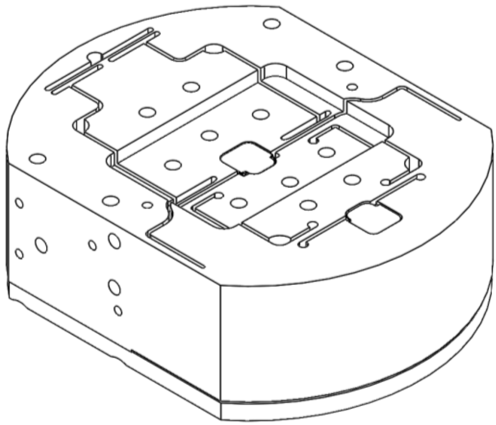
RAZORBILL INSTRUMENTS

DATASHEET



UC200: STRESS-STRAIN CELL

The UC200 universal stress-strain cell is designed to apply tuneable stresses to small samples at temperatures down to less than 1K, while monitoring both sample stress and sample strain. The device is temperature compensated, meaning that the thermal expansion of the piezoelectric stacks used to operate the cell is cancelled out and does not affect the sample. It is somewhat larger than other cells manufactured by Razorbill Instruments, and will fit in any orientation in a 2-inch (51mm) sample space. It is a broadly applicable research tool, designed to be compatible with a wide range of experimental probes, including electrical transport, susceptibility, NMR, and a wide range of scanning probe microscopy measurements. The force and displacement applied to the sample are measured by integrated capacitance sensors, which are well shielded and electrically isolated from the rest of the apparatus.

The stress-strain cell uses high voltages to operate, and there is a risk of shock if it is misused.

Read and understand the safety information sheet provided with your cell before using it. The safety note is also available online on the Razorbill Instruments website.

Some of the tapped holes in this cell lead into internal voids containing delicate components. Inserting too-long screws may damage the cell. Refer to the technical drawing for allowable lengths.

SPECIFICATIONS

Physical Specifications			
Diameter		47.0±0.1	mm
Width	Across flats	37.0±0.1	mm
Height	To top surface	16.0±0.2	mm
	To sample mid-plane[1]	14.9±0.2	mm
Weight	approx.	88	g
Output			
Displacement	At 300K, no load	± 17	µm
	At 4K, no load	± 10	µm
Force	At 300K, zero displacement	± 50[2]	N
	At 4K, zero displacement	± 40	N

[1] Height of sample depends on mounting technique. This figure assumes 100um thick sample, 50um epoxy, and standard sample plates.

[2] The cell is capable of producing more than 50N across much of the temperature range, but this could cause damage, so this must be avoided by using softer samples or monitoring the force sensor.

Feedback Sensor - Force			
Range		± 60[3]	N
Sensitivity	Typ.	2 to 4	fF/N
Capacitance	Typ, zero force	1.1	pF
Hysteresis	max	0.5	%
Drift	24 hours	0.01	%FSR
Feedback Sensor - Displacement			
Range		±20	µm
Sensitivity	Typ.	4 to 8	fF/µm
Capacitance	Typ, zero displacement	0.8	pF
Hysteresis	max	0.5	%
Drift	24 hours, vacuum	0.01	%FSR
Piezoelectronic Stacks			
Drive Voltage	At 300K	-20 to 120	V
	At 4K	±200	V
Drive Current	Min recommended	0.05	mA
	Do not exceed	10	mA
Capacitance (300K)	Tension stack	1.5	µF
	Compression stacks	3.0	µF
Typical Sample			
Length		0.5 to 2	mm
Cross Section		0.01 to 0.1	mm^2
Construction Materials			
Piezoelectric stacks	PZT ceramic		
Chassis	Titanium, pure, grades 1-4		
Drive wires	⌀0.8mm PTFE insulated copper[4]		
Capacitor	⌀1mm coax. copper/FEP[4]		

[3] This specification applies to the sensor only. The cell should be limited to 50N.

[4] The UC200 is normally provided with 10 cm length cables and wires of the type specified in the table above. Alternative lengths or construction of wire/cable can be supplied on request.

cable	⌀0.45mm coax. copper/FEP (used internally)	
Solder	Cryo-compatible Sn/Pb solder	
Connectors	PEEK with gold plated inserts MMCX with PTFE insulators	
Epoxies	Various low outgassing cryogenic types	
Insulators	Kapton film	
Environmental		
Surroundings	Vacuum, cold gas (e.g. helium, nitrogen). Not suitable for use in liquid cryogens	
Temperature	max operating	50 °C (recommended)
	min operating	< 100 mK
	max storage	25 °C
	min storage	5 °C
	max process (e.g . epoxy cure)	100 °C (recommended)
Humidity range	0 – 80% non-condensing Humidity above 0 reduces accuracy	

THERMAL COMPENSATION

The UC200 Cell is thermally compensated, and matched to titanium. The special arrangement of piezo stacks inside the device cancels out their thermal expansion. This means a wide range of sample stresses remain accessible across the full temperature range. For more information about the principle of operation, or how to deal with samples with very large or small thermal expansion ratio, refer to application note AP001.

SAMPLE MOUNTING

The method of sample mounting is fundamentally the responsibility of the user, and must be adapted to suit the users' samples and intended measurements.

Selecting a sample

The most important parameter to bear in mind when specifying a sample and sample mounting method is the sample stiffness. This means the spring constant for compressing or tensioning everything that the user mounts between the two threaded mounting points. At 10 K, the UC200 can provide a displacement of ± 10 µm if the sample is very soft. Alternatively, the cell can provide a force of ± 40 N, if the sample does not stretch at all. It can be accurately modelled as a ± 10 µm displacement in series with a 4 N/µm spring.

A typical sample might be 2 mm long, width 0.5 mm held at each end by the sample plates and epoxy. This will leave 1 mm suspended between the sample plates which will be the effective length of the sample (the part that will actually experience strain). This typical sample may also be 0.2 mm wide and 0.1 mm thick. Assuming a Young's modulus of 120 GPa, this sample would have a spring constant of approximately 2.4 N/µm. By comparing this with the spring constant above, we can see that the maximum extension would be roughly 6 µm and the force would be 14 N. This corresponds to a strain of 0.6 % and a stress of 700 MPa, so the actual achievable strain will most likely be limited by the sample being damaged. Thicker samples will see a higher maximum force, but lower displacement, stress and strain. So sample size is a trade-off between achievable stress/strain, and ease of handling.

Mounting the sample on the cell

The UC200 is supplied with flat sample plates, which can slide backwards and forwards so that the free length of the sample can be adjusted continuously between 0.4 mm and 3 mm

The simplest method to mount a sample is to simply glue it to two sample plates, as illustrated in Figure 4a). 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 bend upwards (or downwards), imposing a strain gradient across the thickness of the sample. How much this matters will depend on what aspect of the sample is being measured.

A more rigorous method, that limits bending and so yields higher strain homogeneity, is illustrated in Figure 4b). Here, the sample is secured between lower and upper sample plates. A spacer foil may be included to protect the sample when the bolt holding the top plate is tightened. By sanding or grinding the spacer carefully, epoxy thicknesses in the range of ~10 µm are achievable.

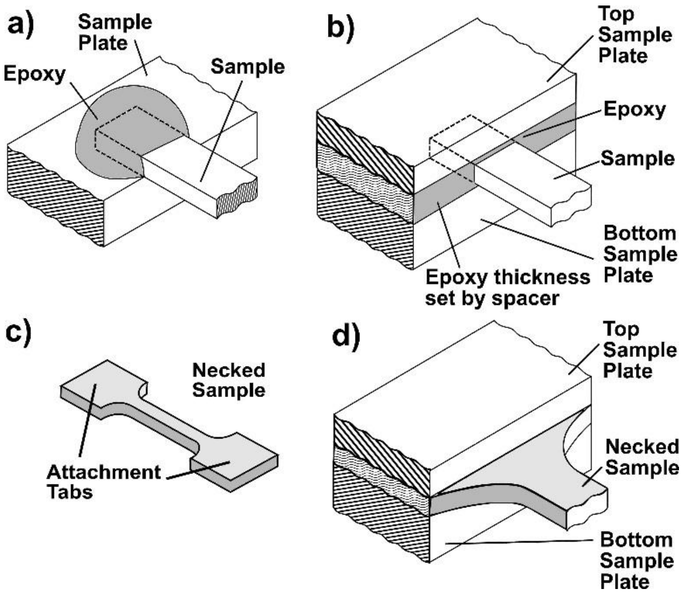


Figure 1. a) It is possible to simply glue the sample to sample plates with a drop of epoxy. b) A more rigorous mounting method, in which the sample is sandwiched between upper and lower plates, to achieve higher strain homogeneity. c) If the sample can be machined or etched, it can be necked. d) Illustrates how a necked sample may be attached to the strain cell. If the attachment tabs are large enough relative to the width of the necked section, the top sample plate can be neglected altogether.

In some situations it may be possible machine or etch or otherwise shape the sample so that it is significantly narrower in the middle than it is at the attachment points. 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 sample plates.

A more in-depth discussion of mechanical considerations for sample mounting can be found in *'Review of Scientific Instruments'* **85**, 065003 (2014). A photographic guide including some practical tips is also available as Application Note AP005.

The maximum temperature to which the cell may be exposed during curing of epoxies is 100 °C. Even if only briefly heating or cooling the stress-strain cell ensure drive wires are a connected as described in the following section.

OPERATING ENVIRONMENT

The drive wires *must* be attached to a suitable discharge resistor during any heating or cooling, as damaging thermal voltages can build up in the piezoelectric stacks. The RP100 has integrated discharge resistors so that it is sufficient to simply ensure that the stress-strain cell is correctly plugged into the RP100 during temperature changes.

The maximum operating temperature is dictated by the piezoelectric stacks and the epoxies used in the device. The recommended maximum is 50 °C and the absolute maximum is 100 °C. 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. It should be noted however that operation at higher temperatures greatly reduces the life of the stacks, and may necessitate early replacement. Increasing the operating temperature from 20 °C to 50 °C reduces the expected life by a factor of 10. Operating at 100 °C reduces expected life by a factor of 200.

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. Other cells in our product range have been operated below 200 mK. The body of the strain cell may become superconducting below 400 mK, but only at very low magnetic fields, $B_c < 6$ mT. The cell functions correctly when superconducting, but maintaining good temperature control of the sample may be harder.

The temperature compensation of the UC200 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 force sensor may be monitored and the UC200 operated to minimize force applied to the sample. We recommend avoiding very rapid temperature changes, and under no circumstances should the heating or cooling rate exceed 10 K/minute.

The UC200 is designed to be operated in a vacuum, dry air, or low pressure helium (exchange gas). When operated in some fluids, dielectric breakdown of the fluid becomes a risk. This is particularly the case in low pressure helium. Insulation prevents arcing within the cell, but the user must take care to ensure that other wiring and connectors inside the cryostat are also appropriately insulated. For more information see application note AP002.

Corrosive or explosive atmospheres must be strictly avoided. Hydrogen rich and high humidity atmospheres will also damage the cell. Moderate humidity will also make the capacitor less accurate, until the cell is dried out.

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

Some of the tapped holes in this cell lead into internal voids containing delicate components. Inserting too-long screws may damage the cell. Refer to the technical drawing for allowable lengths.

The cell has tapped holes suitable for mounting on the bottom, both sides, and on top. Refer to the technical drawing for details.

The cell will expand and contract as the temperature changes. If the cell is attached to a dissimilar metal, this will exert forces on the cell, which may cause small unintended sample strains or offsets in the sensor readings (especially in the force sensor). To avoid this, the cell should be mounted either:

- Using only two of the mounting screw holes, both on the same face of the cell, or
- In a frame or yoke which is made from thin material, which can flex as the cell expands

Razorbill Instruments will be happy to advise on the design of brackets etc. for mounting the UC200. In some cases, Razorbill Instruments can provide brackets and/or cables for use in most types of cryostat.

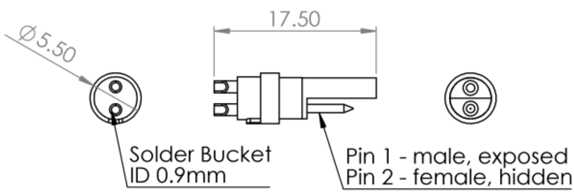
OPERATING THE UC100

Drive electronics

There are two sets of piezoelectric stacks inside the cell, and they work in opposite directions. A positive voltage on the tension stack will tension the sample and a negative voltage will compress it. For the compression stacks, a positive voltage compresses and a negative voltage tensions. Both sets of stacks must be used together to obtain the full range of the cell. Razorbill Instruments can provide a suitable power supply, the RP100. The mechanism is described in more detail in application note AP001, which also covers other power supply options.

When the power supplies are not connected, each pair of drive wires should be connected together, preferably via resistor of a few kΩ, to discharge any charge which builds up on the stacks as a result of temperature changes.

The four drive wires can be identified by colour and pin on the connector. This connector is hermaphroditic: is it mates with another copy of itself, though pin 1 mates with pin 2 and vice versa.



Connector pin (cell side)	**Connector pin (power supply side)**	**Insulation colour**	**Connected to**
2	1	white	Tension stacks -
1	2	red	Tension stacks +
1	2	brown	Compression stacks +
2	1	blue	Compression stacks -

Table 1: Wire colour, pinout and assignments

Operating Voltage

At room temperature, the voltage applied to either the inner or outer stacks is limited to the range - 20 to + 120 V. As the temperature of the device is reduced, it becomes possible to increase the positive voltage limit (V_{max}) and to reduce the negative voltage (V_{min}). Figure 3 shows the safe voltage for different temperatures.

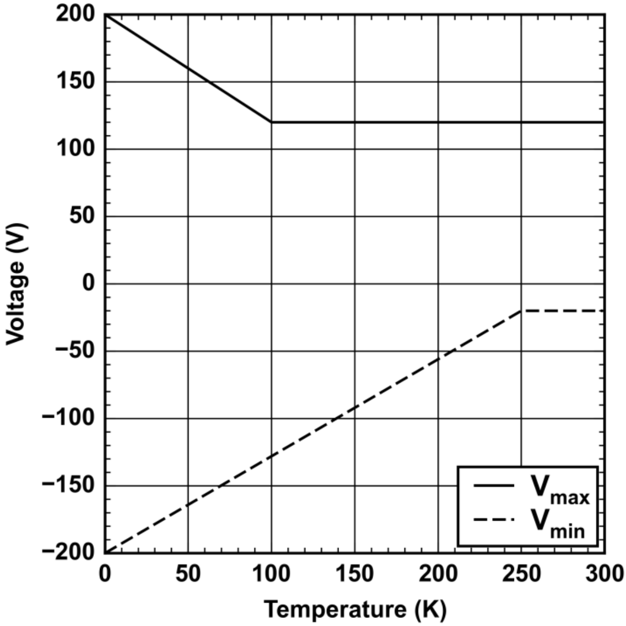


Figure 3: Voltage limits for the piezo stacks at different temperatures. The full rated range is achieved with one set of stacks at V_{min} and one at V_{max}

Measuring the capacitance sensors

Force feedback is provided by a parallel plate capacitor built into the cell, which is designed to measure ± 50 N. Displacement feedback is provided by a very similar capacitor, which is designed to measure ± 30 μm. The capacitance of these sensors is small, similar to 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 40 V ptp, in most cases much smaller voltages will be adequate.

The cores of the coaxial cables are connected to the capacitor plates. 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 body 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 safety reasons.

In general, lower noise will be obtained if the low plate is connected to the “low” or “sense” terminal of the capacitance bridge/meter, and the high plate is connected to the “high” or “force” terminal. For the displacement sensor, the low plate coax is marked by a black band and the high plate is marked with a yellow band. Double bands of the same colours are used for the force sensor.

Accuracy and resolution

Precision is typically limited by the resolution or noise of your capacitance bridge. A resolution of better than 0.002 N and 0.001μm should be achievable in most cases.

The force sensor does show some hysteresis. This will be less than 0.5% at room temperature, and smaller at low temperature. Small changes in force will show smaller hysteresis, meaning that if the force increases from 0 to 0.1 N, and back to 0, there will be no detectable hysteresis. A loop from 0 to 10 N and back will show a hysteresis of less than 0.05 N and from 0 to 50 N and back may show as much as 0.25 N. These figures are upper bounds; normally hysteresis is a factor of ten smaller.

Both sensors also have some temperature dependence. Each cell is provided with a capacitance curve which shows how the zero point capacitance changes with temperature. The zero force curve can also be measured easily by cooling the cell with no sample attached. If this offset is subtracted from the measured capacitance before converting to force, the result will be accurate to a few percent. If hysteresis as a function of temperature is observed, there are temperature gradients within the cell and the temperature changes should be slowed down. Measuring the zero-displacement temperature response can be done the same way, but with a stiff dummy sample (supplied) attached. This is not as reliable as the force though, as the dummy sample can't completely block the movement, and the process of attaching and removing the sample can cause a small offset. For this reason, the force sensor is preferred for identifying the zero strain point.

The cell is designed to operate in a vacuum or dry gas atmosphere. In air, the changes in ambient humidity will cause drift on the scale of 0.2 % of the full range. This is normal, and will go away when the cell is dried out in the cryostat. For best results, keep the cell at 300 K in vacuum for a few hours before cooling, as this will ensure no moisture remains in the capacitor.

Using the two sensors together

The force and displacement sensors provide complementary information about the sample, and are also very useful for diagnosing conditions such as broken samples, plastically deformed samples, or samples which are slipping in their epoxy mounts.

In normal use, the sample force, displacement, stress, and strain are all directly proportional to each other. However, the constants of proportionality may not be well known. The force is linked to the stress by the cross section, the stress to the strain by the elastic modulus. The constant linking displacement and strain is harder to determine, and depends on the behaviour of the sample mountings and the effective free length of the sample. The force sensor is also easier to correct for temperature effects. So for most experiments, the force sensor should be considered the most accurate.

In some cases, the displacement and force sensors will depart from proportionality. One clear example of this would be if the sample has broken, in which case the displacement will still change when a voltage is applied to the stacks, but no force will be measured. Other examples would be plastic deformation of the sample or partial failure of the epoxy holding the sample.

Monitoring both capacitors at all times allows a higher confidence in the experiment being conducted.

While the uncertainties in sample geometry and displacement-to-strain relationship make absolute measurements of the elastic modulus hard, relative changes can be detected more easily, potentially providing valuable information about structural transitions in the sample.

For more information about the advantages and disadvantages of measuring force only, displacement only, and both sensors, refer to application note AP007.

CARE AND MAINTENANCE

The cell does not normally need any routine maintenance. The outer surfaces of the cell may be cleaned with water, detergent, or common solvents such as isopropanol, acetone, or ethanol. Do not immerse the cell, and avoid solvent entering the cell through the slots in the top surface or other holes/slots in the cell. If liquid enters the cell, allow it to dry completely before cooling or operating it.

Calibration

Both sensors will generally be quite stable. They may need recalibration if it is stressed beyond the rated force, or if any part of it has been dismantled. The force sensor can be recalibrated by supporting the cell by one sample mount and hanging weights from the other. The displacement sensor can be recalibrated by attaching a suitable displacement sensor to the top surface. In both cases, it is recommended that you contact Razorbill Instruments first and it may be better to return the device for a factory recalibration.

Curves showing the temperature dependence of the sensors are also included with the cell. For information on how to recreate those curves, see page 12.

Stack replacement

The piezoelectric stacks built into the cell should have a long operating life, however this can be reduced substantially by operating the cell at high temperatures, in a humid atmosphere, or for long times at high voltages. It is also possible to damage the stacks by overloading the cell, charging or discharging them without an appropriate current limit, or changing the temperature with the stacks charged and without a suitable discharge resistor (such as that provided by the RP100 power supply).

The stacks in the cell are mounted in a cartridge, and the cartridge is designed to be replaceable. Replacing the all three stacks requires only basic hand tools and a soldering iron, though some prior experience of working on small electromechanical devices is strongly recommended.

To obtain replacement cartridges, contact Razorbill Instruments. Old cartridges can be returned to Razorbill Instruments for rebuilding, and returning the old cartridge will generally earn a discount on the new one.

RECOMMENDED ACCESSORIES

Some of the items described below are included with the cell, or with the first order. All of them are also available separately.

- **MP240 Multiplexer.** A two-channel four-way multiplexer designed to measure up to four capacitive sensors with one capacitance bridge or LCR meter.
- **RP100 Power Supply.** A two channel ± 200 V power supply, specially designed to operate Razorbill Instruments stress and strain cells.
- **WP100 wiring platform.** A small PCB and copper heatsink which bolts onto the cell, allowing easier electrical connections to the sample. Also has space for a thermometer or heater.
- **TB100 worktable.** An optical breadboard with a hole in the middle to fit a workstand. This is designed to give a large flat surface to make sample mounting easier, and

can support a variety of XYZ stages and micromanipulators from different manufacturers.

- **TB100_STDUC200 workstand.** This stand is required to mount the cell in the worktable above. Unlike some other cells made by Razorbill Instruments, the UC200 sits flat on a surface, so this stand offers little benefit without the table.
- **SP200 Sample plates.** More sample plates to replace those supplied with the cell, if they are lost, damaged, or modified to suit different samples.
- **Other sample plates.** Razorbill instruments can also provide alternative sample plates designed for different sample mounting positions or orientations, or very small samples.