



1-3 Piezo Composites & Transducers for Ultrasound Applications

Arrange&Fill 1-3 Piezo Fiber Composites

Dice&Fill 1-3 Piezo Composites

for SONAR, NDT, MEDICAL

Transducer Design Services



www.smart-material.com

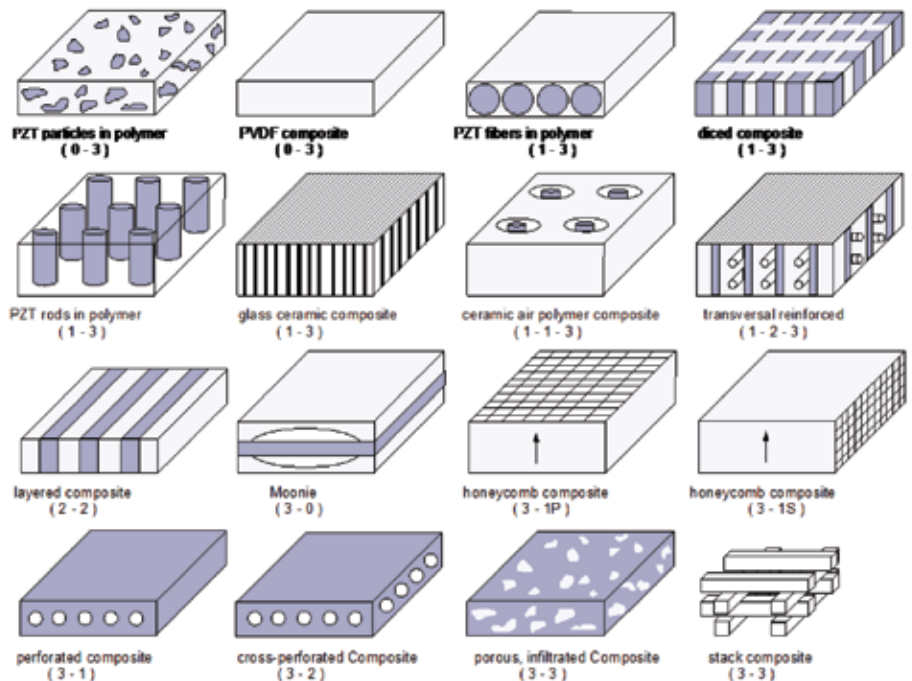
What is a 1-3 Piezo Composite?

1-3 Piezo Composites have become the material of choice for many high performance ultrasound transducer since invented by R.E. Newnham and L.E. Cross in the late 1970's.

A variety of piezocomposite materials can be made by combining piezo ceramic elements with a polymer. Piezo composites are classified according to their connectivity, defined as the number of dimensions through which the material is continuous. It is conventional for the first digit to refer to the piezoelectrically active phase.

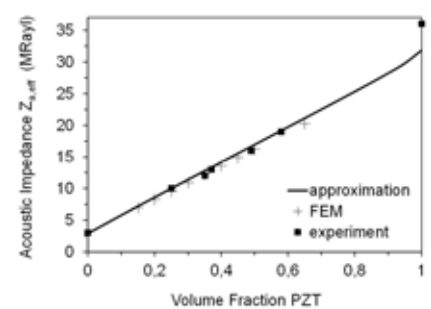
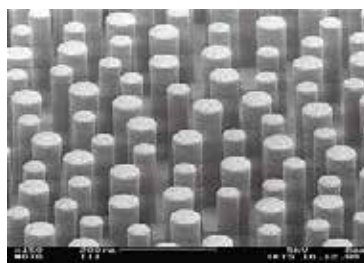
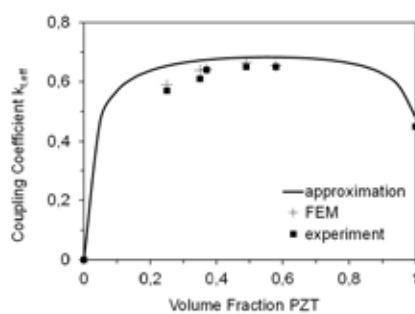
Prof. Newnham defined the family of interconnectivity of piezo electric composites as shown in the schematics. Today, the majority of piezo composites on the market are with the 1-3 and 2-2 connectivity used in ultrasound transducers, actuators and sensors.

Piezo composite materials offer additional design parameters over bulk piezo ceramics. Major acoustic parameters such as acoustic impedance, bandwidth, receiver sensitivity or electric source capacitance can now be easily adjusted by combining different piezo ceramic and polymer mate-



rials with different fill factors. Furthermore, due to the uniaxial dimensions of the piezo electric material, phase lateral clamping effects, sometimes referred to as lateral modes, can be

minimized which allows for much higher coupling coefficients compared with monolithic transducer elements.



Piezo Composite Benefits

- higher coupling coefficients
- better sensitivity
- adjustable acoustic impedance
- built-in bandwidth enhancement
- suppressed lateral modes

Arrange & Fill Technology

Piezo Fiber Composites

Smart Material manufactures piezo electric 1-3 composites using up to 150mm long piezo fibers as active rods.

Our piezo ceramic fibers are manufactured using a textile spinning process.

Next the 1-3 piezo fiber composites are prepared by epoxy infiltration of fiber bundles and cutting of the plate-shaped slices perpendicular to the direction of the fibers. This unique and patented method is also called **Arrange & Fill**.

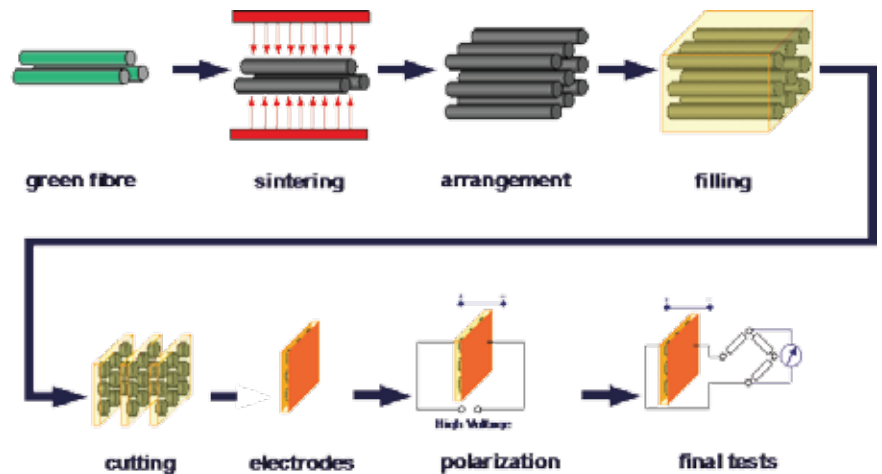
Due to this special manufacturing process the **Arrange & Fill** technology offers both a random fiber distribution as well as composite elements with a regularly distributed

ed fiber pattern.

The overview in the table below lists the most common combinations of the various fiber diameters, frequency range, fill factor and type

of rod distribution.

All composites are available either in Ceramtec's SP505 or SP53 piezo ceramic material.

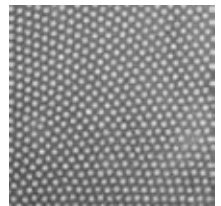


	random	regular
frequency range	40kHz ... 10MHz	40kHz ... 1MHz
available fill factors	Ø 800µm fiber 80%* Ø 250µm fiber 65%* Ø 105µm fiber 35%*	Ø 800 µm fiber 25% ... 48%
acoustic impedance	~14 ... 24 MRayl	~9 ... 16 MRayl
coupling coefficient	~0.65	~0.65
maximum dimensions	60mmx60mm	60mmx60mm
max. temperatures	100°C (130°C HT version)	100°C (130°C HT version)
matrix material	Epoxy / Polyurethane	Epoxy / Polyurethane
available electrodes	1.5µm CuSn ≤ 5MHz ≤ 800nm Au	1.5µm CuSn

* fiber diameter & fill factor depend on frequency



Random Fiber Distribution



Regular Fiber Distribution



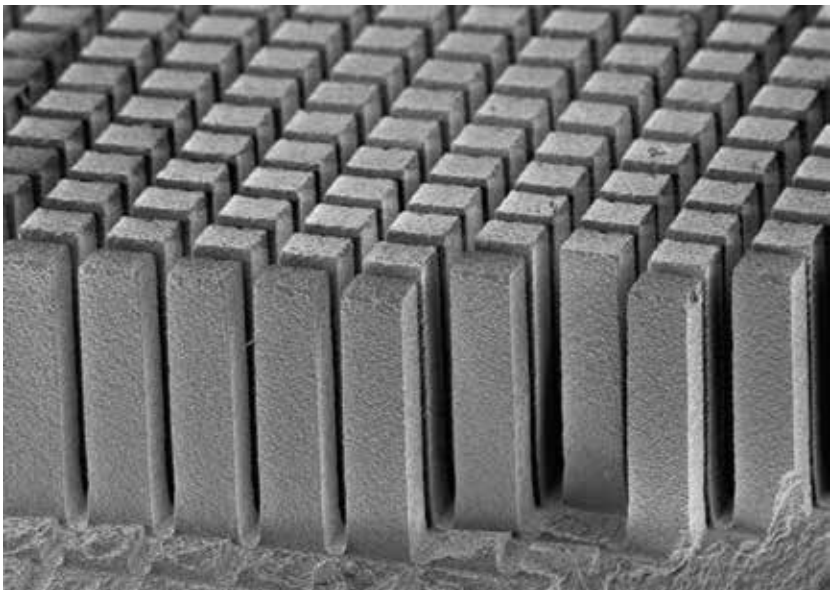
Arrange&Fill Advantages:

- + low frequencies possible
- + only minor lateral modes
- + spurious mode suppression
- + 3D shaping possible
- + cost efficient mass production

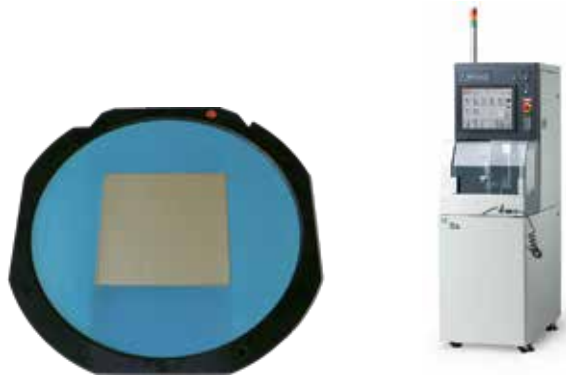
Arrange&Fill Trade-Offs:

- element-to-element variation
- reduced PZT properties in fiber compared with bulk piezo ceramic material

Dice&Fill Technology

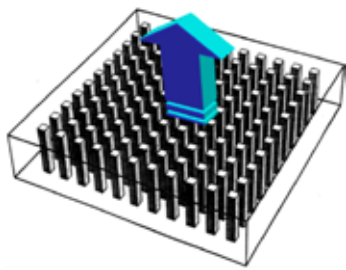
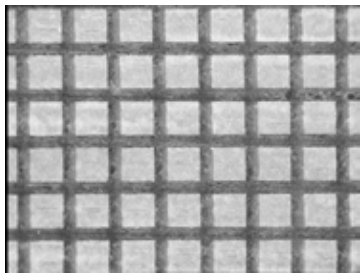


For a 5MHz resonance frequency, for example, it is typically near 100um to avoid lateral and grating modes. The kerfs or trenches are filled with an epoxy or other polymer material. After the interstitial material has cured, the uncut side of the ceramic is grinded down to the rod structure and the thickness is adjusted to the desired resonance frequency. This yields a regular pixel or rod distribution, which is required for phased array ultrasound transducers. Dice&Fill composites are available in APC's 840, 850 or CTS 3203HD piezo ceramic materials.



Smart Material utilizes the **Dice&Fill** method as the second production line to manufacture 1-3 composites. Currently, the **Dice&Fill** method is the industry standard for manufacturing 1-3 piezo composites. For more than 3 decades now, **Dice&Fill** methods have mainly been used for frequencies above 1MHz, especially for medical ultrasound and NDT, including phased arrays for imaging transducers. 1-3 **Dice&Fill** piezo composites are prepared by dicing a piezoceramic plate into an orthogonal array, cutting 80%-90% into the plate thickness. The pitch (distance between rods) must be very small.

Dice&Fill method	
frequency range	500kHz ... 10MHz
available fill factors	45% ... 65%
acoustic impedance	~18 ... 22 MRayl
coupling coefficient	~0.68
maximum dimensions	30mmx30mm / 80mmx80mm
max. temperatures	100°C (130°C HT version)
matrix material	Epoxy / Polyurethane
available electrodes	1.5µm CuSn ≤ 5MHz ≤ 800nm Au



Dice&Fill Advantages:

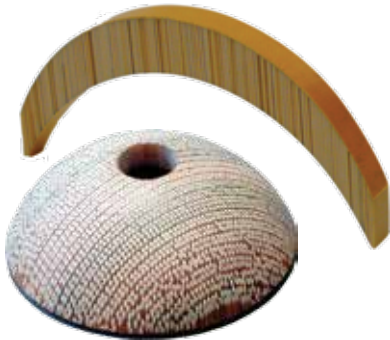
- + low element-to-element tolerance
- + only minor lateral modes
- + adjustable fill factors
- + variable pixel patterns (shading)

Dice&Fill Trade-Offs:

- not for low frequencies < 500kHz
- spurious or lateral modes may occur
- expensive mass production

Advanced Ultrasound Transducers & Arrays

Manufacturing of complex ultrasound transducers elements



3D shaped elements



transducer casting and housing



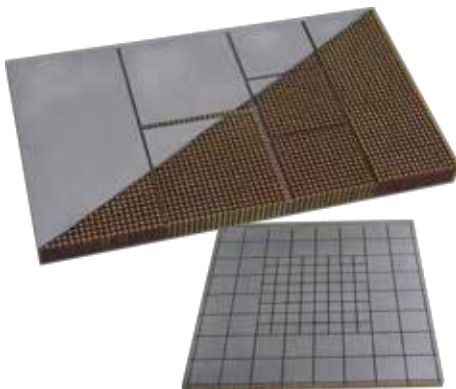
broadband transducers

The unique capabilities of the Arrange & Fill technology, featuring fiber length (rod) off up to 150mm, enables us to manufacture complex, 3-dimensional, and even curved transducer elements. Smart Material's fully equipped, in-house workshop can handle most any shapes that our customers request.

At Smart Material we provide a complete vertical manufacturing service for complex ultrasound transducers. This includes piezo composite element production, machining of backing and matching layers, assembling of the final water proof casting or housing of the transducer.

Smart Material also offers the development, production and assembly of suitable backing and matching materials for our piezo composite materials. This enables an increased bandwidth and reduces insertion losses into the target medium.

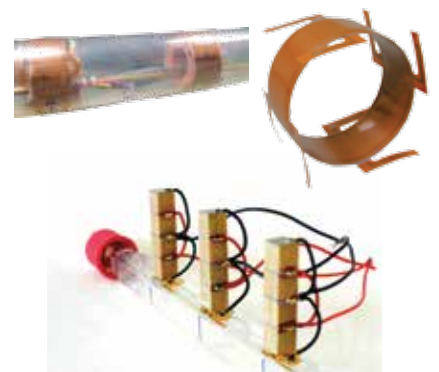
Manufacturing of complex ultrasound transducers elements



Linear receiver arrays



Curved phased array



Low frequency array solutions

Highly sensitive sonar systems require both multiple elements arranged as an array and a composite design that allows for an elastic deformation due to the incoming pressure wave. At Smart Material we use micro spheres filled polymers in combination with a sophisticated assembling to meet these product requirements successfully.

Furthermore, Smart Material is able to provide complex assembling services for array modules in a plane or curved configuration. In cooperation with our customers we develop suitable technologies, manufacturing tools and offering innovative wiring technologies which are often used in other in-house products.

This is especially useful very low frequency applications, most of which often require transducer designs that are typically incompatible with design space or voltage limitations of the amplifiers. As a result Smart Material also offers new composite material approaches (2-2 composite) to increase the overall efficiency of low frequency applications.

Piezo electric materials available for Arrange&Fill and Dice&Fill

			Arrange & Fill Technology ¹		Dice & Fill Technology		
Piezo Characteristics	Symbol	Unit	SP505	SP53	SP4	5A1	5H2
DoD Standard 1376A (SH)			Type II	Type VI	Type I	Type II	Type VI
Electrical Properties							
Permittivity @1kHz	$\epsilon_{33}^T/\epsilon_0$		1850	3600	1274	1900	3800
Dielectric dissipation factor @1kHz	$\tan \delta$		0.015	0.016	0.006	≤ 0.02	0.02
Curie temperature	T_C	°C	335	215	325	360	235
Electromechanical Properties							
Coupling factors	K_p		0.65	0.65	0.59	0.63	0.75
	k_{31}		0.33	0.38	0.35	0.36	0.43
	k_{33}		0.73	0.74	0.72	0.72	0.75
	k_t		0.53	0.51			0.55
	k_{51}		0.71	0.73	0.70	0.68	0.78
Piezoelectric charge coefficients	d_{33}	10^{-12} C/N	475	680	290	400	650
	$-d_{31}$		180	275	125	175	320
	d_{15}		670	770	480	590	
Piezoelectric voltage coefficients	g_{33}	10^{-3} Vm/N	28.5	20.2	26.5	24.8	19.0
Frequency constants	N_L	kHz·mm	1360	1420	1524	1500	
	N_T		1880	1890	2005	2040	2020
	N_P		2010	1960	2130	1980	
Mechanical properties							
Compliance	S_{11}^E	$10^{-12} \text{ m}^2/\text{N}$	17.9	15.8			16.6
	S_{33}^E		24.0	22.9	15.26	18.1	21.0
Stiffness	C_{33}^D	10^{10} N/m^2	14.7	15.2	13.6	11.5	11.0
	C_{55}^D		4.0	6.1			
Mechanical Quality Factor	Q_m		80	75	500	80	30
Vendor					Various Bulk Ceramic suppliers, including APC, CTS, TRS		

¹ PZT fibers (Arrange & fill Technology) do not achieve full bulk material properties due to the fiber manufacturing process and the small dimensions. PZT fibers normally achieve between 65% to 75% of typical bulk material characteristics.

The listed piezo ceramic materials are the standard materials used by Smart Material for the various technologies. Material specifications are for bulk piezo ceramic materials as published by the respective manufacturer.

Other Piezo Ceramic materials are available on request and are treated as custom orders.

1-3 Composite related Questions

Q: What type of electrodes are available for 1-3 Piezo Composite?

A: We offer Copper-Tin (CuSn), Gold (Au) or Silver (Ag) electrodes for our 1-3 composites. All electrodes are applied using a vacuum deposition process and range between 700nm and 1.2 μm in thickness. Our standard electrode is the copper-tin electrode which combines cost effectiveness with electrical properties similar to gold. Soldering wires to CuSn is much easier compared to gold. Our CuSn-electrode is about 1 μm thick with a 500 nm tin-coating as a protective layer to prevent the copper from corroding.

Q: How do I connect wires to electroded 1-3 composites?

A: Most customers report successful soldering of wires to the 1-3 composites using a low temperature solder. Special care should be taken when soldering on a 1-3 composite due to the fact that a considerable area of the composite under the electrode is made of plastic. If the solder iron is too hot or applied too long, the plastic will become soft and the bonding with the sputtered electrode material will fail causing the electrode to come off.

Because of this, special attention should be taken to minimize the contact time between the composite and solder bit. We recommend using a lead-free solder wire with temperatures around 270°C and a contact time less than 0.5 seconds.

If you can not attach the wire to the composite in the first attempt, please give the composite some time to cool down, otherwise this spot will become over-heated and the electrode will fail.

Q: What solders should I use? What is a good solder procedure?

A: Skin the wire from its insulation, plate the stripped length with tin. Use some flux, e.g. "Fludor" to cover the wire tip, take a drop of liquid tin with the solder bit, hold the wire to the solder bit contact the electrode - with both solder bit and wire, remove solder bit, keep wire on electrode, do not apply any loads until the tin has cooled. We recommend the following materials.

Flux: Alpha-Grillo "Fludor"

Wires: stranded, 0,06...0,14 sq.mm or enameled copper wire

Solder wire: leadfree FLUITIN 1532 per ISO 12224-1/1.12,
alloy SAC305 of Cookson Electronics/Alphametals

Q: Can I glue wires to an electroded 1-3 composites?

A: Yes, you can by using a conductive glue for attaching wires to the composites.

Conductive glues allow for a reliable way to connect wires to our 1-3 composites, with comparable and better adhesion as standard soldering.

We recommend the following glues from Epoxy Technology (www.epotek.com):

Epo-Tek 430, Epo-Tek H20E, Epo-Tek EE 129-4.

Q: What is the difference between "dice-and-fill" and "arrange-and-fill" manufacturing methods?

A: Dice-and-fill technique has been around for many years and is more expensive than the arrange-and-fill method used by Smart Material.

Essentially, dice-and-fill begins with a bulk block of PZT, many grooves are diced using a diamond saw, and the grooves are filled with polymer. The extensive cutting is the primary factor in driving up manufacturing cost.

With arrange-and-fill, long strands of fibers are arranged randomly on end, and polymer is poured around them forming a large block of piezo composite. This block can then be diced into different length pieces according to the frequency desired. This translates into a faster, more cost-effective process.



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