PIÉZOTECH S.A.S. Polymères pyro- et piézoélectriques
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PIEZOELECTRIC FILMS

TECHNICAL INFORMATION

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1. Piezoelectric and pyroelectric effects

Since the discovery in 1880, by the brothers Jacques and Pierre Currie, of the piezoelectric effect shown by the some simple asymmetric crystals, the phenomena has raised a lot of interest.

"Piezoelectricity" finds its roots in the Greek word "piezo" which means pressure. When certain materials are subjected to mechanical stress, electrical charges proportional to the stress appear on their surface. Conversely, when an electric potential difference is applied to these materials, mechanical deformation occurs. This effect is known as **piezoelectricity**. Similarly, when the temperature of the material is changed, an electric potential appears between its terminals: it is called the **pyroelectric** effect.

Quartz and some ceramics are widely used in the manufacture of mechanical and acoustic transducers taking advantage of these phenomena. The surfaces of these materials are small and highly rigid.

2. Piezoelectric films

Kawai was the first one to discover on 1969 a highly noticeable piezoelectric effect on polyvinylidene fluoride (PVDF). This material is the most studied and utilized piezoelectric polymer. However, commercialized piezo films only appeared on the world market in 1981.

Piezoelectricity can be obtained by orienting the molecular dipoles of polar polymers such as PVDF in the same direction by subjecting appropriate films to an intense electric field: **this is polarization**. This polarization is mainly attributable to the spatial arrangement of the segments of the macromolecular chains, and the contribution of the injected charges to the piezoelectric effect is of secondary importance. The polarized electrets are **thermodynamically stable up to about 90℃** .

PVDF is particularly suitable for the manufacture of such films because of its molecular structure (polar material), its purity – which makes it possible to produce thin and regular films – and its ability to solidify in the crystalline form suitable for polarization.

3. Characteristics properties of piezoelectric films

The piezoelectric activity of PVDF films is determined by the coefficients of proportionality between the mechanical causes and the electrical effects.

The coefficients "d" are obtained by measuring the density of charge (Coulomb/m²) which appears on the surfaces of the film (direction 3 = thickness) when a mechanical stress of 1 Newton/m² is applied.

- Depending on the thickness: $\mathbf{d_{33}}$
- In the plane of the film, in the direction of the machine: $\mathbf{d_{31}}$

- In the plane of the film, in the transverse direction: $\mathbf{d_{32}}$

In the first case, if the film cannot be deformed freely in its plane, the piezoelectric constant is called d_{33}* or d_T. The coefficients "d" are expressed in Coulomb/Newton (C/N).

If the variation in the electric field is measured per unit of stress, coefficients "g" are obtained. These are connected with coefficients "d" by the correlation g = d/ε, where ε is the dielectric constant depending on the thickness of the film. Coefficients "g" are expressed in V.m/N.

Constants "g" and "d" are most widely used for the design of electromechanical transducers.

The conversion of mechanical energy into electrical energy is represented by the electromechanical coupling coefficient K_T expressed in %:

$$K_T = \sqrt{\frac{converted\_energy}{input\_energy}}$$

The pyroelectric constant "ρ" is the density of the charge at the surface (C/m²) when the film temperature is raised by 1 degree Kelvin; "ρ" is expressed as C/m²K. The coefficient is used for designing thermal pick-ups.

Furthermore, the films are characterized by their mechanical properties: their modulus of elasticity, resistance and elongation at break.

4. Properties of piezoelectric films and sheets

The range of PVDF piezoelectric films presents a unique combination of properties to the markets:

- Flexibility (possibility of application on non-level surfaces),
- High mechanical strength,
- Dimensional stability,
- Balanced piezoelectric activity in the plane of the film.
- High and stable piezoelectric coefficients over time up to approximately 90℃,
- Characteristic chemical inertness of PVDF,
- Continuous polarization for great length spooled onto drums,
- Thickness between 9µm and 1mm,
- Acoustic impedance close to that of water with a flat response curve.

The characteristic properties of our range of piezoelectric films and sheets, mono or bioriented are given in the table and diagram below. Various type of metallization can be applied to these films, depending on their application.

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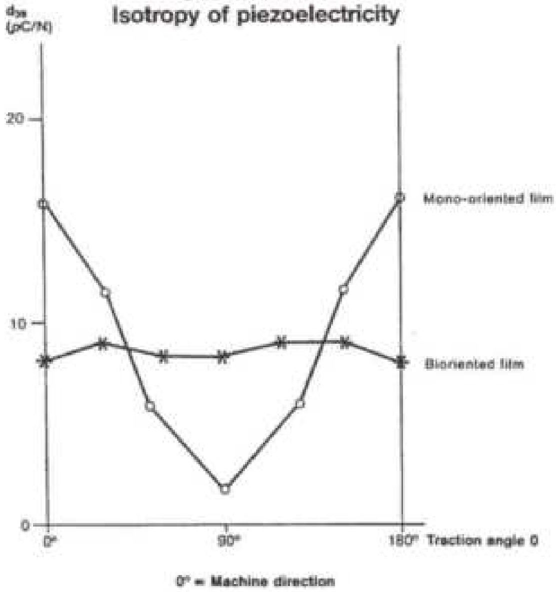
5. Piézotech's PVDF piezoelectric films properties [(1)]

Characteristics	**Bioriented Films**
Nominal thickness (µm)	9 to 50
Thickness regularity (%)	± 10
Poled width of roll (cm)	25
Length of roll (m)	Variable: 5 to > 200
Piezoelectric properties (non metallized films)	**Bioriented Films**
$d_T = d_{33}$*, (10^{-12} C/N)	13 to 22
d_{31}* (10^{-12} C/N)	6 to 10
d_{32}* (10^{-12} C/N)	6 to 10
Regularity of piezoelectric coefficients, (%)	± 10
Variation of the coefficients at metallization, (%)	0 to 15 [(2)]
Relative dielectric constant $\varepsilon/\varepsilon_0$ ($\varepsilon_0 = 8.85.10^{-12}$ F/m), between 50 Hz and 100kHz, T°= 25°C to 90°C	10 to 12
g_{33}* (V.m/N)	0.14 to 0.22
Pyroelectric coefficient, ρ (10^{-6} C/m^2.K)	24 to 26
Transverse resistivity (Ω.cm)	5.10^{14}
Electromechanic coupling factor K_T (%)	10 to 15
Mechanical properties	**Bioriented Films**
Tensile strength (MPa):	
- Machine direction:	60 – 160
- Transverse:	60 – 160
Elongation at break (%):	
- Machine direction:	40 – 140
- Transverse:	40 – 140
Modulus of elasticity (MPa):	
- Machine direction:	1600 – 2200
- Transverse:	1600 – 2200
Shrinkage after 1 hour, Oven at 160°C (%):	
- Machine direction:	2 – 15
- Transverse:	1 – 13
Shrinkage after 100 hour, Oven at 80°C (%):	
- Machine direction:	2 – 3
- Transverse:	N.A.

(1): This range is experimental and susceptible to changes.
(2): Excessive heating may destroy piezoelectricity. It is advised not to heat above 90°C for more that 1 h our.



6. Properties of mono-oriented piezo sheets*

Dimensions	Mono-oriented Films
Nominal thickness (mm)	0.5 to 1
Width, (mm)	
- Sheet 1mm thick:	100
- Sheet 0.5mm thick:	140
Length (mm)	Up to 330
Mechanical properties	**Mono-oriented Films**
Density (kg/m^3), ρ:	1.8
Speed of sound, C_p^E:	1400
Tangent loss angle (%), tg(δ_m)	5
Acoustic impedance (10^6 kg/m^2.s), z_0	2.5
Acoustic compliances (10^{-10} m^2/N):	
- S_{11}^E (at f = 15 kHz):	2.7
- S_{22}^E (at f = 15 kHz):	2.7
- S_{33}^E (at f = 15 kHz):	-1
Electrical properties	**Mono-oriented Films**
Electrodes:	
Thickness for deposition layer Cr/Al (Å):	400
Relative permittivity, ε_r (at f = 1 kHz):	12
Tangent loss angle, (%), tg(δ_e):	1.8

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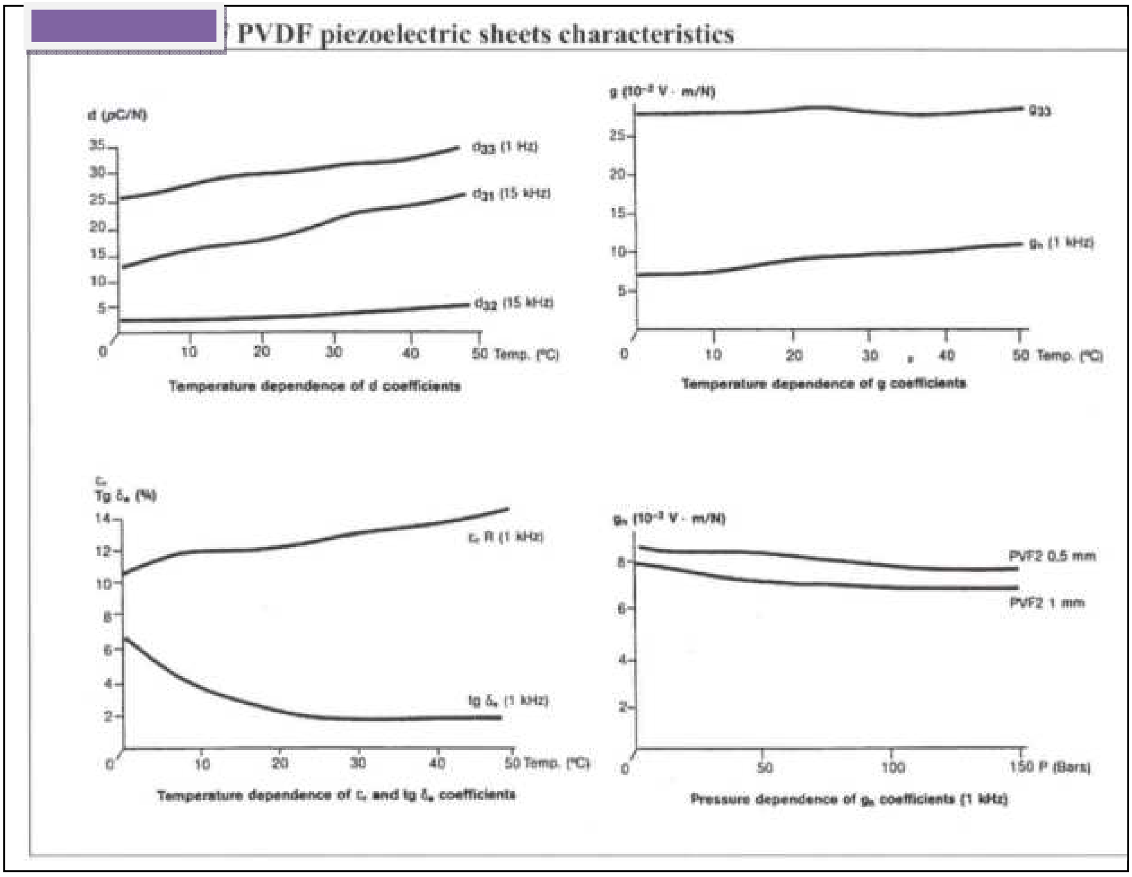
Piezoelectric properties	Mono-oriented Films
Piezoelectric strength constant, d_{33} (at f = 1 kHz), in C/N	30.10^{-12}
Piezoelectric strength constant, d_{31} (at f = 1 kHz), in C/N	-18.10^{-12}
Piezoelectric strength constant, d_{32} (at f = 1 kHz), in C/N	-3.10^{-12}
Electromechanical coupling constant, k_{31} at (f = 15 kHz) in %	10
Electromechanical coupling constant, k_{32} at (f = 15 kHz) in %	1.9



7. Field of applications

The properties of PVDF piezoelectric films suggest that they can be considered for developments in numerous fields of applications where experimentation shows encouraging results. The rate of development of such applications will increase with a wider range of film available in large quantities at competitive prices.

7.1 Example of application

- Acoustic components:
  - Microphones
  - Ultrasonic detector
  - Hydrophones
  - Sonars
- Electrical equipments:
  - Switches
  - Miniature electric fans
- Medical instrumentation:
  - Catheter
  - Pedobarography
  - Osteogenesis
  - Medical echography
  - Blood pressure detector
- Robotics:
  - Artificial sensitive skin
  - Pressure sensors
- Security devices:
  - Intruder alarm
  - IR alarms
  - Vibration sensors
- Optical devices:
  - Laser diameter measurement
  - Variable mirrors
- Transports:
  - Automotive detection on roads
  - Weighing vehicles
- Pressure pick-ups:
  - Distribution of pressure on surfaces
  - Localization of impacts
  - Pick-ups for non destructive testing
  - Accelerometer
  - Keyboards
- Sport and leisure:
  - Tennis court line
  - Display panel on sport grounds
  - Impact detector if shooting targets

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7. Examples of Data Sheets of various piezoelectric films

BIORIENTED FILM – 9 µm (± 5%) THICKNESS TECHNICAL DATASHEET	
Piezo/Pyroelectric Properties (at 23°C)	
d_{33} (pC/N)	16 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.15 ± 20%
p_3 (µC/m^{2}K)	-20 ± 25%
Dielectric properties (at 23°C)	
ε_r	
- at 0.1 kHz,	11.5 ± 10%
- at 1 kHz,	11.5 ± 10%
- at 10 kHz,	11 ± 10%
tan δ	
- at 0.1 kHz,	0.010 ± 10%
- at 1 kHz,	0.015 ± 10%
- at 10 kHz,	0.035 ± 10%
DC breakdown voltage	750 ± 30%
Mechanical properties (at 23°C)	
Young's modulus (MPa)	
- machine direction,	2500 ± 20%
- transverse direction,	2500 ± 20%
Tensile strength at break (MPa)	
- machine direction,	175 ± 15%
- transverse direction,	190 ± 15%
Elongation at break (%)	
- machine direction,	50 ± 30%
- transverse direction,	50 ± 30%
Thermal properties (at 23°C)	
Melting point (°C)	175 ± 5%
Transverse direction	90 - 100

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MONO-ORIENTED FILM – 25 µm (± 5%) THICKNESS
TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	15 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	1 ± 20%
g_{33} (V.m/N) at 1kHz	0.14 ± 20%
p_3 (µC/m^{2}K)	-25 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	11.5 ± 10%
- at 1 kHz,	11.5 ± 10%
- at 10 kHz,	11 ± 10%
tan δ	
- at 0.1 kHz,	0.010 ± 10%
- at 1 kHz,	0.015 ± 10%
- at 10 kHz,	0.035 ± 10%
DC breakdown voltage	670 ± 30%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	3200 ± 20%
- transverse direction,	3200 ± 20%
Tensile strength at break (MPa)	
- machine direction,	240 ± 15%
- transverse direction,	60 ± 15%
Elongation at break (%)	
- machine direction,	20 ± 30%
- transverse direction,	5 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	175 ± 5%
Transverse direction	90 - 100

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BIORIENTED FILM – 40 µm (± 5%) THICKNESS TECHNICAL DATASHEET	
Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	15 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.14 ± 20%
p_3 (µC/m^{2}K)	-19 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	11.5 ± 10%
- at 1 kHz,	11.5 ± 10%
- at 10 kHz,	11 ± 10%
tan δ	
- at 0.1 kHz,	0.010 ± 10%
- at 1 kHz,	0.015 ± 10%
- at 10 kHz,	0.035 ± 10%
DC breakdown voltage	540 ± 30%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	2500 ± 20%
- transverse direction,	2500 ± 20%
Tensile strength at break (MPa)	
- machine direction,	170 ± 15%
- transverse direction,	190 ± 15%
Elongation at break (%)	
- machine direction,	50 ± 30%
- transverse direction,	50 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	175 ± 5%
Transverse direction	90 - 100

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P(VDF-TrFE) COPOLYMER 75/25 FILM – 12 µm (± 5%) THICKNESS TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	16 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.15 ± 20%
p_3 (µC/m^{2}K)	-20 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	9.4 ± 10%
- at 1 kHz,	9.3 ± 10%
- at 10 kHz,	9.1 ± 10%
tan δ	
- at 0.1 kHz,	0.014 ± 10%
- at 1 kHz,	0.014 ± 10%
- at 10 kHz,	0.028 ± 10%
DC breakdown voltage	575 ± 30%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	950 ± 20%
- transverse direction,	1500 ± 20%
Tensile strength at break (MPa)	
- machine direction,	90 ± 15%
- transverse direction,	30 ± 15%
Elongation at break (%)	
- machine direction,	150 ± 30%
- transverse direction,	30 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	150 ± 5%
Curie Temperature (℃)	135 ± 5%
Transverse direction	90 - 100

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P(VDF-TrFE) COPOLYMER 75/25 FILM – 25 µm (± 5%) THICKNESS
TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	15 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.18 ± 20%
p_3 (µC/m^{2}K)	-19 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	9.6 ± 10%
- at 1 kHz,	9.4 ± 10%
- at 10 kHz,	9.2 ± 10%
tan δ	
- at 0.1 kHz,	0.015 ± 10%
- at 1 kHz,	0.016 ± 10%
- at 10 kHz,	0.032 ± 10%
DC breakdown voltage	395 ± 30%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	1000 ± 20%
- transverse direction,	1200 ± 20%
Tensile strength at break (MPa)	
- machine direction,	60 ± 15%
- transverse direction,	20 ± 15%
Elongation at break (%)	
- machine direction,	300 ± 30%
- transverse direction,	300 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	150 ± 5%
Curie Temperature (℃)	135 ± 5%
Transverse direction	90 - 100

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P(VDF-TrFE) COPOLYMER 75/25 FILM – 50 µm (± 5%) THICKNESS
TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	15 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.18 ± 20%
p_3 ($\mu C/m^2K$)	-19 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	9.6 ± 10%
- at 1 kHz,	9.4 ± 10%
- at 10 kHz,	9.2 ± 10%
tan δ	
- at 0.1 kHz,	0.015 ± 10%
- at 1 kHz,	0.016 ± 10%
- at 10 kHz,	0.032 ± 10%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	1000 ± 20%
- transverse direction,	1200 ± 20%
Tensile strength at break (MPa)	
- machine direction,	40 ± 15%
- transverse direction,	30 ± 15%
Elongation at break (%)	
- machine direction,	400 ± 30%
- transverse direction,	450 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	150 ± 5%
Curie Temperature (℃)	135 ± 5%
Transverse direction	90 - 100

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P(VDF-TrFE) COPOLYMER 75/25 FILM – 110 µm (± 5%) THICKNESS TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	15 ± 20%
d_{31} (pC/N)	6 ± 20%
d_{32} (pC/N)	6 ± 20%
g_{33} (V.m/N) at 1kHz	0.18 ± 20%
p_3 (µC/m^{2}K)	-19 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- at 0.1 kHz,	9.6 ± 10%
- at 1 kHz,	9.4 ± 10%
- at 10 kHz,	9.2 ± 10%
tan δ	
- at 0.1 kHz,	0.015 ± 10%
- at 1 kHz,	0.016 ± 10%
- at 10 kHz,	0.032 ± 10%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	
- machine direction,	1000 ± 20%
- transverse direction,	1200 ± 20%
Tensile strength at break (MPa)	
- machine direction,	40 ± 15%
- transverse direction,	30 ± 15%
Elongation at break (%)	
- machine direction,	400 ± 30%
- transverse direction,	450 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	150 ± 5%
Curie Temperature (℃)	135 ± 5%
Transverse direction	90 - 100

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P(VDF-TrFE) COPOLYMER 70/30 FILM – 20 µm (± 10%) THICKNESS TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	-20 ± 10%
d_{31} (pC/N)	6 ± 10%
d_{32} (pC/N)	6 ± 10%
g_{33} (V.m/N) at 1kHz	0.2 ± 20%
Dielectric properties (at 23℃)	
ε_r - From 10 Hz to 1kHz	8 ± 10%
tan δ - at 1 kHz	0.016 ± 10%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	1000 ± 20%
Tensile strength at break (MPa)	60± 15%
Elongation at break (%)	60 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	156 ± 5%
Curie Temperature (℃)	112 ± 5%
Maximal temperature (℃)	95

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P(VDF-TrFE) COPOLYMER 70/30 FILM – 25 µm (± 10%) THICKNESS TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23°C)	
d_{33} (pC/N)	-20 ± 10%
d_{31} (pC/N)	6 ± 10%
d_{32} (pC/N)	6 ± 10%
g_{33} (V.m/N) at 1kHz	0.2 ± 20%
Dielectric properties (at 23°C)	
ε_r - From 10 Hz to 1kHz	8 ± 10%
tan δ - at 1 kHz	0.016 ± 10%
Mechanical properties (at 23°C)	
Young's modulus (MPa)	1000 ± 20%
Tensile strength at break (MPa)	60± 15%
Elongation at break (%)	60 ± 30%
Thermal properties (at 23°C)	
Melting point (°C)	156 ± 5%
Curie Temperature (°C)	112 ± 5%
Maximal temperature (°C)	95

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P(VDF-TrFE) COPOLYMER 70/30 FILM – 40 µm (± 10%) THICKNESS TECHNICAL DATASHEET	
Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	-20 ± 10%
d_{31} (pC/N)	6 ± 10%
d_{32} (pC/N)	6 ± 10%
g_{33} (V.m/N) at 1kHz	0.2 ± 20%
Dielectric properties (at 23℃)	
ε_r - From 10 Hz to 1kHz	8 ± 10%
tan δ - at 1 kHz	0.016 ± 10%
Mechanical properties (at 23℃)	
Young’s modulus (MPa)	1000 ± 20%
Tensile strength at break (MPa)	60± 15%
Elongation at break (%)	60 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	156 ± 5%
Curie Temperature (℃)	112 ± 5%
Maximal temperature (℃)	95

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P(VDF-TrFE) COPOLYMER 77/23 FILM – 6 µm (± 10%) THICKNESS TECHNICAL DATASHEET

Piezo/Pyroelectric Properties (at 23℃)	
d_{33} (pC/N)	-19 ± 10%
d_{31} (pC/N)	6 ± 10%
d_{32} (pC/N)	6 ± 10%
g_{33} (V.m/N) at 1kHz	0.2 ± 20%
P_3 (µC/m²K)	-20 ± 25%
Dielectric properties (at 23℃)	
ε_r	
- From 10 Hz to 1kHz	9.4 ± 10%
tan δ	
- at 1 kHz	0.016 ± 10%
Mechanical properties (at 23℃)	
Young's modulus (MPa)	950 ± 20%
Tensile strength at break (MPa)	30± 15%
Elongation at break (%)	30 ± 30%
Thermal properties (at 23℃)	
Melting point (℃)	150 ± 5%
Curie Temperature (℃)	135 ± 5%
Maximal temperature (℃)	120