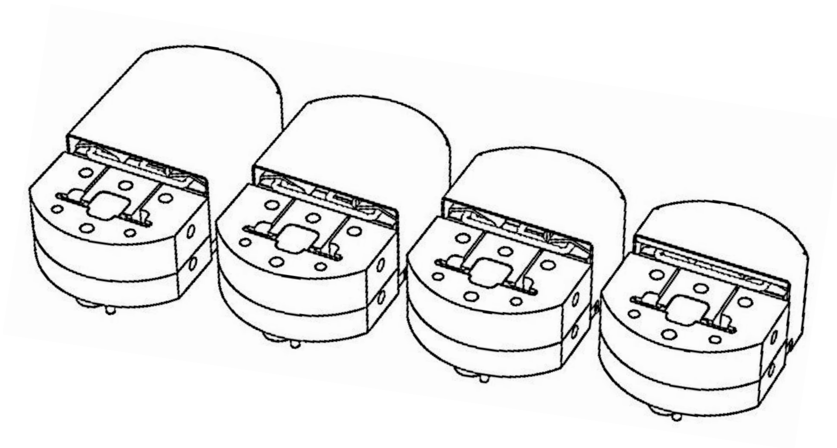

CS1x0: Compact Strain Cell

This Datasheet covers the CS1x0 series cells (CS100, CS110, CS120 and CS130). These cells are piezoelectric, temperature-compensated apparatus for applying tunable uniaxial strain to test samples. They are designed for use at low temperature, high magnetic field and within a highly constrained sample space in e.g. a PPMS. They are suitable for general use, and may be combined with a range of measurements, including electrical and thermal transport, magnetic susceptibility and scanning probe microscopy. The CS100 is sized to fit vertically or horizontally in a 1 inch (25 mm) diameter sample space, and the other cells in the series are slightly larger. The upper surface is ground flat, to provide a precision surface for users to mount their measurement setup. A capacitive position sensor is integrated into the apparatus; to enhance sensitivity, the shielding of this sensor is electrically isolated from the chassis. Spare tapped holes are incorporated, for attachment of, e.g., measurement apparatus or thermometers.

SPECIFICATIONS

		CS100	CS110	CS120	CS130		
Dimensions[1]							
Height		13.3				±0.1	mm
Width		20				±0.1	mm
Length		24.2	28.2	32.7	37.2	±0.1	mm
Weight	inc. cables	23	25	28	31	typ.	g
Performance							
Displacement	at 300K at 4K	±6 ±3	±7 ±4	±13 ±7	±17 ±10	± 10% ± 10%	μm
Typ. sample	Length	2.0		2.5		note[2]	mm
	Width	0.3					mm
	Thickness	0.2					mm
	Stiffness	5	5	3.5	2.6	max[3]	N/μm
Operating Environment							
Temperature	Operating	<0.3 to 325				range	K
	Bakeout	400				max	K
Magn. Field	Operating	0 to >30				range	T
Compatible environments	Operating	Atmosphere; low pressure helium; high vacuum. Contact Razorbill for UHV.					
Drive Electronics							
Drive Voltage	At 300K	-20 to +120				range	V
	At 4K	-200 to +200				range	V
Capacitance at 290K	Comprn. Tension	0.41 0.82	0.6 1.3	1.1 2.2	1.5 3.0	typ	μF

[1] Height excludes cables, which exit on the bottom. See also technical drawings.
[2] A wide range of different sample sizes and geometries are possible, see text
[3] All cells can accept 5N/μm with limited travel range, see text.

		CS100	CS110	CS120	CS130		
Capacitance Sensor							
Area		10				typ	mm^2
Initial gap		40		60		typ	µm
Initial value		1.2		0.8		typ	pF
Response		27		12		typ	fF/µm
Cell Mechanical Parameters							
Stiffness		26	22	19	16	typ	N/um
Electrical Connectors[4]							
Drive Wires	two	Lemo FGG.0S.302.ZLAT					
Sense Cables	two	MMCX Female (Molex 73415-341x)					
Construction Materials							
Chassis		Titanium, unalloyed (Grades 1 and 2)					
Piezos		PZT Ceramic					
Drive Wires[5]	four	⌀0.8mm PTFE insulated copper					
Sense Cables	two	⌀1mm coaxial, copper/FEP					
Solder		Cryo-compatible Sn/Pb (non RoHS)					
Epoxy		Cyro compatible low outgassing					

PRINCIPLE OF OPERATION

Piezoelectric stacks typically have large negative thermal expansion coefficients, which makes it hard to match them to a sample. The CS1x0 cells have a symmetric arrangement of piezoelectric stacks that cancel out their thermal expansion, allowing the sample to remain near zero strain across a wide temperature range. The stacks drive a flexure-constrained mechanism which any unwanted shear or pillowing of the piezo from being transmitted to the sample.

[4] Mating connectors are provided with every order

[5] Cables and wires 20mm long unless provided as part of an order including a PPMS probe. Other lengths are available on request.

The strain cell also has piezoelectric stacks much longer than the sample, allowing large sample strains to be achieved. As the strain depends on the sample length, and with care very short samples can be mounted, the maximum achievable strain is very large.

The test sample may still be strained by the differential thermal expansion between it and the titanium of the cell. If the sample mounting plates are titanium, the sample will in principle see only the differential thermal expansion between itself and the titanium of the apparatus and plates. If the sample plates are, e.g., made from a copper-based alloy, then they will contract more than the apparatus during cooling, placing the sample under tension. Similarly, molybdenum or tungsten plates will place the sample under compression. Careful selection of sample plate material and dimensions can be used to cancel out the relative thermal contraction of the sample. Alternatively, the apparatus may be operated during temperature changes to counteract these thermal effects.

The compensation mechanism cancels out thermal expansion of the piezos, so little or no displacement occurs as a function of temperature when the voltage is zero, and it is possible to reach zero displacement at any temperature, which is not always possible with bare piezos. It does not compensate for the reduced stroke at low temperature, so changes will occur as a function of temperature if the stacks are held at constant nonzero voltage. The compensation mechanism and the remaining thermal expansion is described in more detail in Application Note AP001.

SAMPLE SIZE AND OPERATING RANGE

The achievable strain depends on the model of cell, applied voltage, temperature and the spring constant of the sample and sample mounts. The applied voltage and temperature effects are easy to understand, the stroke of the piezo, and therefore the strain, varies nearly linearly with voltage, and approximately linearly with temperature between the values given in the specification table.

The effect of the sample is more complex. The system can be modelled as two springs in series with the applied displacement, one for the sample and sample mounts, and one for the cell. With no sample, the cell will provide the displacement listed in the specification table, and no force. With an infinitely stiff sample, the cell will in principle provide a force equal to the cell spring constant multiplied by the available displacement. But to limit unwanted transverse movements and rotations which will cause strain inhomogeneities and potentially break the sample, the force should be limited to 45N. The recommended operating limits for the various cells in the CS1x0 series are shown graphically in Figure 1.

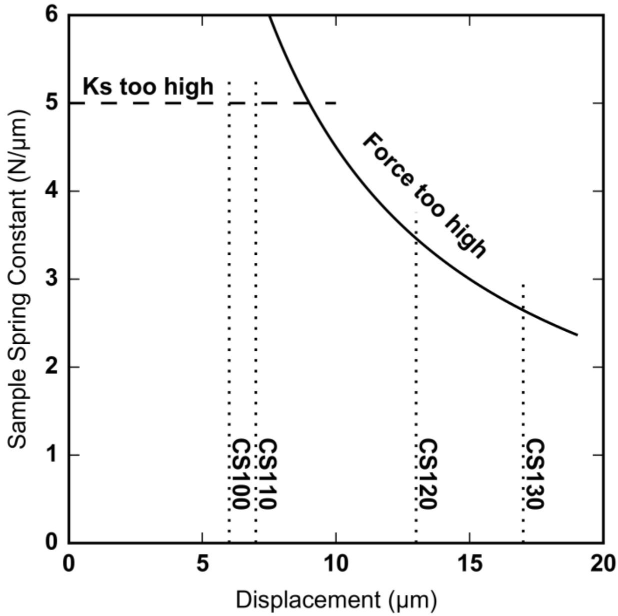

Figure 1. Recommended operating envelope for CS1x0 series cells. Sample spring constant (Ks) should be limited to about 5N/µm, and force to about 45N to avoid unwanted twisting of the cell. Room temperature displacements of the cells are marked for convenience. There is no problem using a CS130 at e.g. 5µm and 4.5N/µm.

To take an example, a typical sample might be 1.5mm long (between sample plates), 0.3mm wide and 0.2mm thick. Assuming a Young's modulus of 120GPa, this sample would have a spring constant of approximately 4.8N/µm. By comparing this with the spring constant for the CS100 cell, we can see that four fifths of the displacement would be transferred to the sample, giving a 4K displacement of 2.4um and a force of about 11N. This corresponds to a strain of 0.16% and a stress of 180MPa. Stiffer samples will see a higher maximum force, but lower displacement, stress and strain. Sample size is a trade-off between achievable stress/strain, and ease of handling.

Larger cells in the series have lower spring constants but larger displacements. Generally speaking, the larger cells can do anything a smaller cell can do, so it is usually best to choose the largest cell in the series which fits into the space available in the cryostat.

SAMPLE MOUNTING

The method of sample mounting is fundamentally the responsibility of the user, and may be adapted to suit the users' purposes. Here we provide a few suggestions, and more information, including a guide to mounting small metal or ceramic matchstick shaped samples is available as application note AP005.

The most important parameter to bear in mind when specifying a sample mounting method is the sample spring constant. This means the spring constant for compressing/tensioning everything that the user mounts between the two moving blocks, using the two taps provided (See technical drawings at the back of this folder) 5×10^6 N/m is an approximate upper limit, at which the stiffness of the sample starts substantially limiting the displacement that the CS1x0 series cells can apply. Typically, the sample + mount combination will consist of two rigid mounts that are bolted to the CS100, and a sample between them sized to keep its spring constant acceptably low.

The simplest method to mount a sample is to simply glue it to two sample plates, as illustrated in Figure 2a). This mounting method is asymmetric: the sample is secured primarily through its lower surface, and in consequence when the sample is compressed (or tensioned) it will bow upwards (or downwards), imposing a strain gradient across the thickness of the sample. However, for applications such as surface probes, where high homogeneity is not required, or for preliminary measurements, this is a practical mounting method.

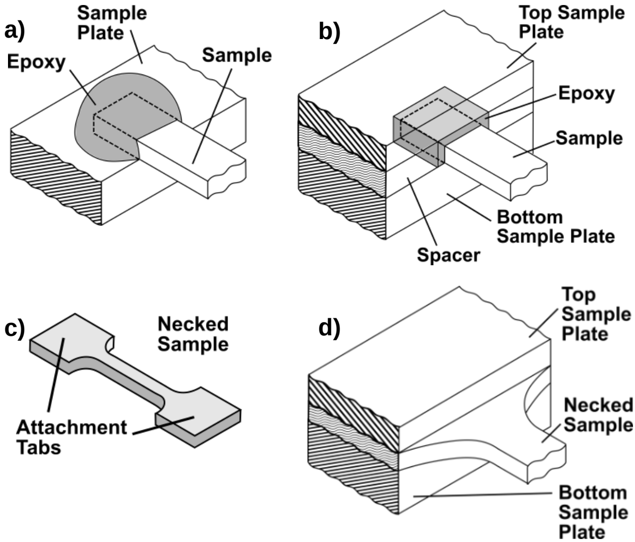

Figure 2. a) It is possible to simply glue the sample to sample plates with a drop of epoxy. b) A better mounting method achieves higher strain homogeneity. c) A necked sample. d) A Necked sample mounted between sample plates.

A more robust method is illustrated in Figure 2b). This method limits bowing, and so gives more homogeneous strain, and, by reducing strain concentrations, higher strains before sample failure. Here, the sample is secured between lower and upper sample plates. A spacer foil may be included to protect the sample when the bolts are tightened. By sanding or grinding the spacer carefully, epoxy thicknesses in the range of ~10 µm are achievable. A more complete overview of the considerations behind this sample mounting method is given in *Review of Scientific Instruments* 85, 065003 (2014).

In some situations it may be possible machine or etch the sample so that it is significantly narrower in the middle than it is at the attachment points. This may be done in silicon, for example, by Deep Reactive Ion Etching (DRIE). A sample which has been ‘necked’ in this way will experience high, uniform strains in the necked area, and the two tabs may be epoxied to or between sample plates.

OPERATING ENVIRONMENT

WARNING! The cell is designed to be used in a cryostat. Observe the usual precautions to avoid cold burns and other injuries. If in doubt, contact the manufacturer of your cryostat for further advice.

WARNING! Do not operate the cell or start cooling if it has condensation or frost on it. Allow the cell to warm up naturally or use desiccant to speed up the drying process. Even quite small quantities of water can cause shorts or damage the cell.

The maximum permissible long-term operating temperature in the specifications table is set by the insulating coating used to protect against arcing in low pressure helium. Exceeding this temperature for long periods degrades the insulation and may cause a hazard. This value assumes that the apparatus is operated quasi-statically, so that negligible power is dissipated in the piezoelectric stacks. If this is not the case, care must be taken that the stacks do not exceed the stated temperature. The bakeout temperature given in the specification table applies for infrequent bakeouts of one or two days each, and assumes that the device is not operated and the drive wires are shorted or connected to a RP100 power supply.

For DC operation, the leakage in the piezoelectric stacks is essentially zero at ultralow temperatures; no heating is expected and we do not anticipate any lower temperature limit on operation. CS100 series cells have been operated successfully below 200 mK. The body of the strain cell may become superconducting below 400mK, but only at very low magnetic fields, B_c<6mT. This will not affect the operation of the cell, but may affect the measurement being carried out on the sample, and the thermal conductivity of the cell.

The temperature compensation of the CS100 presumes that the apparatus is at uniform temperature. During rapid temperature changes this may not be the case, and in consequence large thermal displacements may be applied to the sample. If moderately rapid temperature changes are desired, the displacement sensor may be monitored and the CS100 operated to minimize displacement applied to the sample. We recommend avoiding very rapid temperature changes, and under no circumstances should the heating or cooling rate exceed 10K/minute.

The CS1x0 cells are designed to be operated in a vacuum. It is also safe to operate in air at atmospheric pressure. Low pressure helium, which is often used as an exchange gas in low temperature systems, is also suitable, but care should be taken to avoid dielectric breakdown of the gas. Insulation prevents arcing within the apparatus, but the user must take care to ensure the wiring and connectors inside the cryostat are also appropriately insulated. Where this is not practical, we recommend limiting the voltage to less than the Paschen Law minimum when operating in fluids with a breakdown risk. For helium, this means limiting the voltage to ±120V. Corrosive or explosive atmospheres must be strictly avoided.

The apparatus contains no ferromagnetic components or materials. As such it is suitable for use in both in high magnetic field and environments where stray magnetic fields must be minimised.

MOUNTING THE CELL

The CS1x0 series cells are designed to apply precise deformations to a sample across a wide temperature range. It is important that the cell itself not come under excessive thermal stresses. We recommend that the CS100 be mounted using the taps on the sides, with a compliant holder. There should be nothing in contact with the "bridge", i.e. the part at the other end of the stacks from the bod of the cell, as this needs to be free to move during operation. Figure 3shows a yoke suitable for use in a 1-inch sample space with the cell horizontal or vertical. For the Quantum Design PPMS, Razorbill instruments can provide complete probes, or kits to convert the standard P450 probe for use with the CS100 strain cell. For other cryostats, Razorbill Instruments can provide advice, design assistance, or custom parts to assist with mounting.

With larger sample spaces, it is possible to mount the cell on a sample rotator. However, the PTFE insulated drive wires and micro-coax are not flexible at cryogenic temperatures, so any such rotator must be equipped with suitable flexible wire. This is particularly the case with the drive wires, as an insulation failure on these wires could pose a hazard to the operator.

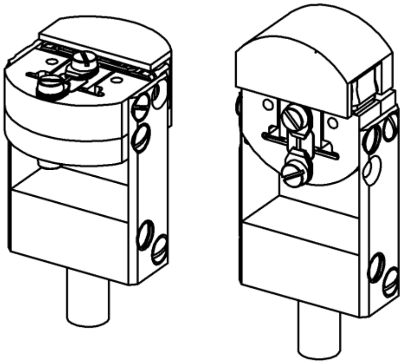

Figure 3. Typical mounting for use in a 1-inch sample space

DRIVE ELECTRONICS

DANGER! The voltages required to operate the cell are high enough to cause serious injury or death. Use a current limited supply – 10mA is sufficient. Use suitable cables and wiring. Only operate the cell above 50V in a grounded metal or completely insulating cryostat, or other suitable container. Ensure piezos in the cell are discharged before removing it from the cryostat/container.

The cell requires a ±200V source and sink (also called four-quadrant) power supply to access the full strain range at all temperatures. The Razorbill Instruments RP100 power supply is suitable, and also builds in in additional safety features to reduce the risk of shock to operators and the risk of equipment damage. It is of course possible to use other power supplies too, and there is more information available in Application Note AP002.

Connection	Colour	Connector	Pin
Compression stack positive	Brown	C	1
Compression stack negative	Blue	C	2
Tension stack positive	Red	T	1
Tension stack negative	White	T	2

The four drive wires can be identified by colour or, on earlier models, by the labels engraved on the base of the device. Earlier models of CS1x0 refer to the compression stack as “inner” and the tension stack as “outer”, and have corresponding labels engraved on, but to avoid confusion in cells where the stacks act in the opposite direction that nomenclature is no longer used.

Unless requested otherwise, the drive wires will be 20cm long and terminated with the connector shown in Figure 4. Mating connectors are supplied with each order, along with a short piece of cryogenic heatshrink to make it easy to encapsulate the solder joins. Connectors are also available directly from LEMO (subject to minimum order) or from Razorbill Instruments. If the strain cell is to be used in a low pressure gas atmosphere, such as helium exchange gas, take extra care to fully insulate all wire and solder joins. The breakdown voltage of helium can be as low as 110V for some combinations of low pressure and moderate spark length, and the abrupt discharge of the piezos resulting from an arc can damage them. Arcs to ground could also pose a risk of electric shock to the user.

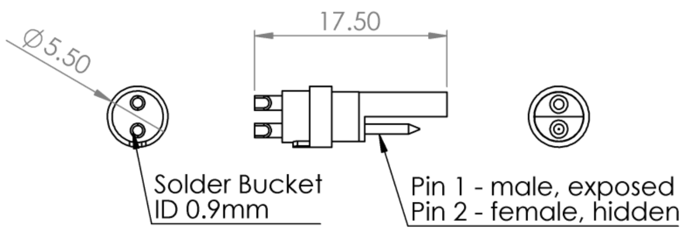

Figure 4. Lemo FGG.0S.302.ZLAT connector. This connector is hermaphroditic, i.e. it mates with another copy of itself. Pin 1 mates with pin 2 and vice versa.

When the cell is in a cryostat but not in use, each pair of drive wires should be connected together, ideally via a resistor of 10-100kΩ, to dissipate any charge that may be produced by temperature changes in the stacks. If an RP100 power supply is used, it connects a suitable resistor whenever the outputs are disabled, even if the power supply is turned off. Razorbill Instruments probes and probe conversion kits include 27kΩ shorting caps which fit the drive wire vacuum feedthoughs, and making similar caps for customer-built wiring is recommended.

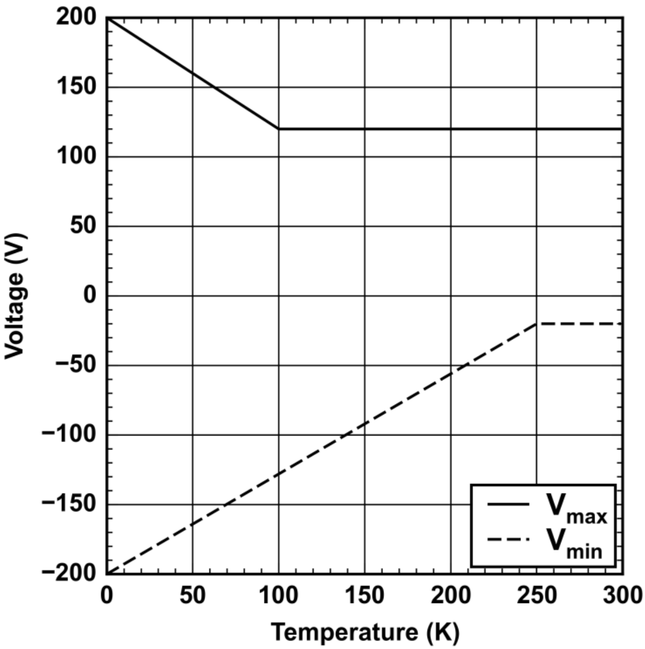

Figure 5. Recommended voltage limits for various temperatures.

A positive voltage applied to the compression stack compresses the sample, and a negative one tensions it. For the tension stacks positive tensions and negative compresses. In general, it is preferable to apply small voltage to both rather than a larger voltage to one. The maximum and minimum voltage which can be applied to the stacks changes as a function of temperature. The limits for room temperature and 4K are given in the specifications table and for intermediate temperatures refer to Figure 5.

POSITION FEEDBACK

Position feedback is provided by a parallel plate capacitor below the sample. The capacitance of this sensor is small, smaller even than the capacitance of a few meters of typical coaxial cable. A precision capacitance bridge or capacitance meter is required to obtain an accurate measurement, contact Razorbill Instruments if you need help selecting a suitable instrument or cryogenic cable. The excitation used by the capacitance bridge should not exceed 40Vptp, in most cases much smaller voltages will be adequate.

Unless requested otherwise, the cell coax cables will be 20cm long, and terminated with standard female MMCX connectors. The specific part used is given in the specifications table. Any standard MMCX male connector should mate with this part, and two connectors suitable for use on cables of about 1mm outer diameter are included with each cell.

The cores of the coaxial cables are connected to the capacitor plates. To obtain the lowest possible noise on the capacitance measurement, the “high” or “drive” output of your capacitance bridge should be connected to the high plate, and the “low” or “sense” output should be connected to the low plate. The capacitor is well shielded and will not interfere with the vast majority of measurements, however if this does become a problem, even with the coax shields connected as described below, you can reduce the effect by swapping over the two coax cables.

The braids of the coaxial cables are connected to a two-part titanium shield which encloses the capacitor and is not electrically connected to the chassis of the strain cell. To obtain the best possible measurement, the braids should be connected to the ground terminal on your capacitance bridge/meter, and nothing else. The chassis of the strain cell should be separately connected to ground both to lower noise and for electrical safety reasons.

Capacitance measurement is discussed in more detail in Application Note AP003.

Temperature compensation

The capacitance of the position sensor is somewhat temperature dependent. The capacitor is designed so that several different sources of thermal expansion cancel out, and in theory there should be no temperature dependence, but in practice the cancellation is imperfect and there could be some temperature dependence in either direction (though usually lower temperature means lower capacitance).

It should be appreciated that even if the temperature dependence is known, it would still be difficult to accurately identify the point of zero strain, as it would be difficult to accurately know the thermal expansion of the sample and epoxy relative to the titanium of the cell. This is discussed in more detail in application note AP001.

For users who wish to measure the temperature dependence of the capacitor to use as a calibration, the following method is recommended:

- At room temperature, with no sample mounted (no screws in the top face of the cell), apply 120V to all three stacks, hold for a few seconds and then bring the voltage slowly back to zero. This ensures the stacks have the same voltage history will keep their thermal expansion as similar as possible.
- Fit a titanium calibration sample[6]. This is a titanium bar which can be screwed onto the cell in place of a normal sample and prevents any actual movement during calibration.
- Cool the cell, and measure the capacitance as a function of temperature.

The cell, sample, and capacitor are all titanium, and all expand together. To make use of this calibration to estimate the zero strain point of the sample, it is necessary to know the thermal expansion of the sample *relative to titanium* and the length of the sample between (titanium) sample plates. The thermal expansion of titanium is given in application note AP001.

[6] For customers who bought their cells before calibration samples were included, Razorbill Instruments will provide them free of charge.

RECOMMENDED ACCESSORIES

Razorbill Instruments can provide the following accessories for use with the CS1x0 series strain cells.

- RP100 Power Supply. The RP100 is a two channel power supply designed to power any of the CS1x0 or FC100 series stress and strain cells, and has extra features built in to help protect the cells from damage and to reduce the risk of dangerous electric shocks.
- WP100 Wiring Platforms. The WP100 is a small copper and PCB platform which screws onto the top of the cell, and provides four wire-bondable and solderable contacts next to the sample. There is also space for a heater or thermometer. Two WP100s can be fitted to each CS1x0 cell.
- SP100 Sample plate. Additional sample plates, the same design as the ones supplied with the cell.
- SP110 Sample plate. Sample plates with thin slots cut into them, for mounting matchstick or plate like samples at 90 degrees to the usual orientation.
- SP120 Sample plate. Two sample plates joined together by flexures with a narrow gap in between, this sample plate is designed for use with very small membrane samples.
- PPMS1 Probe or Probe kit. This probe kit is designed to convert a standard Quantum Design PPMS probe for use with the CS1x0 cells. It is available as a kit or Razorbill Instruments can purchase a probe from Quantum Design, install the kit, and provide the complete probe to the customer.
- TB100 Work table and stands. The stands provide a convenient way of holding the cell while mounting samples etc. and also fit into the work table, which has a pattern of tapped holes designed to accept a wide variety of XYZ stages, positioners and manipulators which might be useful for sample preparation.

RELATED DOCUMENTS

The following application notes and other documents may be useful to users of the CS1x0 series cells. They are available on the Razorbill Instruments website, and new documents are also added from time to time.

- AP001 Thermal Expansion. More detail on the compensation mechanism used in the CS1x0 series cells, its strengths and limitations, and matching the thermal expansion of samples to the cell. It also explains how best to calibrate the temperature dependence of the capacitive position sensor.
- AP002 Drive electronics. Essential information for customers who plan to use their own power supplies, and useful for selecting cryogenic wiring.
- AP003 Measuring Capacitance. More information about capacitance measurement best practice and information about wiring and feedthroughs.
- AP004 Cables and Heat Load. Short worked examples of heat load calculations for customers who are fitting their own cables in cryostats.
- AP005 Sample mounting guide. A photo guide showing how to mount a matchstick shaped sample on a CS1x0 series cell.

Technical drawings are also available. If this is the paper copy of this datasheet delivered with a cell, they should be included at the back of the folder.