Update on Temperature Sensors

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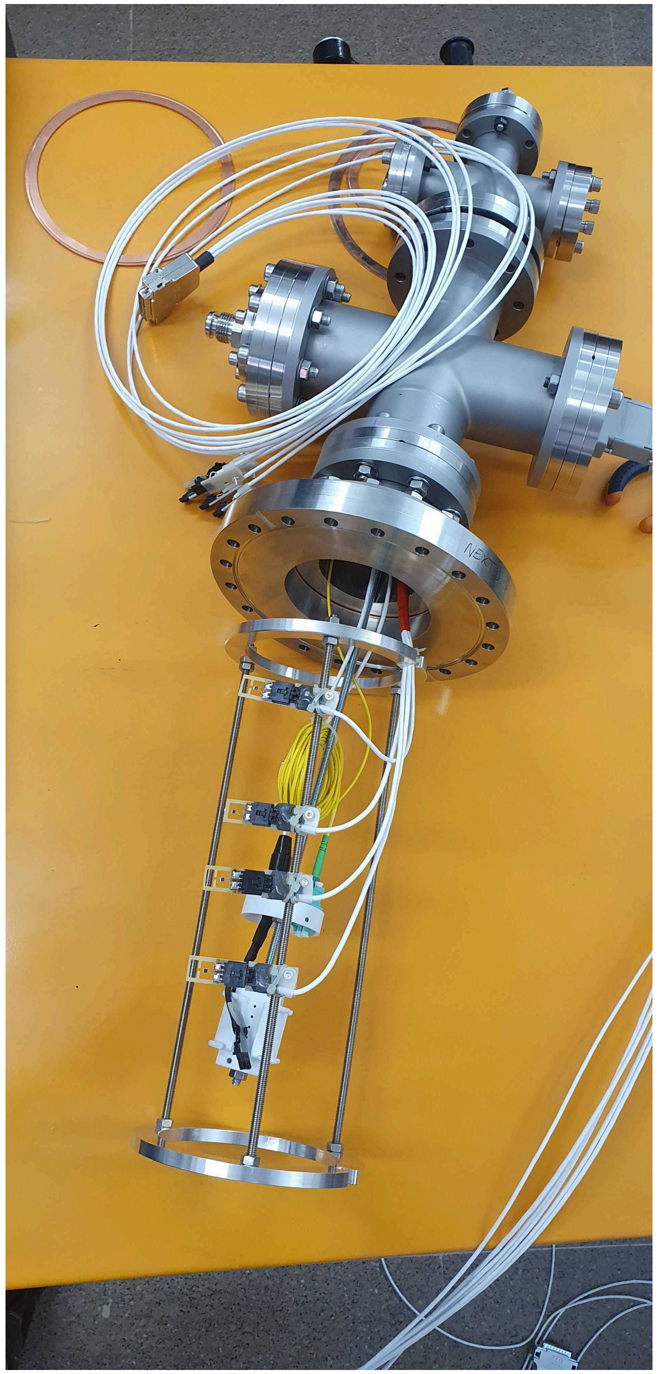
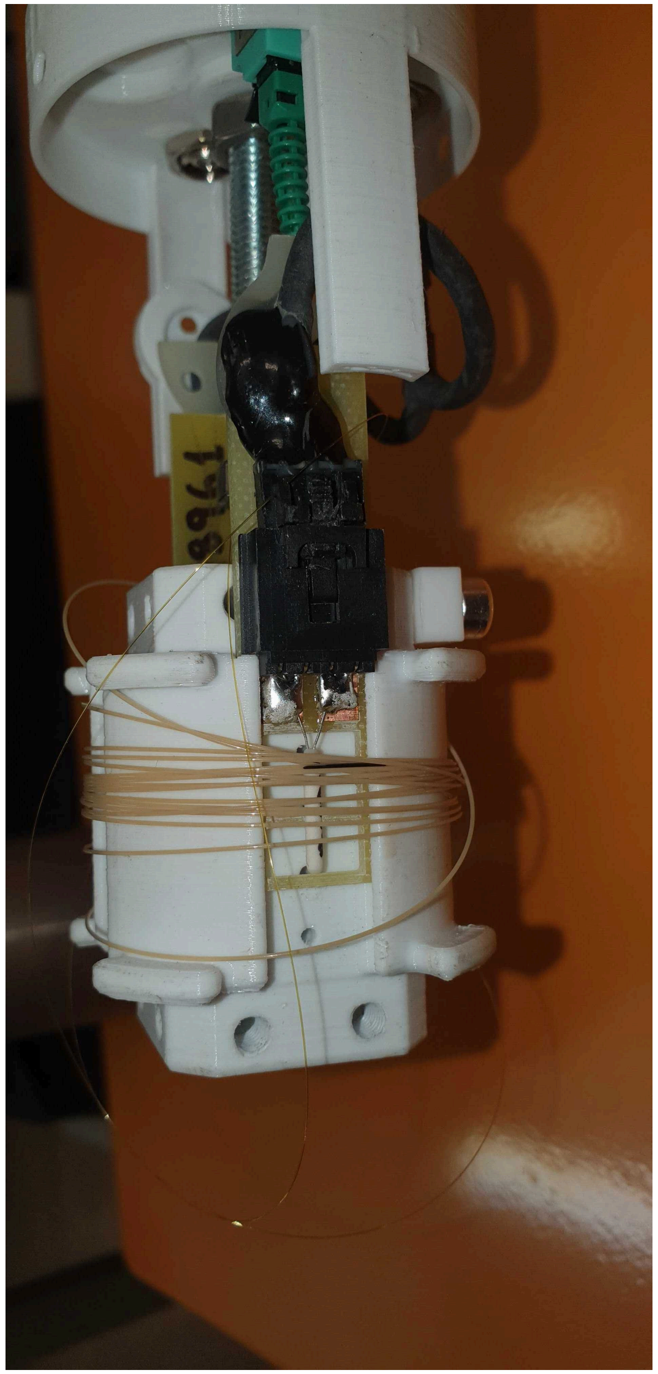
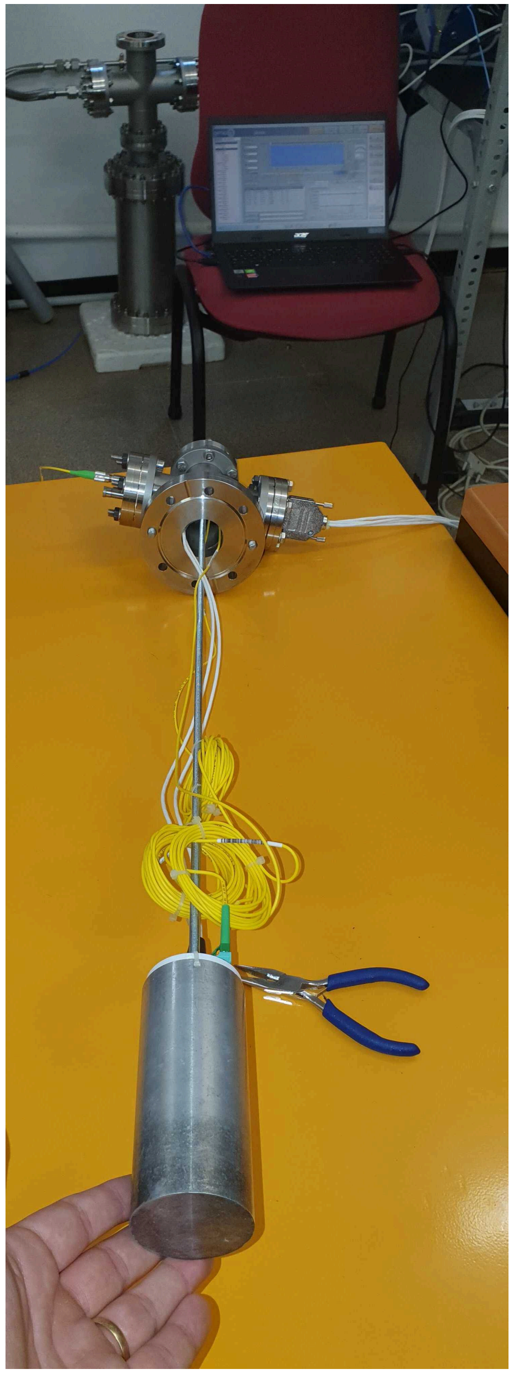
Overview of activities

- The characterisation of a **PEEK-coated** FBG sample has been conducted using a **pressurised setup** and very promising results have been obtained.
- The installation of the **crane** in the DUNE-IFIC laboratory has been conducted successfully.
- Some **issues** with the thermal insulator (**polyurethane**) application for the 1.5M Dewar setup were detected and the thermal insulation has to be **started again** from scratch.
- **One** of the **PD-VD** fibres was found to be **faulty** because of **connector** issues. The fibre has been sent to the manufacturer for reparation and will be installed again before NP02 closes. We have one **spare** at IFIC in case everything fails.

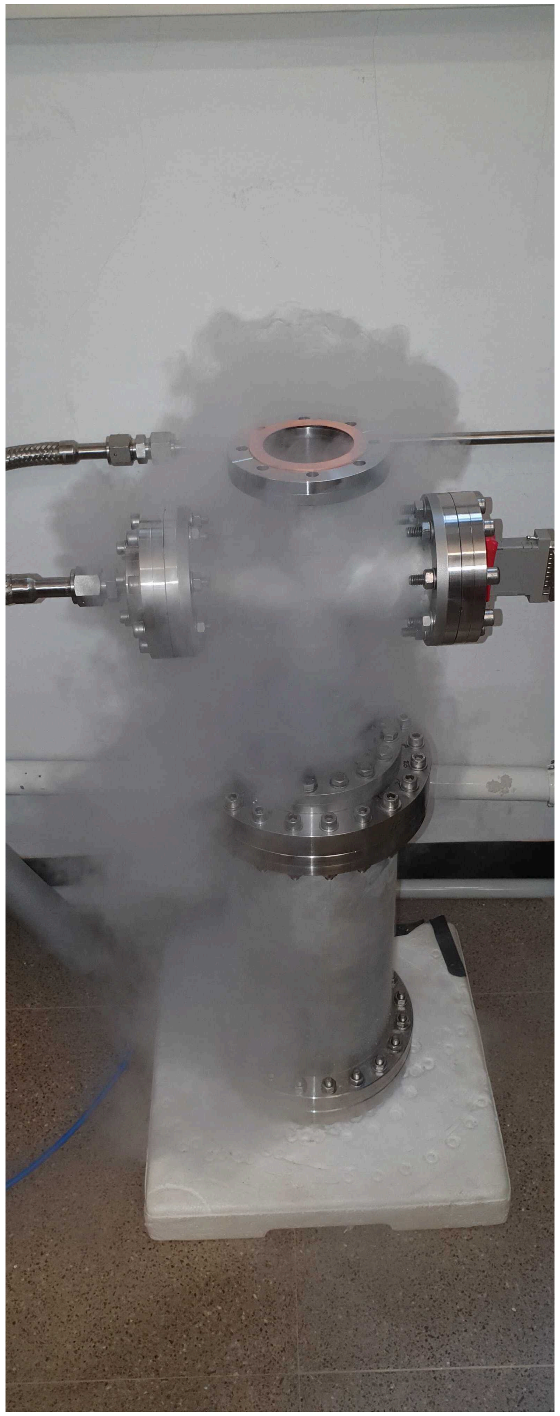
The pressure setup

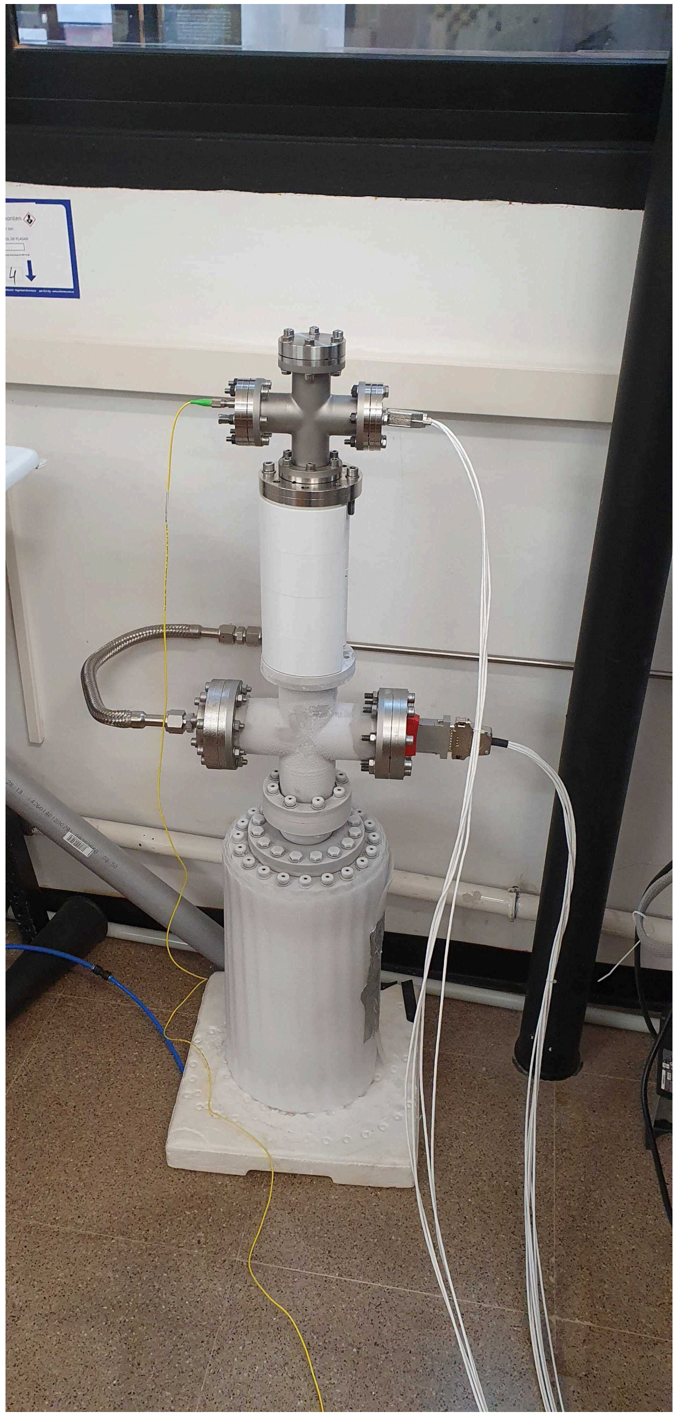






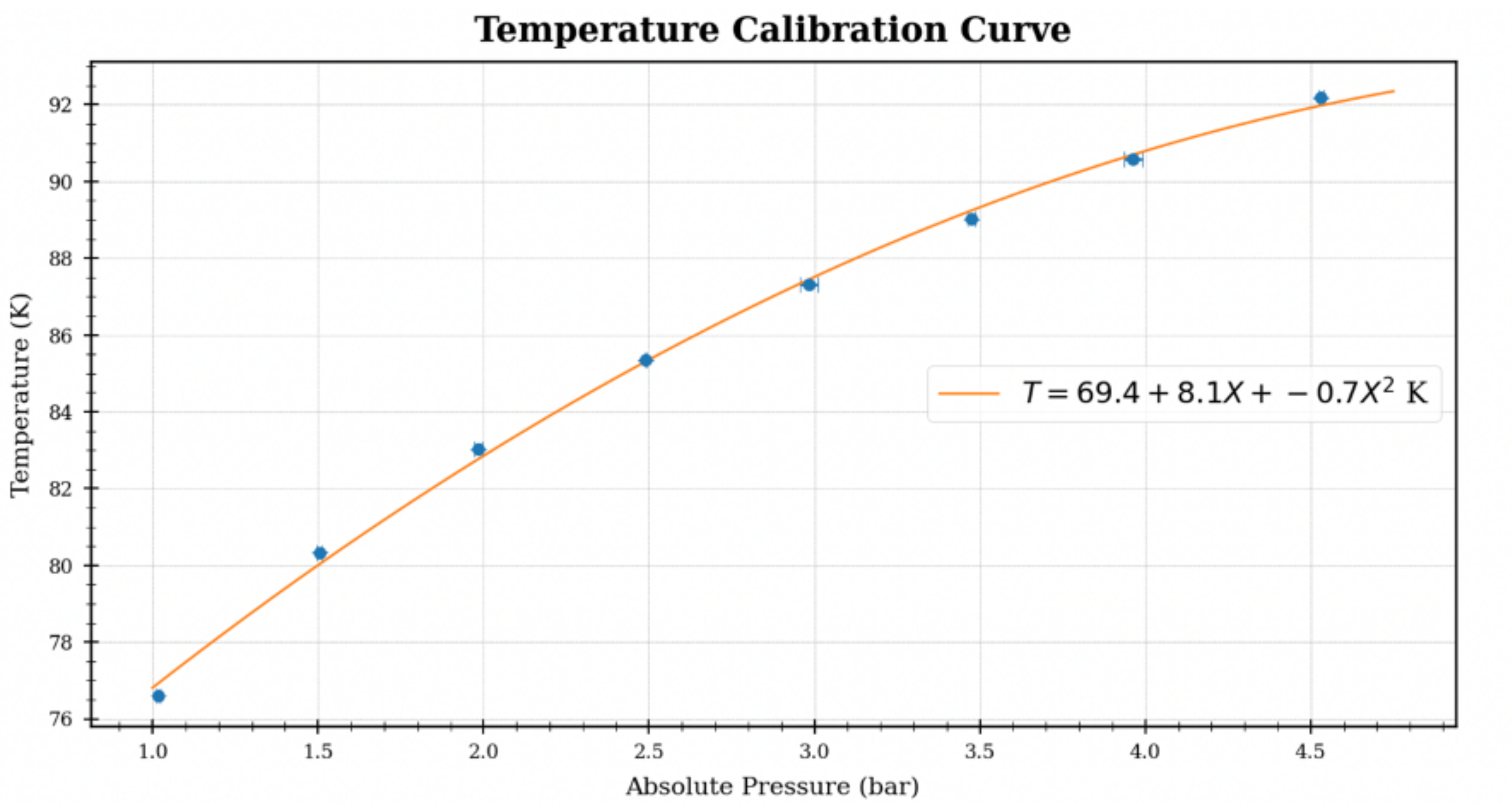
Operation of the pressure setup





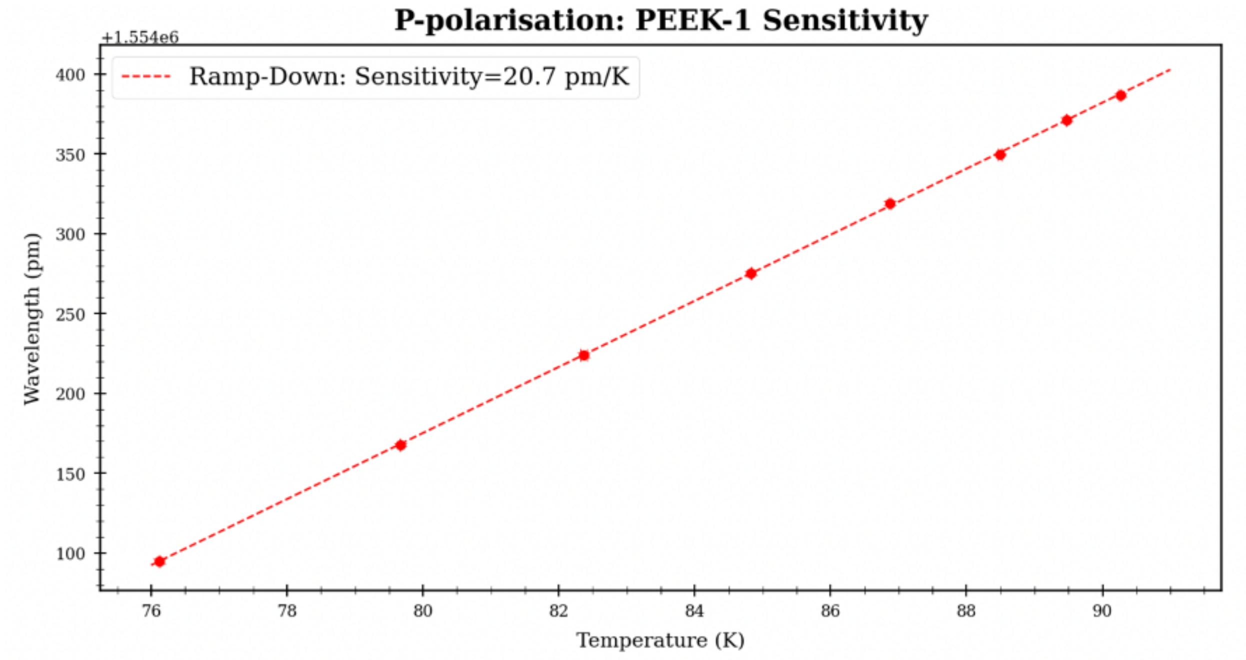
Temperature-Pressure Calibration

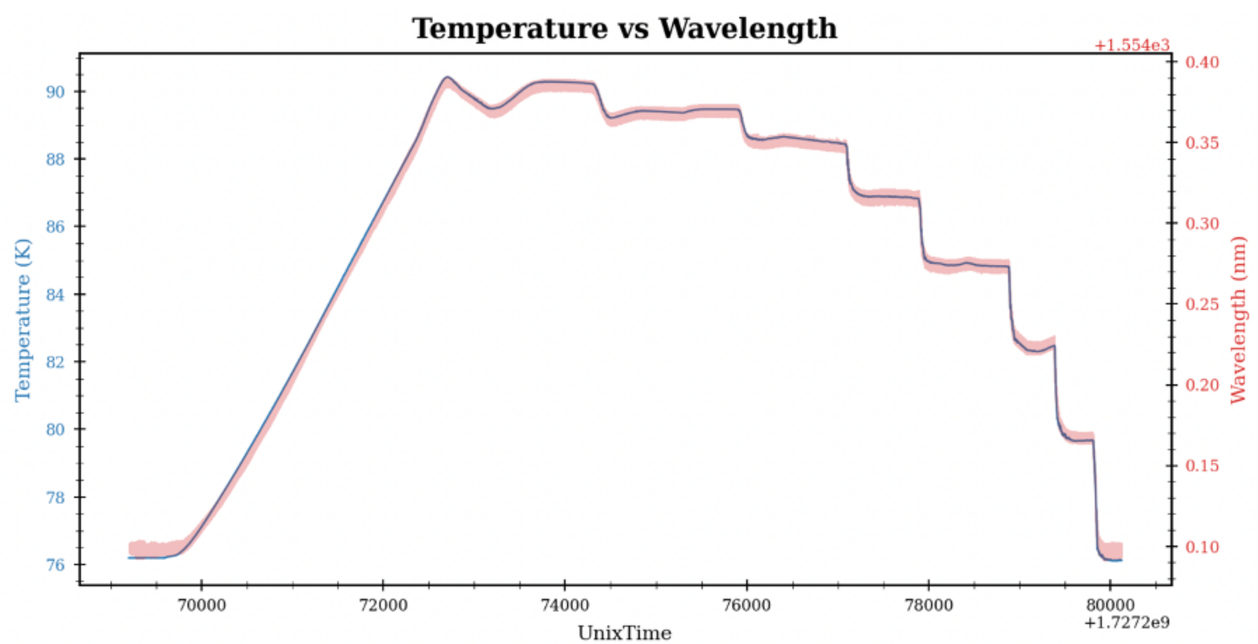
- The temperature can be **adjusted** within the **[77, 92] K** range by varying the pressure from [1, 4.5] absolute bar.
- Absolute temperature measurements are performed by **PT-102 RTDs** from Lakeshore with ~1 mK temperature resolution.

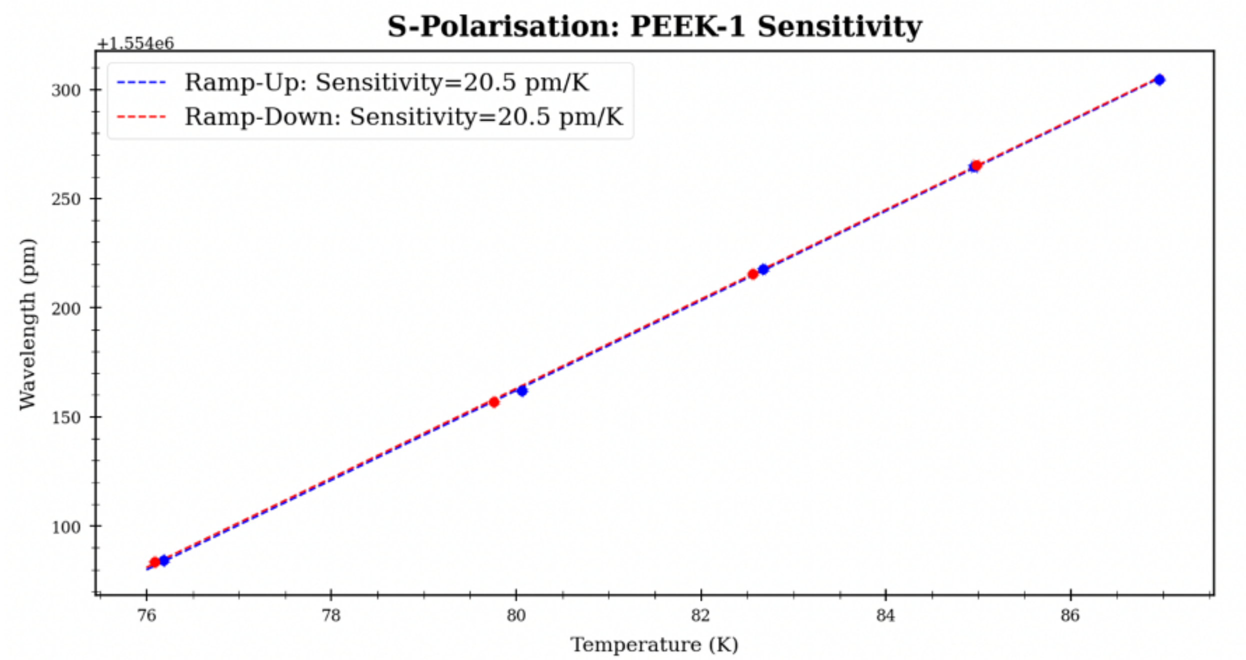


PEEK-coated samples sensitivities

- Long-enough temperature plateaus can be generated at different temperatures that allow to extract the sensitivity of the FBGs over the **[77,92] K** range.
- Observed sensitivities from PEEK-coated samples are about **~20.5 pm/K**.

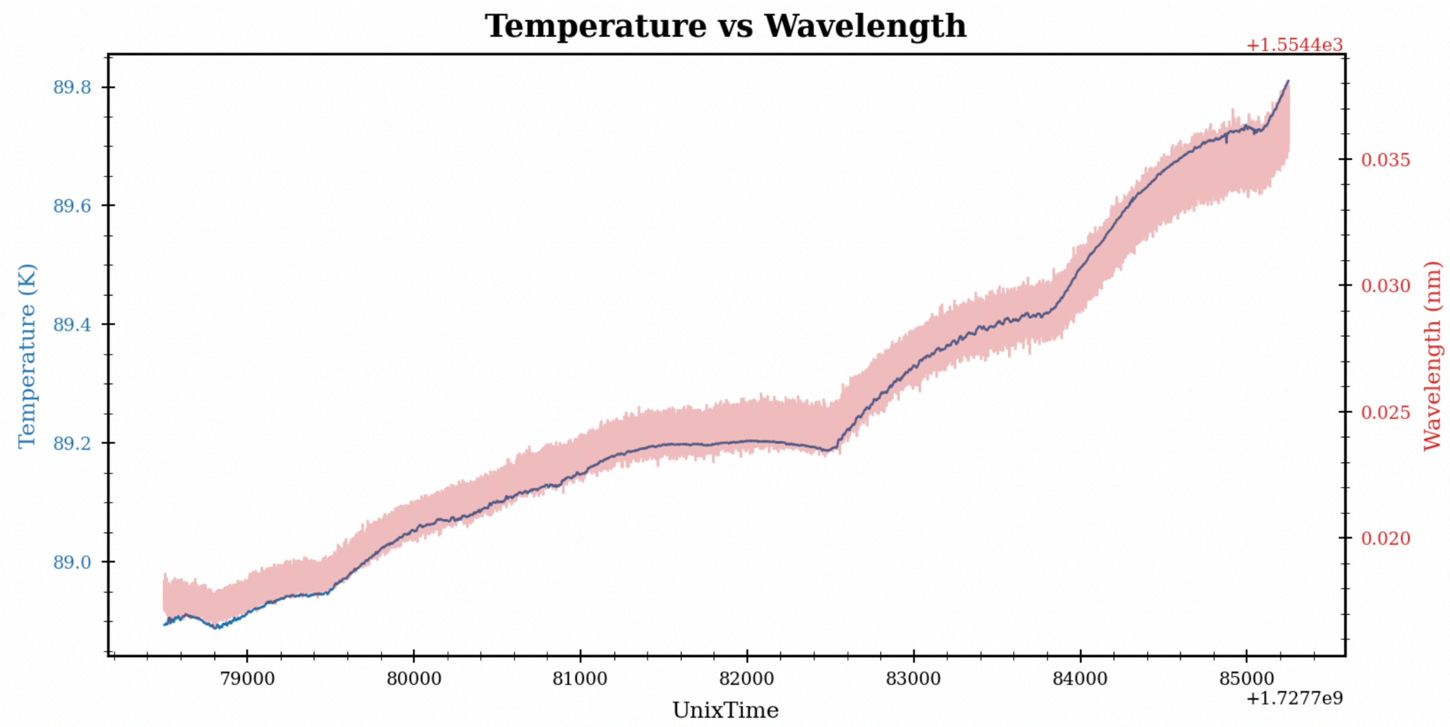


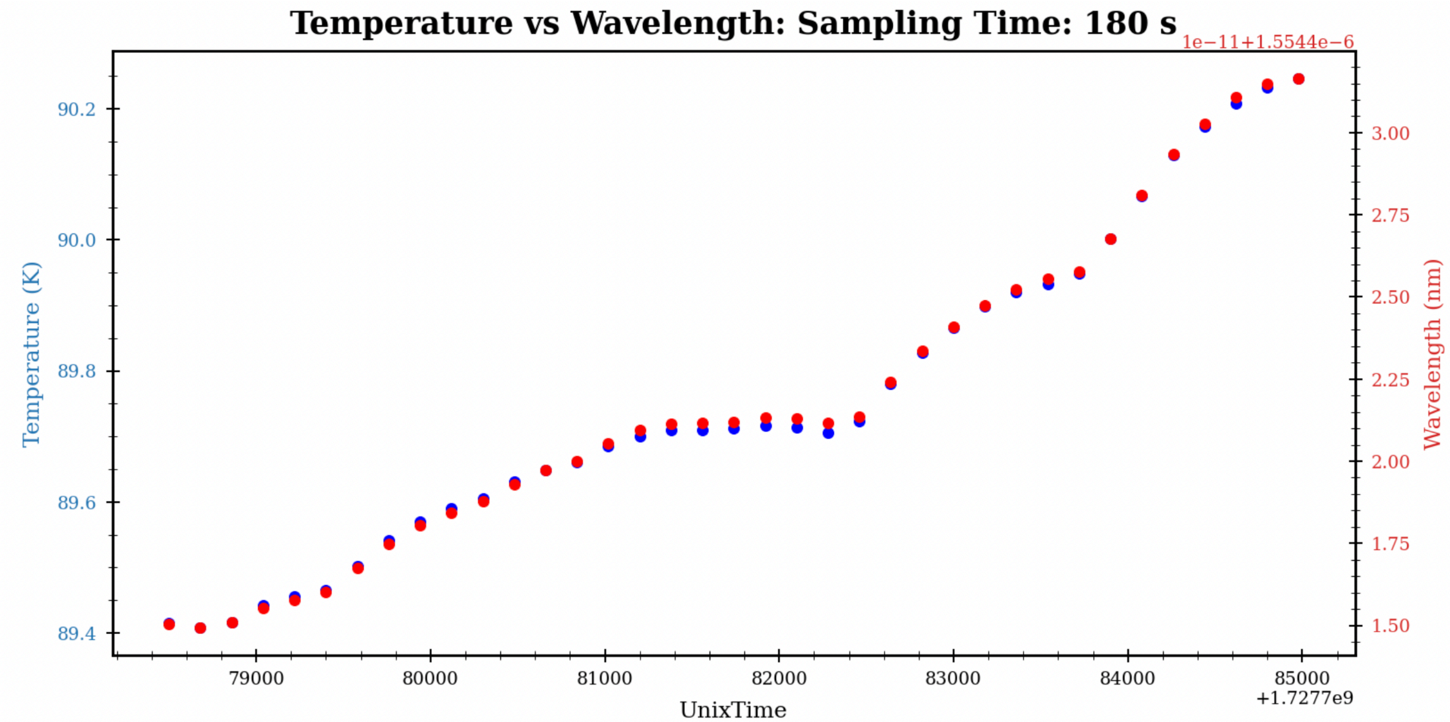




Small temperature-range sensitivity

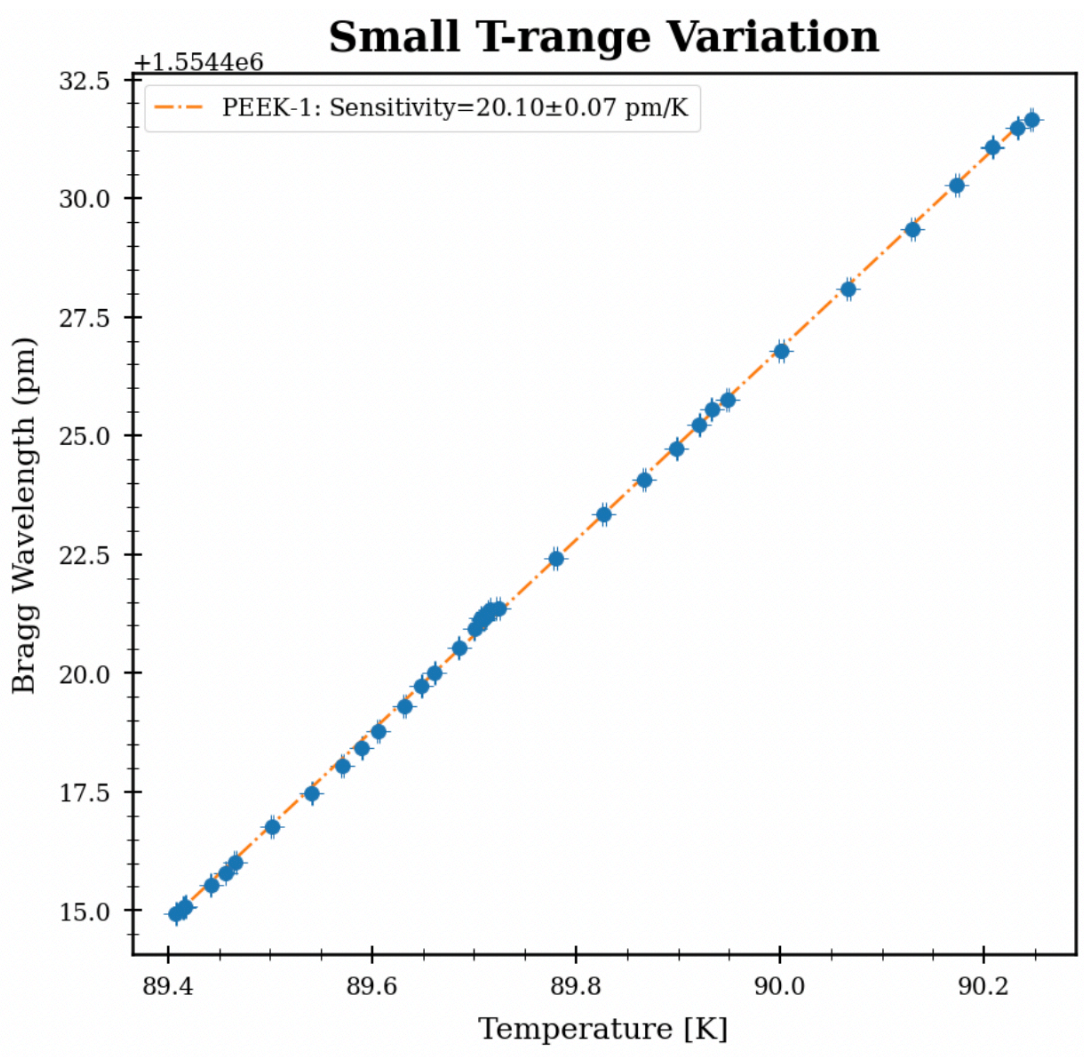
- The ultimate goal is to understand how precisely can an FBG detect an arbitrary temperature change.
- By very slowly vary the temperature, within ~1k range, it is observed how the wavelength profile is very parallel to the RTD profile.
- By downsampling the data (original at **250 Hz**), it is possible to reduce the spread of the curve by a factor sqrt(N).

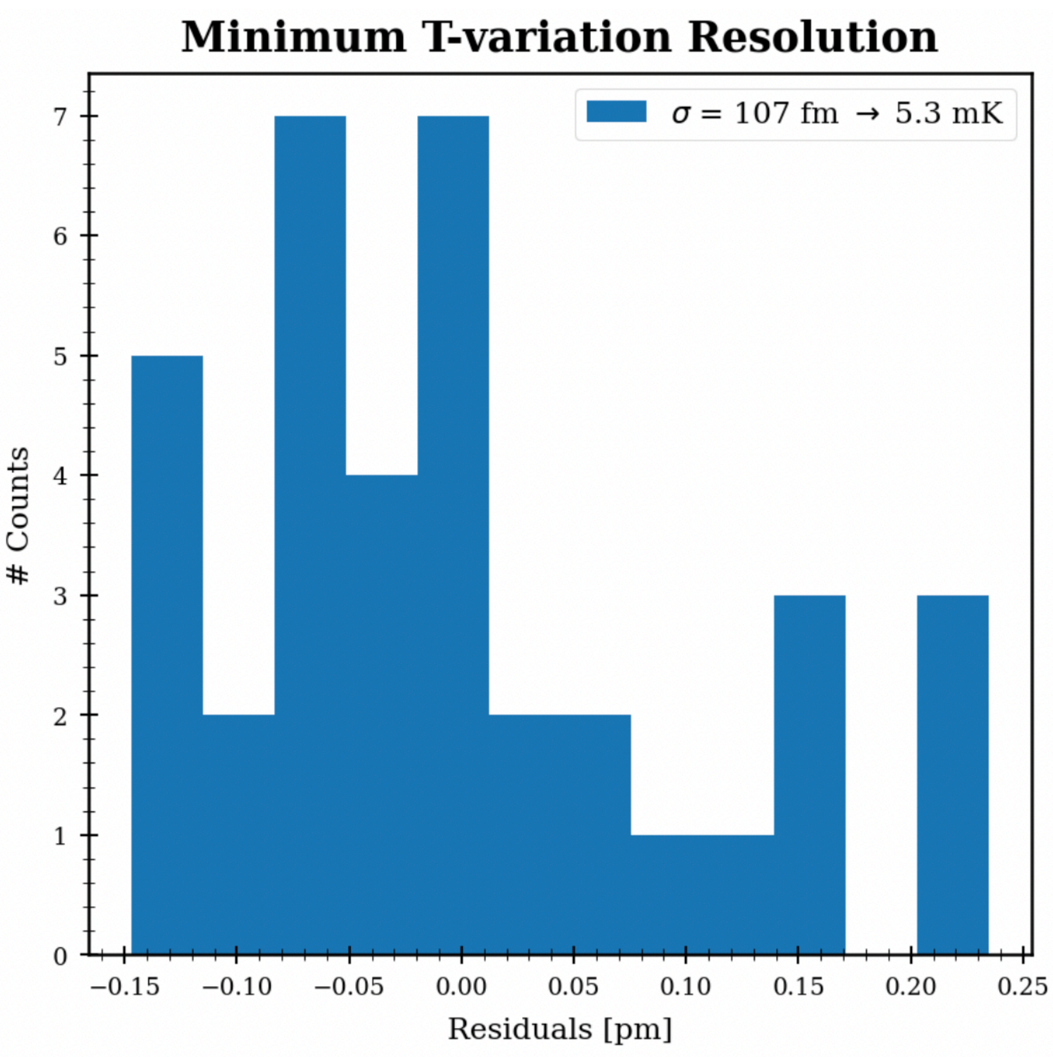




Minimum T-variation detectability

- To estimate the minimum detectable temperature variation, both downsampled curves are plotted one against the other, a line is fitted and the residuals computed.
- The STD of the residuals distribution a **5.3 mK minimum temperature variation detectability**!!



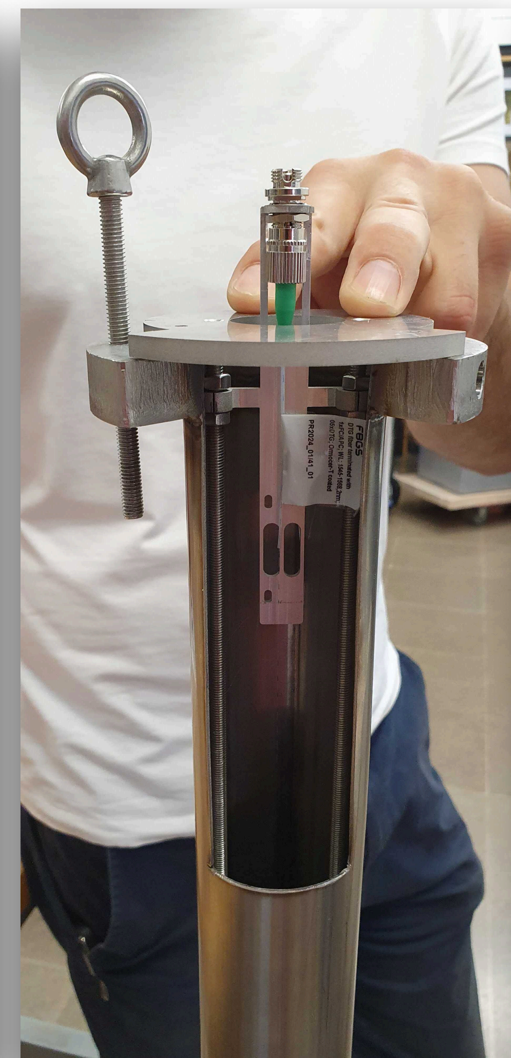


Conclusions on PEEK-coating sensitivity

- The PEEK coating offers sensitivities around ~20.5 pm/K at the LAr temperature.
- There is no significant indication of elastic hysteresis or non-linearities of the PEEK-coating sensitivity under consecutive thermal cycles.
- Temperature changes as smalls as ~5 mK are detectable by monitoring the position of the Bragg peak in the FBGs.
- Considering 20.5 pm/K and a peak resolution (given by the interrogator) of 30 fm, under detector-like conditions it is expected a temperature gradient resolution of ~ 2 mK.
- In the FD-VD design, 3 redundant measurements are taken at every physical point (from 3 independent fibres laying very close) improving the resolution by a factor $\sqrt{3}$ -> ~1.2 mK !!
- The sensitivity chapter about the FBG R&D program is now completed and only small changes are expected to this respect.

The 1.5M Dewar

- The goal of the 1.5M Dewar is to replicate LAr detector-like conditions and study the temperature gradient resolution of FBGs with a setup (sample holder + weight) equivalent to FD.



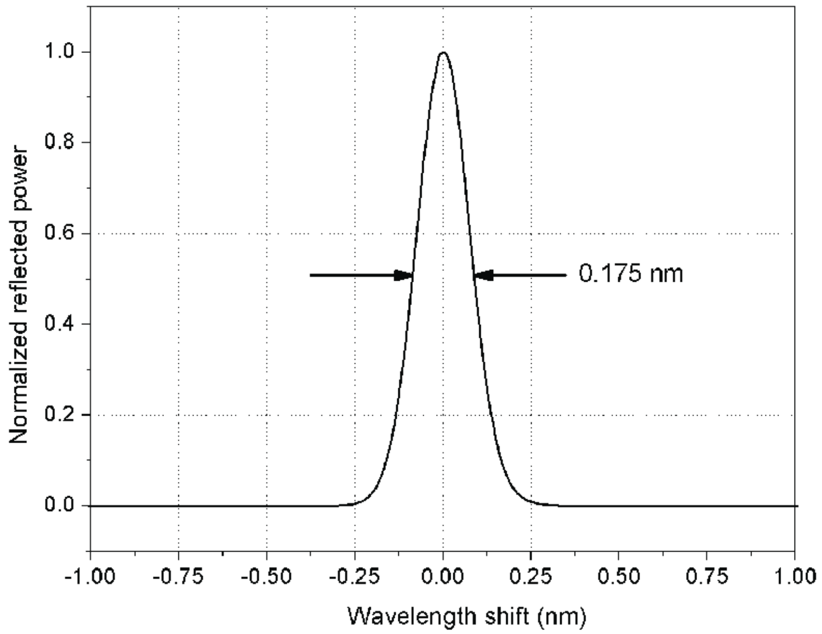
Current activities

- The crane installation has been conducted successfully.
- The load to be lifted fits within the lifting height, that was a major concern for this setup.
- The thermal insulation of the dewar is being carried out after figuring out the issues during the first polyurethane application.

Summary and Next Steps

- We are iterating with the PEEK-coated samples manufacturer to study PEEK coatings with different chemical compositions. Once we understand the possibilities, we will standardise one and proceed with it.
- The R&D now will be focused on the spectra of the Bragg peak, which is what improves the peak finding and therefore the resolution.
- The analysis of the details of the sensitivity studies and the characterisation of more samples with different coatings will help us understand better the effect of other coating properties such as hysteresis, humidity effect, adhesion to buffer…
- Temperature gradient resolution studies will start as soon as the 1.5M Dewar setup is ready (~4 weeks).

Typical FBG spectra



The narrower the peak is, the better the peak is defined

Backup

Fused Silica

	Parameter	Electrically Fused Quartz	Flame Fused Quartz	Fused Silica
Electrical resistivity in $\Omega \times m$	20 °C 400 °C 800 °C 1200 °C	10^{18} 10^{10} 6.3×10^6 1.3×10^5	10^{18} 10^{10} 6.3×10^6 1.3×10^5	10^{16} 10^{10} 6.3×10^6 1.3×10^5
Dielectric strength in KV/mm (sample thickness ≥ 5 mm)	20 °C 500 °C	25 ... 40 4 ... 5	25 ... 40 4 ... 5	25 ... 40 4 ... 5
Dielectric loss angle (tg δ)	1 kHZ 1 MHz 30 GHz	5.0×10^{-4} 1.0×10^{-4} 4.0×10^{-4}	5.0×10^{-4} 1.0×10^{-4} 4.0×10^{-4}	5.0×10^{-4} 1.0×10^{-4} 4.0×10^{-4}
Dielectric constant (ε)	20 °C: 0 ... 10^6 Hz 23 °C: 9×10^8 Hz 23 °C: 3×10^{10} Hz	3.70 3.77 3.81	3.70 3.77 3.81	3.70 3.77 3.81

PTFE

Property	Value
Melting Temperature (°C)	317-337
Tensile Modulus (MPa)	550
Elongation at Break (%)	300-550
Dielectric strength (kV/mm)	19.7
Dielectric Constant	2.0
Dynamic Co-efficient of Friction	0.04
Surface Energy (Dynes/g)	18
Appl. Temperature (°C)	260
Refractive Index	1.35

Get more information about polymer properties here »

226 D. W. Wisander and R. L. Johnson

Table 1

Some Thermal Properties of Material

Components of base materials
(Numbers in parentheses refer to bibliography)

Material	Specific gravity	Average expansion coefficient at *RT*	Expansion coefficient at −320 F	Total contraction 70 to −320 F, % (measured)	Average expansion coefficient 70 to −320 F (calc.)
PTFE	2.33	55×10^{-6}/°F (3)	47.5×10/°F (3)	1.9	48×10^{-6}/°F
Cured epoxy	1.48	$\approx 50 \times 10^{-6}$/°F	—	1.2	32×10^{-6}/°F
Lithium-alumina-silicate	2.40	-3.36×10^{-6}/°F (4)	—	−0.1*	-2.5×10^{-6}/°F
304 Stainless steel	7.9	9.2×10^{-6}/°F (9)	$\approx 3.7 \times 10^{-6}$/°F (9)	0.3	8.2×01^{-6}/°F
Electrolytic copper	8.96	$\approx 8.9 \times 10^{-6}$/°F (6)	$\approx 4.4 \times 10^{-6}$/°F (6)	0.4	9.0×10^{-6}/°F

* Cold-pressed solid body.

Experimental composition
(10% PTFE (8 mesh); 40% diglycidyl ether of bisphenyl-A; 50% lithium-alumina-silicate)

Coefficient of expansion by weight (calc.)	16×10^{-6}/°F
Coefficient of expansion by volume (calc.)	19×10^{-6}/°F
Coefficient of expansion by volume (exp.)	14×10^{-6}/°F

PEEK

TYPICAL PROPERTIES of VIRGIN (UNFILLED) PEEK				
ASTM or UL test	**Property**	**Injection Molded**	**Extruded**	**Compression Molded**
	PHYSICAL			
D792	Density (lb/in³) (g/cm³)	0.048 1.32	0.048 1.32	0.048 1.32
D570	Water Absorption, 24 hrs (%)	0.15	0.10	0.15
	MECHANICAL			
D638	Tensile Strength (psi)	14,500	16,000	15,000
D638	Tensile Modulus (psi)	550,000	500,000	450,000
D638	Tensile Elongation at Break (%)	35	20	10
D790	Flexural Strength (psi)	24,000	25,000	25,000
D790	Flexural Modulus (psi)	600,000	600,000	600,000
D695	Compressive Strength (psi)	17,000	20,000	17,000
D695	Compressive Modulus (psi)	650,000	500,000	450,000
D785	Hardness, Rockwell	M99 / R126	M100 / R126	M99 / R126
D256	IZOD Impact Notched (ft-lb/in)	1.5	1.0	1.0
	THERMAL			
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	2.6	2.6	2.6
D648	Heat Deflection Temp (°F / °C) at 264 psi	320 / 160	320 / 160	320 / 160
D3418	Melting Point Temp (°F / °C)	644 / 340	644 / 340	644 / 340
-	Max Operating Temp (°F / °C)	480 / 249	480 / 249	480 / 249
C177	Thermal Conductivity (BTU-in/ft²-hr-°F) (x 10^{-4} cal/cm-sec-°C)	1.75 6.03	1.75 6.03	1.75 6.03
UL94	Flammability Rating	V-O	V-O	V-O
	ELECTRICAL			
D149	Dielectric Strength (V/mil) short time, 1/8" thick	480	480	480
D150	Dielectric Constant at 1 MHz	3.30	3.30	3.30
D150	Dissipation Factor at 1 MHz	0.003	0.003	0.003
D257	Volume Resistivity (ohm-cm) at 50% RH			

TYPICAL PROPERTIES of EXTRUDED PEEK					
ASTM or UL test	**Property**	**Unfilled**	**30% Glass Fibers**	**30% Carbon Fibers**	**Bearing Grade**
	PHYSICAL				
D792	Density (lb/in³) (g/cm³)	0.047 1.31	0.056 1.54	0.051 1.41	0.052 1.44
D570	Water Absorption, 24 hrs (%)	0.10	0.10	0.06	0.05
	MECHANICAL				
D638	Tensile Strength (psi)	16,000	15,000	19,000	11,000
D638	Tensile Modulus (psi)	500,000	900,000	1,100,000	850,000
D638	Tensile Elongation at Break (%)	20	3	5	2
D790	Flexural Strength (psi)	25,000	28,000	25,750	27,500
D790	Flexural Modulus (psi)	600,000	1,000,000	1,250,000	1,100,000
D695	Compressive Strength (psi)	20,000	26,000	29,000	26,700
D695	Compressive Modulus (psi)	500,000	1,000,000	-	1,000,000
D785	Hardness, Rockwell	M100 (R126)	M103	M102	M85
D256	IZOD Impact Notched (ft-lb/in)	1.0	1.4	1.0	0.7
	THERMAL				
D696	Coefficient of Linear Thermal Expansion (x 10^{-5} in./in./°F)	2.6	1.2	1.0	1.7
D648	Heat Deflection Temp (°F / °C) at 264 psi	320 / 160	600 / 315	550 / 288	383 / 195
D3418	Melting Temp (°F / °C)	644 / 340	644 / 340	644 / 340	-
-	Max Operating Temp (°F / °C)	480 / 249	480 / 249	500 / 260	482 / 250
C177	Thermal Conductivity (BTU-in/ft²-hr-°F) (x 10^{-4} cal/cm-sec-°C)	1.75 6.03	2.98 10.3	6.4 22.0	1.7 5.9
UL94	Flammability Rating	V-0	V-0	V-0	V-0
	ELECTRICAL				
D149	Dielectric Strength (V/mil) short time, 1/8" thick	480	500	32	-
D150	Dielectric Constant at 1 MHz	3.30	3.70	-	-
D150	Dissipation Factor at 1 MHz	0.003	-	-	-
D257	Volume Resistivity (ohm-cm) at 50% RH	4.9 x 10^{16}	5 x 10^{16}	10^{5}	10^{3}