Transducción electromecánica II: Materiales, tecnologías y aplicaciones.

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CSIC.

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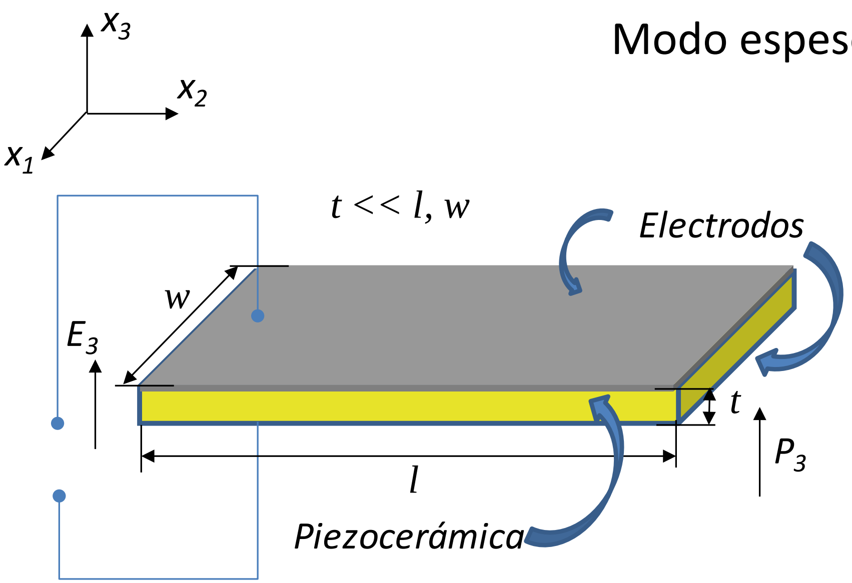
Transducción electromecánica II:
Materiales, tecnologías y aplicaciones.

I. Modos de vibración en sólidos piezoeléctricos simples

Modo espesor (thickness mode)



Condiciones de contorno:

$$\left.\begin{array}{l} \varepsilon_{ij} = 0, \quad \text{excepto: } \varepsilon_{33} \\ \sigma_{33} = 0, \ \text{en } x_3 = 0 \ \text{y} \ x_3 = t \\ D_1 = D_2 = 0, \quad \dfrac{\partial D_3}{\partial x_3} = 0 \end{array}\right\}$$

$$\left.\begin{array}{l} \sigma_{ij} = c^{D}_{ijkl}\,\varepsilon_{kl} - h_{ijl}\,D_l \\ E_k = -h_{ijk}\,\varepsilon_{ij} + \beta^{\varepsilon}_{kl} D_l \end{array}\right\}$$

$$\left.\begin{array}{l} \sigma_{33} = -h_{333}\,D_3 + c^{D}_{3333}\,\varepsilon_{33} \\ E_k = -h_{33k}\,\varepsilon_{33} + \beta^{\varepsilon}_{33} D_3 \end{array}\right\}$$

D. A. Berlincourt, D. R. Curran, H. Jaffe, 3. Piezoelectric and piezomagnetic materials and their function in transducers, en Physical Acoustics Vol. I, parte A. Ed. W. P. Mason. pp. 170-269, Academic Press, New York, 1964.

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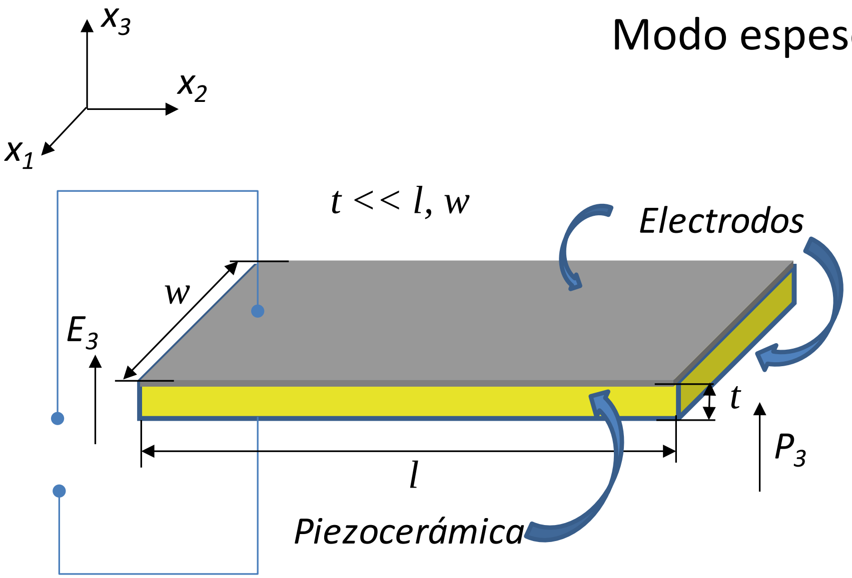

$$\varepsilon_{33} = \frac{\partial u_3}{\partial x_3}, \qquad D_3 = D_0 e^{i\omega t}$$

$$u_3 = \frac{v^D h_{33} D_3}{\omega c_{33}^D}\left[\sin\frac{\omega x_3}{v^D} - \tan\frac{\omega t}{2v^D}\cos\frac{\omega x_3}{v^D}\right]$$

$$Z = \frac{\int_0^t E_3 dx_3}{i\omega l w D_3} = \frac{1}{i\omega C_c}\left[1 - k_t^2\frac{\tan(\omega t/2v^D)}{\omega t/2v^D}\right]$$

$$\left.\begin{aligned} \sigma_{33} &= h_{333}\, D_3 + c_{3333}^D\, \varepsilon_{33} \\ E_k &= h_{33k}\, \varepsilon_{33} + \beta_{33}^{\varepsilon} D_3 \end{aligned}\right\}$$

$$f_a = \frac{v^D}{2t}, \quad k_t^2 = \frac{\pi}{2}\frac{f_r}{f_a}\cot\frac{\pi}{2}\frac{f_r}{f_a}$$

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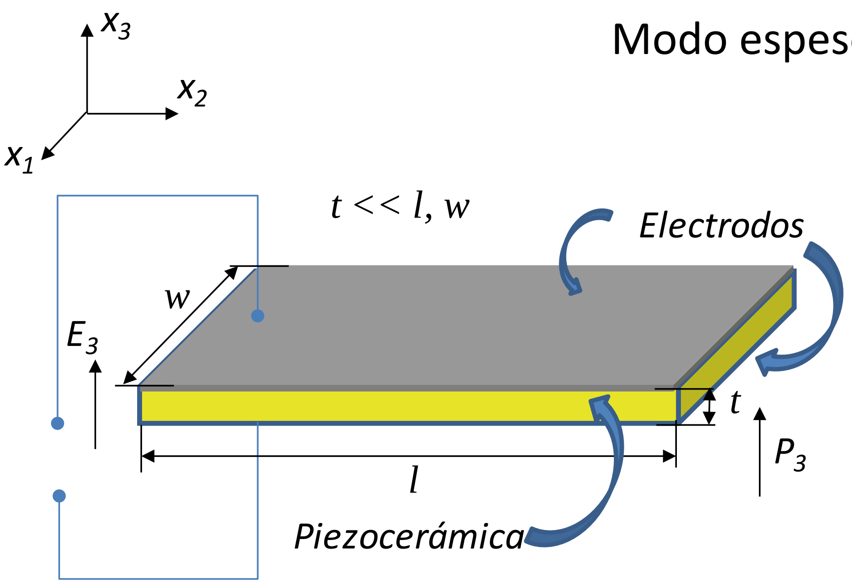

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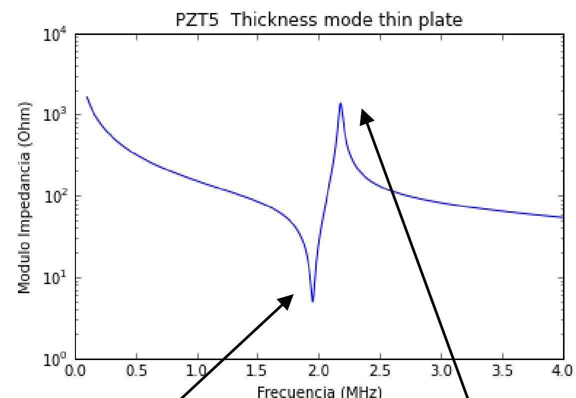

$$\left.\begin{aligned} \sigma_{33} &= h_{333}\, D_3 + c_{3333}^{D}\, \varepsilon_{33} \\ E_k &= h_{33k}\, \varepsilon_{33} + \beta_{33}^{\varepsilon} D_3 \end{aligned}\right\}$$

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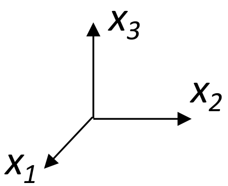
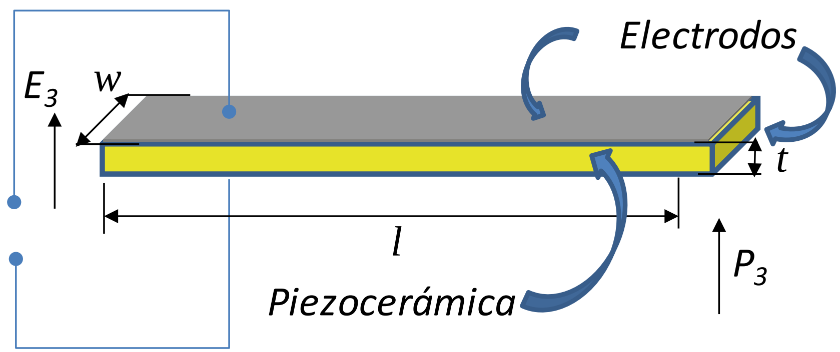


Modo barra $E \perp l$ (length expander mode)

$t\,,\, w << l$



Condiciones de contorno:

$$\left.\begin{array}{ll} \sigma_{ij} = 0, & \text{excepto: } \sigma_{11} \\ E_i = 0, & \text{excepto } E_3 \\ \sigma_{11} = 0, \text{ en } x_1 = 0 \text{ y } x_1 = l & \end{array}\right\}$$

$$\rho \frac{\partial^2 u_1}{\partial t^2} = \frac{\partial \sigma_1}{\partial x_1}$$

$$\left.\begin{array}{l} \varepsilon_{11} = d_{311}\, E_3 + s^E_{1111}\sigma_{11} \\ D_3 = d_{311}\, \sigma_{11} + \epsilon^\sigma_{33} E_3 \end{array}\right\}$$

$$\varepsilon_{11} = \frac{\partial u_1}{\partial x_1}, \qquad E_3 = E_0 e^{i\omega t}, \qquad \frac{\partial E_3}{\partial x} = 0$$

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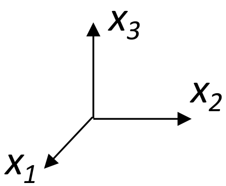

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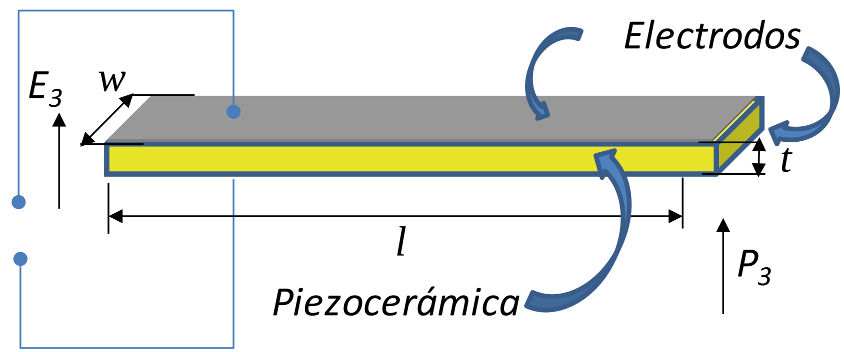

$$u_1 = \frac{v_b^E}{\omega}\left[sin \frac{\omega x_1}{v_b^E} + \frac{[cos(\omega l / v_b^E) - 1]}{sin(\omega l / v_b^E)} cos \frac{\omega x_1}{v_b^E} \right]$$

$$\varepsilon_{11} = \frac{\partial u_1}{\partial x_1},$$

$$\left.\begin{aligned} \varepsilon_{11} &= d_{311}\, E_3 + s_{1111}^E \sigma_{11} \\ D_3 &= d_{311}\, \sigma_{11} + \epsilon_{33}^{\sigma} E_3 \end{aligned}\right\}$$

$$Z = \frac{\int_0^t E_3 dx_3}{w \int_0^t \dot{D}_3 dx_3} = \left(i\omega \frac{lw}{t} \epsilon_{33}^{\sigma} \left[(1 - k_{31}^2) + k_{31}^2 \frac{tan(\omega l / 2 v_b^E)}{\omega t / 2 v_b^E} \right] \right)^{-1}$$

$$tan \frac{\omega l}{2 v_b^E} = \infty, \quad f_r = \frac{v_b^E}{2l}$$

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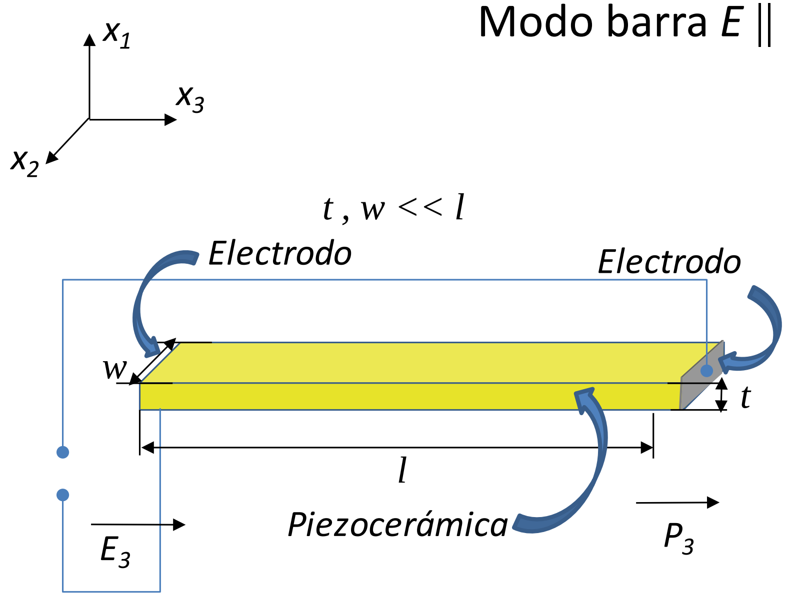
Modo barra $E \parallel l$ (length expander mode)



Condiciones de contorno:

$$\left.\begin{array}{l} \sigma_{ij} = 0, \qquad \text{excepto: } \sigma_{33} \\ D_1 = D_2 = 0, \quad y \ \dfrac{\partial D_3}{\partial x_3} = 0 \\ \sigma_{33} = 0, \ \text{ en } x_3 = 0 \ \text{ y } \ x_3 = l \end{array}\right\}$$

$$\left.\begin{array}{l} \varepsilon_{33} = g_{333} E_3 + s^D_{3333} \sigma_{33} \\ E_3 = -g_{333} \sigma_{33} + \beta^\sigma_{33} D_3 \end{array}\right\}$$

$$\rho \frac{\partial^2 u_3}{\partial t^2} = \frac{1}{s^D_{3333}} \frac{\partial^2 u_3}{\partial^2 x_3}$$

$$u_3 = \frac{v_b^D g_{33} D_3}{\omega}\left[sin\frac{\omega x_3}{v_b^D} - tan\frac{\omega l}{2 v_b^D} cos\frac{\omega x_3}{v_b^D}\right]$$

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I. Modos de vibración en sólidos piezoeléctricos simples

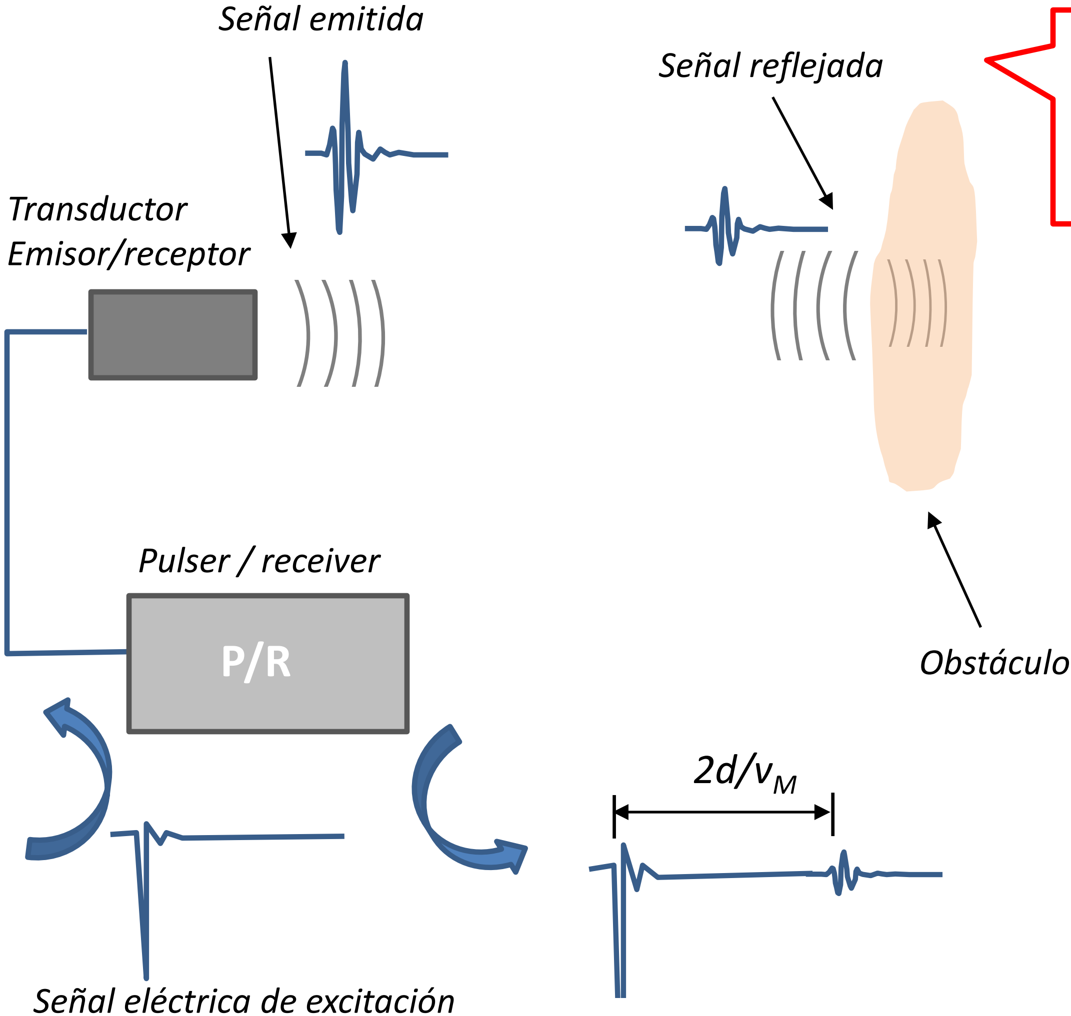
Material Data

SPECIFIC PARAMETERS OF THE STANDARD MATERIALS

				Soft PZT materials			
			Unit	PIC151	PIC255/ PIC252*	PIC155	PIC153
Physical and dielectric properties							
Density		ρ	g/cm³	7.80	7.80	7.80	7.60
Curie temperature		T_c	°C	250	350	345	185
Relative permittivity	in the polarization direction	$\varepsilon_{33}^T/\varepsilon_0$		2400	1750	1450	4200
	⊥ to polarity	$\varepsilon_{11}^T/\varepsilon_0$		1980	1650	1400	
Dielectric loss factor		$\tan\delta$	10^{-3}	20	20	20	30
Electromechanical properties							
Coupling factor		k_p		0.62	0.62	0.62	0.62
		k_t		0.53	0.47	0.48	
		k_{31}		0.38	0.35	0.35	
		k_{33}		0.69	0.69	0.69	
		k_{15}			0.66		
Piezoelectric charge coefficient		d_{31}		-210	-180	-165	
		d_{33}	10^{-12} C/N	500	400	360	600
		d_{15}			550		
Piezoelectric voltage coefficient		g_{31}		-11.5	-11.3	-12.9	
		g_{33}	10^{-3} Vm/N	22	25	27	16
Acousto-mechanical properties							
Frequency coefficients		N_p		1950	2000	1960	1960
		N_1		1500	1420	1500	
		N_3	Hz · m	1750		1780	
		N_t		1950	2000	1990	1960
Elastic compliance coefficient		s_{11}^E		15.0	16.1	15.6	
		s_{33}^E	10^{-12} m²/N	19.0	20.7	19.7	
Elastic stiffness coefficient		c_{33}^D	10^{10} N/m²	10.0		11.1	
Mechanical quality factor		Q_m		100	80	80	50
Temperature stability							
Temperature coefficient of ε_{33}^T (in the range -20 °C to +125 °C)		$TK\,\varepsilon_{33}$	10^{-3}/K	4	4	6	5
Time stability (relative change of the parameter per decade of time in %)							
Relative permittivity		C_ε			-1.0	-2.0	
Coupling factor		C_k			-1.0	-2.0	

https://www.piceramic.com/en/piezo-technology/piezoelectric-materials/#c15193

II. Ultrasonidos, aspectos básicos.



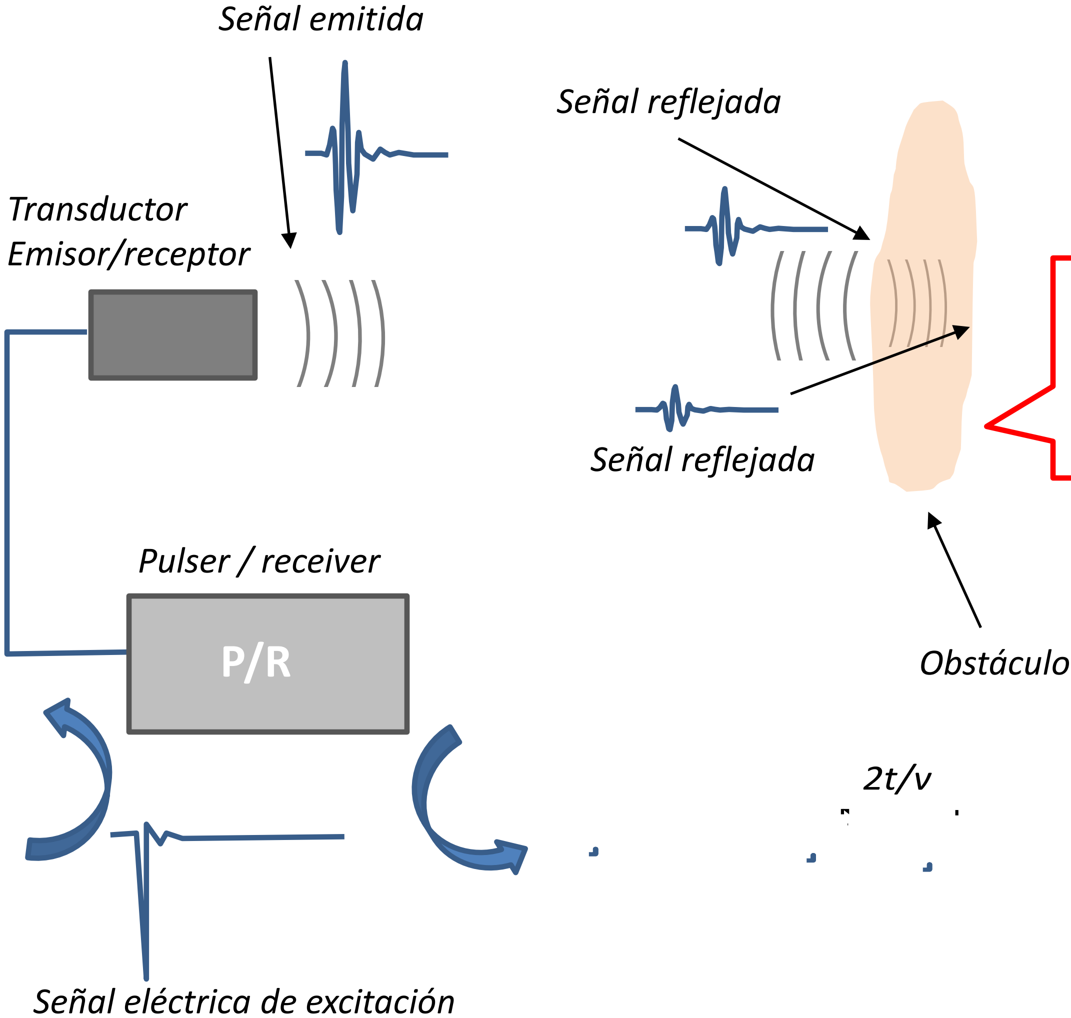
$$R = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$$

R ≡ coeficiente de reflexión ≡ ratio de flujo de energía reflejada a flujo de energía incidente.

Z ≡ Impedancia acústica ≡ ρ v

Material	ρ	v	Z (S.I.)
Agua	1000	1450	1.45×10^6
Grasa	950	1450	1.38×10^6
Cerámica	7000	5000	35.00×10^6
Metal	8000	6000	48.00×10^6
Aire	1.2	340	408

II. Ultrasonidos, aspectos básicos.



$$T = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$

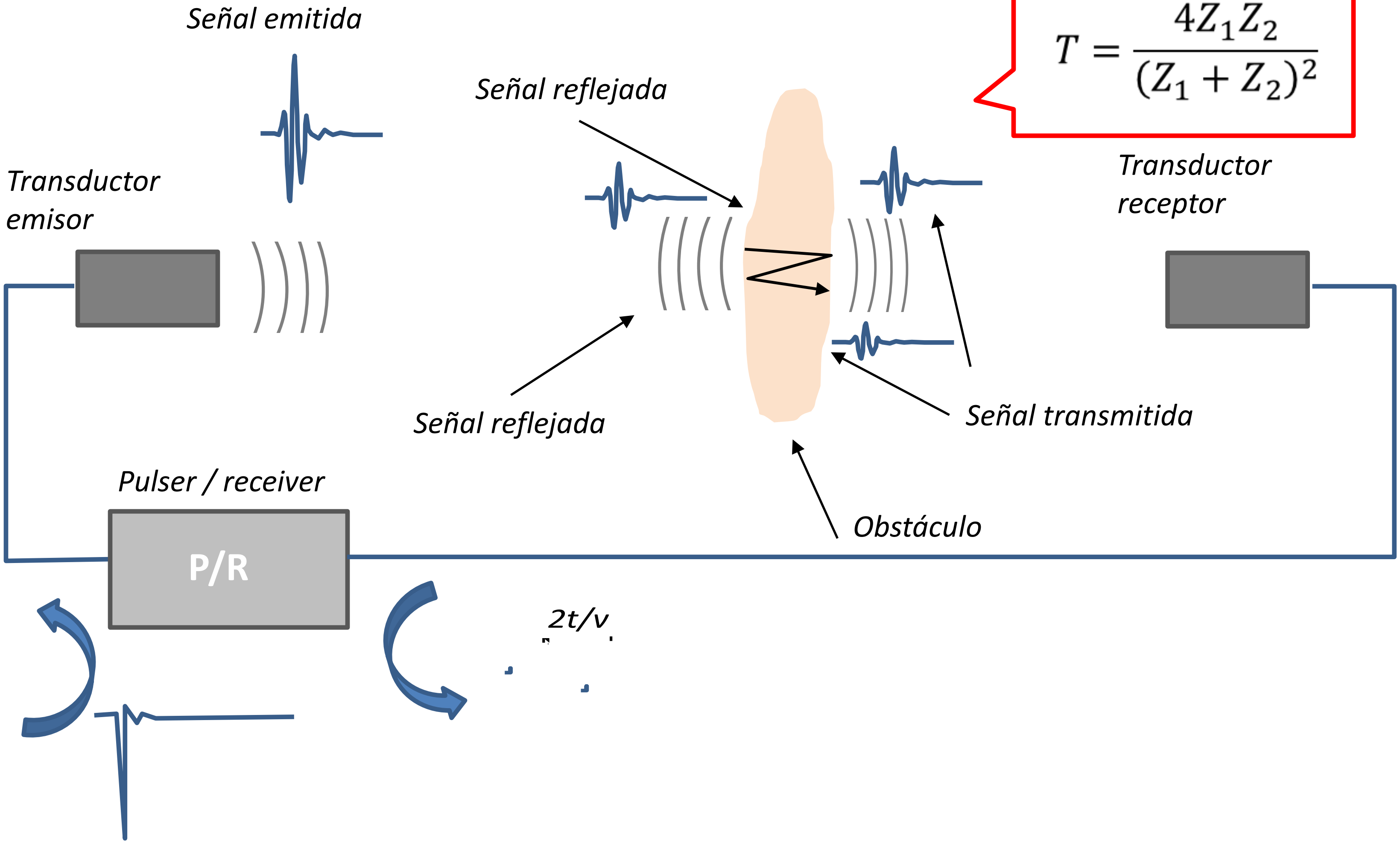
T ≡ coeficiente de transmisión ≡ ratio de flujo de energía transmitida a flujo de energía incidente.

Z ≡ Impedancia acústica ≡ ρ v

R + T = 1

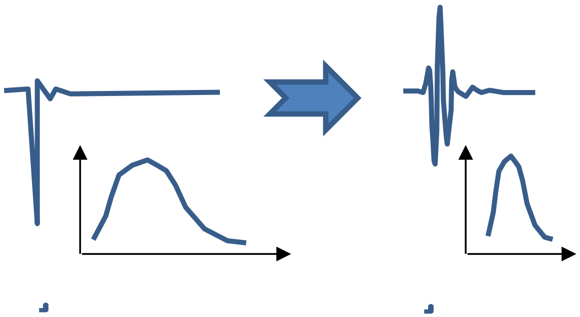
II. Ultrasonidos, aspectos básicos.

$$T = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$



III. El transductor piezoeléctrico para ultrasonidos.

Emisor ultrasonidos: convierte una señal eléctrica en una señal ultrasónica

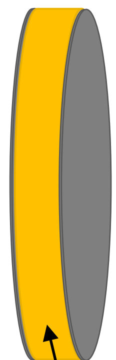


Receptor ultrasonidos: convierte una señal acústica en una eléctrica

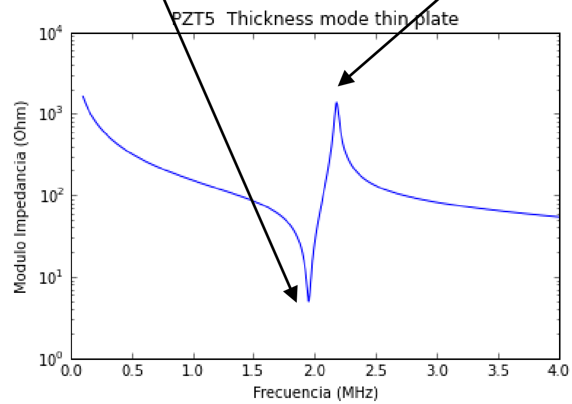
- Frecuencia central, ancho de banda: resolución espacial (axial) y temporal.
- Geometría del campo (plano, focalizado), resolución espacial (lateral).
- Sensibilidad.
- Tipo de onda (longitudinales, cizalla, etc.), tipo de material al que emitir o del que recibir.
- Numero de elementos (monolítico, bicristal, array lineal, array 1.5D, array 2D)
- Propiedades eléctricas: Impedancia, etc.

III.a. El transductor ultrasónico: diseño básico.

$$f_a = \frac{v^D}{2t}, \quad k_t^2 = \frac{\pi}{2}\frac{f_r}{f_a}\cot\frac{\pi}{2}\frac{f_r}{f_a}$$



Piezoeléctrico + electrodos



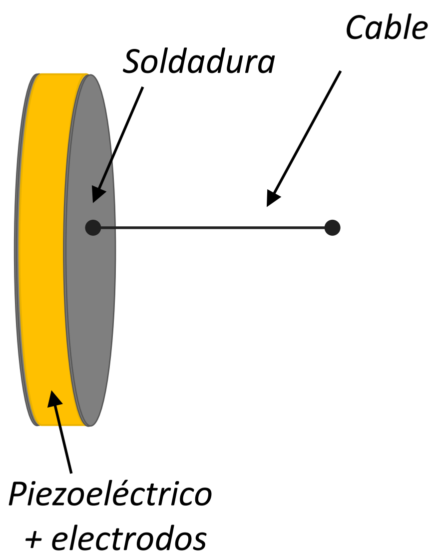
$$\left.\begin{aligned} \sigma_{33} &= -h_{333}\, D_3 + c^D_{3333}\,\varepsilon_{33} \\ E_k &= -\,h_{33k}\,\varepsilon_{33} + \beta^{\varepsilon}_{33} D_3 \end{aligned}\right\} \xrightarrow[P_3]{}$$

$$Z = \frac{1}{i\omega C_c}\left[1 - k_t^2\,\frac{tan(\omega t/2v^D)}{\omega t/2v^D}\right]$$

El espesor del disco y el material determinan la frecuencia central del transductor.

El material piezoeléctrico elegido determina, inicialmente, el ancho de banda del transductor.

III.a. El transductor ultrasónico: diseño básico.



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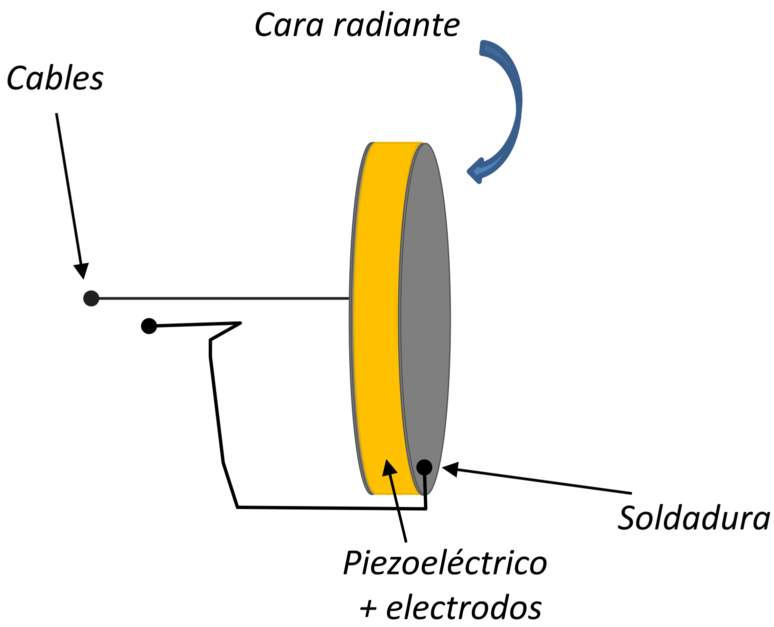

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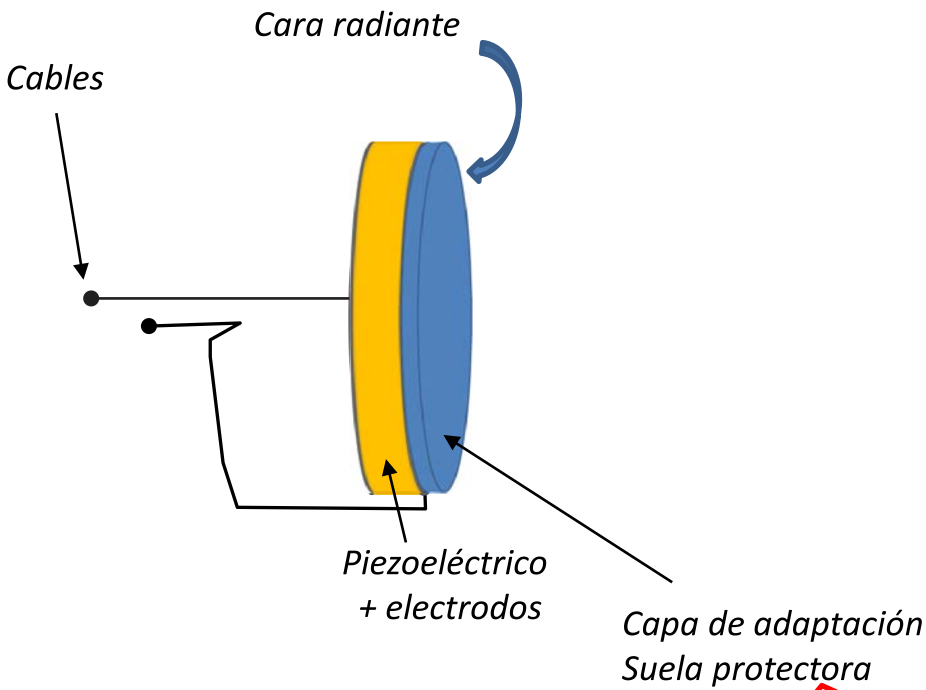
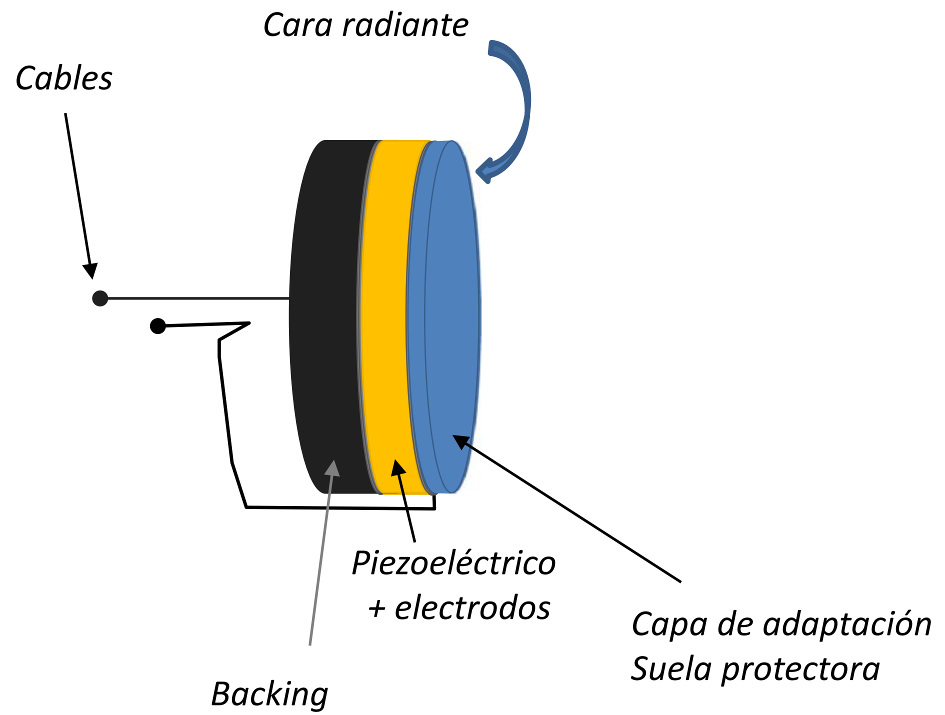


Las capas de adaptación modifican la banda y la sensibilidad. Se pueden emplear capas $\lambda/2$ y $\lambda/4$.

III.a. El transductor ultrasónico: diseño básico.



El backing reduce la sensibilidad y aumenta la banda relativa (6 dB)

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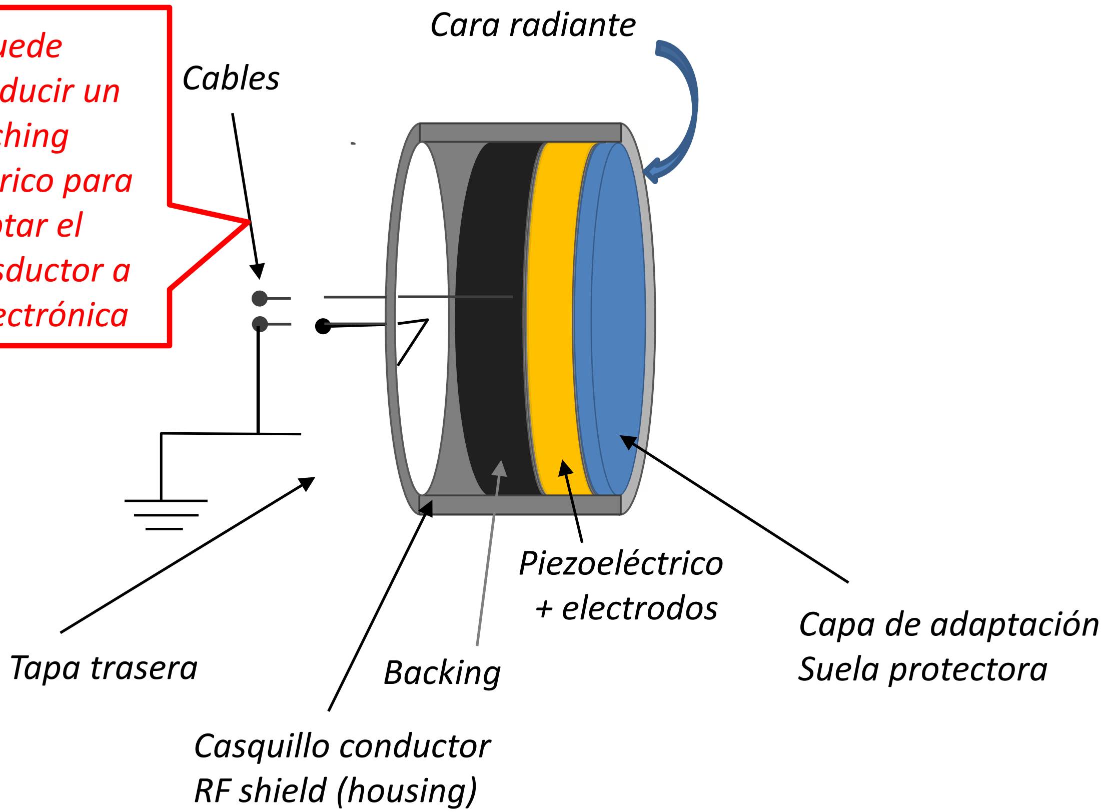
USBIOMAT

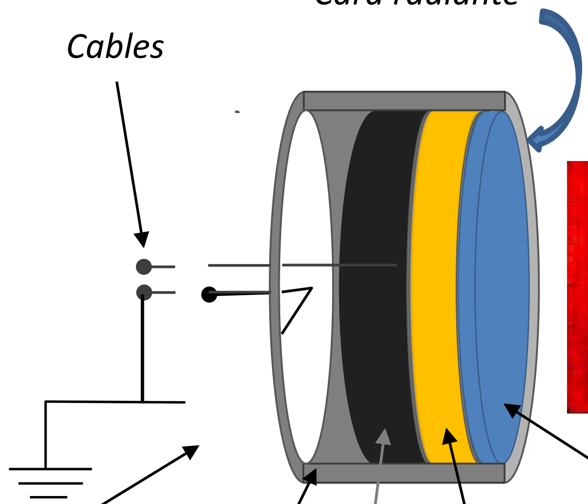
III.a. El transductor ultrasónico: diseño básico.

Se puede introducir un matching eléctrico para adaptar el transductor a la electrónica



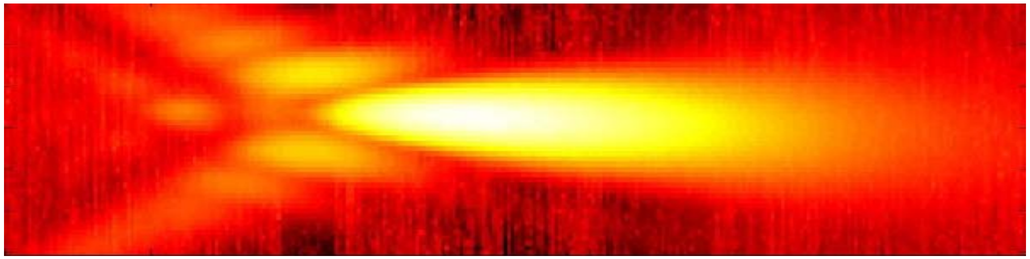
III.a. El transductor ultrasónico: diseño básico.

Caracterización básica : campo acústico, respuesta impulsiva, impedancia eléctrica

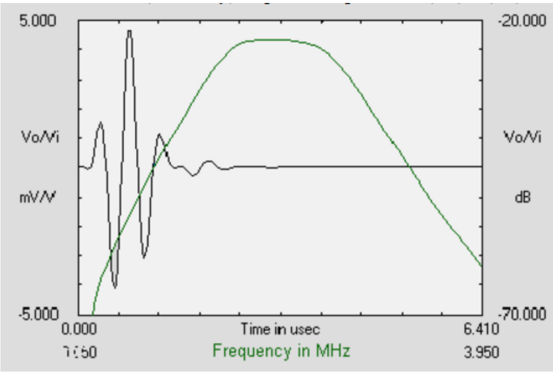


Campo acústico

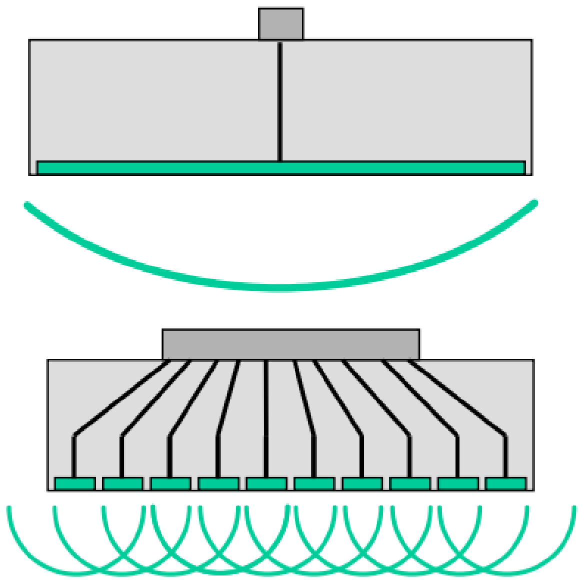
Campo próximo a^2/λ *Campo lejano*



Respuesta impulsiva

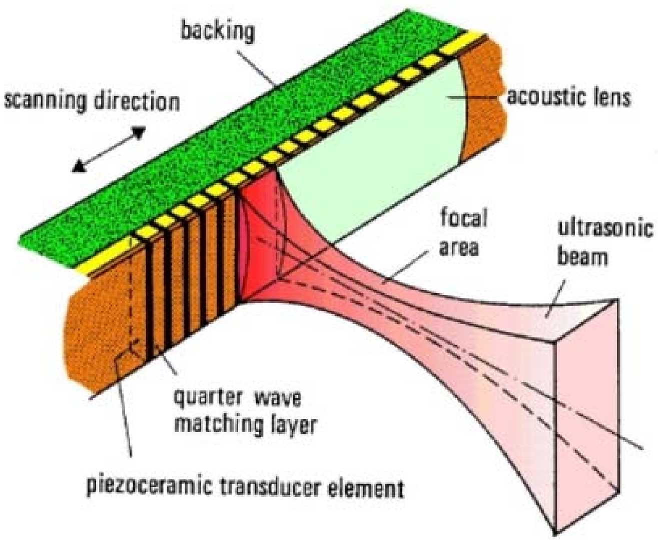


III.b. El transductor ultrasónico: Arrays.



Monoelemento

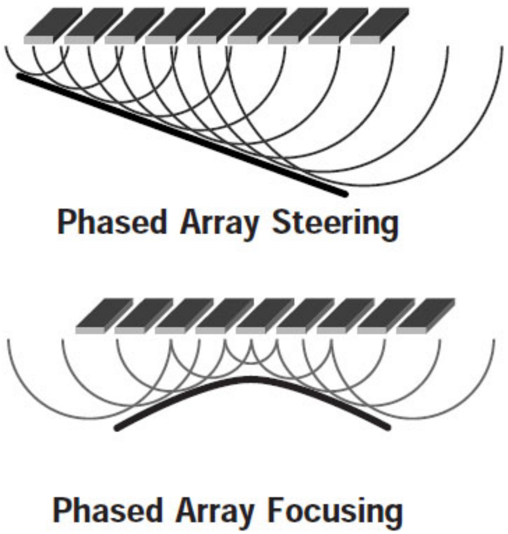
Array lineal



https://www.ricam.oeaw.ac.at/specsem/sscm/srs_ev/kaltenbacher/overview/

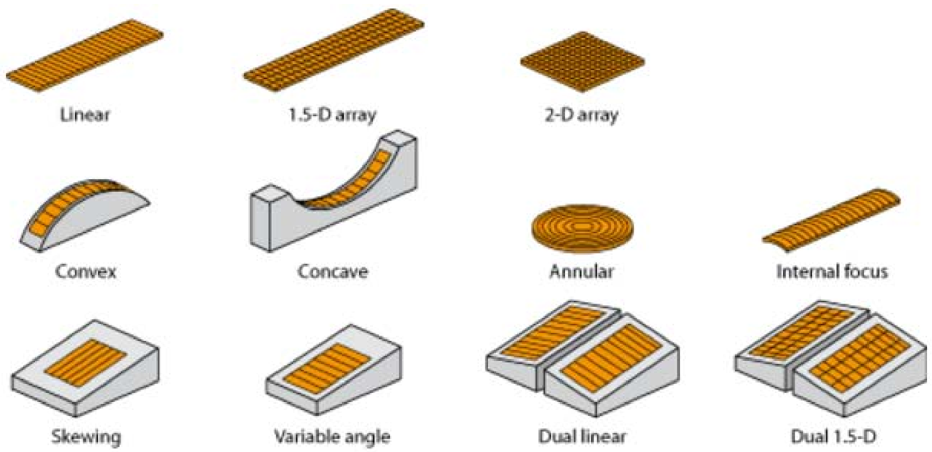
III.b. El transductor ultrasónico: Arrays.

Beam forming



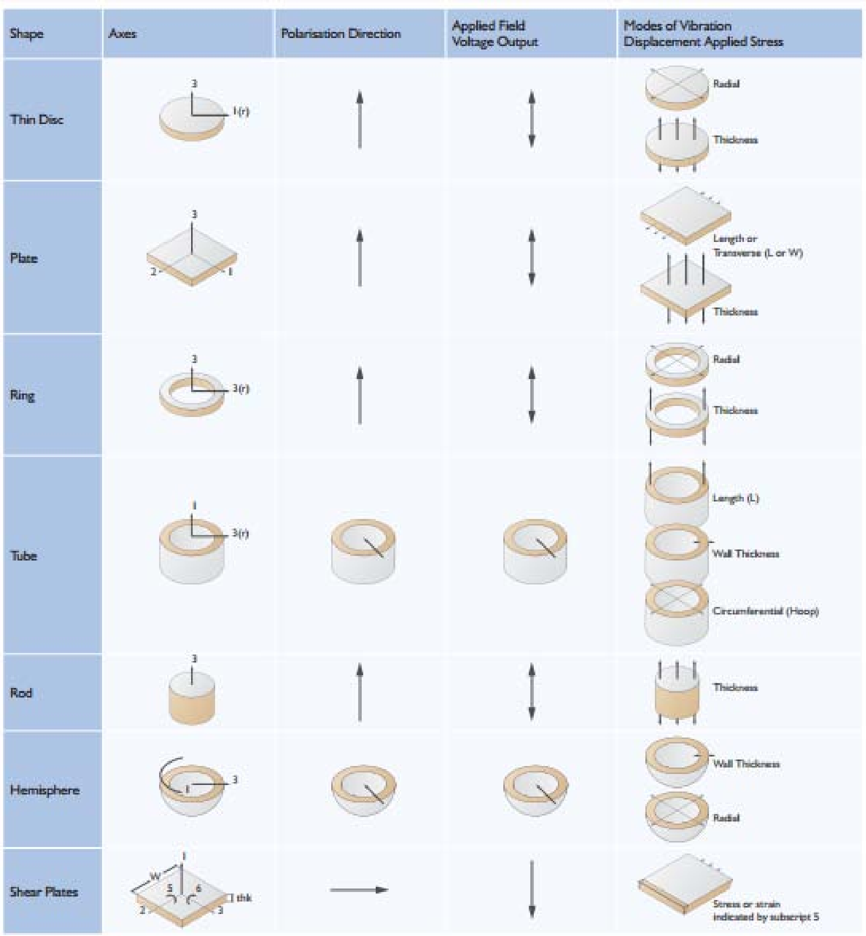
http://www.ndt-kits.com/blog/?p=198

Geomerías de arrays.



http://hyperiongroup.in/Sirius/Olympus/PhasedArrayProbes.aspx

IV. Modos de vibración en estructuras compuestas.



Combinar varios elementos pe simples.

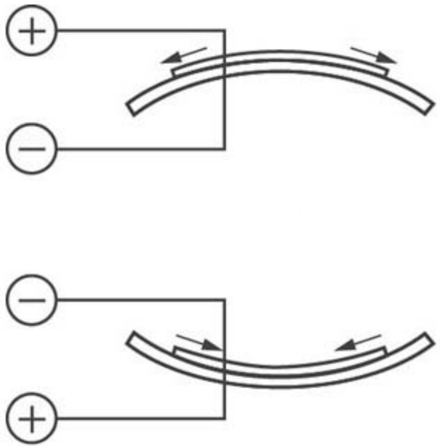
Combinar un elemento pe simple con una estructura simple

Combinar varios elementos pe simples con una estructura compleja

✓*Desplazamientos grandes.*

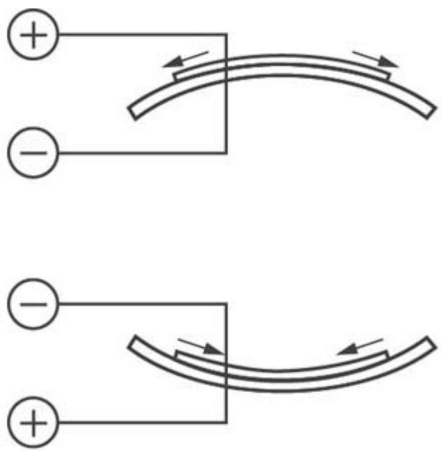
✓*Frecuencias relativamente bajas*

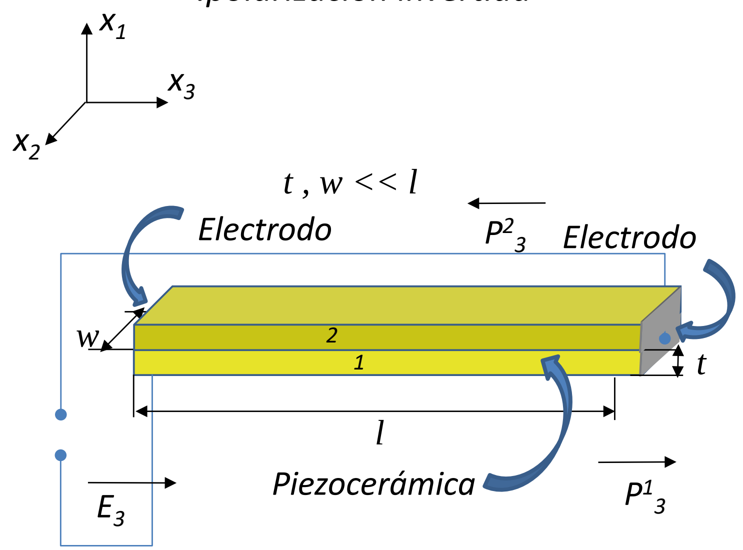
IV.a. Bimorfos.



IV.a. Bimorfos.

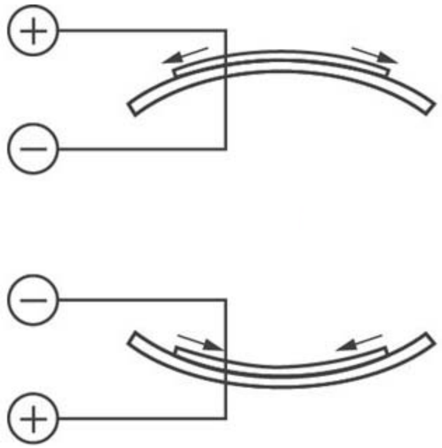
Ejemplo 1: Dos láminas piezoeléctricas, .polarización invertida

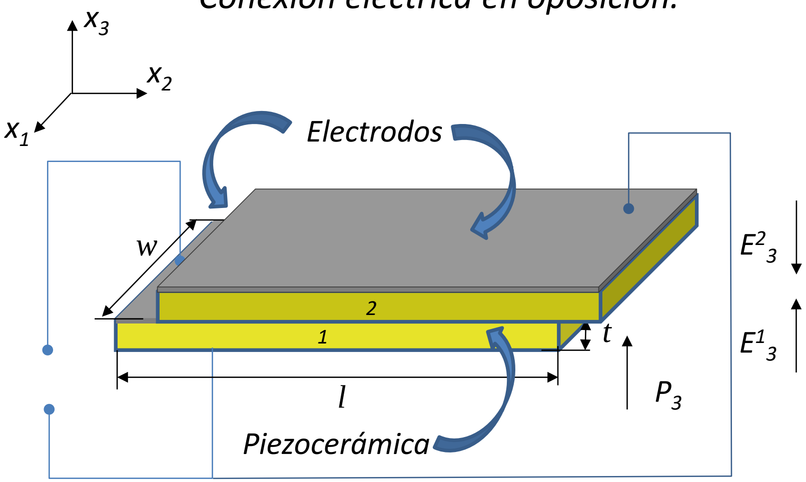


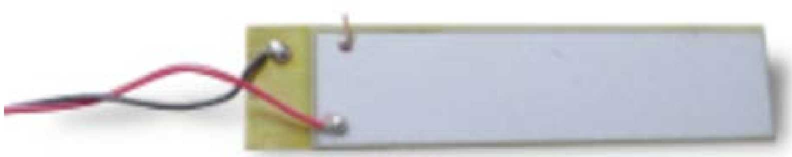


IV.a. Bimorfos.

Ejemplo 2: Dos láminas piezoelectricas.
Conexión eléctrica en oposición.



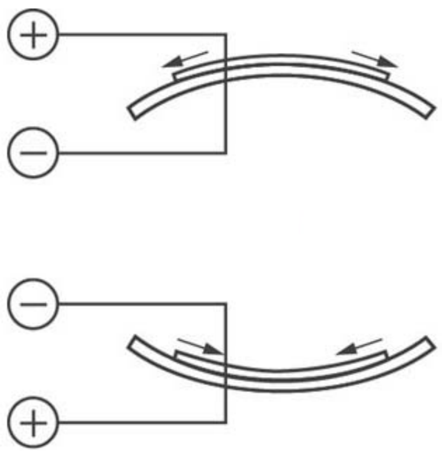




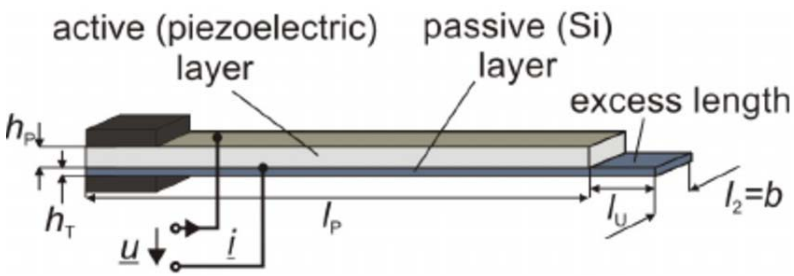
Actuator	Range	Voltage	Force	Length	Width
BA4510	2 mm	+/-100 V	0.2 N	45 mm	10 mm

http://www.piezodrive.com/actuators.html

IV.a. Bimorfos.

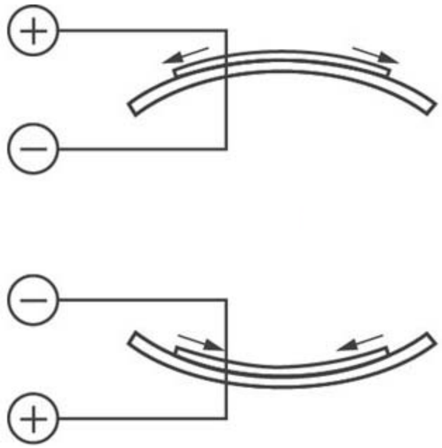


Ejemplo 3. Lámina piezoeléctrica y lámina rigida

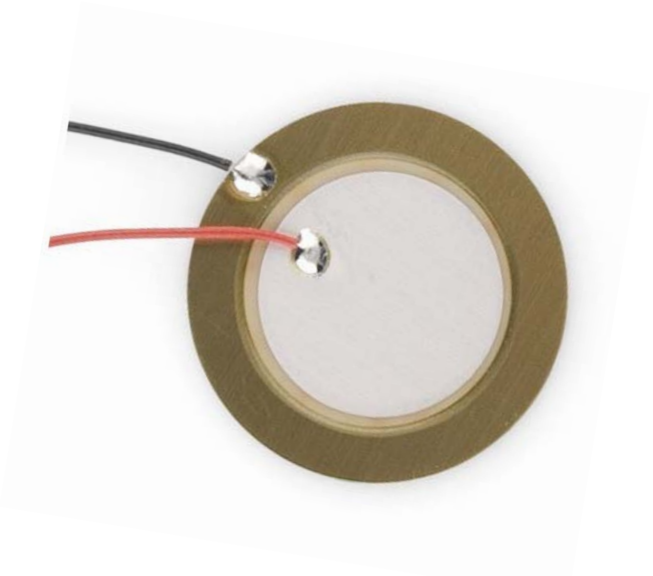


- ✓ *Energy harvesting.*
- ✓ *AFM*

IV.a. Bimorfos.



Ejemplo 4. Disco piezoeléctrico y un disco rígido

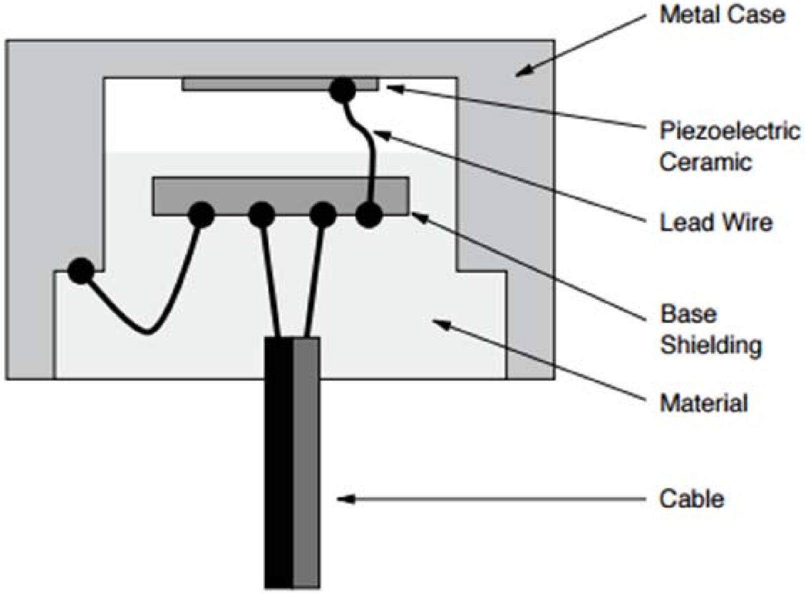


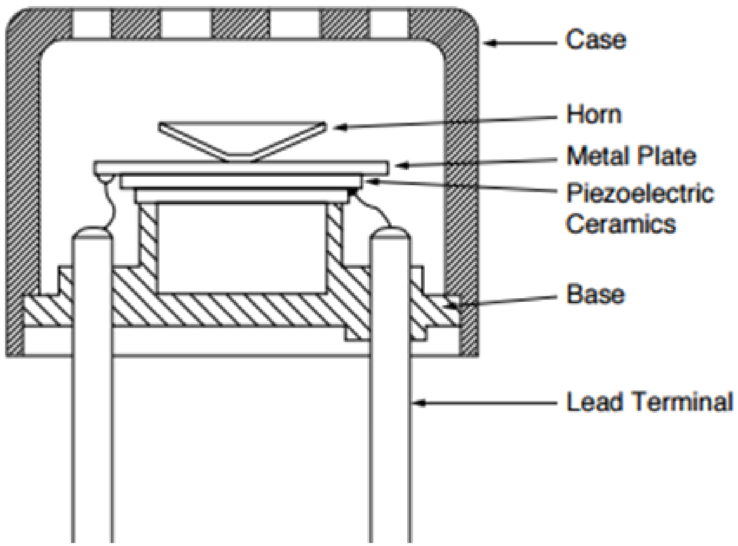
- ✓ *Detector de vibraciones*
- ✓ *Zumbador*
- ✓ *Altavoz*

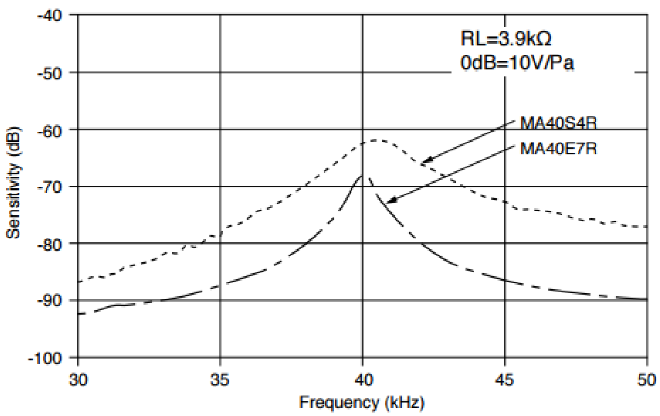
IV.b Estructuras más complejas.

1. Transductores para medida de distancia (sensores).

http://www.murata.com/en-eu/products/sensor/ultrasonic





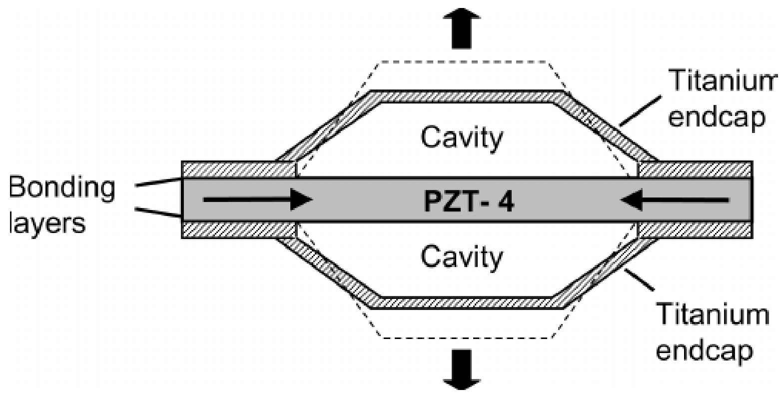


IV.b Estructuras más complejas.

2. Cymbal transducer.

Metal-electroactive ceramic composite transducer

Cymbal actuator/transducer



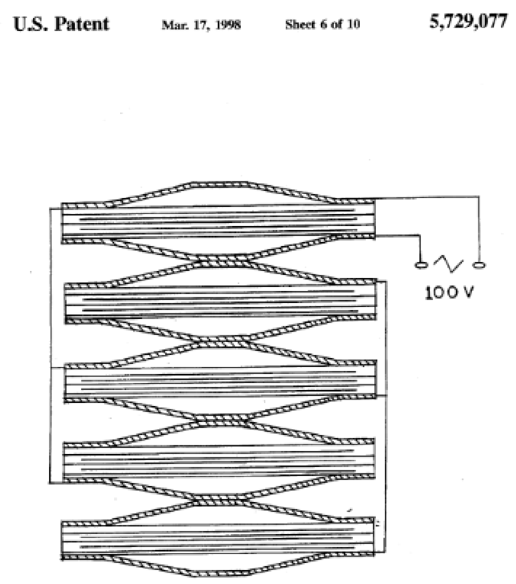


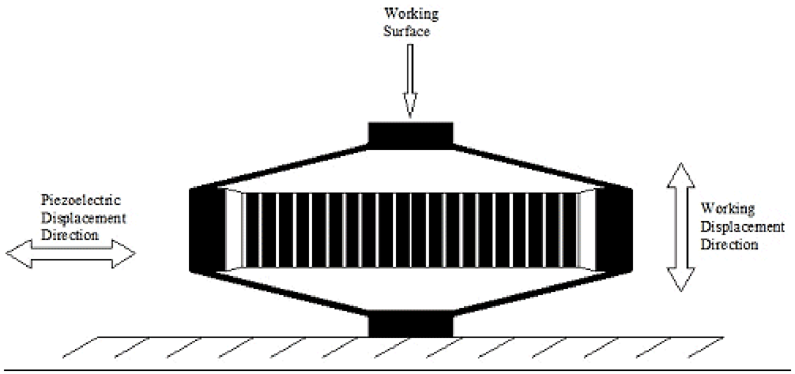
FIGURE 8

R. E. Newnham and A. Dogan, "Metal-electroactive ceramic composite transducer," USA Patent 5,729,077, 1998.

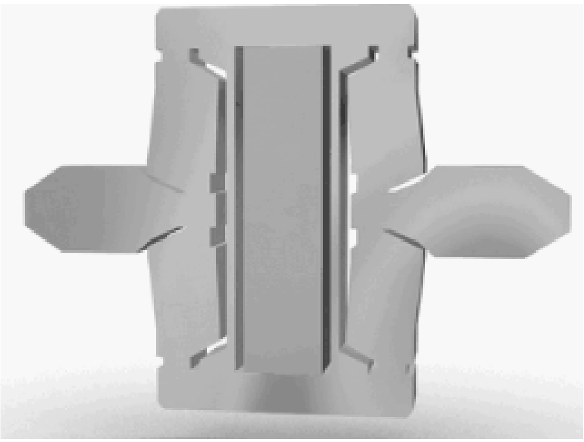
IV.b Estructuras más complejas.

3. Flextensional transducer.

Flextensional acuator (Hayes 1936)



http://www.morpheus.umd.edu/research/systems/piex-flex-actuators.html

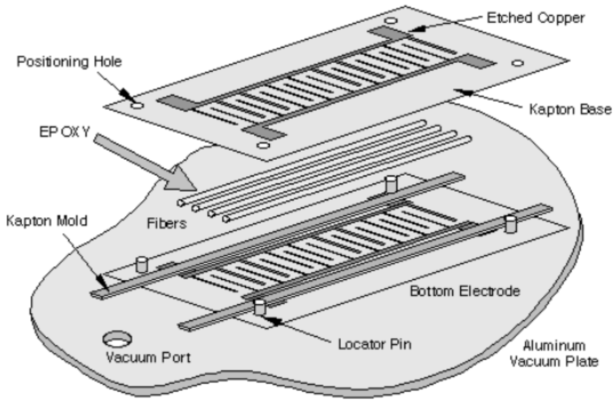


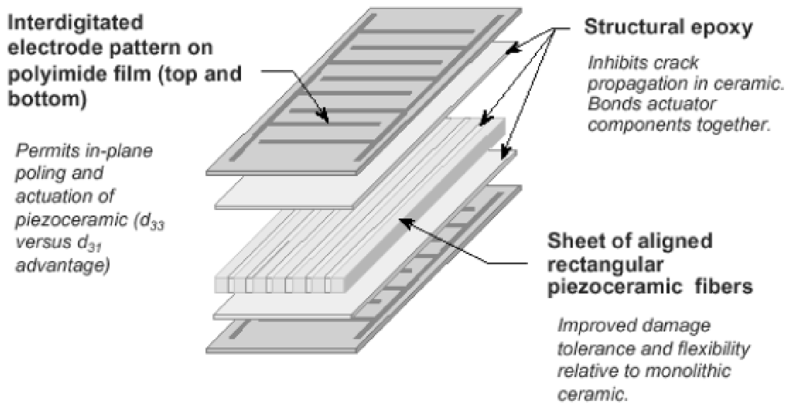
http://www.linear-actuator.net/Flexure_Guided_Actuators.php

K. D. Rolt, “History of the flextensional electroacoustic transducer,” *J. Acoust. Soc. Am.*, vol. 87, no. May 1929, p. 1340, 1990.

IV.c. Actuadores basados en fibras piezoeléctricas.

Active fiber composites (MIT)
Macro fiber Composite (NASA, 1996)
Hollow Tube Active Fiber composite (Michigan, 2000)



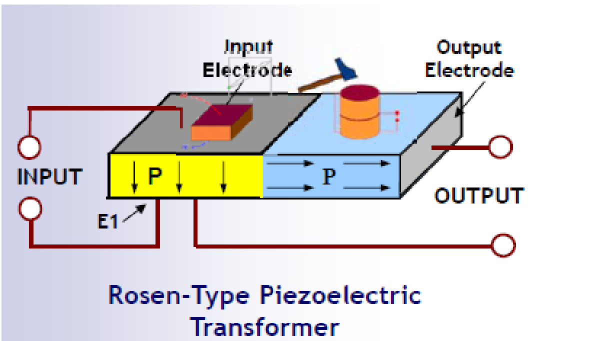


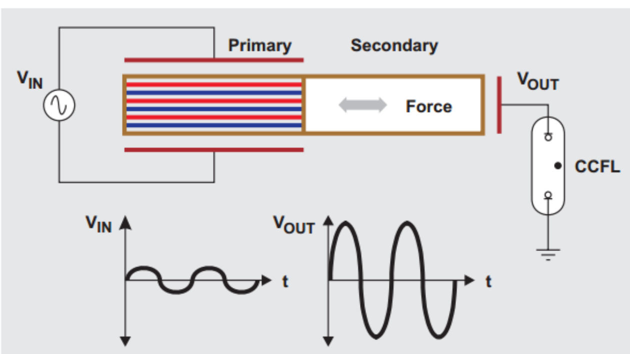
https://www.youtube.com/watch?v=L5KKumkXTqo

R. B. Williams, G. Park, D. J. Inman, and W. K. Wilkie, "An Overview of Composite Actuators with Piezoceramic Fibers," *2002 IMAC-XX Conf. Expo. Struct. Dyn.*, pp. 421–427, 2002.

IV.d. Transformadores piezoeléctricos.

Rosen 1956





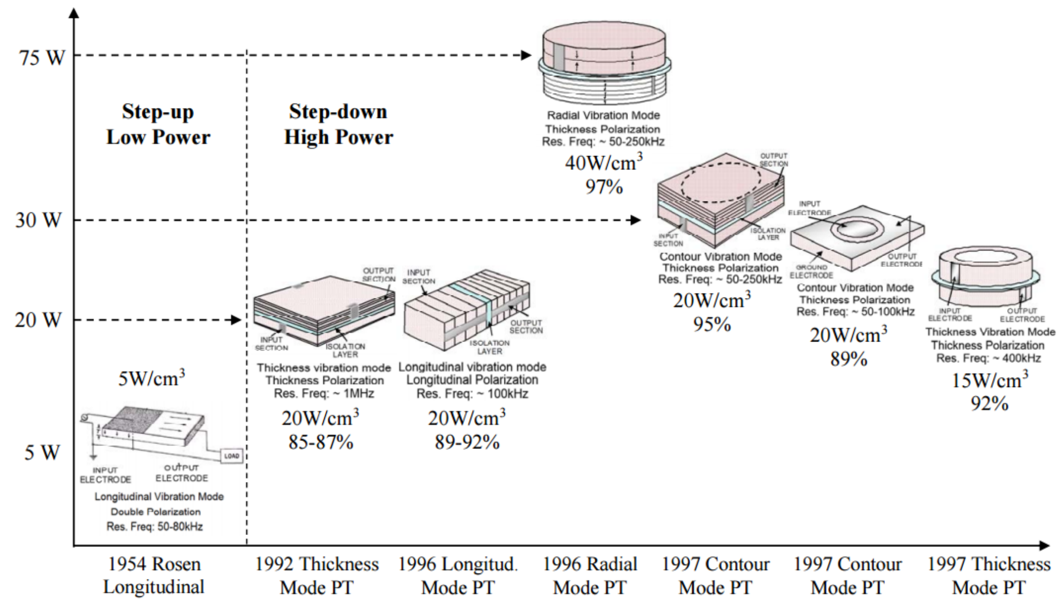


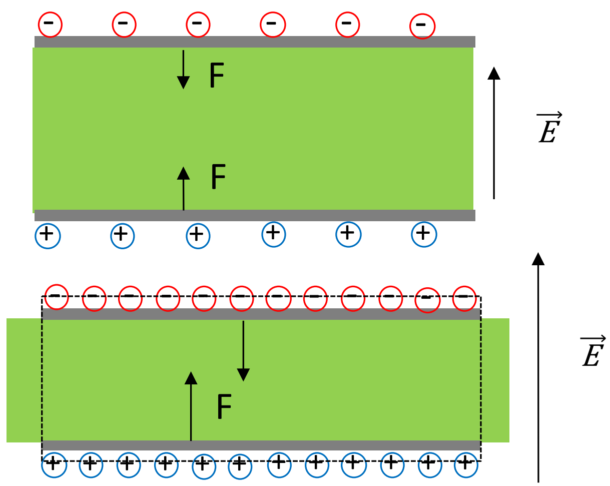
Figure 19. The state of the art of power piezoelectric transformers (PTs) technology (courtesy of Micromechatronics, Inc.).

M. Day and B. Lee, "Understanding piezoelectric transformers in CCFL backlight applications," *Analog Appl. Journal, Texas Instruments*, 2002.

A. Vazquez Carazo, "Piezoelectric Transformers: An Historical Review," *Actuators*, vol. 5, no. 2, p. 12, 2016.

V. Actuadores basados en EAP (Electroactive Polymers)

Sólido entre dos placas cargadas



σ_{33}, ε_{33}, ε_{31}, ε_{32}

Si c_{iiii} es pequeño: maximizamos ε_{ii}.

Si Poisson ratio $\approx$ 0.5: maximizamos ε_{ik}.

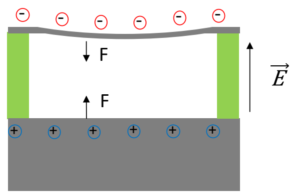
ElectroActive Polymer (EAP) Actuator

https://www.youtube.com/watch?v=uw8FLgiXsmk

VI. Transductores ultrasónicos capacitivos.

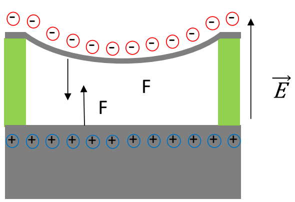
IV.a. CUT (Capacitive Ultrasonic Transducer)

Vacío entre una membrana cargada y un sólido



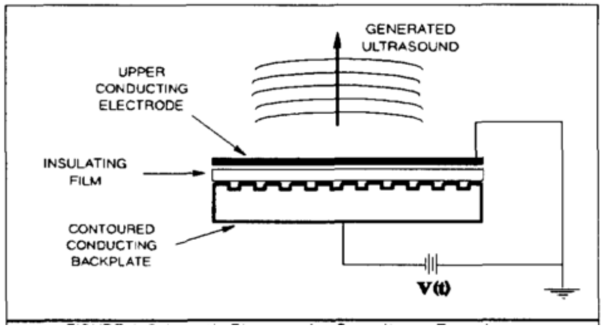
Micrófonos de condensador

Transductores capacitivos



Trans. capacitivos micromecanizados CMUT

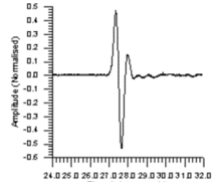
D. W. Schindel, L. Zou, D. a. Hutchins, and M. Sayer, “Capacitance devices for the generation of airborne ultrasonic fields,” *IEEE 1992 Ultrason. Symp. Proc.*, pp. 843–846, 1992.

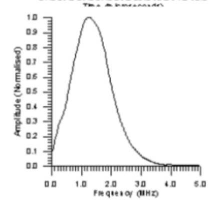


Emitir al aire
Recibir del aire

Banda ancha

Bias de alto voltage

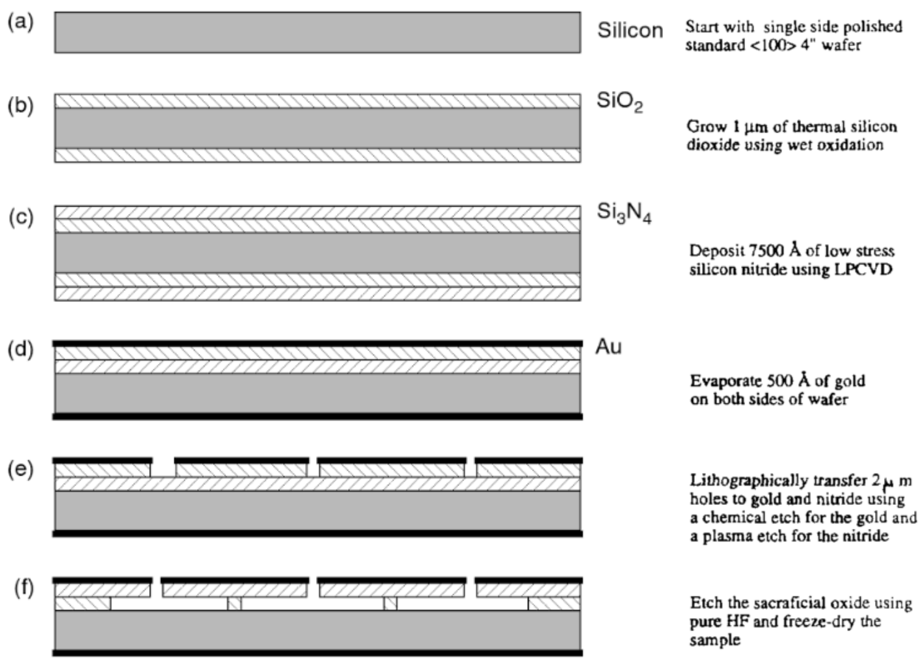




VI. Transductores ultrasónicos capacitivos.

IV.a. CMUT (Capacitive Micromachined Ultrasonic Transducer)

1. Sacrificial layer method / surface micromachining



M. I. Haller and B. T. . Khuri-Yakub, "A surface micromachined electrostatic ultrasonic air transducer," in *IEEE Ultrasonics Symposium*, 1994, pp. 1241–1244.

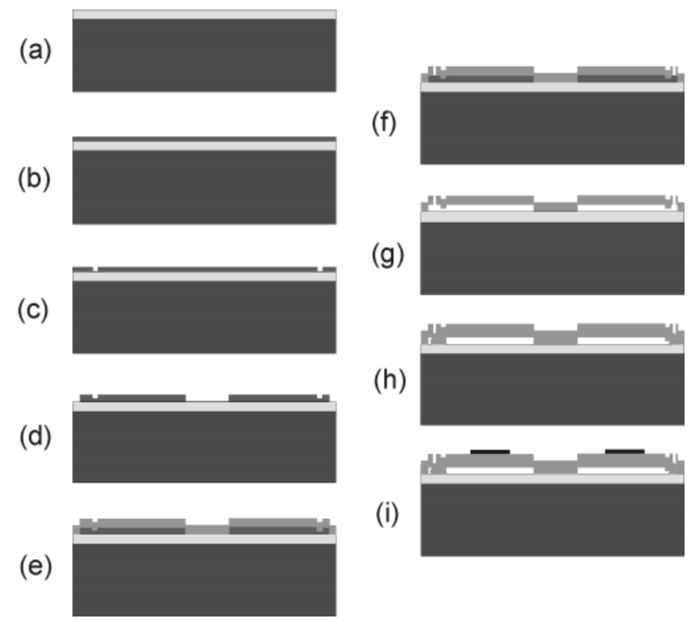
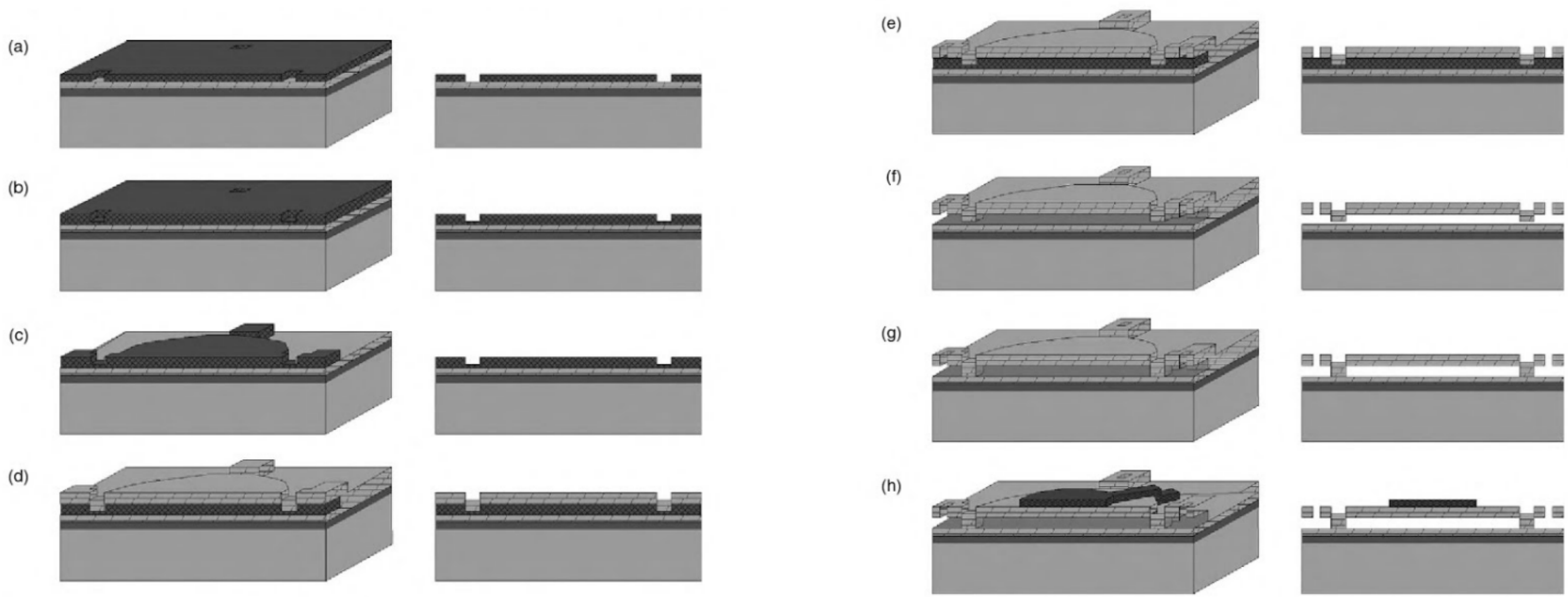


Figure 2.6: Basic process steps for the sacrificial release. (a) deposition of insulation/etch stop layer. (b) first deposition of the sacrificial layer. (c) etch sacrificial layer to define etch channels. (d) deposit second layer of sacrificial release material and define cell cavities and membrane. (e) deposit first layer of membrane material. (f) open etch channels. (g) release membranes. (h) seal etch channels. (i) expose bottom electrode for contact pads (not shown), metalize top electrodes and contact pads.

VI. Transductores ultrasónicos capacitivos.

IV.a. CMUT (Capacitive Micromachined Ultrasonic Transducer)

2. Wafer bonding method



5.5 Sacrificial-release process with the LPCVD Si_3N_4 membrane. (a) Substrate doping, etch-stop layer deposition, first sacrificial layer deposition and patterning. (b) Reduced etch channel height regions. (c) Active area definition. (d) Membrane deposition. (e) The sacrificial layer etch hole definition and Si_3N_4 etch. (f) Membrane release in KOH. (g) Membrane sealing with more Si_3N_4 deposition. (h) Top electrode deposition and patterning. (*Source*: Reprinted with permission from Institute of Electrical and Electronics Engineers.)

VI. Transductores ultrasónicos capacitivos.

IV.a. CMUT (Capacitive Micromachined Ultrasonic Transducer)

Fusion Bonding method (Huang 2003)

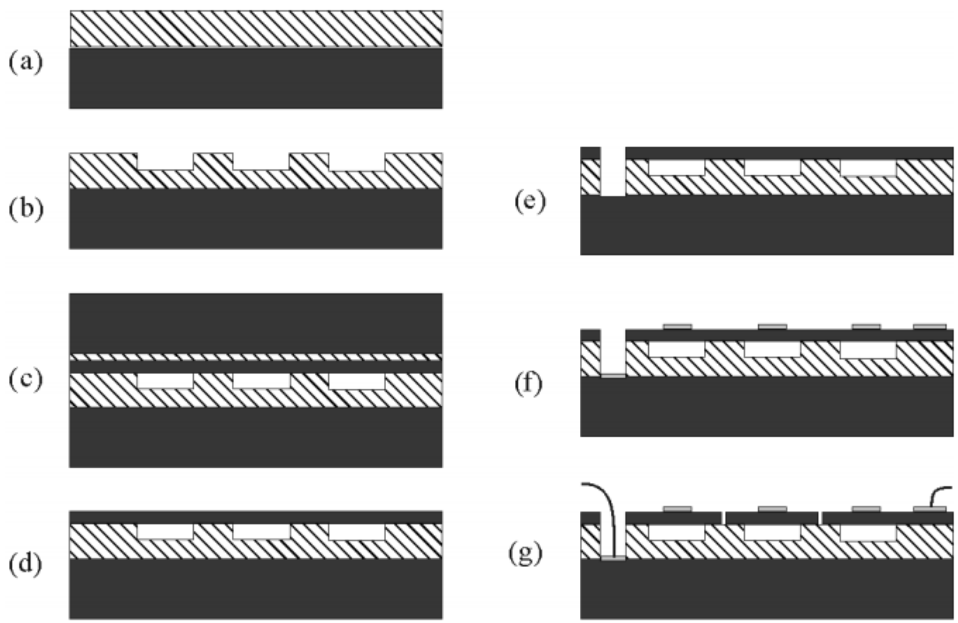
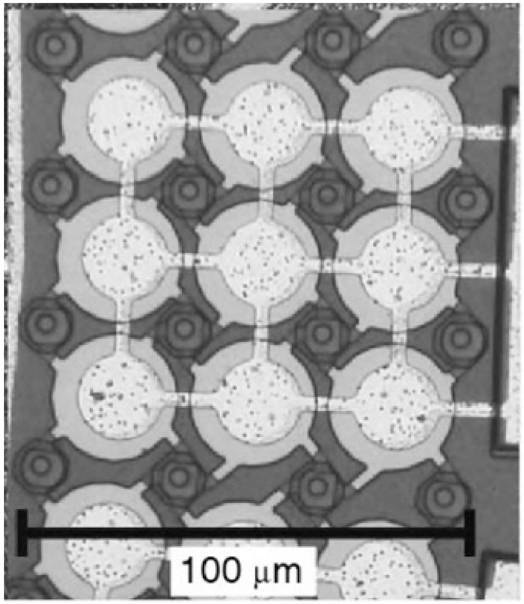


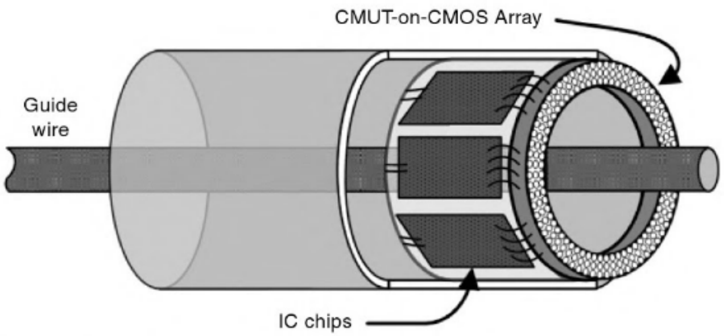
Figure 2.7: Process flow for a typical fusion bonding process. (a) growth of thermal oxide for insulation and cell side walls. (b) etching the cell cavities. (c) fusion bonding the SOI wafer to the bottom wafer, then annealing. (d) release the membrane by grinding and wet chemistry. (e) expose the bottom electrode contact pad. (f) metalize the contact pads and top electrodes. (g) silicon etch to electrically isolate each element from one another.

VI. Transductores ultrasónicos capacitivos.

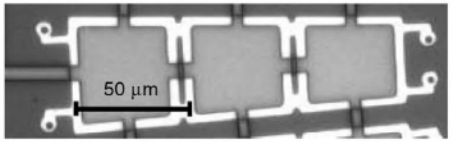
IV.a. CMUT (Capacitive Micromachined Ultrasonic Transducer)

Integración



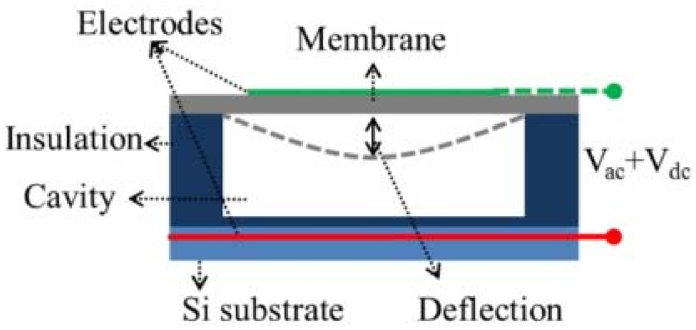


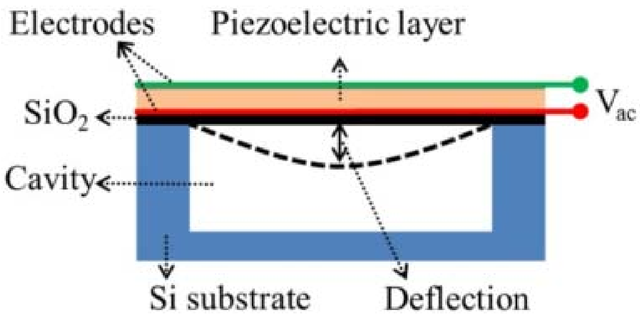
5.10 Schematic diagram of the IVUS catheter employing forward looking CMUT array with integrated front-end electronics. (*Source*: Reprinted with permission from Institute of Electrical and Electronics Engineers.)



VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)

CMUT **vs** **PMUT**





Y. Qiu, J. V. Gigliotti, M. Wallace, F. Griggio, C. E. M. Demore, S. Cochran, and S. Trolier-McKinstry, "Piezoelectric micromachined ultrasound transducer (PMUT) arrays for integrated sensing, actuation and imaging," *Sensors (Switzerland)*, vol. 15, no. 4, pp. 8020–8041, 2015.

VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)

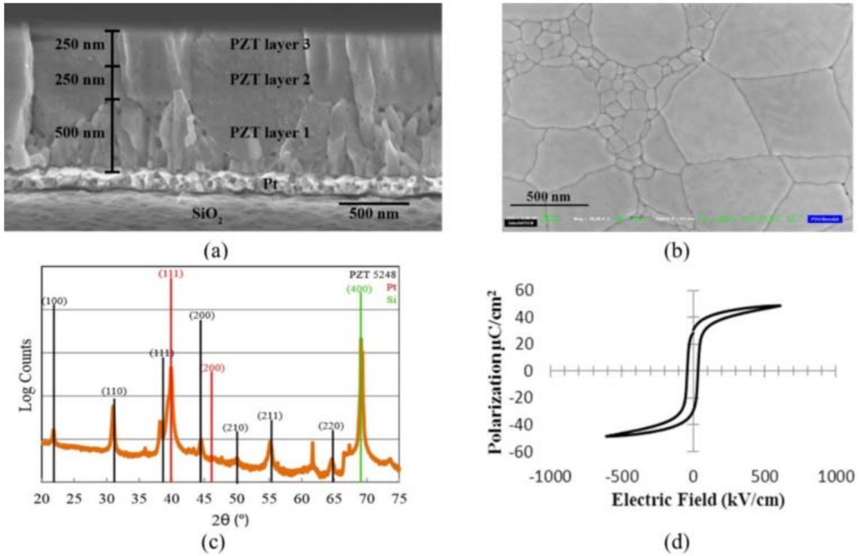


Figure 2. FESEM images of (**a**) cross-sectional and (**b**) top surface of PZT thin film; (**c**) XRD pattern of the PZT film with the absence of PbO ($2\theta = 29.09°$) and pyrochlore/fluorite ($2\theta = 29.55°$); (**d**) hysteresis loop of the sputtered PZT thin film.

¿Es posible crecer una membrana de cerámica ferroeléctrica?

Y. Qiu, J. V. Gigliotti, M. Wallace, F. Griggio, C. E. M. Demore, S. Cochran, and S. Trolier-McKinstry, "Piezoelectric micromachined ultrasound transducer (PMUT) arrays for integrated sensing, actuation and imaging," *Sensors* , vol. 15, no. 4, pp. 8020–8041, 2015.

CSIC

USBIOMAT

VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)

Backside etching

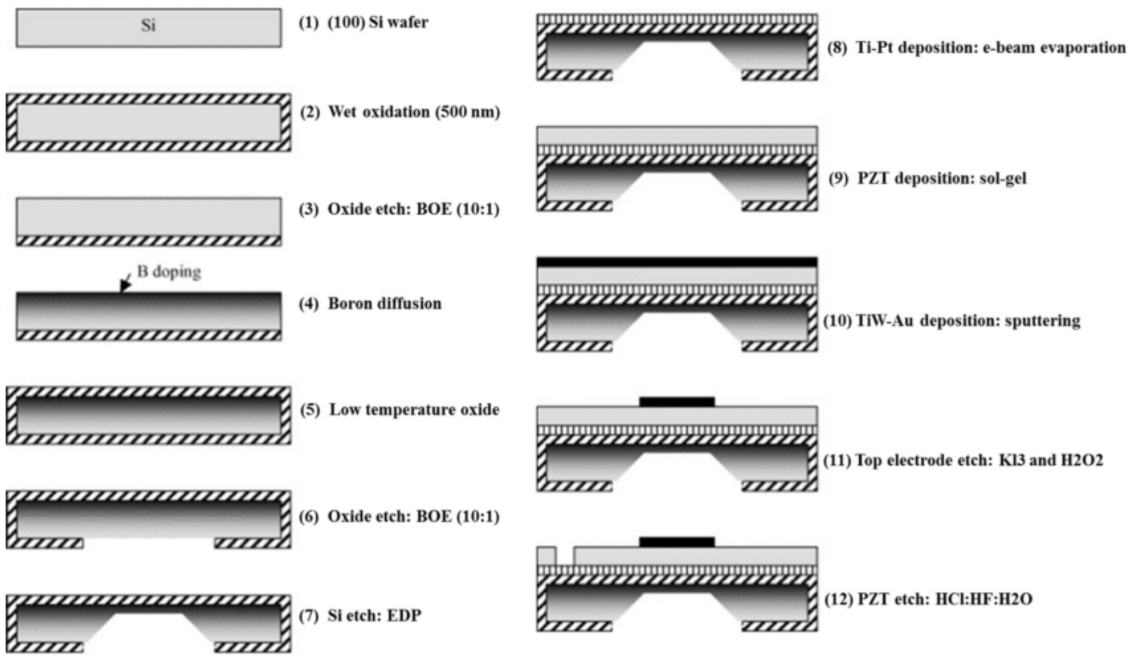
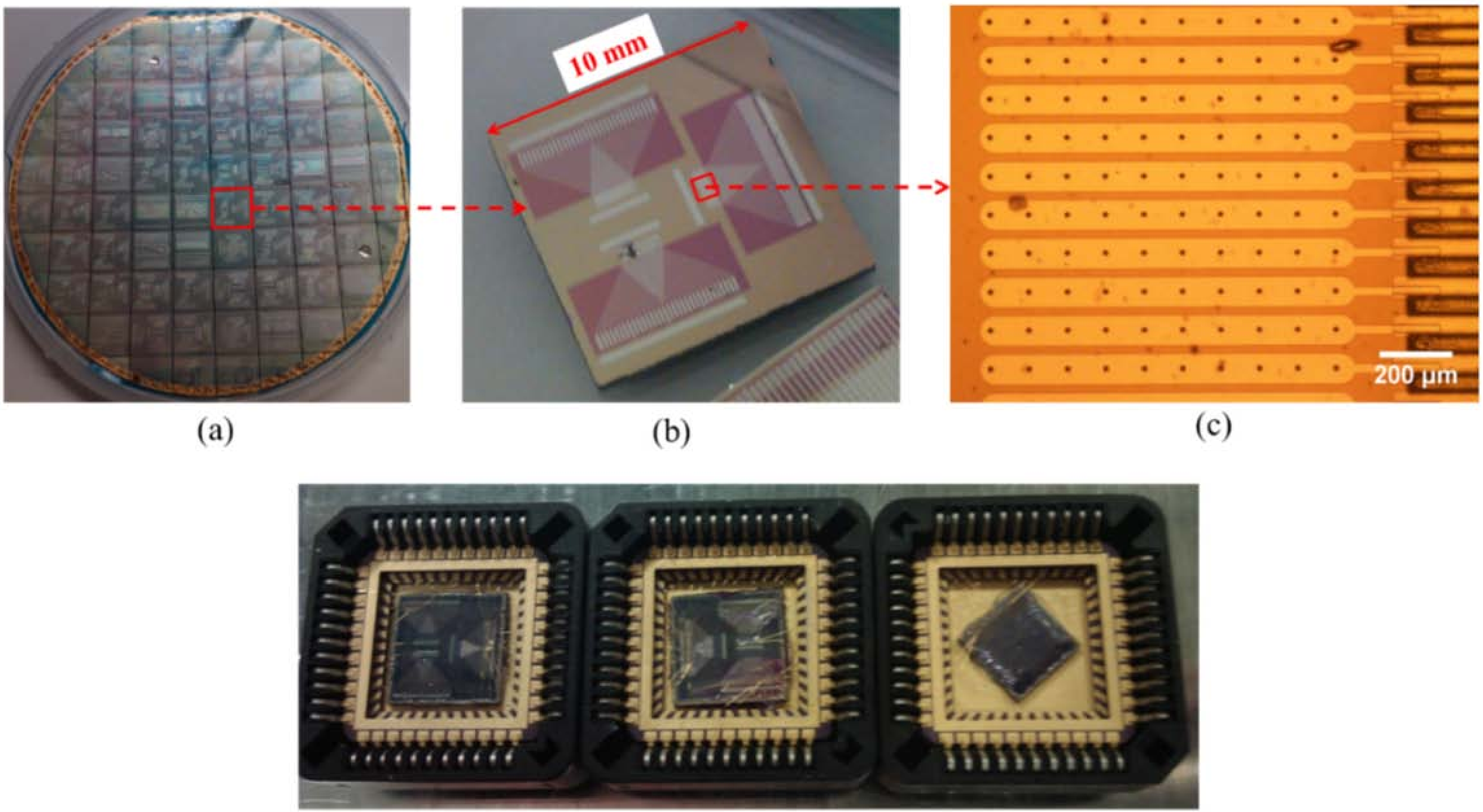


Figure 4. Fabrication process flow of PMUT element with diaphragm defined by back-side etching © 2004 Elsevier B.V. Reprinted with permission from [30].

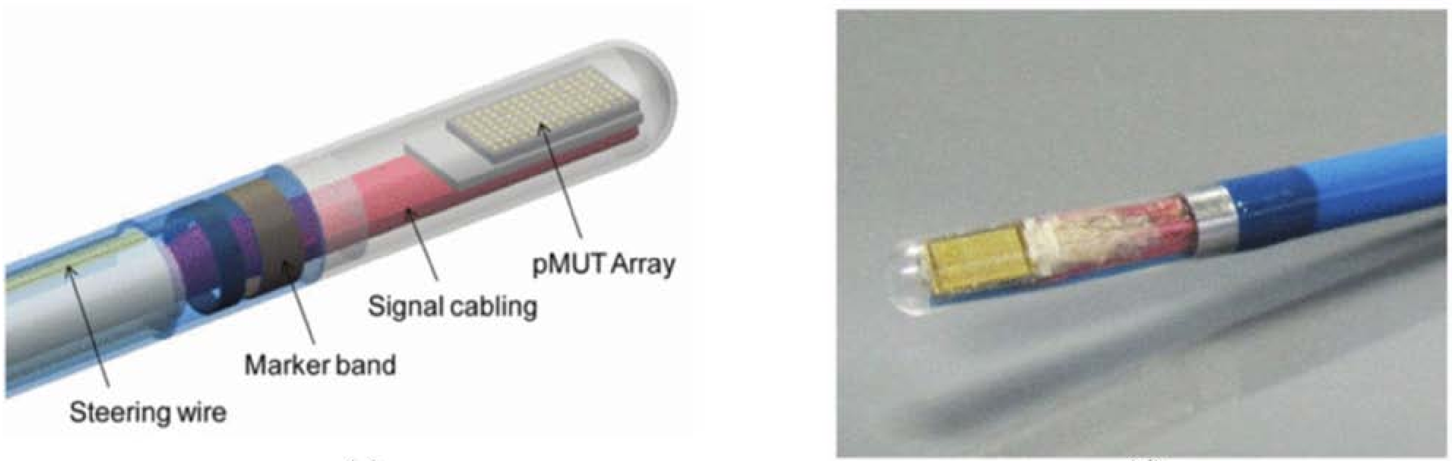
Y. Qiu, J. V. Gigliotti, M. Wallace, F. Griggio, C. E. M. Demore, S. Cochran, and S. Trolier-McKinstry, "Piezoelectric micromachined ultrasound transducer (PMUT) arrays for integrated sensing, actuation and imaging," *Sensors* , vol. 15, no. 4, pp. 8020–8041, 2015.



(d)

Figure 10. Images of (**a**) a 4-inch wafer with multiple PMUT dies with different diameter diaphragms; (**b**) three PMUT arrays on one die; (**c**) several elements of a PMUT array, each consisting of ten diaphragms; and (**d**) three fully packaged wire-bonded devices.

VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)



(c) (d)

Figure 14. Cross-sectional schematic diagrams of (**a**) PMUTs with through-Si interconnects and (**b**) a PMUT array substrate bonded onto a wiring substrate; (**c**) a mechanical model and (**d**) photograph of the distal end of a steerable 14-Fr (Ø4.667 mm) ICE catheter containing a 512-element PMUT matrix array. © 2013 IEEE. Reprinted with permission from [35].

VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)

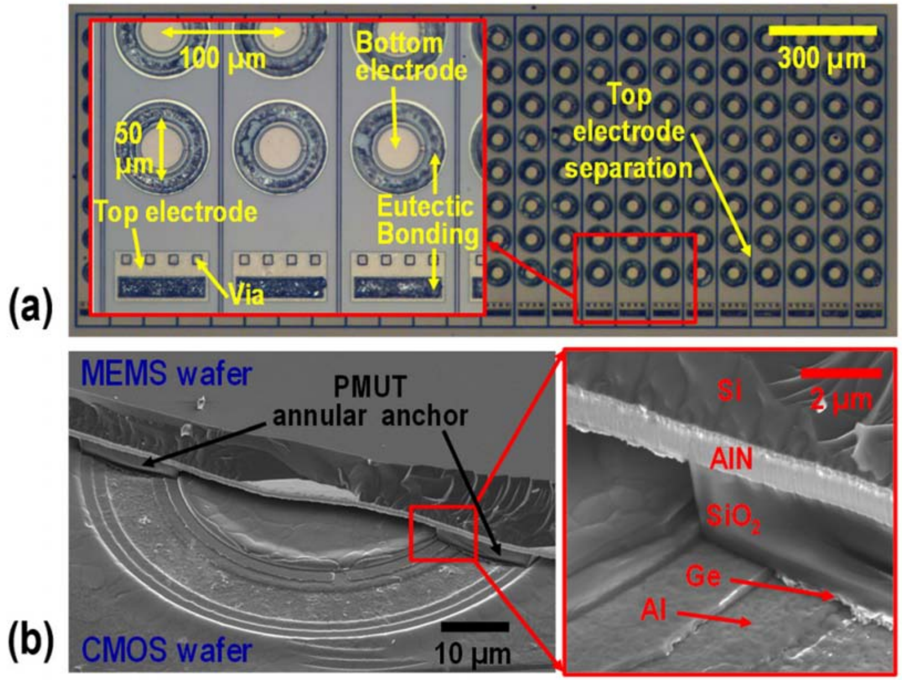


FIG. 2. (a) Optical images of the 24 × 8 PMUT array after de-bonding to remove the CMOS wafer; (b) cross-sectional SEM images of a single PMUT after partial de-bonding to remove the MEMS wafer.

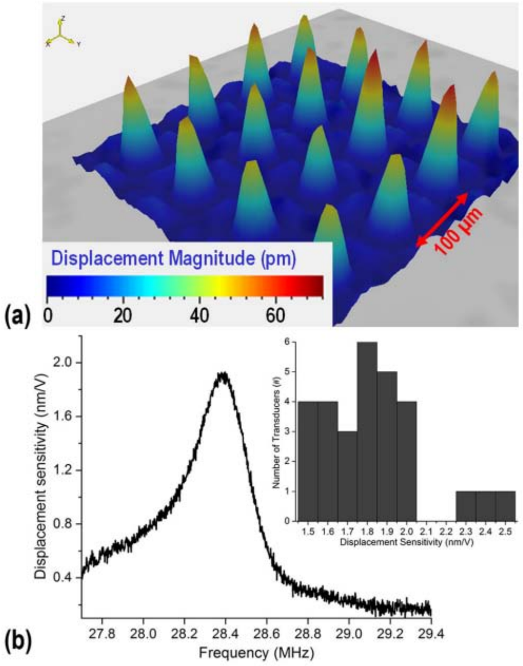
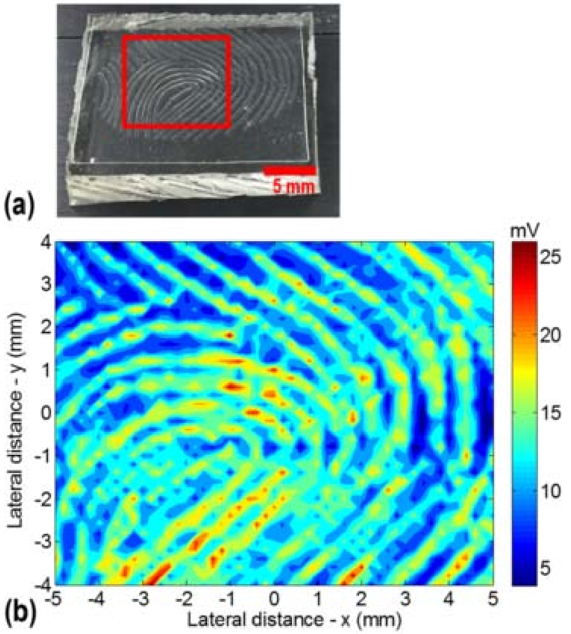
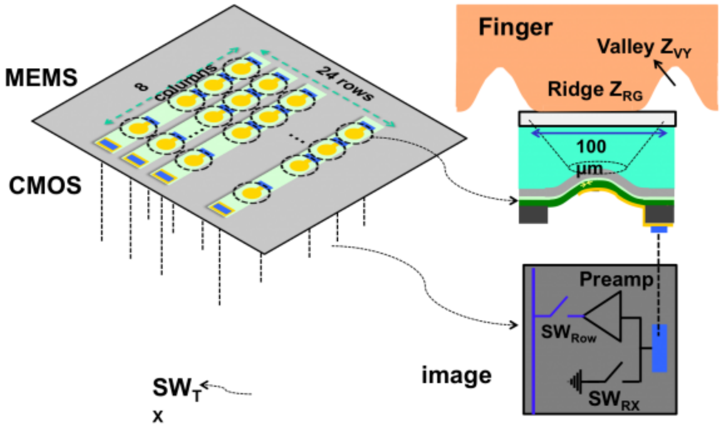


FIG. 3. (a) Mode-shape of a 5 × 5 sub-array measured at 28.4 MHz using a scanning LDV; (b) displacement frequency response of the 25 PMUTs. Inset: histogram of the peak displacement sensitivity for the 25 PMUTs tested.

VII. PMUT (Piezoelectric Micromachined Ultrasonic Transducer)

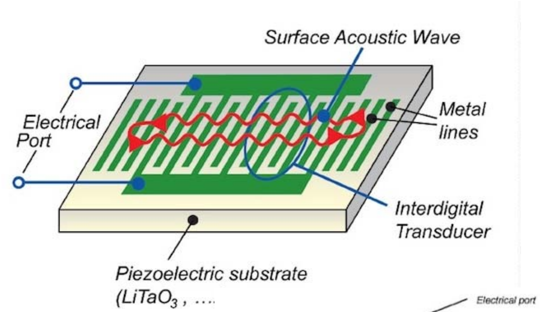


ULTRASONIC FINGER PRINT SENSOR



Y. Lu, H. Tang, S. Fung, Q. Wang, J. M. Tsai, M. Daneman, B. E. Boser, and D. A. Horsley, "Ultrasonic fingerprint sensor using a piezoelectric micromachined ultrasonic transducer array integrated with complementary metal oxide semiconductor electronics," *Appl. Phys. Lett.*, vol. 106, no. 26, 2015.

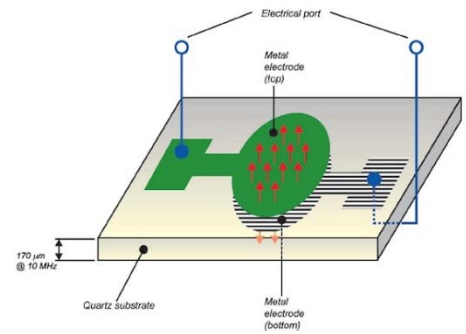
VIII. Otras aplicaciones.



… solo algunos ejemplos.

Motores ultrasónicos

Filtros SAW y BAW



Comunicaciones por ultrasonidos

Interfaz hombre-máquina sin contacto

Micro-manipulación de células

Energy harvesting

Health monitoring

…. ECERES.