

# Hall effect measurement systems 8400 series



# Hall effect measurement systems

## 8400 series

### Capable of measuring materials with very low mobilities

Many contemporary semiconductor and electronic materials are being developed for applications including photovoltaic (solar cell) and thermoelectric materials, new display technologies, organic electronics, and high power devices. The electronic properties of these materials are increasingly difficult to measure. In fact, current DC field electronic transport property measurement systems cannot measure many of these materials due to their low charge carrier mobilities and the high temperatures needed to characterize high power devices. A new measurement method is needed.

This emerging class of materials typically have mobilities below  $1 \text{ cm}^2/\text{Vs}$ . The challenge is to extract the diminishingly small Hall voltage from the background noise they produce. Lake Shore and Toyo have collaborated to develop the 8400 Series Hall effect measurement system (HMS), with an AC field Hall measurement option capable of measuring mobilities down to  $0.001 \text{ cm}^2/\text{Vs}$ . This offers a significant breakthrough in research productivity, allowing these materials to easily be measured.

The 8400 Series provides a range of Hall measurements on both van der Pauw and Hall bar geometries. The standard system is capable of DC field measurements and has a resistance range from  $0.5 \text{ m}\Omega$  to  $10 \text{ M}\Omega$ . AC field capability tops the list of options, which also include variable temperature assemblies, high and low resistance (allowing you to measure down to  $0.5 \mu\Omega$  and as high as  $200 \text{ G}\Omega$ ), and optical access. These add-ons broaden your measurement opportunities and simplify experimental processes. The 8400 Series HMS provides a robust platform to which you can add new features as your material measurement needs evolve.

*At Lake Shore, we understand your applications and your measurements. We're there for you on every step of your journey... from choosing the best system to meet your unique requirements, to getting you started in your lab and interpreting your measurement results. If you have questions at any time, we have the expertise to help you work toward a resolution.*

***Together, we can transform the research of today into the technology of tomorrow.***

### Contents

Fields of study and research.....	4
Materials and measurements.....	5
System overview.....	6-7
System application software.....	8
Optional DC Hall system with integrated cryogenic probe station.....	9
System selection guide.....	10
Specifications.....	12
Hardware/measurements.....	13
Standard sample module.....	14
Sample mounting accessories.....	15
Options.....	16-20
Application notes.....	22
Site requirements.....	22
Ordering information.....	23

### An international collaboration

Lake Shore Cryotronics, Inc. and Toyo Corporation in Japan have served the scientific community for a total of nearly a century. And for about fifty years combined, both companies have provided high performance Hall effect measurement systems to researchers in academia, national labs and industry so that they can measure the electronic and magneto-transport properties of the novel electronic materials they are developing. The AC measurement technology offered in the 8400 Series has been adapted from techniques proven in Japan for over 15 years. Lake Shore and Toyo Corporation combined the unique strengths of both company's products and jointly developed a new AC and DC field HMS with performance that is unparalleled in the industry.



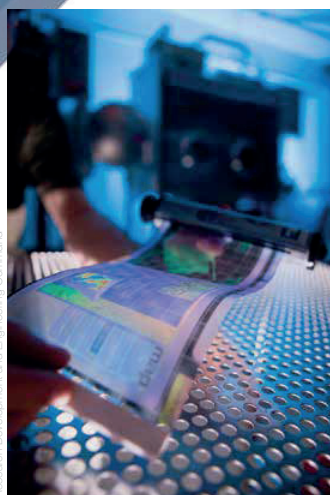
## Hall effect measurement systems 8400 series

Work with confidence knowing that the fully integrated 8400 Series HMS is backed and supported by industry leading experts in materials characterization systems

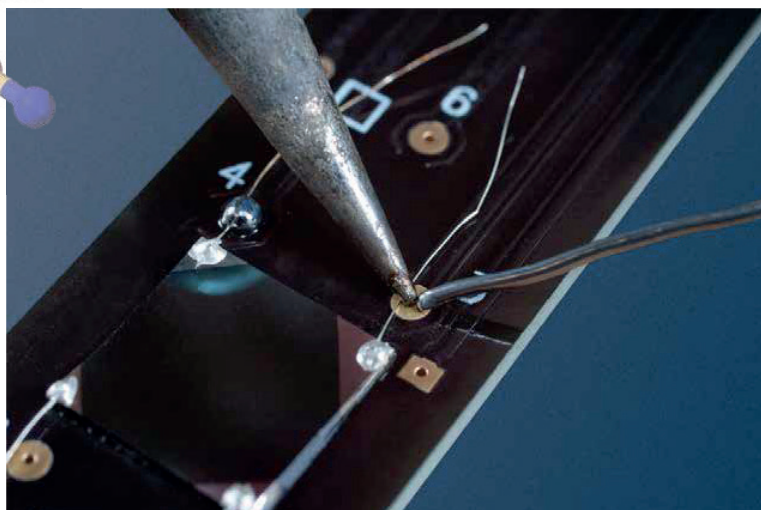
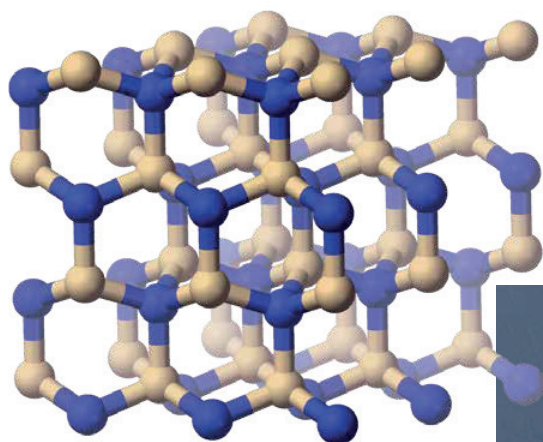


# Hall effect measurement systems

## 8400 series



Research Development and Engineering Command



*A sample is soldered onto a sample card*

### Fields of Study and Research

The 8400 Series HMS combines the best of both DC and AC field Hall measurement methodologies to facilitate the broadest range of research applications. Optional variable temperature modules and measurement platforms extend the utility of your HMS by allowing you to configure your system to meet your specific needs.

### Photovoltaic and thermoelectric applications

Photovoltaic (solar cell) and thermoelectric materials are often characterized by low mobilities. This characteristic makes them difficult or impossible to measure using traditional DC field Hall methods. The 8400 Series with AC field Hall measurement option makes it possible to easily characterize these materials.

### Organics

The AC field measurement option of the 8400 Series provides an opportunity, not easily realized until now, to reliably measure the Hall effect in low mobility organic electronics. These materials are the basis for printable and flexible electronic devices, as well as organic light emitting diodes and organic solar cell materials.

# Hall effect measurement systems

## 8400 series

### Materials

#### Solar cells

OPVs, a:Si,  $\mu\text{c-Si}$ , CdTe, CuInGaSe (CIGS)

#### Organic Electronics

OTFTs, Pentacene, Chalcogenides, OLEDs

#### Transparent Conducting Oxides

InSnO (ITO), ZnO, GaZnO, InGaZnO (IGZO)

#### III-V Semiconductors

InP, InSb, InAs, GaN, GaP, GaSb, AlN based devices, high electron mobility transistors (HEMTs) and heterojunction bipolar transistors

#### II-VI Semiconductors

CdS, CdSe, ZnS, ZnSe, ZnTe, HgCdTe

#### Elemental Semiconductors

Ge, Si on insulator devices (SOI), SiC, doped diamond  
SiGe based devices: HBTs and FETs

#### Dilute Magnetic Semiconductors

GaMnAs, MnZnO

#### Other Conducting Materials

Metal oxides  
Organic and inorganic conductors

#### High Temperature Superconductors

### Direct and Derived Measurements as a Function of Field and Temperature

#### Direct measurements

- DC/AC field  
Hall voltage
- Resistivity
- Ohmic check
- Four-wire resistance
- IV curves

#### Derived measurements

- Hall coefficient
- Hall mobility
- Magneto-resistance
- Carrier type
- Carrier density and concentration

Fully integrated hardware and software dramatically improves research productivity and yields results you can trust



# Hall effect measurement systems 8400 series

**Integrated software** — define samples and create measurement profiles from the Windows® menu-driven interface

**Ergonomic workstation** — in addition to housing all of the integrated electronics, the workstation offers a convenient tabletop and drawer to store sample cards and other convenience items

**AC field Hall measurement option** — measure Hall mobilities down to  $0.001 \text{ cm}^2/\text{Vs}$  — lower than ever possible using traditional DC field Hall measurement techniques

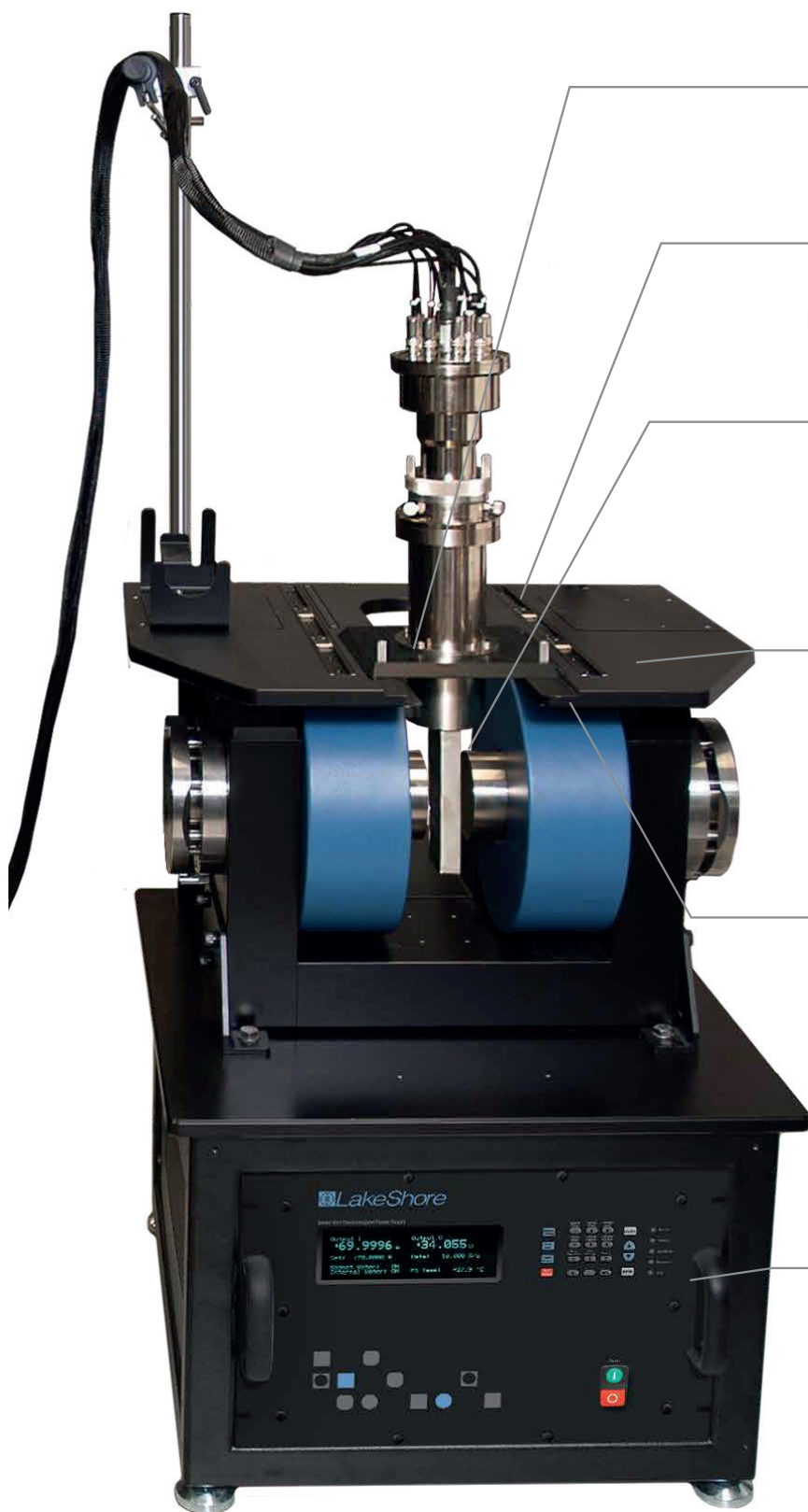
**High resistance option** — widens range to  $200 \text{ G}\Omega$

**Low resistance option** — significantly reduces resistance noise floor

Precision design  
details deliver  
superior performance  
and functionality



# Hall effect measurement systems 8400 series



**Easy setup** — for ease of sample module exchange, modules slide forward out of the magnet gap

**Storage** — while not in use, conveniently and safely store sample modules and inserts within close reach

**Settable magnet gap** — guarantees precise gap spacing, ensuring repeatability and reproducibility

**Future expansion** — the robust platform allows you to add new features as your material measurement needs change

**Temperature-dependent measurement options** — measure samples from 15 K to 1273 K with a closed cycle refrigerator and high temperature oven, or take dedicated 77 K measurements with an optional single-point LN<sub>2</sub> body

**Quiet magnet power** — linear, bipolar design generates very low electronic noise; water-cooled for silent operation

# Hall effect measurement systems 8400 series

## System application software

Along with sophisticated hardware, you get fully integrated HMS software, which is Windows® graphic menu-driven interface for system operation, data acquisition, and analysis.

The menu structure and navigation functions make the platform easy to use. The software controls magnetic field, sample temperature, and sample excitation while delivering a comprehensive collection of measurement capabilities. The sample module ID feature automatically recognizes attached hardware and configures the software accordingly.

You can define and save specifications and experimental configurations, as well as record and display data in laboratory and SI units for further analysis. Real-time feedback of processed data can be displayed in graphical and tabular format. With the software's SQL reporting capabilities, data and plots can be printed or exported directly to a Microsoft Excel® spreadsheet as well as PDF or Microsoft Word® documents.

## Performs both van der Pauw and Hall bar measurements

To measure sample sheet resistivity, the 8400 Series supports both van der Pauw and Hall bar measurement geometries. The Hall bar method uses one dimensional current flow approximation. You can also measure samples with gated Hall bars to account for gate bias—important for measurement of device-level material. Measure Hall density in a channel as a function of gate voltage and, as you change the gate voltage, create more or fewer carriers.

The system's program mode makes it easy to conduct gated Hall bar measurements. You can, for instance, set up a loop with varying temperatures and gate voltages and easily perform a Hall measurement using the software.

## Toolbox with resistance utility

Through the software's toolbox, you have complete control over the measurement parameters and can change them in real time. When combined with environmental settings like temperature, experimental parameters can be quickly determined.

In addition to standard Hall measurements, the software's toolbox enables you to perform resistance measurements at the start of an experiment. This is a very useful tool when you need to do a quick and initial check of a sample, to determine usable current, for instance. Once that's known, you can then proceed with experimentation to determine further integrity of the sample.

## Advanced programming functions

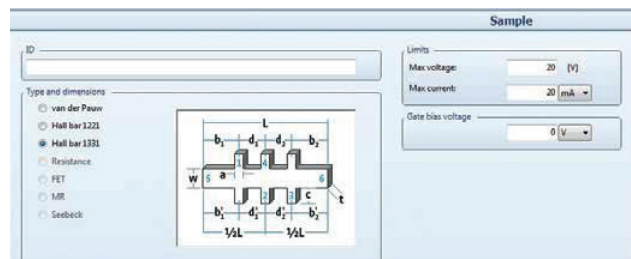
The system easily supports variable temperature measurements, enabling you to start and end at your convenience. But the software also enables you to perform time loops, so you can set the system up to repeat Hall measurements according to a preset schedule for unattended experiments throughout the day. You can also program it to insert a resistance measurement into a sequence of Hall measurements.

Commands enable you to "Go to Temperature," "Go to Field," and "Go to GBV" (gate bias voltage). You can also program it to "Wait," that is, start a measurement then have the system pause and settle before continuing. This way, you have the flexibility to automate and customize your experiment procedure.



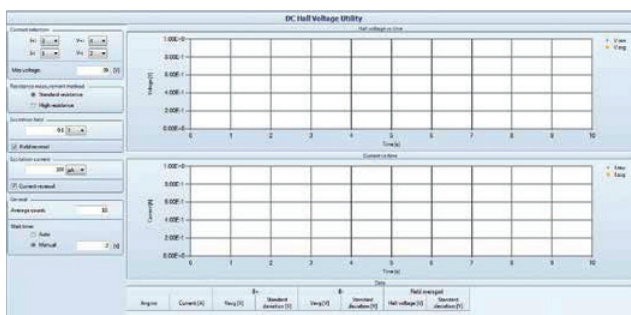
## Hall measurement setup

Hall measurement setup is used to define the three basic steps in a Hall measurement. These steps include checking the quality of your sample contacts, measuring the resistivity of your sample, and measuring the Hall voltage.



## Define a sample

Define your sample geometry and contact arrangement, as well as the maximum voltage and current applied to your sample. Sample definition parameters include thickness and sample dimensions. You can assign sample identifications and add user comments. An ASTM compliance check can also be performed.



## Toolbox

The toolbox includes utilities that allow you to determine measurement parameters, collect and log data, and display the data on screen as a chart recorder. You have complete control over the measurement parameters and can change them in real-time. When combined with environmental settings like temperature, experimental parameters can be quickly determined.

See larger software screen shots at [www.lakeshore.com](http://www.lakeshore.com)

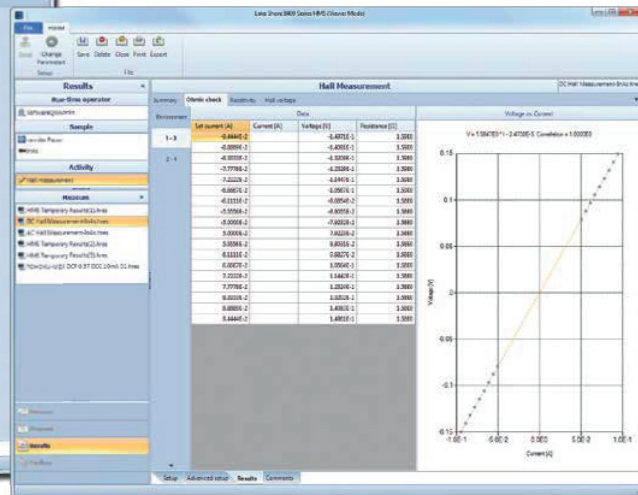


# Hall effect measurement systems

## 8400 series



Example of a DC measurement results screen



Example of an ohmic check

### An unmatched suite of capabilities provided by the 8400 Series software

#### Sample types

- van der Pauw
- Hall bar 1221 and 1331

#### Direct measurements

- DC/AC field Hall voltage
- Resistivity
- Ohmic check
- Four-wire resistance
- IV curves

#### Derived (calculated) measurements

- Hall coefficient
- Hall mobility
- Magneto-resistance
- Carrier type
- Carrier density

#### User-defined programs

- Measurement loops for:
  - Variable temperature
  - Variable gate bias voltage
  - Time (repeatability)
  - Variable field
- Measurements for:
  - DC/AC field Hall voltage
  - Resistivity
  - Ohmic check
  - Four-wire resistance
  - IV curves
- Environmental control for:
  - Go to temperature
  - Go to field
  - Go to gate bias voltage
  - Wait

#### Field control

- Open-loop DC/AC field control
- Closed-loop DC field control

#### Temperature control

- Closed-loop

#### Toolbox

- Chart recorder/logger utilities
  - DC/AC field voltage vs. time
  - Temperature vs. time
  - Four-wire resistance vs. time
- DC/AC field calibrations (for open-loop field control)

#### Reports and exports

- Printing and exporting for Excel®, PDF, and Word®
- Export for QMSA® See below

### Plus, use the software with our optional QMSA software for advanced multi-carrier analysis

The system can also be used with our Quantitative Mobility Spectrum Analysis (QMSA) software for advanced multi-carrier analysis. This way, you can acquire detailed transport property information about the individual carriers, going beyond what's possible with single field Hall measurements. It's particularly useful for resolving individual carrier mobilities and densities in quantum wells and HEMTs. This software automatically segregates the mobility spectrum for each carrier species (electrons and holes) that comprise a multilayer or multi-carrier material. Input parameters for the software analysis include Hall coefficient, resistivity, and magnetic field. Output parameters include conductivity spectra as a function of mobility, number of carriers (peaks in the mobility graph), density, mobility, and sign of each carrier.

# Hall effect measurement systems

## 8400 series

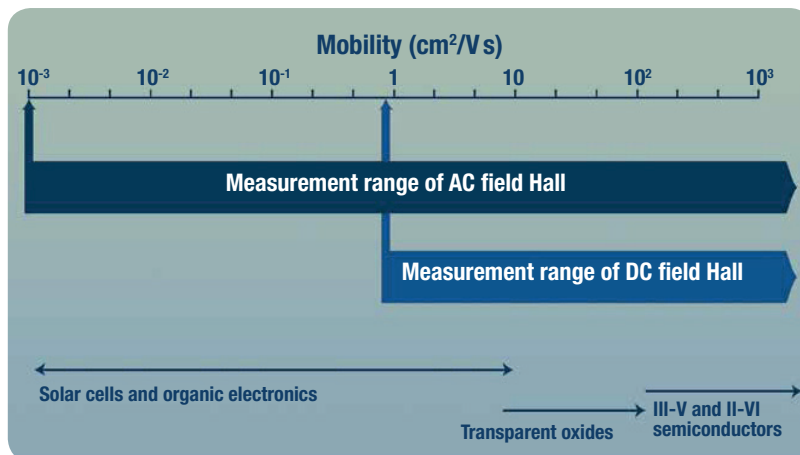
# Select system options to fit your applications

A variety of measurement options are available to configure your system for best performance with your samples and their characteristic properties. Parameters to consider when selecting your configuration:

## 1 Mobility range

Mobility is one of the most important and commonly derived electronic transport properties measured in an HMS, as it is often directly related to the material performance in an electronic device. The type of magnet field, whether DC or AC, along with the integration of precision electronics and software determines the mobility range you will be able to measure.

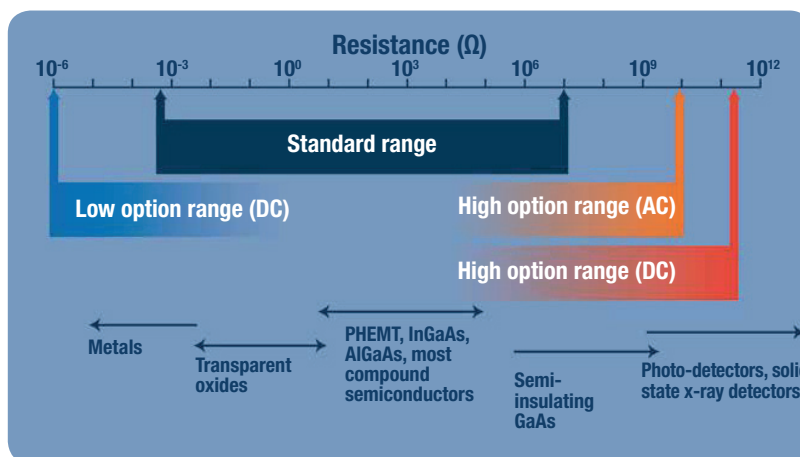
The 8400 Series combines the best of both DC and AC field measurement capabilities, which means it has the widest mobility range of any commercially available HMS. The system comes standard equipped with the traditional DC field method, capable of measuring mobilities down to  $1 \text{ cm}^2/\text{Vs}$ . While the DC field method can measure a wide range of materials, it is not capable of measuring the emerging class of materials characterized by very low mobilities. For these applications, the unique AC field measurement option extends your mobility measurements down to  $0.001 \text{ cm}^2/\text{Vs}$ .



## 2 Resistance range

Along with Hall mobility and other sample parameters, resistance measurements are one of the fundamental building blocks that define the capabilities and performance specifications of your 8400 Series HMS. In order to enable measurement of the broadest range of materials, it is critical that your system be capable of measuring a very wide range of resistances.

Like the mobility range, the 8400 Series offers the widest possible resistance range. The system takes great care in controlling low currents and small voltages present in electron transport systems. While the standard system is capable of measuring resistances from  $0.5 \text{ m}\Omega$  to  $10 \text{ M}\Omega$ , resistance measurement options allow you to measure resistances down to  $0.5 \mu\Omega$  and as high as  $200 \text{ G}\Omega$  when working in DC fields. The high end is limited to  $8 \text{ G}\Omega$  when working in AC field. This wide resistance range ensures you can study the broadest range of materials.



# Hall effect measurement systems

## 8400 series

### 3 Magnet configuration

The magnet is one of the key components of any HMS. It determines, in part, what kind of measurements you can perform. The standard magnet configuration of the 8400 Series is optimized to maximize field strength and ensure uniformity of the field over your sample area. Optional pole cap diameters are available to configure the field and uniformity to your specific requirements. The magnet can also be configured for axial optical access to accommodate lasers and other optical devices.

The unique magnet pole adjustment feature of the 8400 Series takes the guesswork out of setting a consistently repeatable pole gap. It is equipped with spacers that allow you to adjust the gap within a defined set of distances without the use of any measurement tools. You can be confident in your repeatability when changing between pole gaps.

The Model 8404 has a 4 in magnet with a maximum field of 1.67 T, while the Model 8407 has a 7 in magnet with a maximum field of 2.25 T.

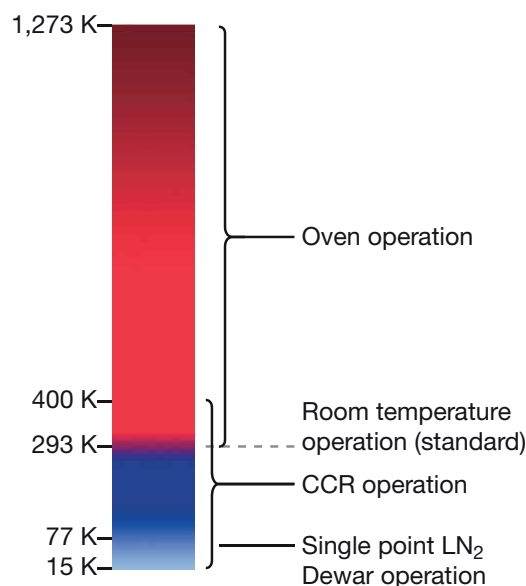


*Easily adjust pole gaps to precise, repeatable widths*

### 4 Temperature range

While room temperature measurements are sufficient in many cases, transport properties can change significantly as temperature varies. Measuring a sample at variable temperatures allows carriers to be identified by their excitation energies and provides clues to the dominating scattering mechanism. For materials intended for applications requiring variable temperature ranges, testing them at these temperatures can determine their suitability. The 8400 Series is designed to control temperature and magnetic flux to produce accurate, reliable Hall effect and electronic transport measurements.

The system is available with a variety of temperature options to further extend its functionality. A single point LN<sub>2</sub> body is available if you only need to measure samples at room temperature and at 77 K. A closed cycle refrigerator (CCR) is available for taking measurements from 15 K to 400 K, and an oven extends your temperature measurement capabilities from room temperature to 1,273 K. The 8400 Series is field configurable, so while any of these temperature options can be ordered with a system, they can also be added in the field at any time.



### 5 Additional measurement options

The 8400 Series options are modular, allowing you to create the exact system you need. Additional measurement options and hardware options can be configured at the time of order, or you can upgrade in the field at any time. This flexibility preserves your investment, allowing you to keep up with the rapidly changing landscape of characterization measurements. Additional future upgrades are also in development.

# Hall effect measurement systems

## 8400 series

### 8400 Series specifications

	8404		8407	
	DC	AC	DC	AC
<b>Measurement specifications</b>				
Mobility	1 to $1 \times 10^6$ cm <sup>2</sup> /Vs		1 to $1 \times 10^6$ cm <sup>2</sup> /Vs	
Carrier concentration density	$8 \times 10^2$ to $8 \times 10^{23}$ cm <sup>-3</sup>		$8 \times 10^2$ to $8 \times 10^{23}$ cm <sup>-3</sup>	
Resistivity	$1 \times 10^{-5}$ to $1 \times 10^5$ Ω-cm		$1 \times 10^{-5}$ to $1 \times 10^5$ Ω-cm	
<b>Electronic specifications*</b>				
Standard resistance range	±0.5% rdg ±0.5% range: VdP/Hall bar minimum: 0.5 mΩ Maximum: 10 MΩ ±0.075% rdg ±0.05% range: Maximum: 5 MΩ	VdP/Hall bar: 0.5 mΩ to 10 MΩ 300 nV RMS noise floor for sample resistances up to 100 Ω; 500 nV RMS over most of the recommended resistance range above 100 Ω	±0.5% rdg ±0.5% range: VdP/Hall bar minimum: 0.5 mΩ Maximum: 10 MΩ ±0.075% rdg ±0.05% range: Maximum: 5 MΩ	VdP/Hall bar: 0.5 mΩ to 10 MΩ 300 nV RMS noise floor for sample resistances up to 100 Ω; 500 nV RMS over most of the recommended resistance range above 100 Ω
Optional high resistance configuration	±0.25% rdg: VdP/Hall bar minimum: 10 kΩ Maximum: 50 GΩ ±1.5% rdg: Maximum: 100 GΩ ±5% rdg: Maximum: 200 GΩ	VdP/Hall bar: 10 kΩ to 8 GΩ <1250 nV RMS noise floor for sample resistances up to 10 MΩ	±0.25% rdg: VdP/Hall bar minimum: 10 kΩ Maximum: 50 GΩ ±1.5% rdg: Maximum: 100 GΩ ±5% rdg: Maximum: 200 GΩ	VdP/Hall bar: 10 kΩ to 8 GΩ <1250 nV RMS noise floor for sample resistances up to 10 MΩ
Optional low resistance configuration	For resistance <0.1 Ω, voltage noise floor of the low resistance mode is 5 nV; voltage noise floor for standard resistance mode is 150 nV; noise floor is independent of current used in the measurement	NA	For resistance <0.1 Ω, voltage noise floor of the low resistance mode is 5 nV; voltage noise floor for standard resistance mode is 150 nV; noise floor is independent of current used in the measurement	NA
Current	±1 pA to ±100 mA		±1 pA to ±100 mA	
Compliance voltage	100 V		100 V	
<b>Environment</b>				
Room temperature field** (25 mm [1 in] airgap)	1.67 T with standard 50 mm (2 in) pole caps 1.35 T with optional 100 mm (4 in) pole caps	1.18 T with standard 50 mm (2 in) pole caps 0.95 T with optional 100 mm (4 in) pole caps	2.10 T with standard 100 mm (4 in) pole caps 2.25 T with optional 50 mm (2 in) pole caps	1.20 T with standard 100 mm (4 in) pole caps 1.31 T with optional 50 mm (2 in) pole caps
Variable temperature field** (50 mm [2 in] airgap)	0.89 T with standard 50 mm (2 in) pole caps 0.88 T with optional 100 mm (4 in) pole caps	0.63 T with standard 50 mm (2 in) pole caps 0.62 T with optional 100 mm (4 in) pole caps	1.45 T with standard 100 mm (4 in) pole caps	0.69 T with standard 100 mm (4 in) pole caps
Optional AC field frequency ranges	NA	0.05 and 0.1 Hz	NA	0.05 and 0.1 Hz
Sample size	Up to 10 mm × 10 mm × 3 mm standard, up to 50 mm diameter × 3 mm optional		Up to 10 mm × 10 mm × 3 mm standard, up to 50 mm diameter × 3 mm optional	
Standard module temperature	Room temperature		Room temperature	
Single point LN <sub>2</sub> module temperature	77 K point		77 K point	
CCR module temperature	15 K to 400 K with standard CCR, 15 K to 350 K with optical CCR		15 K to 400 K with standard CCR, 15 K to 350 K with optical CCR	
Oven module temperature	Room temperature to 1,273 K; at 773 K and ±1% rdg: maximum = 1 MΩ; at 1,273 K and ±1% rdg: maximum = 1 kΩ		Room temperature to 1,273 K; at 773 K and ±1% rdg: maximum = 1 MΩ; at 1,273 K and ±1% rdg: maximum = 1 kΩ	
<b>Magnet</b>				
Pole diameter	4 in		7 in	
Pole cap diameter	50 mm (2 in) standard, 100 mm (4 in) optional		100 mm (4 in) standard, 50 mm (2 in) optional	
Air gap (room temperature)	25 mm (1 in)		25 mm (1 in)	
Air gap (variable temperature options)	50 mm (2 in)		50 mm (2 in)	
Field uniformity	25 mm air gap, 50 mm pole caps: ±0.35% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> ) 25 mm air gap, 100 mm pole caps: ±0.05% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> ) 50 mm air gap, 100 mm pole caps: ±0.15% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> )		25 mm air gap, 50 mm pole caps: ±0.35% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> ) 25 mm air gap, 100 mm pole caps: ±0.05% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> ) 50 mm air gap, 100 mm pole caps: ±0.15% over 1 cm <sup>3</sup> (0.4 in <sup>3</sup> )	
Cooling (magnet and power supply)	7.6 L/min (2 gal/min), 10.3 L/min (2.7 gal/min) with CCR option		19 L/min (5 gal/min), 23 L/min (6 gal/min) with CCR option	
<b>3-phase bipolar magnet power supply</b>				
Maximum output	±35 V ±70 A (2.5 kW)		±75 V ±135 A (9.1 kW)	
<b>Utilities</b>				
Total system cooling water power dissipation (50 or 60 Hz) — contact Lake Shore for available recirculating chillers	4.25 kW; 7.45 kW with optional CCR		13.4 kW; 16.6 kW with optional CCR	

\*Probe contact resistance may vary with sample

\*\*All field values are nominal and can vary ±1%.

# Hall effect measurement systems

## 8400 series

### 8400 Series hardware

	Standard room temperature	TEMPERATURE OPTIONS		
		Model 84015 77 K LN <sub>2</sub> body option	Model 84016 CCR option	Model 84017 oven option
<b>Standard insert</b>	Standard with system	Used together		
<b>Standard body</b>	Standard with system			
<b>Optical access body</b>	84006, requires 84060		84016-O, requires 84060	
<b>Sample rotation</b>	84010	84010	Standard with 84016	Standard with 84017
<b>Sample mounting kit</b> Five 10 mm solder cards, one with PT sensor, wire and foil	Standard with system	840930		
<b>Sample card kit</b> Five 10 mm solder cards	840931	840931		
<b>Sample card kit</b> Five 10 mm solder cards with PT sensors	840932	840932		
<b>10 mm probe pin sample card</b> with PT sensor	840910	840910		
<b>50 mm probe pin sample card</b> with PT sensor	840911			
<b>Temperature monitoring</b>	841-STM or 840-VTA*	841-STM or 840-VTA*		
<b>Variable temperature</b>			840-VTA	840-VTA
<b>Pump</b>	Not required	Not required	TPS-FRG or equivalent	E2M or equivalent (or TPS-FRG)
<b>Chiller</b>	See <a href="http://www.lakeshore.com">www.lakeshore.com</a>	Not applicable	See <a href="http://www.lakeshore.com">www.lakeshore.com</a>	Not applicable
<b>Floor mount hardware</b>	840950	Not applicable	Not applicable	Not applicable
<b>High uniformity</b>	8404: EM4-4PB 8407: Standard	8404: EM4-4PB 8407: Standard	8404: EM4-4PB 8407: Standard	8404: EM4-4PB 8407: Standard

\*If you do not order a variable temperature option but might want to add one to your HMS at a later time, 840-VTA or 841-STM should be chosen (841-STM can be upgraded to the Model 840-VTA)

### 8400 Series measurements

	Standard DC	Model 84030 AC option
<b>VdP and Hall bar</b>	Standard with system	Can use with AC
<b>High resistance</b>	84031	Can use with AC*
<b>Gate bias</b>	84032	Can use with AC
<b>Low resistance</b>	84033	

\*Limits maximum resistance to 8 GΩ

- = Included
- = Option available (model number)
- = Option required (model number)
- = Not compatible



# Hall effect measurement systems

## 8400 series

### The standard module

#### Standard insert

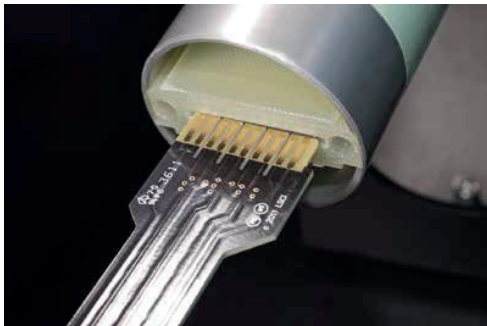
The standard insert provides physical mounting and electrical connection to the sample card. The standard insert is compatible with the standard light tight body and optical access body for operation at room temperature and the optional Model 84015 single point LN<sub>2</sub> body for operation near 77 K. It includes eight triaxial connectors for guarded signals to the sample for resistance measurements up to 200 G) depending on your system's configuration. Its circular connector contains temperature monitor leads, insert identification, and safety interlock. The standard insert is compatible with a variety of standard and optional sample cards depending on whether it is used with the light tight body or single point LN<sub>2</sub> option.

#### Light tight body

The light tight body serves as a support for the standard insert, allows for consistent sample alignment, and provides a light tight environment for samples that are light sensitive.



*The triaxial cables being attached to the standard insert*



*Sliding a sample card into the standard insert*



# Hall effect measurement systems

## 8400 series

### Sample mounting accessories

A variety of sample cards are available for the standard insert to facilitate sample mounting and storage as well as expedite sample exchange. Standard plug-in sample cards allow mounting of up to a 10 mm sample. An optional card can accommodate up to a 50 mm sample. The 10 mm sample cards are available in prober pin or solder pad style while the 50 mm sample card is available in prober pin style only. The prober pin style sample cards allow you to mount your samples without requiring contact pad soldering.

Even subtle changes in room temperature can sometimes influence your measurement results. As such, our sample cards are available with an integrated platinum RTD to ensure you get the most information out of your measurement. When used in combination with the temperature monitor or control options, you can log and record small fluctuations in sample temperature, helping you gain the most knowledge of the materials you are studying.

### Available sample cards and kits include:

**340910:** 10 mm prober pin sample card with PT sensor for use with standard insert; compatible with 840-VTA and 841-STM

**340911:** 50 mm prober pin sample card kit for use with standard insert; includes 50 mm prober pin sample card with PT sensor and required guide stem; compatible with 840-VTA and 841-STM. NOTE: Not compatible with variable temperature (84015, 84016, 84017) or sample rotation (84010) options.

**340930:** Sample mounting kit for use with standard insert: includes (4) 10 mm solder pad sample cards, (1) 10 mm solder pad sample card with PT sensor, copper wire, and indium foil; (1) included with system purchase; compatible with 840-VTA and 841-STM

**340931:** Sample card kit for use with standard insert: includes (5) 10 mm solder pad sample cards

**340932:** Sample card kit with PT sensors for use with standard insert: includes (5) 10 mm solder pad sample cards with PT sensors; compatible with 840-VTA and 841-STM

10 mm solder pad sample card



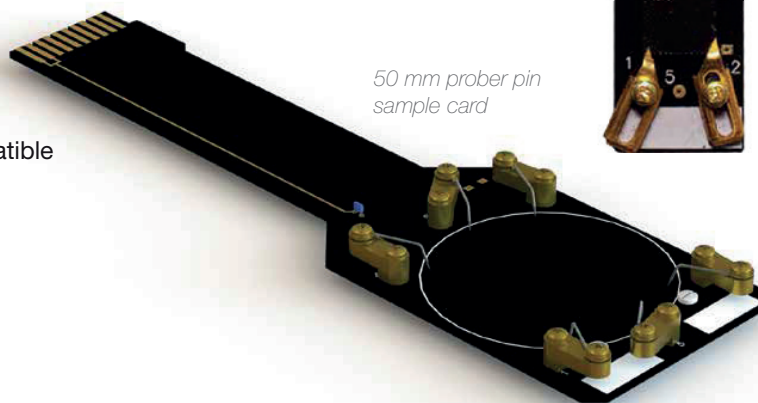
10 mm prober pin sample card



Field calibration card (included with the system)



50 mm prober pin sample card



# Hall effect measurement systems

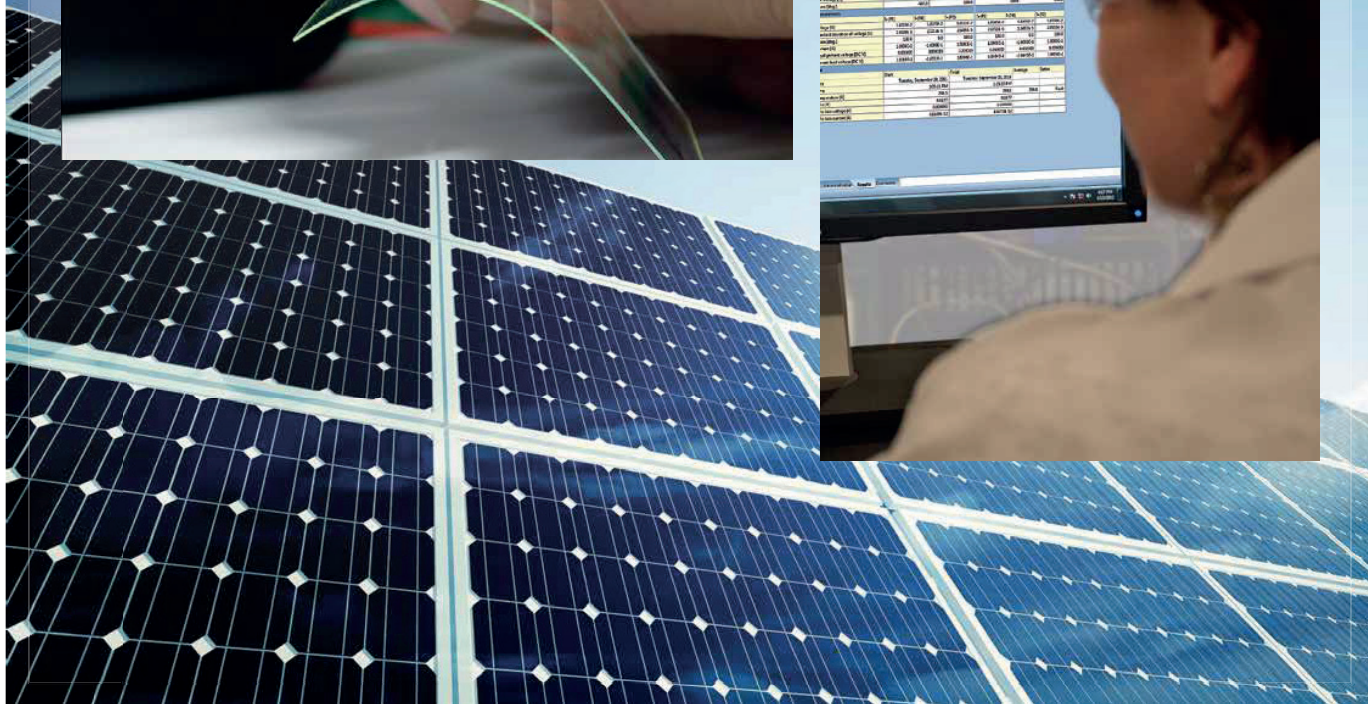
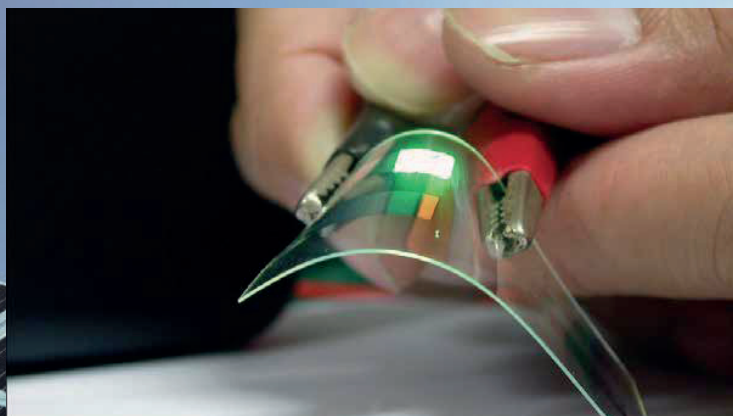
## 8400 series

### Sample measurement options

#### 84030 AC Field Hall

The traditional DC field Hall measurement methodology, while sufficient for studying a wide range of materials, is limited to measuring Hall mobilities down to about  $1 \text{ cm}^2/\text{Vs}$ . This makes it impossible to measure materials that are characterized by very low mobilities such as photovoltaic, thermoelectric, and organic electronic materials. The exclusive 84030 HMS AC field measurement option breaks through the barriers of traditional DC field Hall measurements. It extends your Hall mobility measurement capabilities down to  $0.001 \text{ cm}^2/\text{Vs}$ , allowing you to measure these low mobility materials with far greater resolution.

The AC field Hall measurement option is compatible with the Model 84031 high resistance measurement option, as well as all temperature options (with some reduced operation). It is not compatible with the Model 84033 low resistance measurement option.





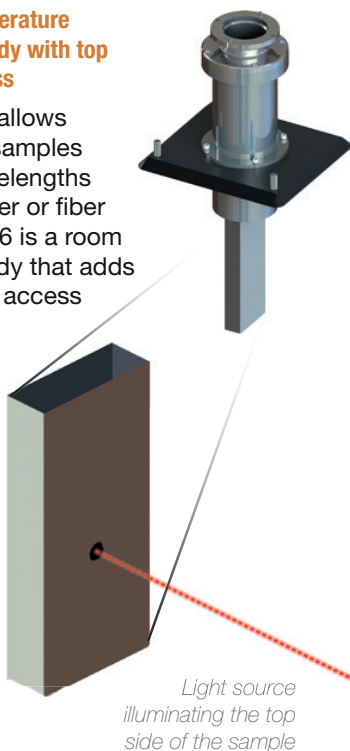
# Hall effect measurement systems

## 8400 series

### 84006 room temperature optical access body with top side optical access

Optical access allows you to expose samples to different wavelengths of light via a laser or fiber optic. The 84006 is a room temperature body that adds top side optical access capability to the standard HMS sample insert.

The 84060 sample top side optical access kit is required for operation and must be ordered separately (see page 20).



### 84031 high resistance

Materials such as semi-insulating GaAs, photo-detectors and solid state x-ray detectors are characterized by very high resistances and can be difficult to measure in a traditional Hall effect measurement system. The high resistance option extends the resistance measurement capabilities of your HMS up to 200 G $\Omega$  for DC measurements and 8 G $\Omega$  for AC measurements. When this option is added to your system, electrometer grade buffers are used to minimize loading, and the guard in the signal leads minimizes the effect of current leakage. The challenges in measuring high resistance samples in a Hall effect measurement system are no match when you add the high resistance measurement option to your configuration.

### 84032 gate bias

Adding a gate terminal to materials increases the flexibility of the Hall measurement. For instance, a gate voltage can be used to control the carrier density of a material. With this option, the gate bias voltage can be set to the user-determined value. The standard AC or DC Hall measurement and resistivity measurement are then available.

### 84033 low resistance

Metals, superconductors, and certain other materials are characterized by low resistances and can sometimes be difficult to measure in a Hall measurement system. This is because below about 1  $\Omega$ , the voltage across the sample becomes too small to measure reliably. In theory, it may seem practical to simply increase the current in an attempt to increase the sample voltage, but this is rarely a viable option. Doing so may cause self-heating and could damage your sample. While current reversal and measurement averaging can combat these effects, it can take a very long time to achieve the desired resolution. So this method can be both inefficient and unreliable.

The best solution is the 84033 low resistance measurement option. It extends the low resistance measurement capabilities of DC field Hall measurements, allowing you to measure low resistance samples or thermoelectric materials in your HMS with confidence. When measuring certain metals, for example, it reduces the resistance noise floor of DC measurements from 100 nV to 3 nV (from 1  $\mu\Omega$  to 0.03  $\mu\Omega$  at 100 mA).

The 84033 option can also help with the quality and speed of certain *standard* resistance measurements. For instance, the low resistance operation narrows the frequency bandwidth of the Hall measurement, which lowers the voltage noise (to 3 nV) for a better signal/noise ratio. As a result, DC field Hall measurements of standard resistance materials can be performed up to 2x faster and with greater measurement stability.

This option can be added to the system in the field at any time (but it is not usable at the same time as the 84030 AC field measurement option).

### 84010 sample rotation

The sample rotation option adds 0° to 360° manual sample rotation to your HMS. It is available as an option with either the standard tight tight body or the 84015 single point LN<sub>2</sub> body. (It comes standard with the 84016 CCR and the 84017 oven.) Sample rotation is usable with the 10 mm sized sample cards. It is not compatible with 50 mm cards.



# Hall effect measurement systems

## 8400 series

### Temperature options



*Uses standard insert with interchangeable sample cards*

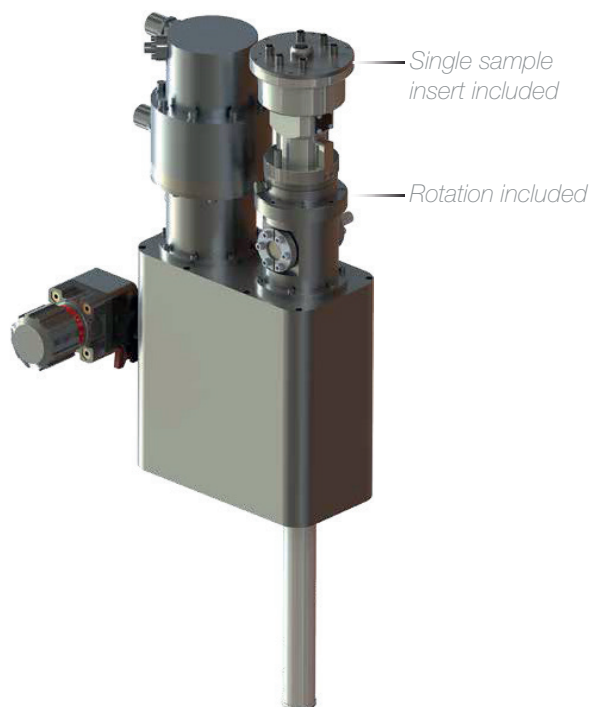
#### 84015 single point LN<sub>2</sub> body

The single point LN<sub>2</sub> body combined with the standard insert allows you to take a measurement at a fixed temperature of 77 K in addition to room temperature. You can then determine if the temperature behavior of the resistivity and Hall coefficient of your samples is as expected without having to add a full variable temperature assembly. Simply fill the sample environment with liquid nitrogen, and proceed with your measurements. Operation is both easy and efficient. The 84010 sample rotation option is available for applications requiring sample rotation (see page 17).

While not required, if you would like to monitor the temperature of your samples, you may choose to purchase one of our sample temperature monitoring or variable temperature control options separately. The optional Lake Shore sample cards with an integrated platinum RTD are required to monitor temperature (see page 15).



*Comes with custom funnel and plug*



#### 84016 closed cycle refrigerator (CCR)

CCRs provide a variable temperature cryogenic environment by cooling helium exchange gas. No liquid cryogenics are required so ongoing operating costs are minimal. In order to optimize efficiency and throughput, your sample is surrounded by helium gas at a pressure slightly above atmosphere, allowing samples to be exchanged without breaking vacuum or warming the CCR. Pump out of the vacuum jacket to 100 Pa (0.1 Torr) is required prior to cool down.



*The CCR single sample insert has a sapphire pad and solder posts*

#### 84016-0 optical access CCR

The CCR is also available in a sample top side optical access version: 84016-O. When combined with the 84060 sample top side optical access kit (see page 20), the optical access CCR allows you to study the effects that various wavelengths of light may have on your material samples at cryogenic temperatures.

# Hall effect measurement systems

## 8400 series



### 84017 oven

The Hall system oven allows you to study the effects on your material as you heat your sample to as hot as 1,273 K\*. It is rigidly mounted to the electromagnet frame and positioned between the electromagnet pole faces. The oven insert is placed into the top of the oven body and attaches via captive thumb screws. Because the oven body and oven insert form a vacuum-tight enclosure, sample heating can be done under an inert gas atmosphere—argon is recommended. The oven insert has a temperature sensor mounted near the sample location to ensure a reliable temperature measurement feedback loop.

\*At 773 K and  $\pm 1\%$  rdg: maximum = 1 M $\Omega$ ; at 1,273 K and  $\pm 1\%$  rdg: maximum = 1 k $\Omega$



The oven single sample insert has 4 probe pins

### 840-VTA variable temperature control

The 840-VTA is used to support the operation of the optional CCR or oven. It includes a Lake Shore Model 336 temperature controller and a gas handler to control the sample space gas/vacuum environment during measurements. It can also be used to monitor your sample temperature in the single point LN<sub>2</sub> body, as well as monitor subtle fluctuations in room temperature. The 840-VTA requires a sample card with integrated platinum RTD if monitoring temperatures in the 84015 or at RT (see page 15).



Gas handler



### 841-STM sample temperature monitoring

Conveniently monitor the temperature of your samples through the standard insert with a Lake Shore Model 336 temperature controller. The 841-STM can be upgraded to the 840-VTA at any time, so if you feel you may at some point add variable temperature capability to your HMS, this option should be chosen. The 841-STM requires a sample card with integrated platinum RTD if monitoring temperatures in the 84015 or at RT (see page 15).

### TPS-FRG compact turbo pumping system with gauge



The pumping system is used to pump out the vacuum jacket and transfer line spaces. It can also be used in place of a mechanical fore vacuum pump with the 84017 oven.

# Field-upgradable options ensure you keep up with demanding, ever changing research requirements

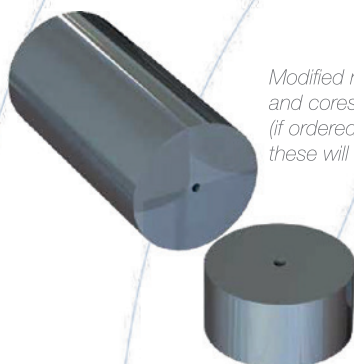
# Hall effect measurement systems

## 8400 series

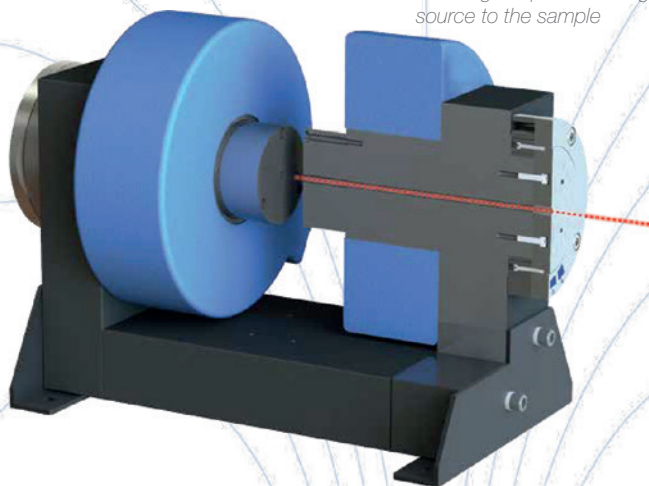
### Magnet field options

#### 84060 sample top side optical access kit

Used in combination with the 84006 room temperature optical access body or 84016-O CCR with optical access, this option includes core pole cap modifications for 6.35 mm (0.25 in) optical access to the top side of the sample (in the magnetic field direction).



*Modified magnet pole caps and cores for optical access (if ordered with the system, these will already be installed)*



*Showing the path of the light source to the sample*

#### Pole cap choices for higher uniformity or higher field density

With the Model 8404 system, you receive 51 mm (2 in) face diameter pole caps for the system's 4 in electromagnet. These tapered caps yield higher fields but lower field uniformity. However, as an option, you can order cylindrical 102 mm (4 in) face diameter pole caps for the Model 8404 by specifying the EM4-4PB field option. Because they feature a larger pole cap face diameter, these caps ensure higher uniformity over the full surface of your sample (while sacrificing a small amount of magnetic field density).

The Model 8407 system includes cylindrical 102 mm (4 in) face diameter pole caps as standard for higher field uniformity over the full surface. Higher uniformity is required when using the closed loop field control capability that is standard in the Model 8407 (optional in the Model 8404) and also provides better measurement results when using any temperature options. If you value magnet strength over uniformity and want to maximize the larger field of the 7 in electromagnet, you can optionally order 51 mm (2 in) face diameter pole caps (EM7-2P). These focus the magnetic flux from the pole core to the face.

Because the pole caps are bolted on, they can easily be exchanged for different pole face diameters at any time.

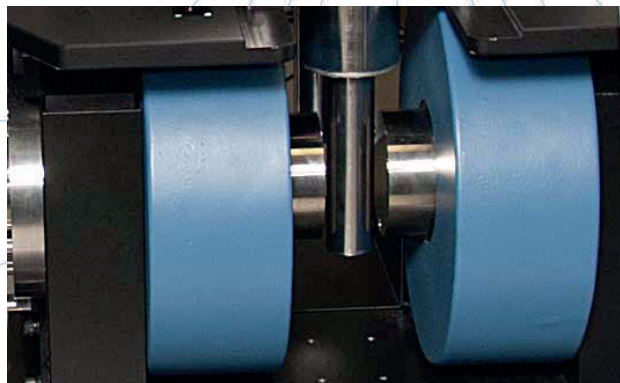


*The 51 mm (2 in) EM7-2P pole cap*



*The 102 mm (4 in) EM4-4PB pole cap*

*Model 8404 system shown with the optional 102 mm (4 in) EM4-4PB pole caps installed*



# Hall effect measurement systems 8400 series

## Also available:

### An 8400 system with an integrated cryogenic probe station

#### Model 8425 DC Hall system with CRX-VF probe station

- A complete Hall effect measurement system using device probing under vacuum in a probe station
- Enables non-destructive Hall measurements of wafer-scale materials in a controlled environment
- DC fields to 2 T, resistances from 0.5 mΩ to 100 GΩ
- Vary temperatures from 10 K to 400 K using closed-cycle refrigerator—no cryogen required
- Up to six ultra-stable probe arms (four arms are provided on the station as standard)
- Includes patented CVT probes for continuous measurement over a wide temperature range

The Model 8425 combines the advanced Hall measurement capabilities of our 8400 Series with the flexibility and convenience of our CRX-VF probe station.

The ability to probe full or partial wafers up to 51 mm (2 in) in diameter eliminates dicing of fabricated wafers, as typically required with a Hall system. And because the sample is under vacuum (a function not available on standard Hall systems), it's an ideal measurement platform for materials susceptible to degradation caused by atmospheric exposure or that may require initial baking to drive out moisture.

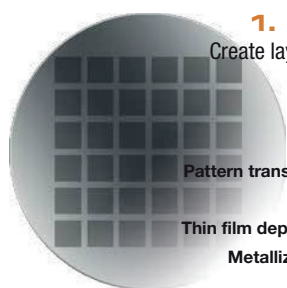
Probing also offers the flexibility to measure more Hall structures and to use smaller devices. Test structures can be as small as a millimeter in size.



*In addition to the 8400 Series software, the system includes all the hardware necessary for probe station-based measurements: a vertical field superconducting magnet, a closed-cycle refrigerator, a Model 336 temperature controller, a vacuum turbopump, a separate monitor (not shown) for examining magnified samples, and more. For a complete list of contents, see [www.lakeshore.com](http://www.lakeshore.com).*

## Use when fabricating new device designs

The system is also ideal for probing multiple structures under identical conditions and enables you to repeat measurements of Hall structures at progressive steps in the formation of devices co-located on the wafer. For instance, in applications where you have patterned a variety of different test structures on the same wafer, you can shift the probes from measuring one Hall structure to the next without affecting the overall sample environment.



### 1. FABRICATE

Create layers of your device design, using techniques such as:

- Oxidation
- Lithography
- Pattern transfer-etching
- Doping
- Thin film deposition
- Metallization

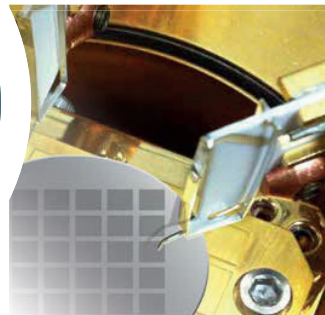
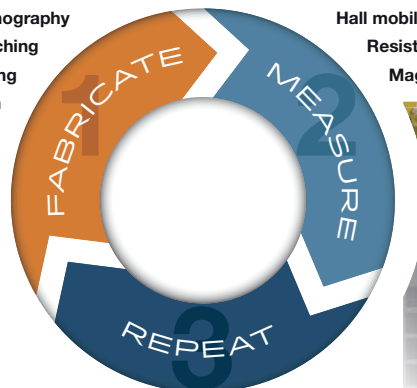
### 3. REPEAT

Continue this process until you achieve your desired results

### 2. MEASURE

Load your wafer into the Model 8425 and take many measurements at multiple locations, including:

- Hall voltage · Hall coefficient
- Hall mobility · IV curve
- Resistance · Magnetoresistance
- Magnetotransport · AHE



# Hall effect measurement systems 8400 series



## Use us as a resource!

Our experts can advise you on the optimal system for your applications. To demonstrate the performance of our HMS and to ensure the proper configuration is selected, we can measure one of your actual samples at no charge to you. Get us involved early and benefit from our many years of experience.

Also see our HMS related application notes available for download at [www.lakeshore.com](http://www.lakeshore.com):

- An Introduction to AC Field Hall Effect Measurements
- Hall Measurements on Low Mobility Materials and High Resistivity Materials
- Extraction of Low Mobility, Low Conductivity Carriers from Field Dependent Hall Data
- Anomalous Hall Effect Magnetometry Studies of Magnetization Processes of Thin Films
- Compound Semiconductors: Electronic Transport Characterization of HEMT Structures
- Measurement of the Magnetic Properties of Double Layered Perpendicular Magnetic Recording Media Using an Anomalous Hall Effect Magnetometer
- Low Resistance Option: Hall Measurements of Metals and Measurement of Resistance

## Base system site requirements

### Power

Instrumentation and computer requires one standard single-phase electrical outlet (15 A maximum). Power supply requires a 3-phase electrical (15 A/phase maximum).

### Water

System requires cooling with up to 31 L/min with 45 to 75 psi at +15 °C to +24 °C water temperature.

### Floor

The floor must support the weight of the magnet and the supply.

### Environment

The Hall system requires an environment between 18 °C and 28 °C that is relatively free of airborne dust and debris. There should be no equipment placed next to the Hall system that would emit or be susceptible to high levels of magnetic interference (distribution boxes, vibration equipment, x-ray machines, etc.)

# Hall effect measurement systems

## 8400 series

### Ordering Information for 8400 Hall Systems

#### 8400 Series system

- 8407** Hall system, 7 in EM/102 mm (4 in) high-uniformity pole caps with DC closed-loop field control, 9 kW MPS, 0.5 mΩ to 10 MΩ limit. Must specify single phase (100, 120, 220 CE, 240 CE VAC) and 3-phase (200, 208, 220, 230, 380, 400, 415 VAC) line voltage at order
- 8404** Hall system, 4 in EM/51 mm (2 in) pole caps, 2.5 kW MPS, 0.5 mΩ to 10 MΩ limit; must specify single phase (100, 120, 220 CE, 240 CE VAC) and 3-phase (200/208, 220/230, 380, 400/415 VAC) line voltage at order

#### 8400 Series options

##### Temperature options

- 84016-I** CCR insert for 84016; (1) included with purchase of 84016
- 84017-I** Oven insert for 84017; (1) included with the purchase of 84017
- 84015** Single point LN<sub>2</sub> body; compatible with 840-VTA and 841-STM
- 84016** Closed cycle refrigerator (CCR) body with 84016-I CCR insert; requires 840-VTA, TPS-FRG or equivalent, LHe gas cylinder and regulator; must specify single phase (208/230, 200, 220 CE, 240 CE VAC) line voltage at order **NOTE:** requires 1 additional training day
- 84016-0** 84016 with sample top side optical access; requires 84060 **NOTE:** requires 1 additional training day
- 84016A** Air-cooled 84016 **NOTE:** requires 1 additional training day
- 84016A-0** Air-cooled 84016-0 **NOTE:** requires 1 additional training day
- 84017** Oven body with 84017-I oven insert; requires 840-VTA, E2M or equivalent (compatible with TPS-FRG), Ar or He gas cylinder with regulator and hose barb **NOTE:** at 773 K and ±1% rdg: maximum = 1 MΩ; at 1,273 K and ±1% rdg: maximum = 1 kΩ; requires 1 additional training day
- 840-VTA** Variable temperature control: includes software, temperature controller, gas handler, associated gas lines, cables, and rack mount kit
- 840-VTA-ARW** Upgrade to convert 841-STM to 840-VTA
- 841-STM** Sample temperature monitoring: includes software, temperature controller, cables, and rack mount kit; requires sample card with PT sensor

##### Sample measurement options

- 84006** Room temperature optical access body with sample top side optical access for use with standard insert; requires 84060
- 84010** Sample rotation—0 to 360° manual rotation for 10 mm sample cards
- 84030** AC field Hall measurement: includes software, lock-in amp, cables, and rack mount kit
- 84031** High resistance measurement; includes software, electrometer/ammeter, cables, and rack mount kit
- 84033** Low resistance measurement; useful when measuring either very low resistance materials or thermoelectric materials; includes required cables **NOTE:** only operates in DC field mode; cannot be used in conjunction with 84030 option
- 84032** Gate bias measurement: includes software, voltage source, cables, and rack mount kit
- 750QMSA** QMSA<sup>®</sup> software option (requires 8400 system software version 4)

##### Magnet field options

- 846-VFC** DC closed-loop field control: includes software, serial cable, gaussmeter, Hall probe, and rack mounting kit **NOTE:** Included with the 8407; 846-VFC option is for 8404 users requiring DC closed-loop field control; for best 846-VFC performance, 8404 users should also order EM4-4PB pole caps
- 84060** Optical access magnet option for 84006 or 84016-0
- EM7-2P** Pole cap option for 8407; 178 mm (7 in) dia pole cap with 51 mm (2 in) face diameter; bolt on
- EM4-4PB** High uniformity: 102 mm (4 in) dia pole cap; bolt on for Model 8404

#### 8400 Series accessories

##### Sample mounting accessories

- 840910** 10 mm prober pin sample card with PT sensor for use with standard insert; compatible with 840-VTA, 841-STM and 84015 **NOTE:** not compatible with variable temperature (84016, 84017)
- 840911** 50 mm prober pin sample card kit with PT sensor for use with standard insert; includes 50 mm prober pin sample card with PT sensor and required guide stem; compatible with 840-VTA and 841-STM **NOTE:** not compatible with variable temperature (84015, 84016, 84017) or sample rotation (84010) options
- 840930** Sample mounting kit for use with standard insert: includes (4) 10 mm solder pad sample cards, (1) 10 mm solder pad sample card with PT sensor, copper wire, and indium foil; (1) included with purchase of 8404; compatible with 840-VTA and 841-STM
- 840931** Sample card kit for use with standard insert: includes (5) 10 mm solder pad sample cards
- 840932** Sample card kit with PT sensors for use with standard insert: includes (5) 10 mm solder pad sample cards with PT sensors; compatible with 840-VTA and 841-STM

#### General accessories

- 840950** Floor mounting hardware kit
- Pumps**
- TPS-FRG-100/120V** Compact turbo pumping system; includes V-81 turbo pump (NW 40) with oil free dry scroll backing pump, FRG-700 full range gauge, controller, and interface cable to USB port; **NOTE: requires SYS-TP-KIT**
- TPS-FRG-220/240V-CE** Compact turbo pumping system; includes V-81 turbo pump (NW 40) with oil free dry scroll backing pump, FRG-700 full range gauge, controller, and interface cable to USB port; **NOTE: requires SYS-TP-KIT**
- SYS-TP-KIT** Includes all components necessary to connect NW 40 turbo pumping system to the vacuum port of any Lake Shore system (except probe stations)
- E2M-110/120V** Two-stage rotary vacuum pump with mist filter; 110 to 120 VAC **NOTE: requires SYS-RP-KIT**
- E2M-220/240V** Two-stage rotary vacuum pump with mist filter; 220 to 240 VAC **NOTE: requires SYS-RP-KIT**
- SYS-RP-KIT** Includes all components necessary to connect E2M rotary pump to the vacuum port of any Lake Shore system (except probe stations)

Chillers available—see the Lake Shore website for current models

#### 8400 Series system with cryogenic probe station

- 8425** Hall system with Model CRX-VF probe station including: 4 probe arms for van der Pauw measurements with cabling and probe mounts; 12 CVT probes (ZN50R-CVT-25-W); isolated 51 mm (2 in) sample holder (installed), grounded 32 mm (1.25 in) sample holder; turbo vacuum pumping system; 7:1 zoom microscope system; must specify single phase (100, 120, 220 CE, 240 CE VAC) and 3-phase (200, 208, 220, 230, 380, 400, 415 VAC) line voltage at time of order

##### Sample measurement options

- 84-HBM** Hall bar measurement; 6 total arms required for Hall bar measurement; option provides 2 additional probe arms, each with cabling and probe mount; software is already enabled
- 84032P** Gate bias voltage measurement; includes voltage source and triaxial sample holder
- 84031** High resistance measurement; includes software, electrometer/ammeter, cables, and rack mount kit
- PS-HV-CPX** High vacuum kit; lowers base pressure and eliminates condensation; includes HVAC port, vacuum pump kit, and gauge
- PS-Z16** High resolution microscope upgrade
- Also available:** Optical excitation with topside illumination of sample using UV/IR; some restrictions apply; consult Lake Shore for details

##### Probe station accessories

- ZN50R-CVT-25-W** Additional probe, 25 μm tip radius, tungsten **NOTE:** 12 of these probes are included with the system
- ZN50R-CVT-10-W** Additional probe, 10 μm tip radius, tungsten
- ZN50R-CVT-25-BECU** Additional probe, 25 μm tip radius, beryllium copper

##### Recirculating chillers

For our available chillers, please see the Lake Shore website.

# Hall effect measurement systems

## 8400 series

*Established in 1968, Lake Shore Cryotronics, Inc. is an international leader in developing innovative measurement and control solutions. Founded by Dr. John M. Swartz, a former professor of electrical engineering at the Ohio State University, and his brother David, Lake Shore produces equipment for the measurement of cryogenic temperatures, magnetic fields, and the characterization of the physical properties of materials in temperature and magnetic environments.*



*©2015 Lake Shore Cryotronics, Inc. All rights reserved.*

*The technical and pricing information contained herein is subject to change at any time.*

*All trademarks or service marks noted herein are either property of Lake Shore Cryotronics, Inc., or their respective companies.*

030817