THz employs high-speed asynchronous optical sampling (ASOPS). High-speed ASOPS allows for a high scan-rate and a high frequency-resolution at the same time. This unique combination is impossible with conventional ultrafast time-domain measurement techniques based on a single femtosecond (fs)-laser and mechanical time-delay stages. High-speed ASOPS employs two separate fs-lasers whose 1 GHz repetition rates are detuned by $\Delta f_R = 10$ kHz (2 kHz with -GaP option) and thus deliver pump and probe pulse trains with a time-delay that is automatically ramped between zero and 1 ns at a rate given by Δf_R . A mechanical delay stage is not required.

HASSP-THz measures the transmission of a specimen by dividing

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the Fourier-transform of the transmitted THz radiation by a stored reference spectrum acquired without sample present at the interaction area. Transmission spectra are continuously displayed by HASSP-Scope at a user-definable update rate.

The signal-to-noise ratio of signals acquired by HASSP-THz is limited by detection shot-noise. It is thus directly proportional to the user-definable acquisition time. At video-rate (35 ms per spectrum), the peak dynamic range is ~30 dB. Higher values are accomplished by an increase in acquisition time. More than of 60 dB can be achieved within just 1 minute. See figures below for typical data.

A precision on the order of 150 MHz has been demonstrated for HASSP-THz, a value that out-performs any other published time-domain spectroscopy instrument [G. Klatt et al., Opt. Expr. 17, 22847 (2009)].

HASSP-THz components

HASSP-THz consists of different modules that are arranged on a breadboard with an enclosure. See figure on previous page for a system sketch. The components and their functionality are described in the following. See component specification sheets for details.

GIGAJET TWIN dual femtosecond oscillator - GIGAJET TWIN contains two GIGAJET 20 femtosecond oscillators with 1 GHz repetition rate. The oscillators are pumped by an external low-noise green cw-laser and deliver more than 800 mW of average power each with ≤ 30 fs pulse duration. The oscillators deliver the pump and probe pulse trains, respectively.

TL-1000-ASOPS repetition rate offset stabilization unit - The repetition rate offset stabilization unit TL-1000-ASOPS is used



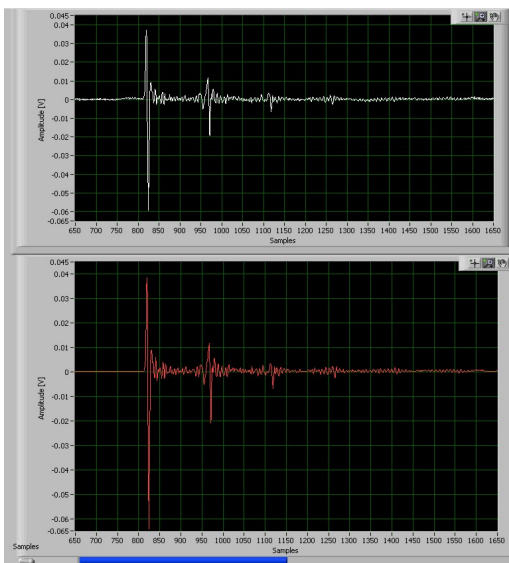
GIGAJET TWIN dual femtosecond oscillator



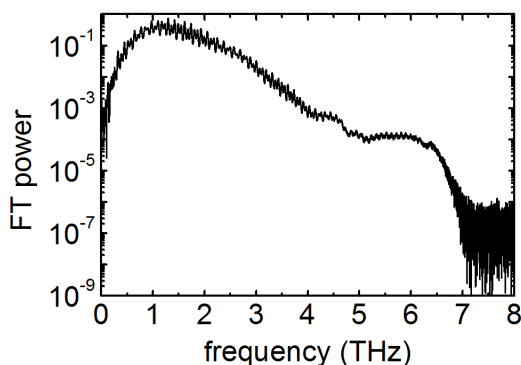
TL-1000-ASOPS repetition rate offset stabilization control unit

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Screen shot of signal display field of HASSP-Scope software. Time-axis of raw data is scaled in samples, one sample equals 100 fs time-delay (20 fs with -GaP option). A zoom into the first ~100 ps is shown for better visibility. Water vapour was present for the displayed traces. Upper panel: Hardware-based average over 1024 single scan traces displayed at ~10 Hz update rate on the screen. Lower panel: Software-based average over 100 of the hardware-based averaged traces with increased signal-to-noise ratio.



Spectrum of the nitrogen purged spectrometer with -GaP option (100 s acquisition time). Spectral modulation is due to Fabry-Perot resonance of emitter chip.

to phase-lock the pump oscillator to the probe oscillator with a +10kHz offset (+2 kHz with -GaP option) as required for high-speed ASOPS. The time-resolution of the system is better than 60 fs (typically 45 fs) over the full 1 ns time-delay window. The TL-1000-ASOPS unit also provides a TTL signal at the repetition rate difference to trigger the data acquisition hardware.

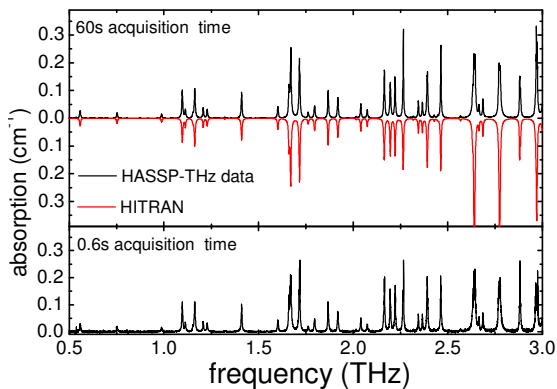
Tera-SED 3 large area THz emitter - The pulse train from the pump oscillator illuminates a Tera-SED 3 large-area THz emitter and launches a THz pulse into the spectroscopy system.

THz interaction area and electro-optic detection - The THz pulses are guided to the sample interaction area and from there to the (110)-ZnTe detector crystal (GaP with -GaP option) via off-axis parabolic mirrors. In the simplest configuration, the THz radiation is focused to a 0.5 mm spot at the sample interaction area and measurements are performed in transmission geometry. Other geometries and solutions specifically tailored to meet customer requirements are possible. The entire area through which the THz radiation travels is contained in an enclosure which can be purged to minimize water vapour absorption. The pulse train from the probe oscillator is used to electro-optically probe the THz field via an electro-optic detector crystal. Our high-speed photoreceiver PR130 is used for detection.

Data acquisition board and HASSP-Scope software - The signal from the photoreceiver is sampled by a digitizer board at 125 MS/s with 14 Bit resolution. Data acquisition is triggered by a square wave generated by the TL-1000-ASOPS unit or by an adjustable optically generated trigger signal which is synchronous with the time-delay ramping of the optical pulse trains. The real-time scale t is converted to a time-delay scale $\tau(t)$ by applying a scaling factor of $(\Delta f_R / 1 \text{ GHz})$ to the time-axis of the acquired data. The data acquisition board has on-board capability of averaging over up to 1024 single-scan measurements. The time required for 1024 hardware averages is ~110 ms (~550 ms with

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Absorption spectrum of atmospheric air (black lines) compared to data compiled from HITRAN database for 60 s and 0.6 s acquisition time.

–GaP option). The HASSP-Scope software displays the signal which is directly proportional to the detected THz field. HASSP-Scope also permits to acquire an arbitrary number of additional software based averages over the hardware-averaged traces in order to increase the signal-to-noise ratio. Live Fourier transform capability and displaying of transmission spectra is also provided.

System specifications

spectral coverage	0.05 - 3 THz 0.05 - 6 THz with -GaP option
frequency resolution	1 GHz (0.03 cm^{-1})
scan frequency	10 kHz 2 kHz with -GaP option
time-delay window	1 ns
peak dynamic range @ 3 GHz resolution *	$\geq 30 \text{ dB}$ @ 100 ms acquisition time $\geq 60 \text{ dB}$ @ 100 s acquisition time
peak dynamic range @ 1 GHz resolution *	$\geq 25 \text{ dB}$ @ 100 ms acquisition time $\geq 55 \text{ dB}$ @ 100 s acquisition time
focal spot at sample area	$\varnothing \sim 0.5 \text{ mm}$
dimensions (main spectrometer unit)	approx. $90 \times 150 \times 30 \text{ cm}^3$
sample holder	to customer specifications
power requirement	110 - 230 V single phase 50 - 60 Hz
operating temperature	$15^\circ\text{C} - 25^\circ\text{C}$

*between 0.5 and 1.5 THz, lower at other frequencies, reduced by 5 dB with -GaP option

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