Using the Lake Shore MeasureReady M91 FastHall in a Quantum Design OptiCool

The highly configurable Quantum Design OptiCool® can be integrated with a wide range of scientific equipment. In this Application Note, we will demonstrate how to use the Lake Shore MeasureReady® M91 FastHall™ measurement system to control the temperature and field in an OptiCool to perform resistivity, Hall, and mobility measurements in van der Pauw geometry or Hall measurements in 6-wire geometry. The optical access granted by the OptiCool, combined with the high sensitivity of the M91 FastHall opens the opportunity to perform Carrier-resolved photo-Hall effect measurements.

Necessary Hardware

To integrate the M91 controller into the OptiCool, as shown in Figure 1, the following hardware is needed:

- OptiCool Standard Sample Wiring (X300) installed into one of the sample pod bays.
- Lake Shore DB25-M91-Triax feedthrough box (4105-222). Note, this comes with the Standard Resistance M91 FastHall Kit (8105-546).
- 16-pin Fischer to DB-25 sample cable (3318-404-01).

Finally, we recommend the Wired Sample Mount Kit (X150) for ease of sample wiring. This is not necessary, but provides a gold-plated copper plane that is thermally connected to the sample pod and 16 pre-wired pads for connecting electrical leads to your sample.

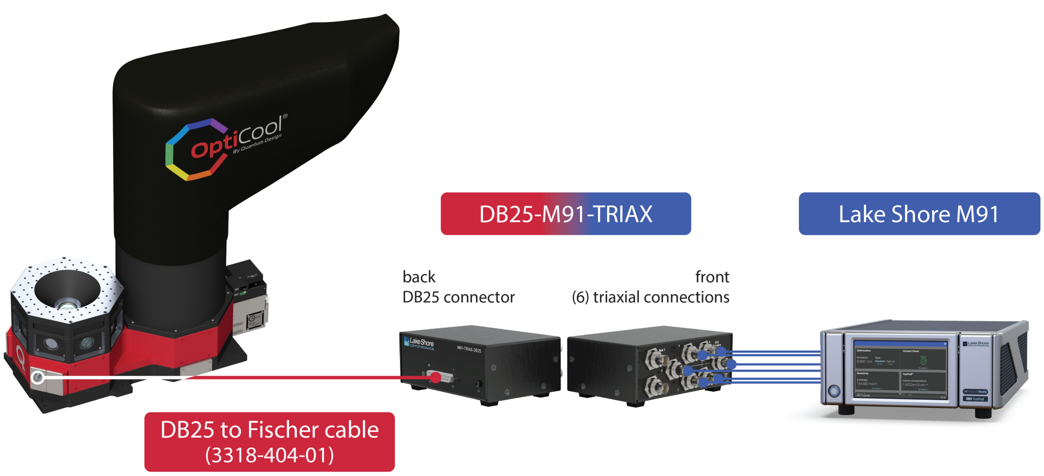

Figure 1: *OptiCool connection to the M91 via the feedthrough box and Fischer-DB25 sample cable.*

Software

With OptiCool MultiVu running, LakeShore's MeasureLINK® software can connect to the OptiCool and control the temperature and field. It is important to make sure in the MeasureLINK configuration panel that the QD Application package is set to communicate with the OptiCool in the **Instrument** drop-down menu under **Communication**, as shown in Figure 2.

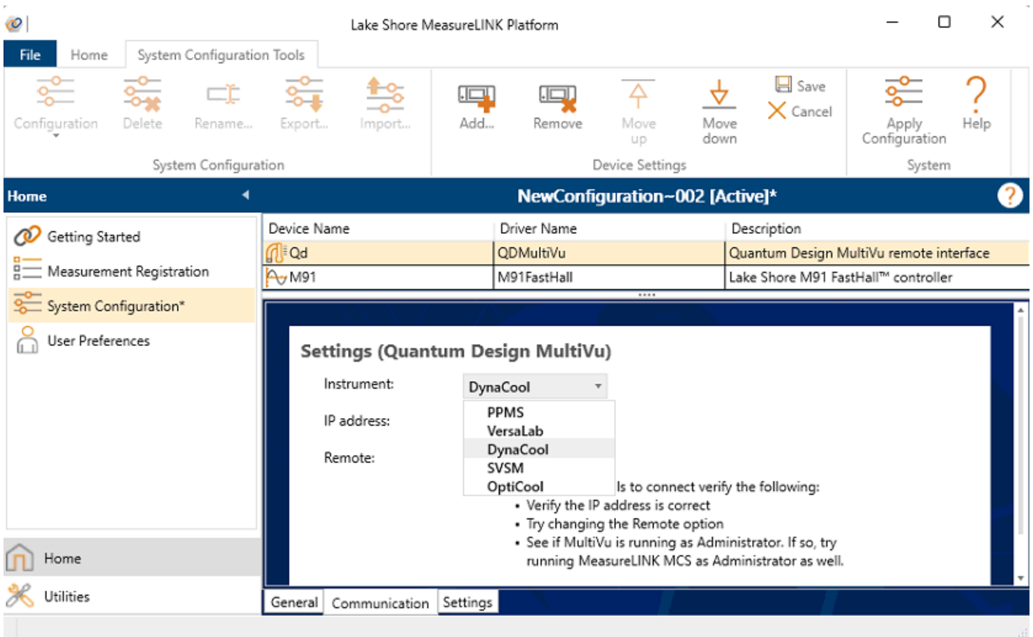

***Figure 2:** To setup MeasureLINK to use with the OptiCool, make sure the QD MultiVu Application package is installed and then under **Home > System Configutation > QDMultiVu > Communications**, select **OptiCool** from the **Instrument** dropdown.*

Sample Mounting and Wiring

The M91 supports both van der Pauw (4 connections) and Hall bar (6 connections) geometries. These samples can be wired to the Quantum Design Wired Sample Mount, as shown in Figure 3. When connected to the OptiCool, these sample connections are present on the Fischer connector on the side of the OptiCool. The DB25-M91-Triax feedthrough box enables these pins to connect to the M91. When using the Wired Sample Mount, you need to reroute the triax from the DB25-M91-Triax box to the M91 Fasthall in order to avoid wire crossing at the sample. This involves switching the connections of the wires that would cross. It is important that the correct M91 port number is connected to the correct attachment point on the sample, but these numbers will be different on the DB25-M91-Triax box due to the pad layout on the Wired Sample Mount. For van der Pauw geometry, this involves swapping the connections such that port 2 on the M91 connects to port 3 on the DB25-M91-Triax and similarly ports 3 and 2. For Hall bar geometry, ports 5 and 1 need to be switched and as in van der Pauw geometry ports 2 and 3 need to be switched. See Table 1 for the connections from the Fisher port to DB25-M91-Triax box to the M91 for either van der Pauw geometry or Hall bar geometry. Six triaxial cables are included in the kit.

NOTE: Guarding is only up to the feedthrough box.

Fischer (Wired Sample Mount) Pins	DB25-M91-Triax	M91 port vdP Geometry	M91 port Hall Bar Geometry
1 (CH A, I+)	Triax 1	1	5
5 (CH B, I+)	Triax 2	3	3
6 (CH B, I-)	Triax 3	2	2
10 (CH C, I-)	Triax 4	4	4
2 (CH A, I-)	Triax 5	n/a	1
9 (CH C, I+)	Triax 6	n/a	6
8 (CH B, V-)	AUX 1	----	----
7 (CH B, V+)	AUX 2	----	----
4 (CH A, V-)	Measure Common	----	----

Table 1: *Pinouts for connections from the Fischer port (Wired Sample Mount), to the DB25 -M91-Triax box, and to the M91 FastHall for either van der Pauw or Hall bar geometry.*

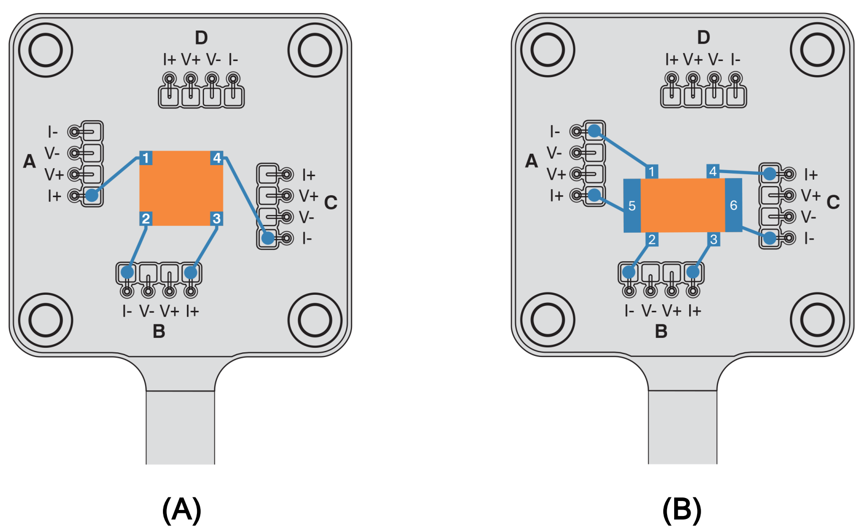

Figure 3: *Wiring configurations for van der Pauw (**A**) and Hall bar (**B**) geometries on the Wired Sample Mount.*

Figure 4 shows an InAs sample ((100), undoped 5 x 5 x 0.45 mm, 2sp from MTI corp) mounted to the Wired Sample Mount. A piece of cigarette paper soaked in thinned GE-7031 varnish was first placed on the Wired Sample Mount to provide an electrically insulating but relatively thermally conductive layer between the sample and the sample mount. The sample was then attached via GE-7031 varnish. The sample was connected with gold wires which were soldered to the sample via indium bonds and soldered to the appropriate pads in accordance with Figure 3.

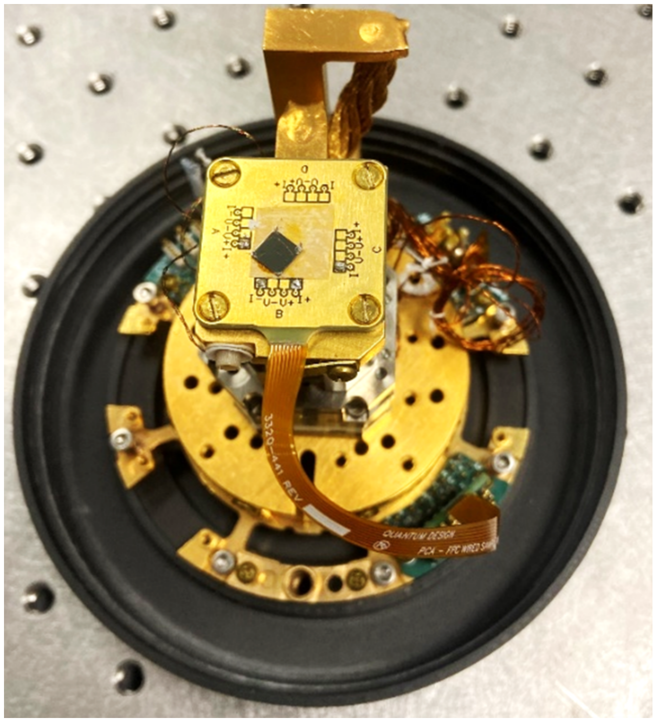

Figure 4: *InAs sample mounted to Wired Sample Mount with insulating cigarette paper between the sample and sample mount.*

Example Measurement

Measurements of resistivity, Hall coefficient, and mobility made on the InAs sample from 2 K to 300 K are shown in Figure 5. This room temperature mobility lines up with literature values, though it is important to note that the mobility is reduced by increased impurity concentration and microscopic inhomogeneity, which can be difficult to control **[1]**. As the temperature decreases, the behavior we see can be understood as the contributions of different carriers with different mobilities, as the interactions between impurity states effectively forms an impurity band **[2]**. At high temperatures the contributions of the impurity band are negligible; however, since the charge density of the conduction band decreases with temperature, the contributions of the impurity band become important at low temperatures **[3]**. The behavior of the resistivity and Hall coefficient at low temperatures is influenced by these impurities.

Since this describes measurements being performed in an optical cryostat, one should carefully consider the effects of optical excitation on these measurements. This can often excite charge carries, sometimes referred to as a photocurrent, can complicate the interpretation of this data.

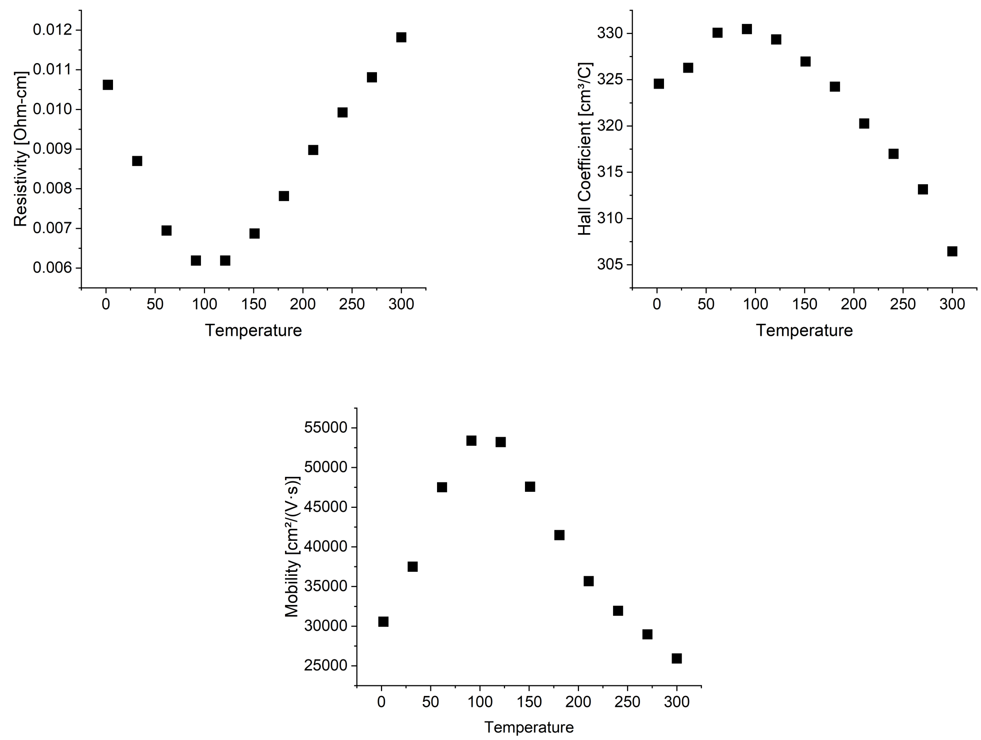

Figure 5: *Resistivity, Hall coefficient, and mobility measurements of InAs from 2 K to 300 K measured in an OptiCool with the M91 FastHall measurement system.*

Carrier-Resolved Photo-Hall Effect

When performing Hall measurements under photo excitation, one must be aware of the photocurrent generated. The work of Gunawan, O. E., et al describes a method for using photo excitation to distinguish the majority and minority carriers in a sample **[4]**. By looking at the slope of the conductivity vs Hall coefficient, which are changed by varying laser excitation intensity, they can determine densities of both electrons and holes in a sample.

References

[1] T. C. HARMAN, H. L. (1956). Electrical Properties of n-Type InAs. *Phys. Rev. Vol 104, 6*, 1562-64.

[2] Hung, C. S. (1950). Theory of Resistivity and Hall Effect at Very Low Temperatures. *Phys. Rev. 79, 727*, 727-8.

[3] See Hung, C. S. (1950).

[4] Gunawan, O., Pae, S.R., Bishop, D.M. et al.(2019). Carrier-resolved photo-Hall effect. *Nature, 575*, 151-155.