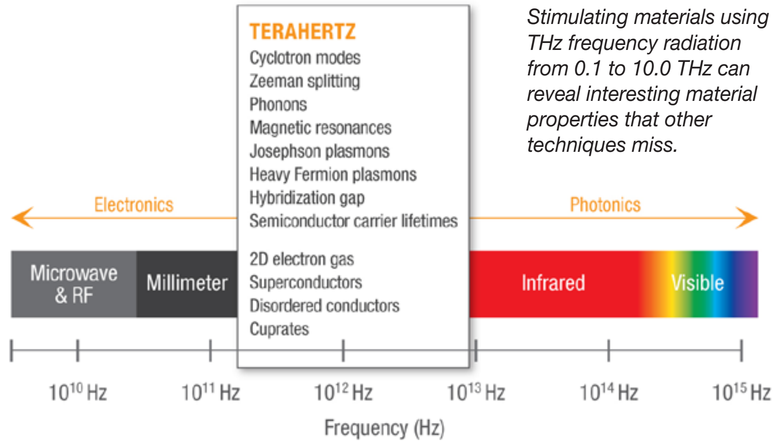
8500 Series THz System
for Material Characterization

Lake Shore CRYOTRONICS

Integrated THz system for material characterization

A new type of measurement system

- For electronic, magnetic, and chemical materials research and characterization.
- Uses THz-frequency energy and an integrated high-field cryostat to measure material spectroscopic responses across a wide range of frequencies, temperatures, and field strengths.
- No special knowledge of THz optics required. Fully integrated solution is ready to use and eliminates complicated optics setups typically associated with THz spectroscopy. Just load a sample and start taking measurements.



Stimulating materials using THz frequency radiation from 0.1 to 10.0 THz can reveal interesting material properties that other techniques miss.

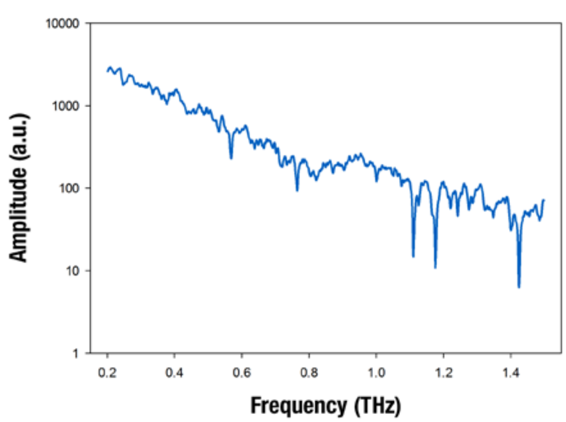
Supports advanced materials research

Characterizes properties of emerging electronic, magnetic, and chemical materials in next-generation applications, such as:

- High-speed computing and communications
- THz sensors and detectors
- Photovoltaics
- Organic electronics
- Spin-based computing
- Thin-film semiconductors

Performs spectroscopic response measurements to derive key material properties, including:

- Dielectric constant
- Dynamic conductivity
- Carrier scattering times and mobilities
- Vibrational resonances
- Magnetic resonances



Reference THz spectrum — resonances denote locations of known water lines.

For breakthrough science

THz represents the "last unexplored frontier" in the electromagnetic spectrum. Because THz frequency energy aligns well with many phenomena of interest in emerging electronic and magnetic materials, it's rapidly gaining the interest of researchers who see THz as a brand new characterization tool that may help uncover groundbreaking new material properties.

Previously, even room-temperature THz spectroscopic systems have been inaccessible to many researchers due to high cost and complexity of use, and there have been no commercial solutions with integrated cryogenics and high-field capabilities required for electronic materials research.

Until now. Lake Shore's new 8500 Series THz system is the first affordable, integrated, convenient solution specifically tailored for characterization of research-scale electronic and magnetic materials. It enables fully automated high-resolution THz spectroscopic characterization over a wide range of frequencies, temperatures, and magnetic fields, yielding detailed profiles of material responses. Analysis of these spectral profiles can lead to discovery of interesting physical phenomena not visible with other conventional characterization techniques.

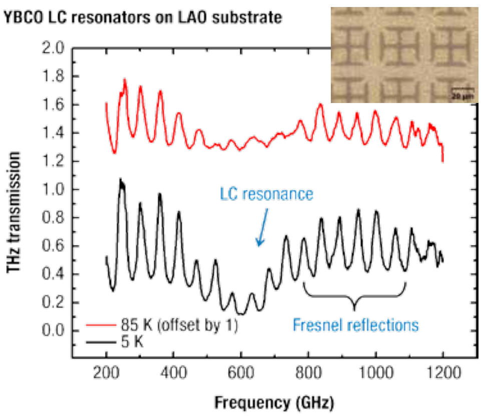
What's more, it's been proven effective. For more than two years, Lake Shore has been working in close collaboration with leading materials research institutions to validate the capabilities and measurement methodologies of this system. Now Lake Shore is making the 8500 Series THz system commercially available to all researchers who strive to be at the forefront of their field.

Applications of terahertz spectroscopy

Optically probe the low-energy excitations underlying electronic transport and magnetism in complex materials

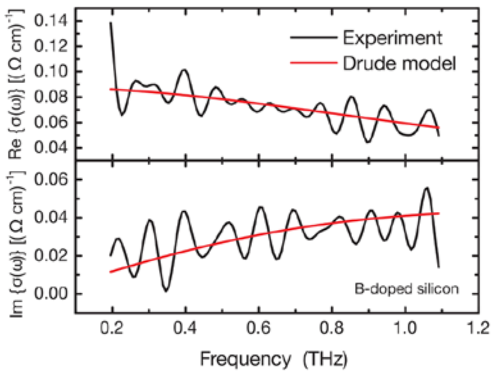
THz-frequency studies investigate basic material parameters and fundamental excitations in semiconductors, novel magnetic materials, and their nanostructures. THz-based measurements have been used to characterize and explore various applications of new materials such as topological insulators, graphene, and functional complex oxides.

Superconducting metamaterials



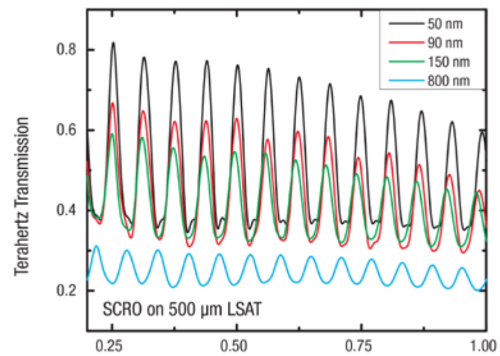
Compared to structures aimed at optical wavelengths, the longer length scales associated with THz active metamaterials simplifies fabrication. At THz frequencies, superconducting resonators for metamaterials exhibit enhanced Q-factors due to reduced dissipation below the transition temperature. External magnetic fields can be used to tune the resonant structure frequencies.

Bulk semiconductors



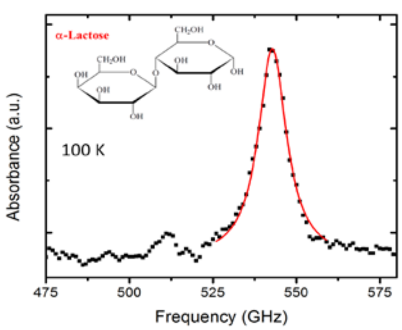
For homogenous semiconductor materials, the frequency-dependent complex conductivity can be derived from the Fresnel equations and appropriate conductivity models (e.g., Drude). DC mobilities calculated from the THz transmission data are consistent with Hall effect measurements.

Complex oxide epilayers



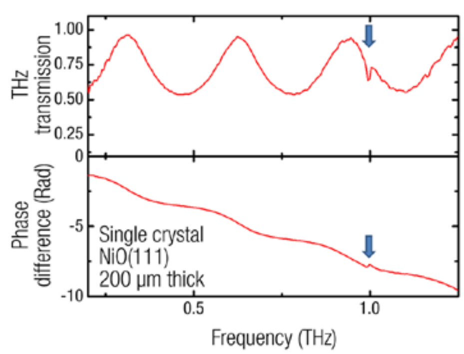
Temperature and magnetic field dependent terahertz spectroscopies have proven useful in elucidating the interplay between structure, charge, and magnetism in complex oxide systems. Substrate etalons are useful in characterizing thin epitaxial thins films of Sr_2CrReO_6 (SCRO), a double-perovskite, ferrimagnetic, semiconductor.

Organic electronic materials



Intramolecular and intermolecular vibrations can play an important role in determining the electronic properties of functional organic materials. Both linewidth and frequency of THz vibrational resonances are sensitive to temperature and the crystalline environment.

Unconventional spin materials



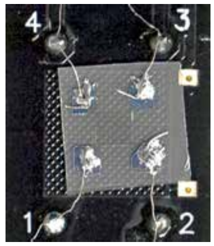
Studies of terahertz frequency excitations, like antiferromagnetic resonances, provide a powerful window into exotic properties of spin-functional materials.

Other possible applications

- Studying thin films of high-temperature superconductors
- Determining cyclotron resonance of high-mobility semiconductor materials (THz radiation is resonantly absorbed by a material when the frequency of light matches cyclotron frequency)
- Research into novel spin materials (such as bare ferroics, multiferroics, and magnetoelectrics)
- Characterization of molecular solids
- Plasmonic research
- Studying the mobility of electrons in graphene materials
- Mobility of carriers in 2D materials

Avantages of the THz system

- THz characterization is a non-contact method that avoids the time and difficulties of soldering ohmic contacts on delicate and costly new material samples.

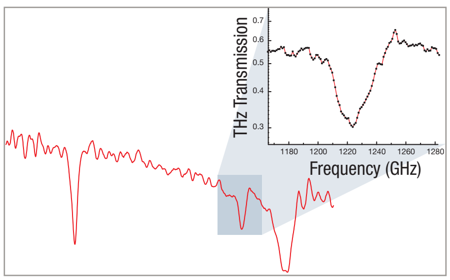


Messy and time consuming soldering is not required

- Actual sample size — The system requires only small samples, 10 mm × 10 mm, respecting that early stage development-grade materials are often in limited supply.

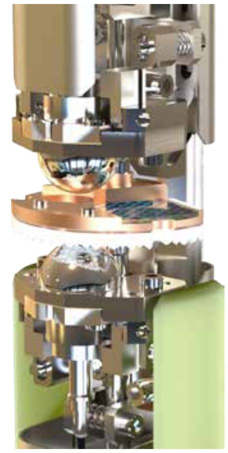
- Use of frequency-domain or "continuous wave" THz spectroscopy (CW-THz) allows the system to be very affordable. It also enables significantly higher spectral resolution (under 500 MHz), revealing features in the spectral profiles that would otherwise be missed with more expensive and more complex time-domain THz (THz-TDS) systems. (See box below.)

- The flexible frequency range capability of the CW-THz system also enables you to focus your time and attention to selected narrower bands of frequencies around observed points of interest in your data. Likewise, temperature and magnetic field bands are similarly selectable.



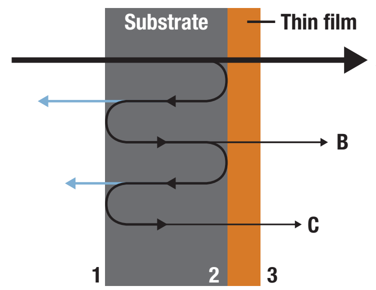
- Lake Shore's complete turnkey system is intended for researchers who want to maximize their time measuring materials. System setup is fast because all of the cryostat integration and optical setup is already done. Using the system requires no special knowledge of THz optics.

- Lake Shore's THz emitter and detector devices have been specially engineered to work right inside the cryostat and are positioned up close to the sample for maximum effectiveness. This avoids the long optical path lengths, energy losses, reflections, and alignment difficulties associated with using optical cryostats and general purpose room-temperature THz spectrometers.



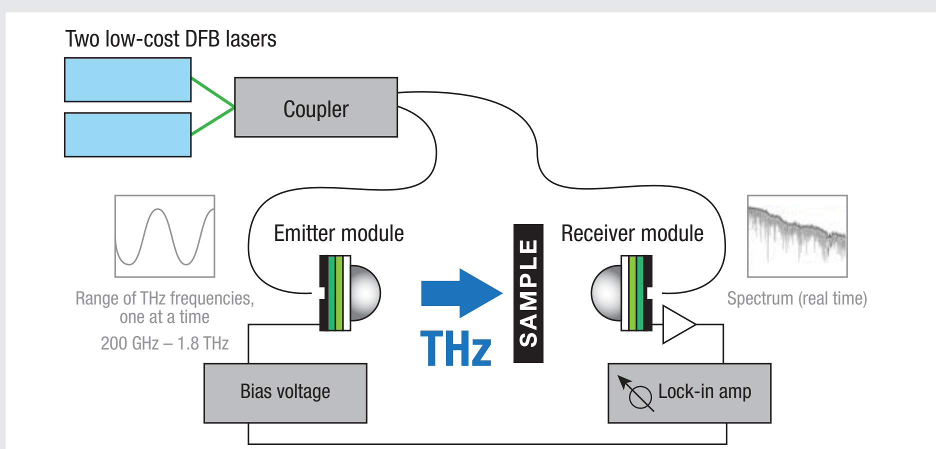
Emitter and detector with sample holder in between (shown in the sample insertion orientation)

- The system's configuration is particularly well suited to the characterization of thin-film semiconductor materials, taking advantage of the compounding effects of CW-THz reflections within the substrate material and avoiding detrimental reflections and complexities that would occur with THz-TDS through cryostat windows.



CW-THz: Lake Shore's novel approach

The continuous wave (CW-THz) system uses specially designed photoconductive mixers to provide a wide continuously tunable range of THz frequencies. The photomixers operate by illuminating narrow gaps in the DC-biased electrodes of an internal photoconductive switch (PCS) with a fraction of the combined output of two single-color diode lasers. The mixed optical beams induce an oscillation in the photocurrent at the (THz) difference frequency between the two lasers. A broadband antenna and silicon lens convert THz frequency photocurrent oscillations in the PCS to propagating THz beams. The THz output frequency can be tuned by varying the wavelength of the lasers. Coherent detection is achieved by mixing the CW signal incident on a second PCS with the same optical radiation used to drive the emitter.



System overview

Application software

- Experiment setup/run
- Program temperature and magnetic field measurements
- Display of spectral data

CW THz spectroscopy

- Uses continuous wave (CW) terahertz energy to measure
- Amplitude and phase detection from 200 GHz to 1.8 THz
- Spectral resolution under 500 MHz

Integrated controls

- Model 336 cryogenic temperature controller
- Model 625 superconducting magnet power supply
- Helium level meter
- Motorized sample positioning controls

Integrated cryostat and sample insert

- Variable temperatures from 5 K to 300 K
- Superconducting magnet—fields to 9 T
- THz devices tailored to fit 26 mm bore of cryostat
- Insert lift assist mechanism

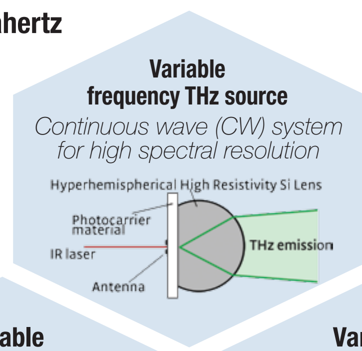
Sample tray

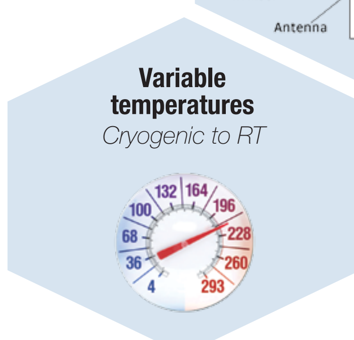
- Sample size—10 mm
- Measurement—THz transmission
- Automated mechanical adjustment of sample position

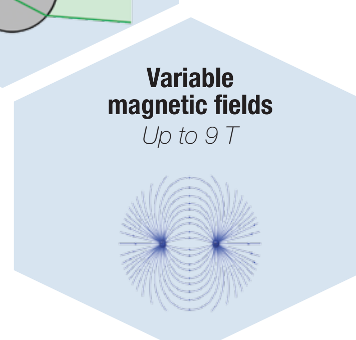
System specifications

Measurement:	Continuous wave (CW) THz transmission measurement with integrated variable temperature and variable magnetic field capability; coherent measurement for both amplitude and phase
THz generation/detection:	Cryogenic/magnetic field compatible photomixers inside cryostat
THz bandwidth:	0.2 to 1.8 THz
THz antenna:	Square spiral antenna (optional insert with reversed helicity antenna also available for spin material measurement)
Frequency resolution (min):	<500 MHz
THz dynamic range:	0.2 THz: 30 dB 1.2 THz: 40 dB 1.8 THz: 20 dB
Scan time:	<10 min for full bandwidth scan with 1 GHz resolution
Platform:	Liquid helium cryostat with ±9 T superconducting magnet Liquid nitrogen operation to 85 K without magnetic field
Temperature range:	5 K to 300 K
Magnet field:	±9 T
Sample insert:	Cryostat insert with automated three-position rotating tray for sample and reference measurement
Sample size:	10 mm (0.4 in) × 10 mm (0.4 in), maximum 4 mm (0.16 in) thickness, maximum
Orientation:	THz parallel to magnetic field; both perpendicular to sample plane
Sample space atmosphere:	Helium gas
Software:	Lake Shore software for full control of THz measurement and cryogenic/magnetic field environment
Data processing:	Full visualization of THz raw data, averaged scans, and processed THz transmission spectra Spectral feature identification and frequency measurement traces Datasets saved per temperature and magnetic field point CSV output format for convenient offline processing

Complete terahertz experimental platform includes:



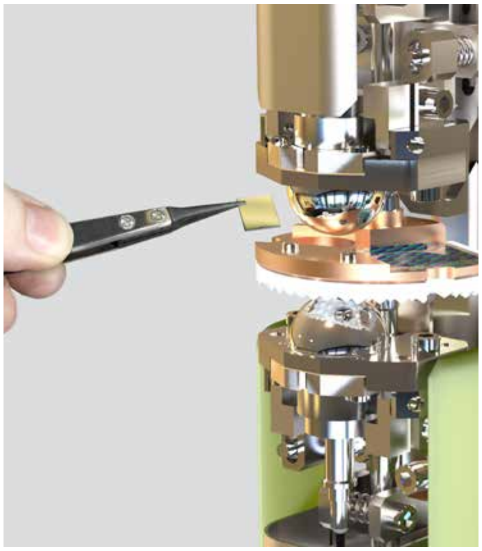




1 THz = 10^{12} Hz = 300 µm ~ 33 cm^{-1} ~ 4 meV ~ 50 K

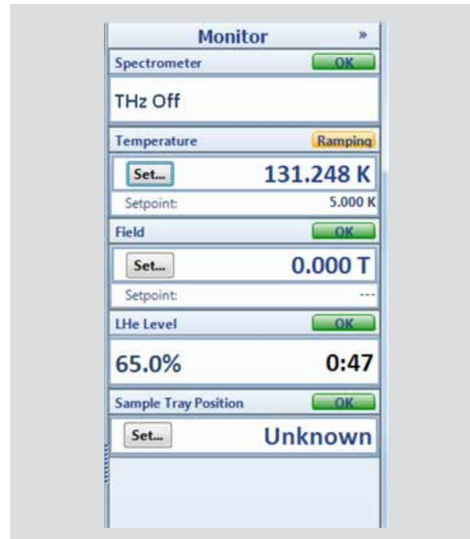
System operation

Operating the system generally follows this procedure:



① Mount the 10 × 10 mm sample in the sample tray

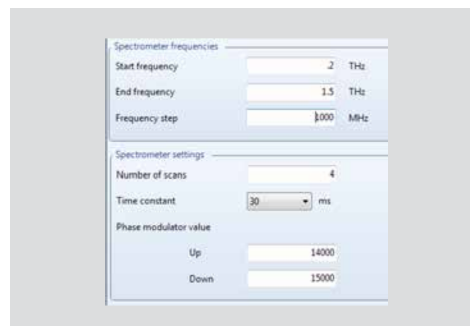
② Transfer the insert to the cryostat with the lift assist



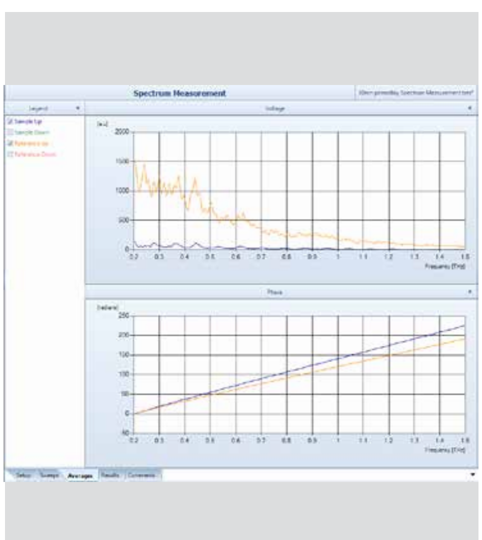
③ Cool the insert to the desired base temperature

④ Record sample details in data repository

⑤ Set up a programmatic temperature and field profile



⑥ Set up spectrum and acquisition parameters and press Start



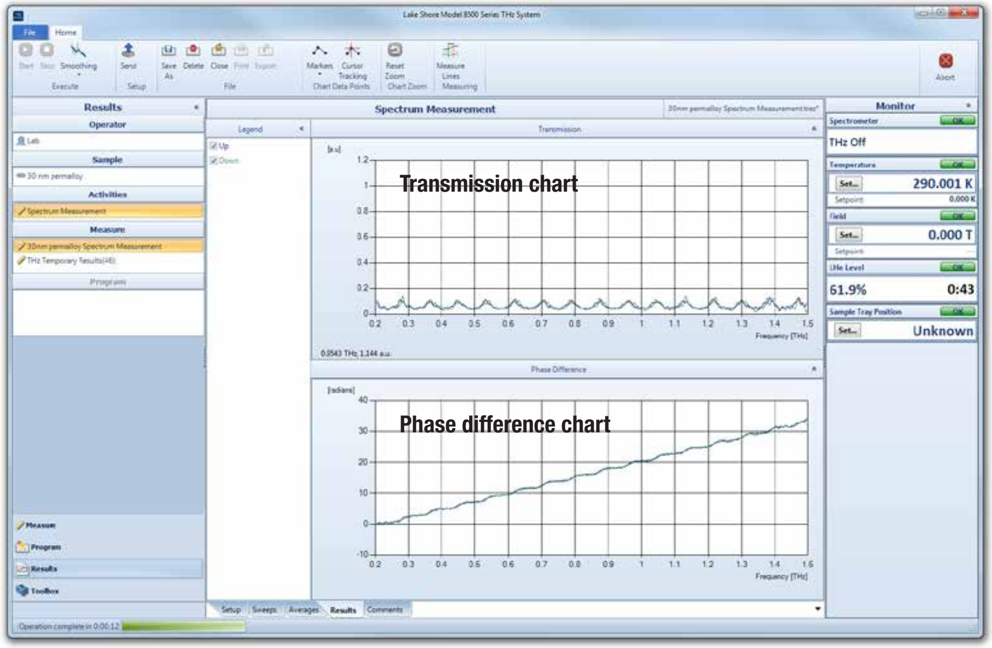
⑦ Sample, reference, and background data are automatically acquired for each profile point

⑧ When spectra measurements are complete, warm the sample to 300 K

⑨ Remove insert from cryostat and exchange sample

System software

The 8500 Series system software provides an intuitive GUI and a full set of system tools to enable easy setup of measurement profiles, automated execution of measurement runs, and real-time visualization of data as it is being collected, as well as review of completed measurements.



The Results tab is populated once all the sweep data is collected and averaged. The data is separated into up sweeps vs. down sweeps. The top chart displays the transmission curve over frequency calculated by dividing the sample position data by the reference position data. The bottom chart calculates the phase shift difference by subtracting the reference phase data from the sample phase data.

Easy setup

Via simple on-screen menus, the parameters of a measurement run are defined.

- For the frequency profile, select the frequency band and step intervals desired, as well as the number of scans (and averaging time) desired over that range.
- Field and temperature profiles are defined via a simple, versatile sequence builder.

Automated execution

The entire measurement process can be run unattended, guided by the automated execution software.

- Temperature stabilization protocols in the software ensure sufficient settling time at each temperature step. Accurate sample temperature is recorded via a sensor mounted near the sample stage.
- Frequency is scanned over the range specified in the profile. Transmission amplitude, power, and phase data are captured along with real-time field and temperature values.
- A motorized sample stage provides automated switching between three scans taken at each temperature setting: “sample” (measuring THz signal through the sample material), “background” (a blocked path measurement to determine instrument sensitivity), and “reference” (an open path measurement to normalize transmission spectra).
- Helium level is constantly monitored to prevent quenching of the superconducting magnet.

Real-time visualization

The software processes the raw scans into normalized THz spectra.

- The charting tool allows raw and processed data to be visualized in real-time, for fast confirmation of progress.
- Coherent data includes measurements of amplitude, power and phase, from which material properties can then be derived.

Data comparison tools

With the built-in tools, spectral data can be examined in detail.

- Zoom in to areas of interest, pinpoint measured values precisely, and compare data side-by-side with previous runs.
- Cross-hair cursor provides a display of all the relevant experimental values (amplitude, power, phase, frequency, temperature, and field) for any data point selected on the chart.
- Raw, averaged, and processed measurement data can be exported as a CSV file for further comparison and offline analysis.

Ordering information

The 8500 Series system includes these components:

- Electronics console with:
  - CW-THz spectrometer
  - Model 336 cryogenic temperature controller
  - Model 625 superconducting magnet power supply
  - Liquid helium level monitor
  - Other system electronics
- PC with monitor, keyboard, and mouse
- 8500 Series system software
- Liquid helium Dewar with integral cryostat and superconducting magnet
- Cryostat insert with THz emitter and detector, and 3-position sample holder
- Dewar stand with insert lift assist
- Vacuum pump
- Liquid helium transfer line
- Sample handling kit

8500 Series THz system for material characterization

Part number	Description
8501-0000	Model 8501 THz system; includes cryostat insert with standard THz emitter and detector; NOTE: must specify 100/120 or 220/240 VAC power at time of order

8500 Series accessories

Part number	Description
85-CI-OH	Additional cryostat insert for Model 8501 with opposite helicity THz emitter and detector (for measuring spin materials)
85-CI-SH	Spare cryostat insert for Model 8501 with standard helicity THz emitter and detector

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About Lake Shore Cryotronics, Inc.

Supporting advanced research since 1968, Lake Shore is a leading innovator in measurement and control solutions for materials characterization under extreme temperature and magnetic field conditions. High-performance product solutions from Lake Shore include cryogenic temperature sensors and instrumentation, magnetic test and measurement systems, probe stations, and precision materials characterizations systems that explore the electronic and magnetic properties of next-generation materials. Lake Shore serves an international base of research customers at leading university, government, aerospace, and commercial research institutions and is supported by a global network of sales and service facilities.