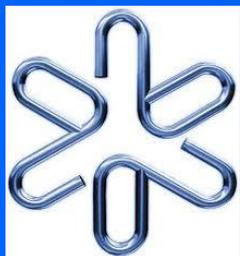


Ultrassom e suas aplicações

Marco A. B. Andrade



Departamento de Física Aplicada
Instituto de Física - Universidade de São Paulo



Sumário

- O que é ultrassom?
- Geração de ultrassom por materiais piezelétricos
- Aplicações médicas
- Aplicações industriais
- Levitação acústica

Ultrassom



fonte: <http://mypreciousbump.wordpress.com>



fonte: <http://www.yourultrasound.com>

O que é ULTRASSOM?

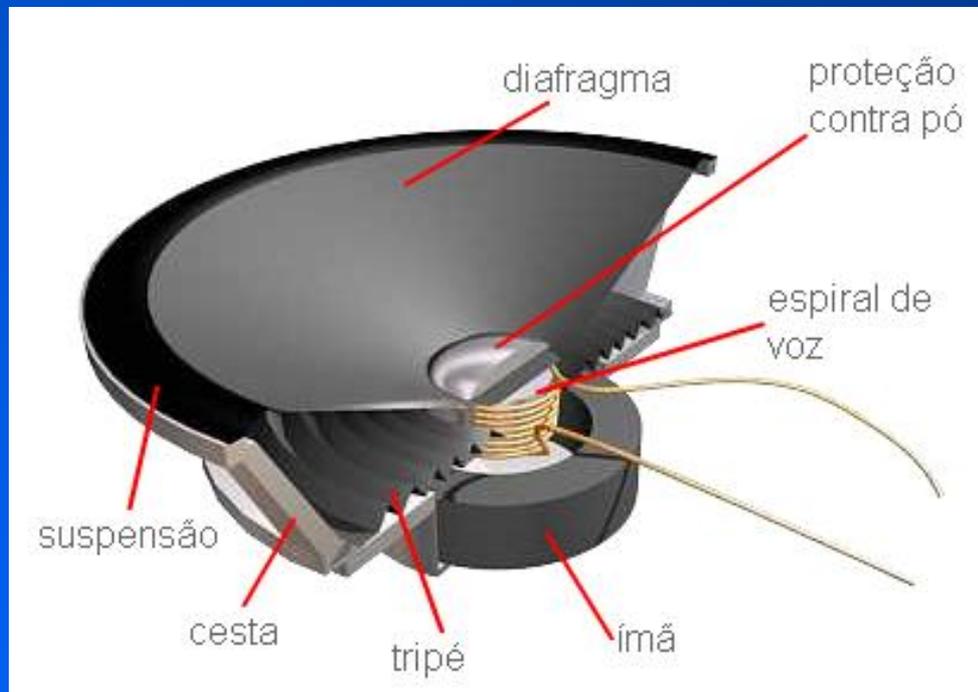
ULTRASSOM

O que é ULTRASSOM?

Propagação de **ondas mecânicas** que possuem **frequência** superior a **20 kHz**.

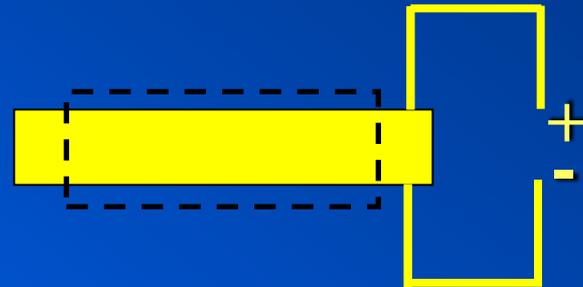
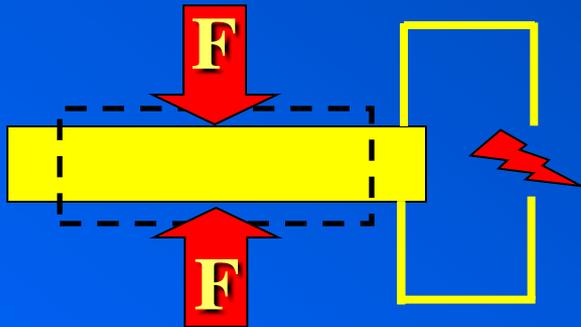
Geração e recepção de ondas de ultrassom

Geração de som

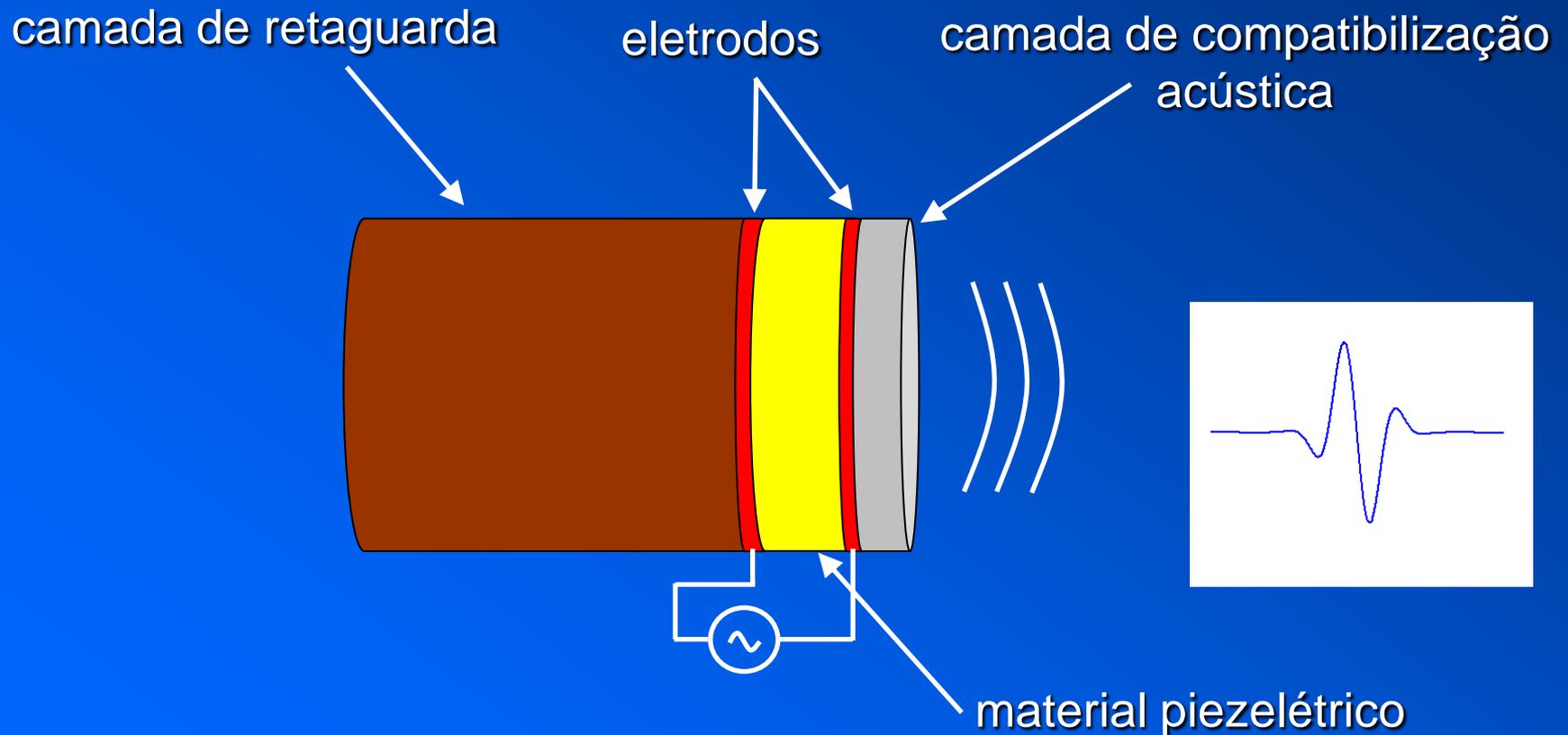


Retirado de: <http://eletronicos.hsw.uol.com.br/alto-falantes3.htm>

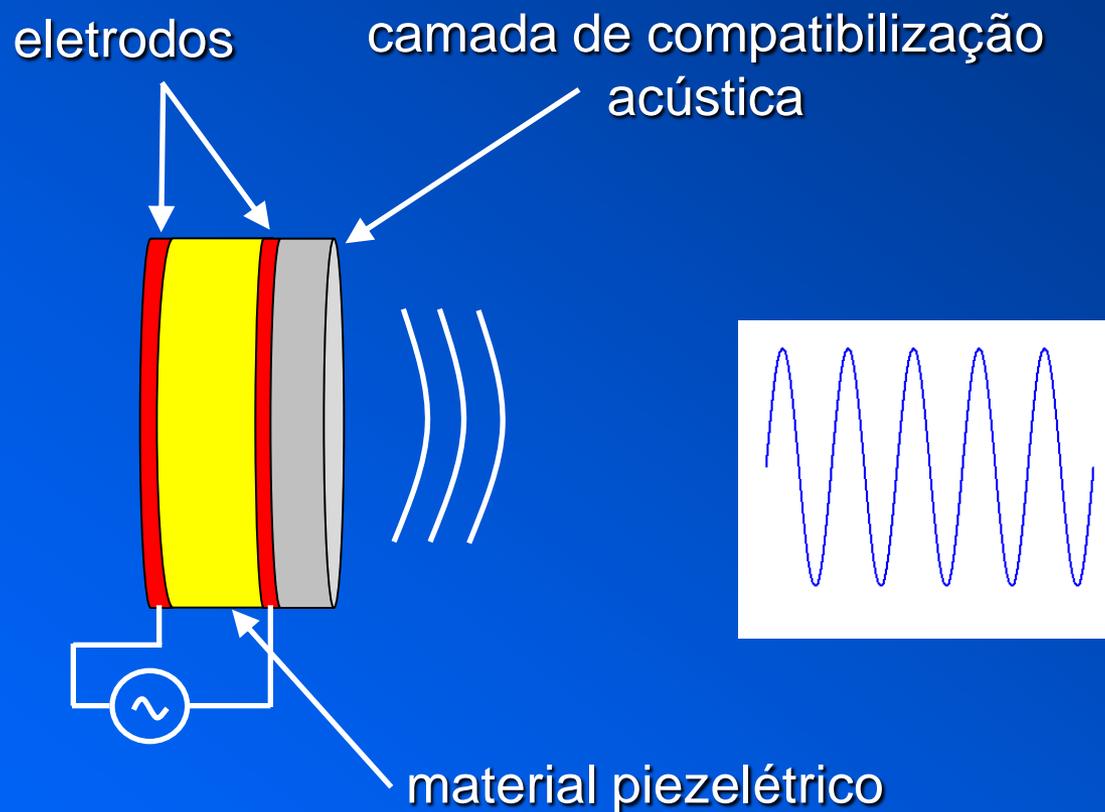
Materials piezelétricos



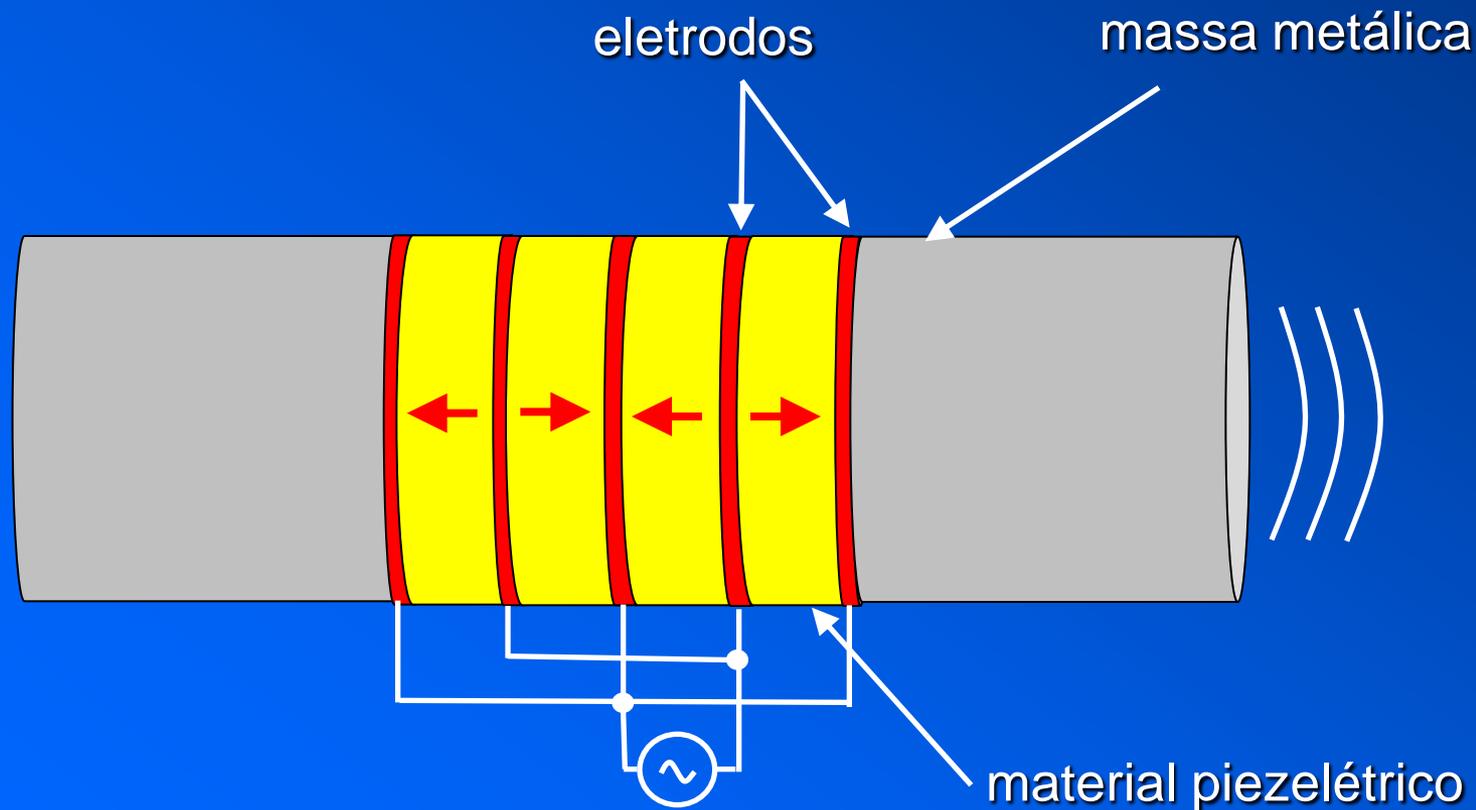
Transdutores de ultrassom (banda larga)



Transdutores de ultrassom (fisioterapia)



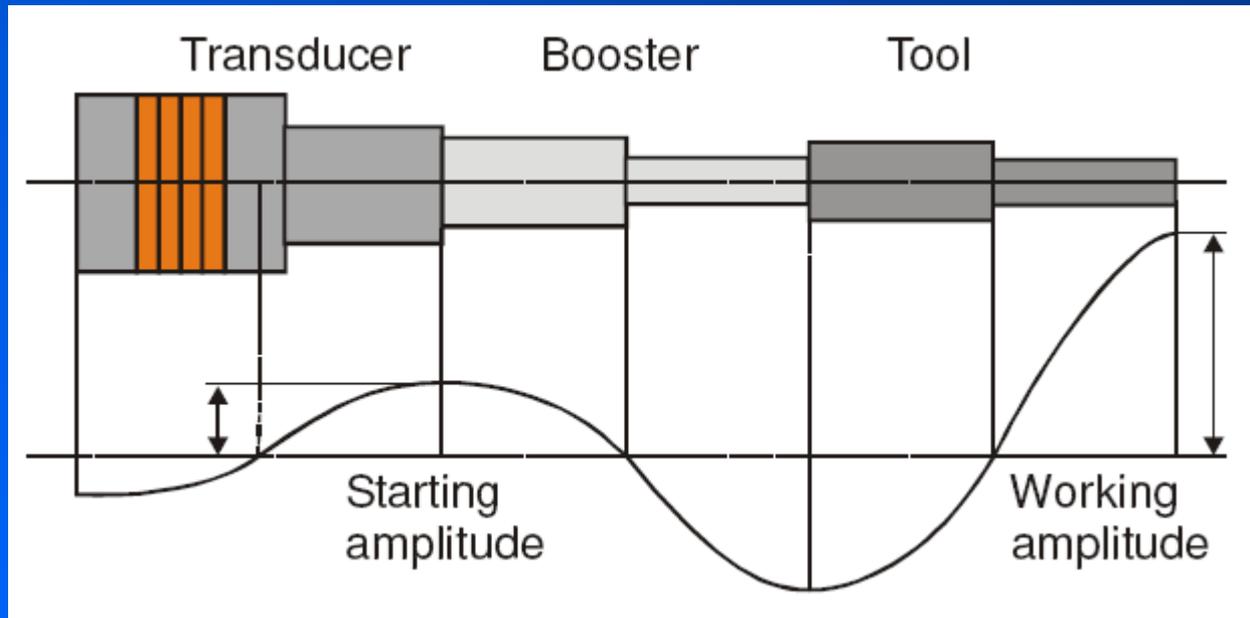
Transdutores de ultrassom (Langevin)



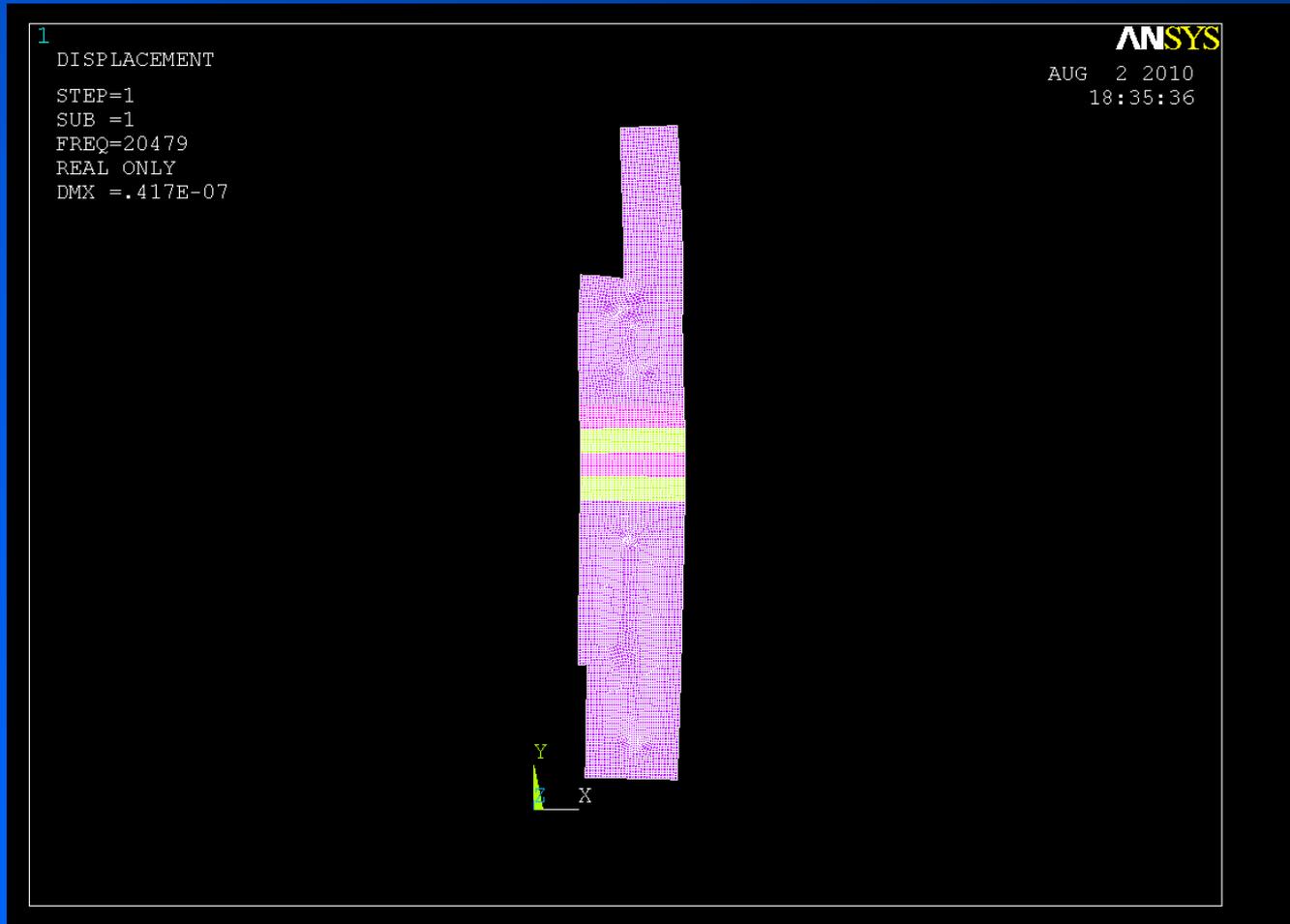
Transdutores de ultrassom (Langevin)



Transdutores de ultrassom (Langevin)



Transdutores de ultrassom (Langevin)



Aplicações médicas

**Ultrasonografia:
formação de imagens com ultrassom**

Ultrasonografia

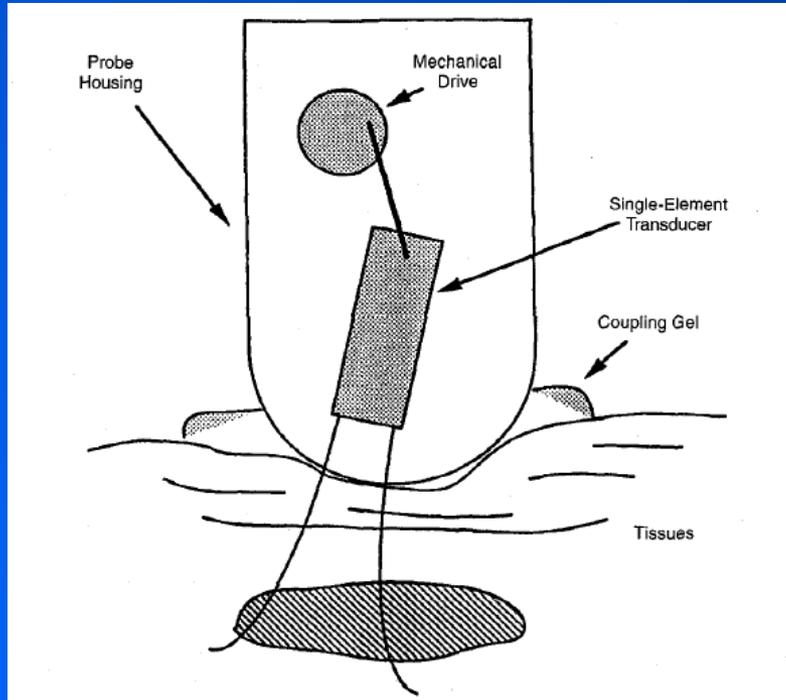


fonte: <http://mypreciousbump.wordpress.com>



fonte: <http://www.yourultrasound.com>

Transdutor monoelemento



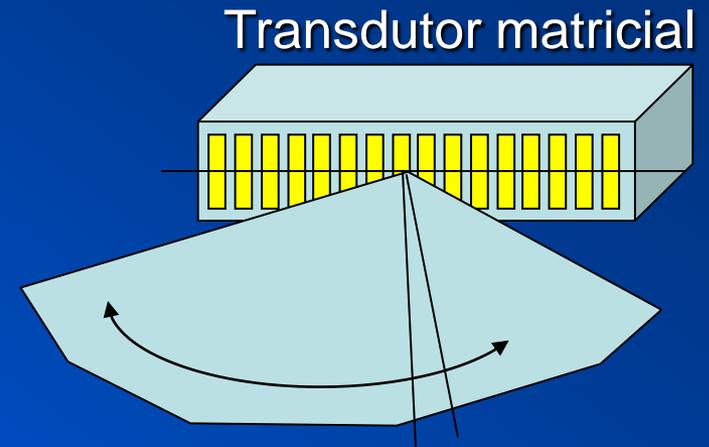
fonte: IEEE Engineering in Medicine and
biology 15(6), 20-30 (1996)



fonte: <http://www.yourultrasound.com>

Introdução – transdutores matriciais

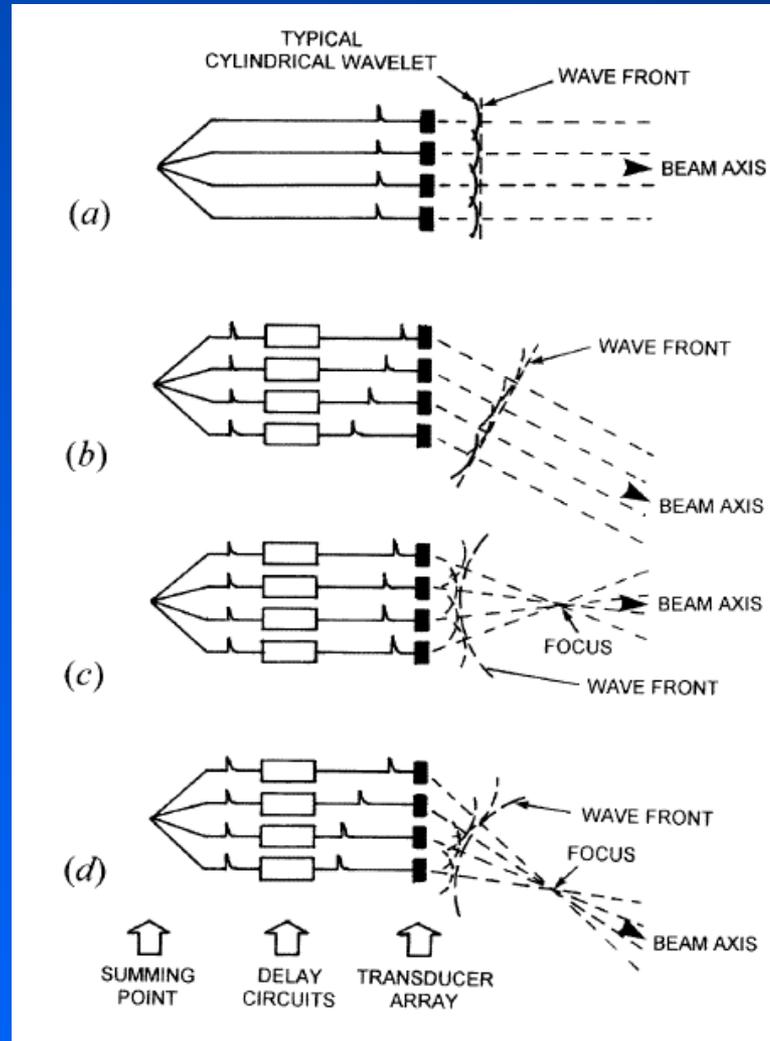
- Transdutores matriciais (*arrays*) são amplamente utilizados em imagens médicas.



- Esse tipo de transdutor possibilita defletir e focalizar eletronicamente o feixe ultra-sônico sem necessidade de mover o transdutor.

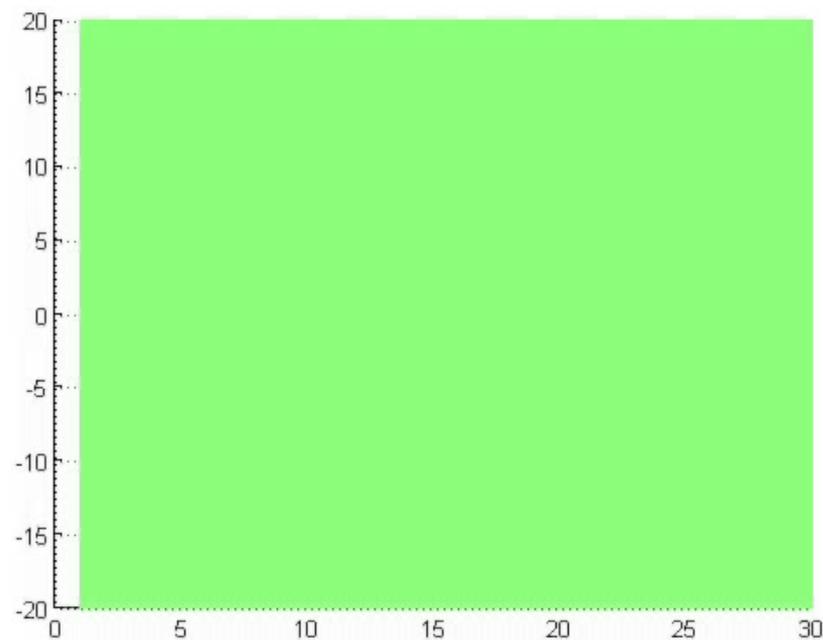
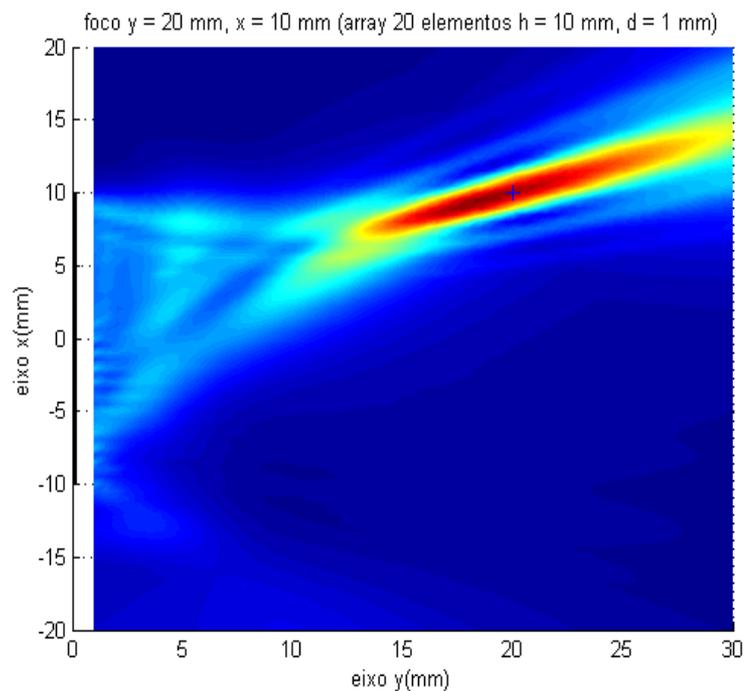
- A focalização e a deflexão é feita aplicando-se diferentes atrasos na excitação dos elementos do transdutor.

transdutores matriciais



fonte: Rep. Prog. Phys 62, 671-722 (1999)

Introdução – transdutores matriciais



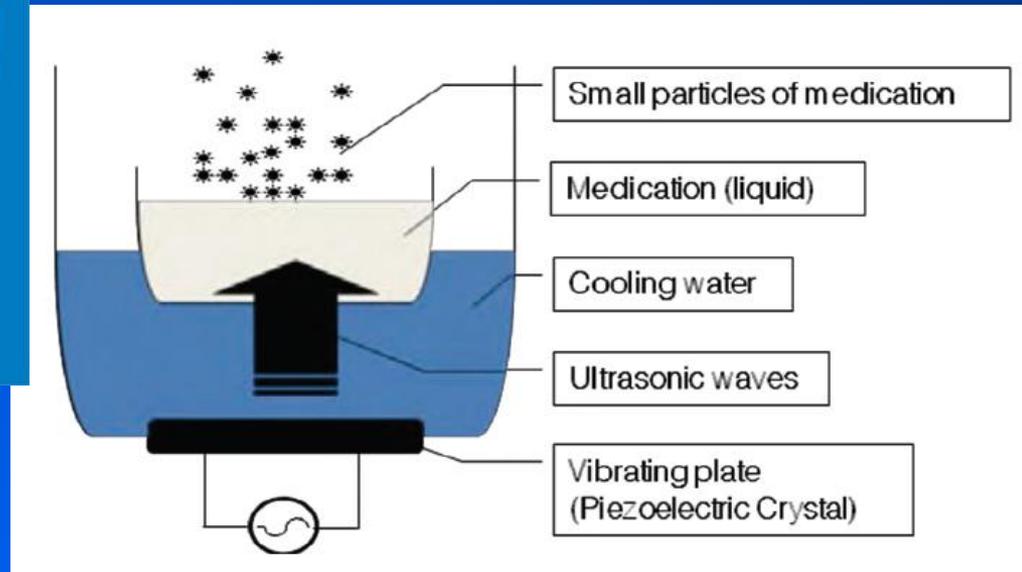
Outras aplicações de ultrassom na área biomédica

Inalador Ultrassônico

Inalador ultrassônico



fonte:
<http://www.mickeyoo.com/UploadFiles/ProImage/2009071410372021d6.jpg>



fonte: **New approaches to Nebulizer Drug Delivery**

International Symposium on Advanced Topics in
Electrical Engineering

Litotripsia extra-corpórea

Litotripsy extra-corpórea

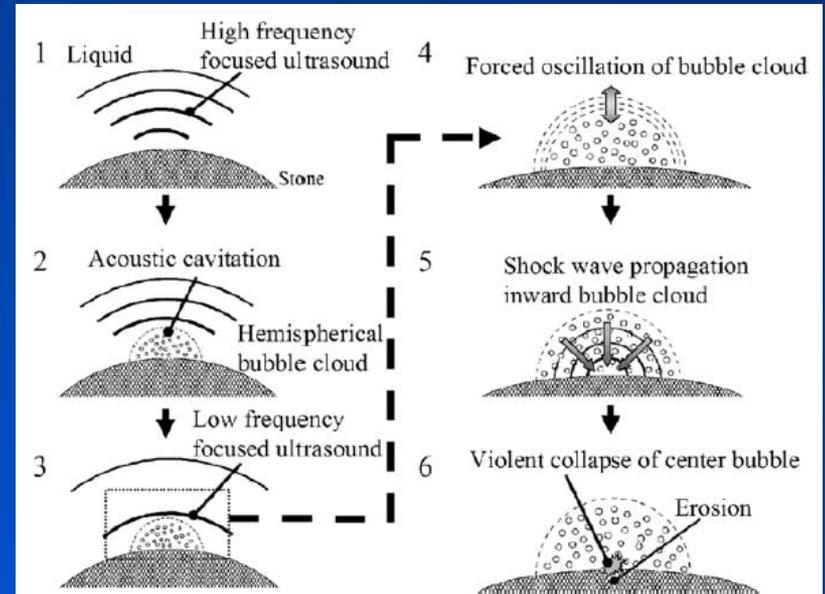
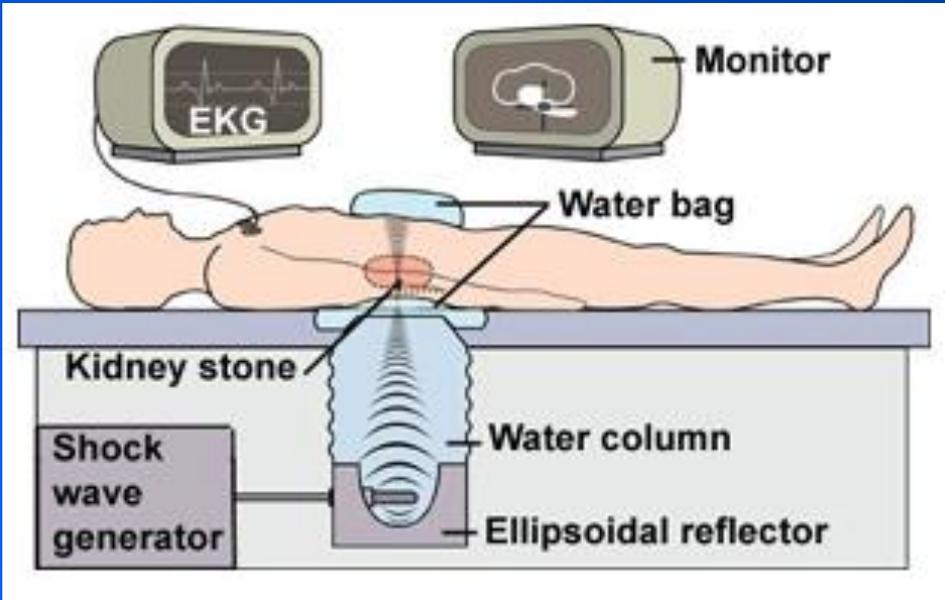
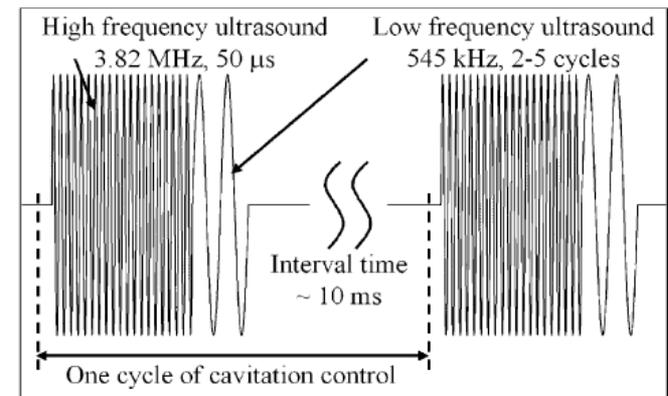
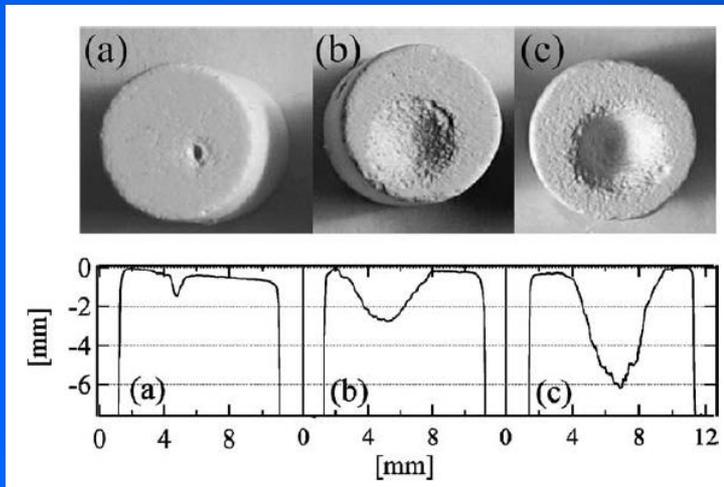
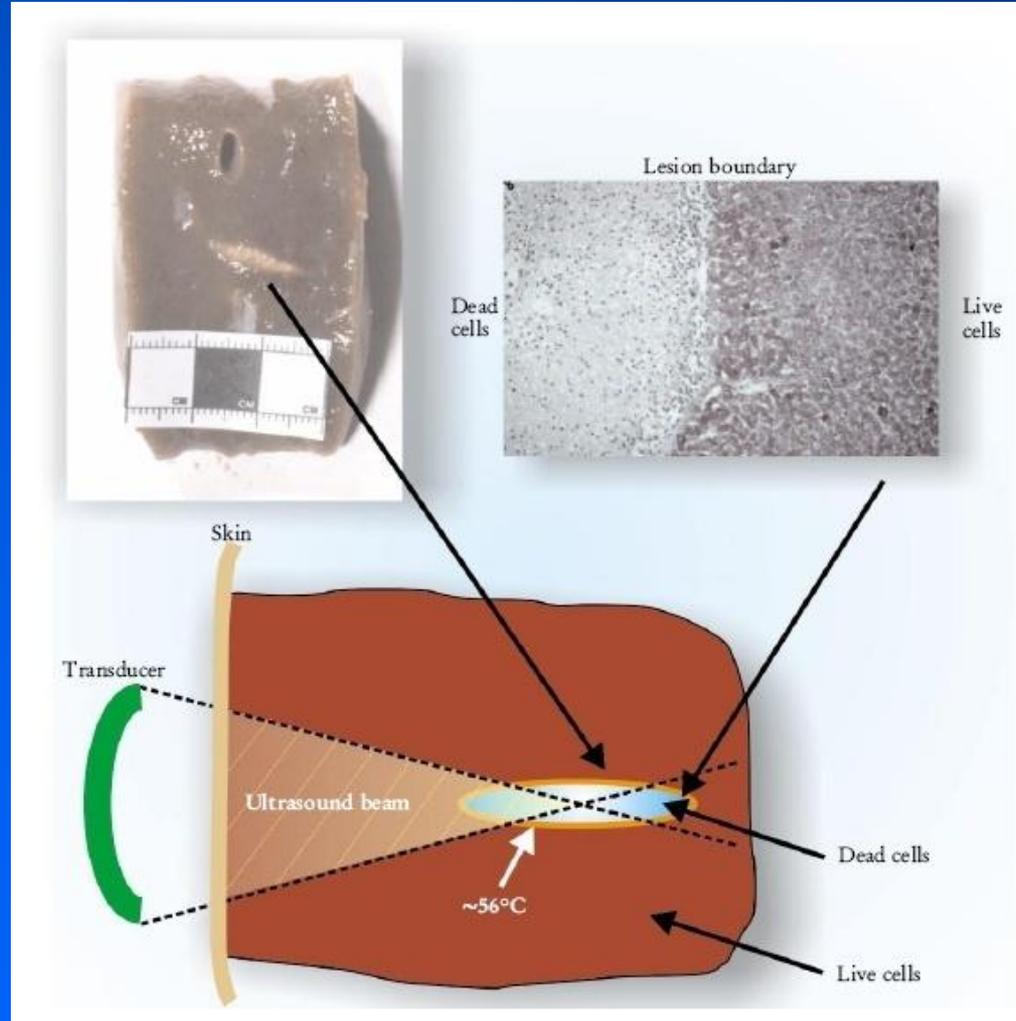


Fig. 10. Schematic of cloud cavitation control.



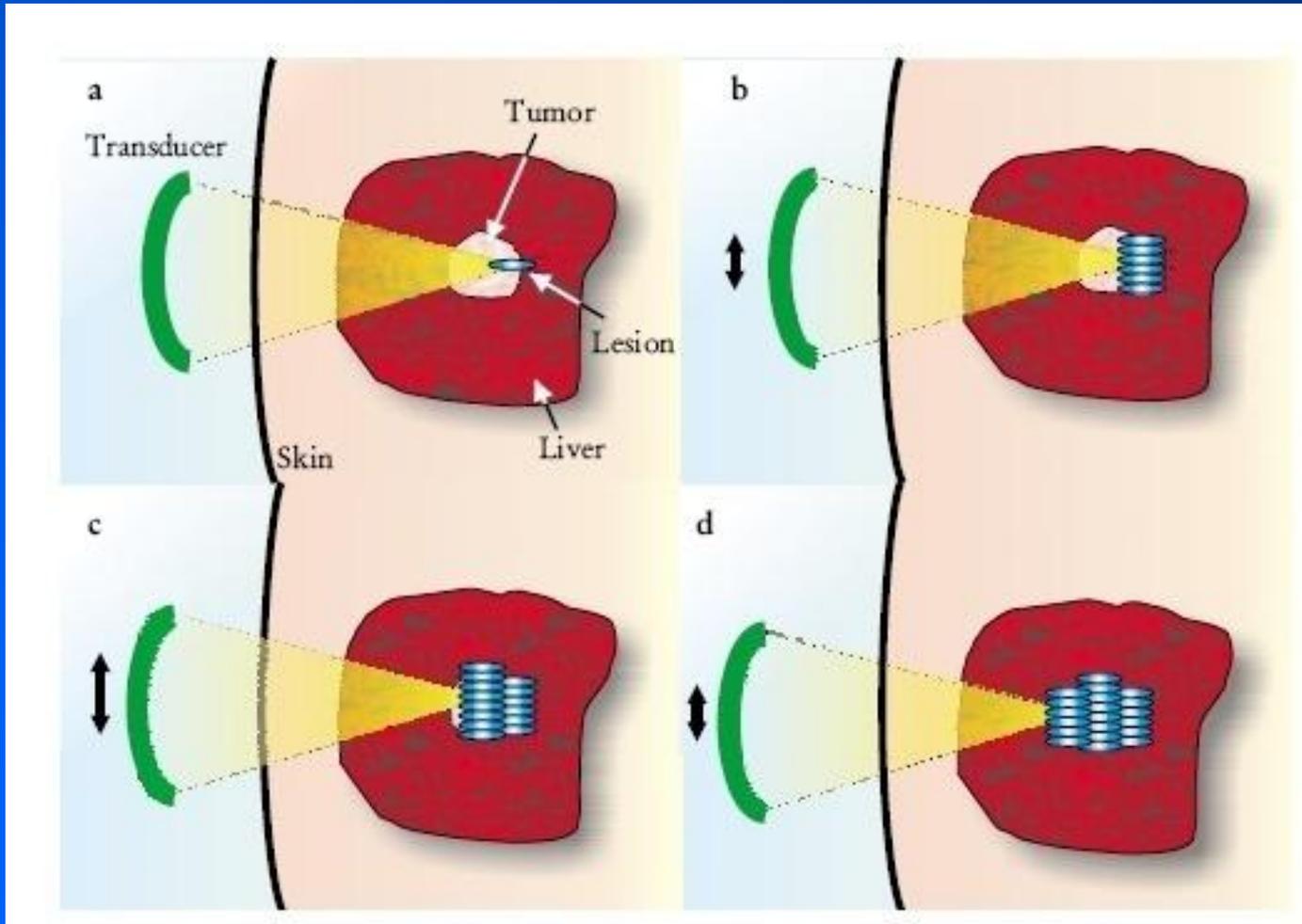
Cirurgia acústica

Cirurgia Acústica



fonte: Phys. Today 54(12), 29 (2001)

Cirurgia Acústica



fonte: Phys. Today 54(12), 29 (2001)

Tratamento de gordura localizada

Liposonix



fonte: <http://www.liposonix.com>



BEFORE

AFTER



BEFORE

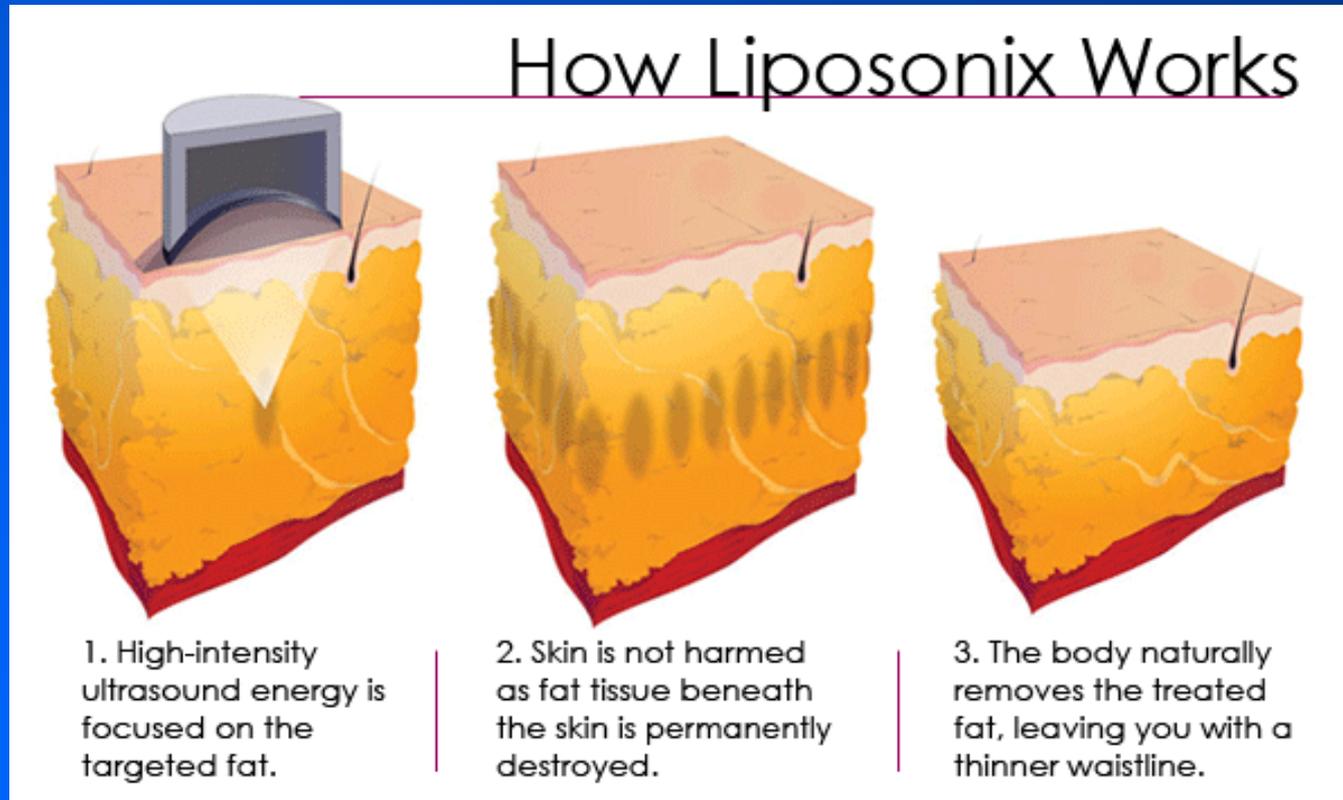
AFTER



BEFORE

AFTER

Liposonix

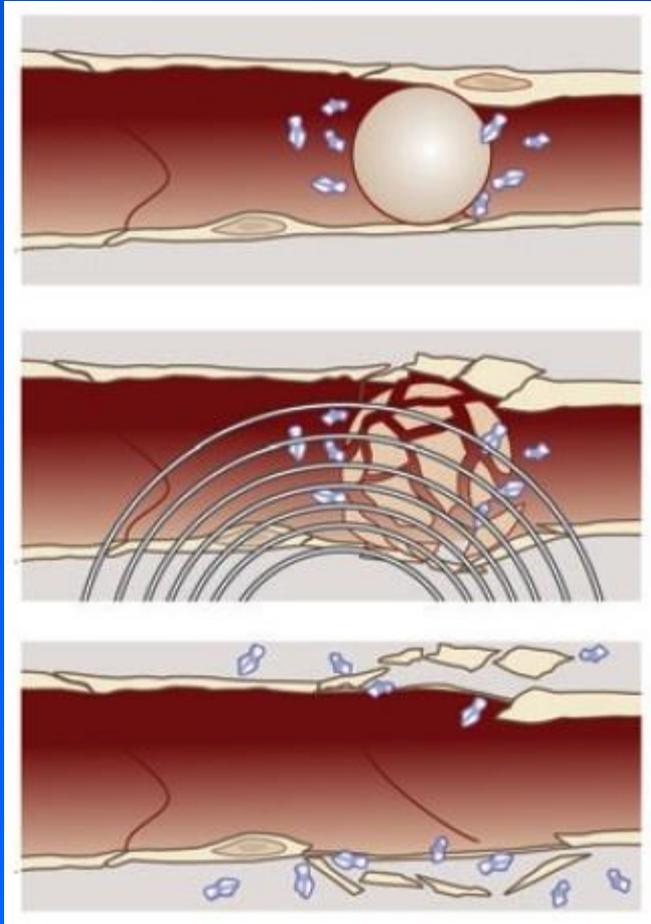


fonte: <http://www.liposonix.com>

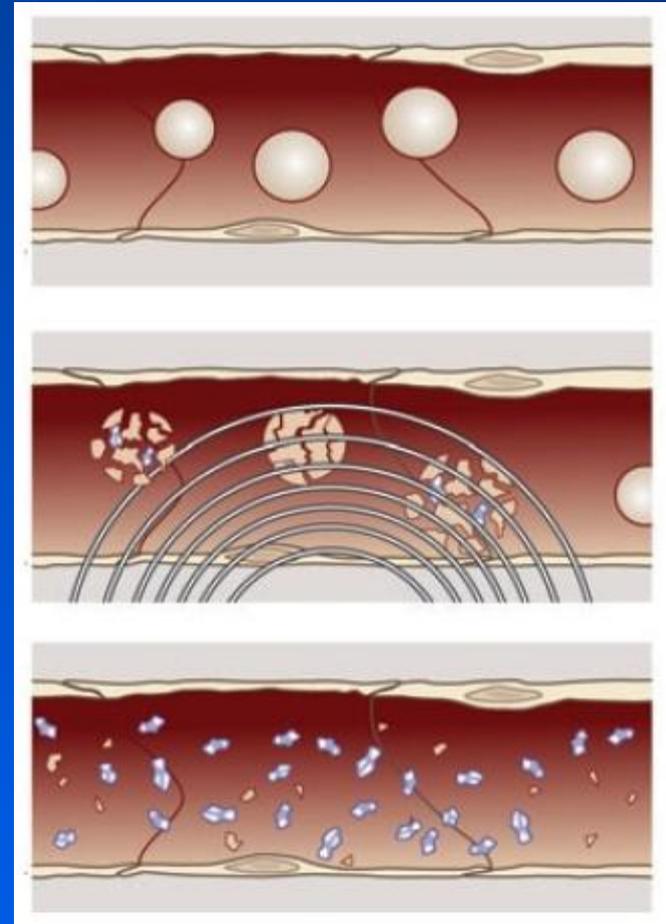
Drug delivery

Drug Delivery

primeira abordagem

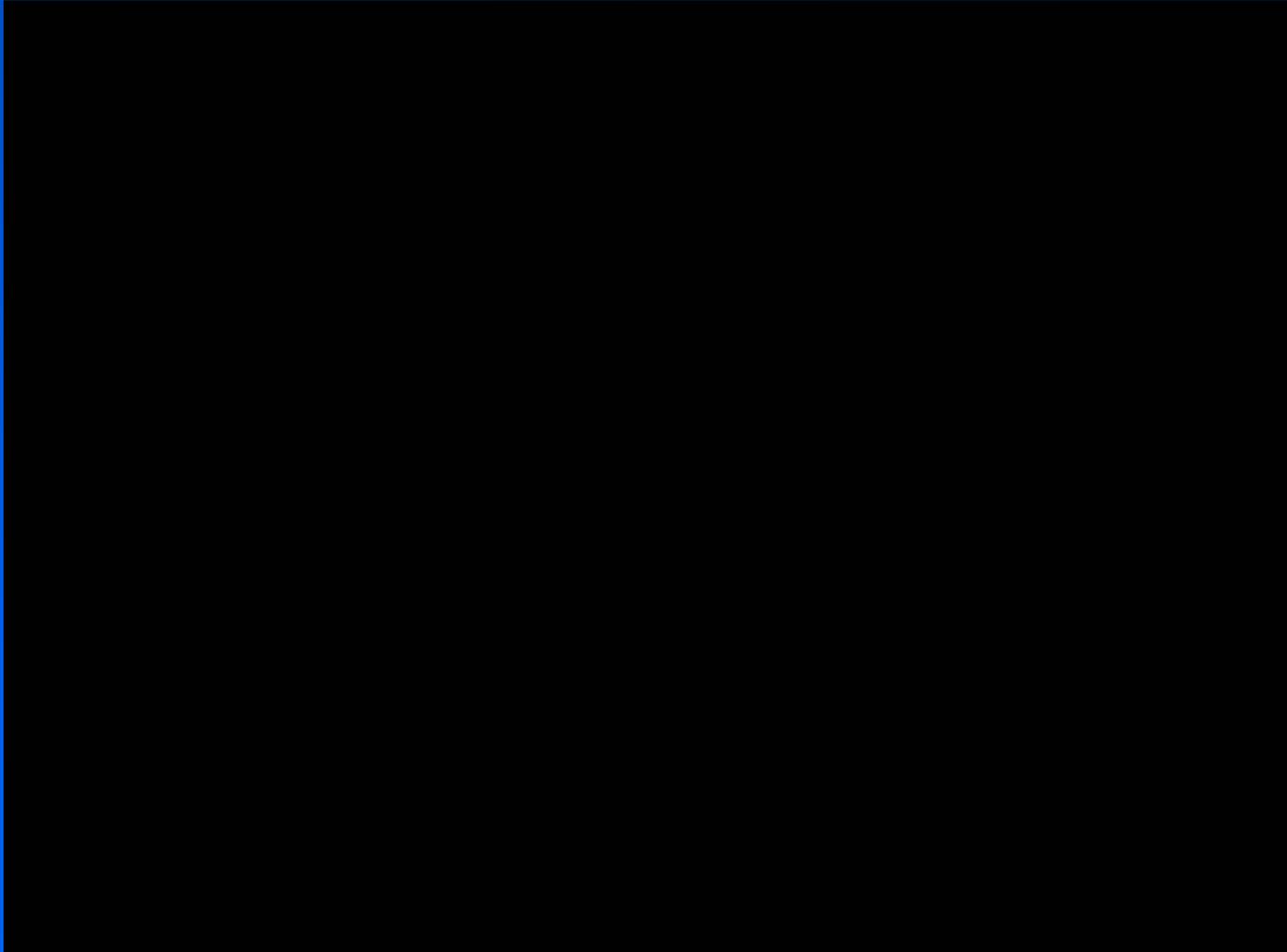


segunda abordagem



Aplicação odontológica

Aplicação odontológica



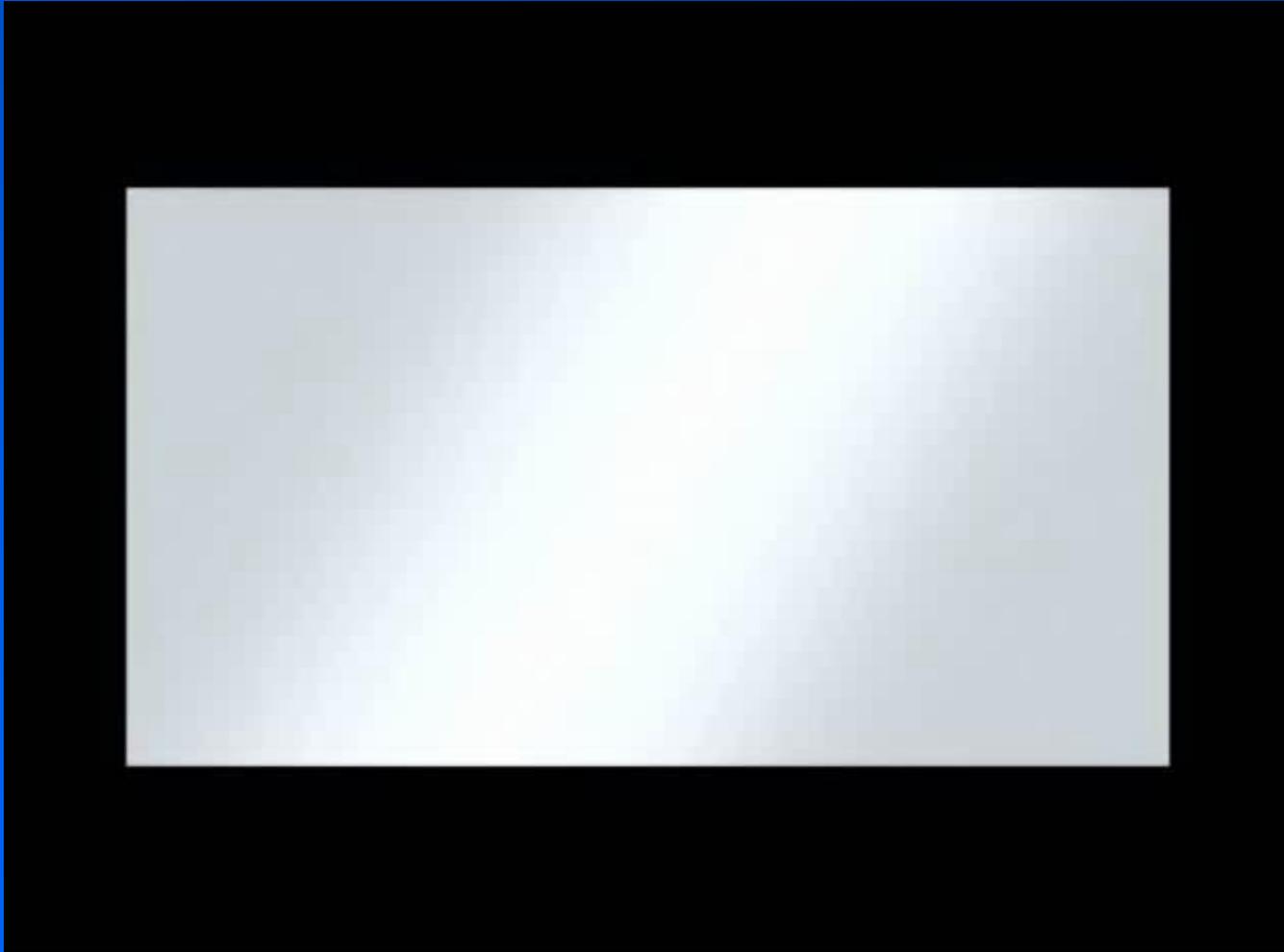
fonte: <https://www.youtube.com/watch?v=bx4GgAKYvEc>

Video: Dental Ultrasonic Scaler tools supply

Aplicações industriais

Soldagem de plásticos

Soldagem de plásticos

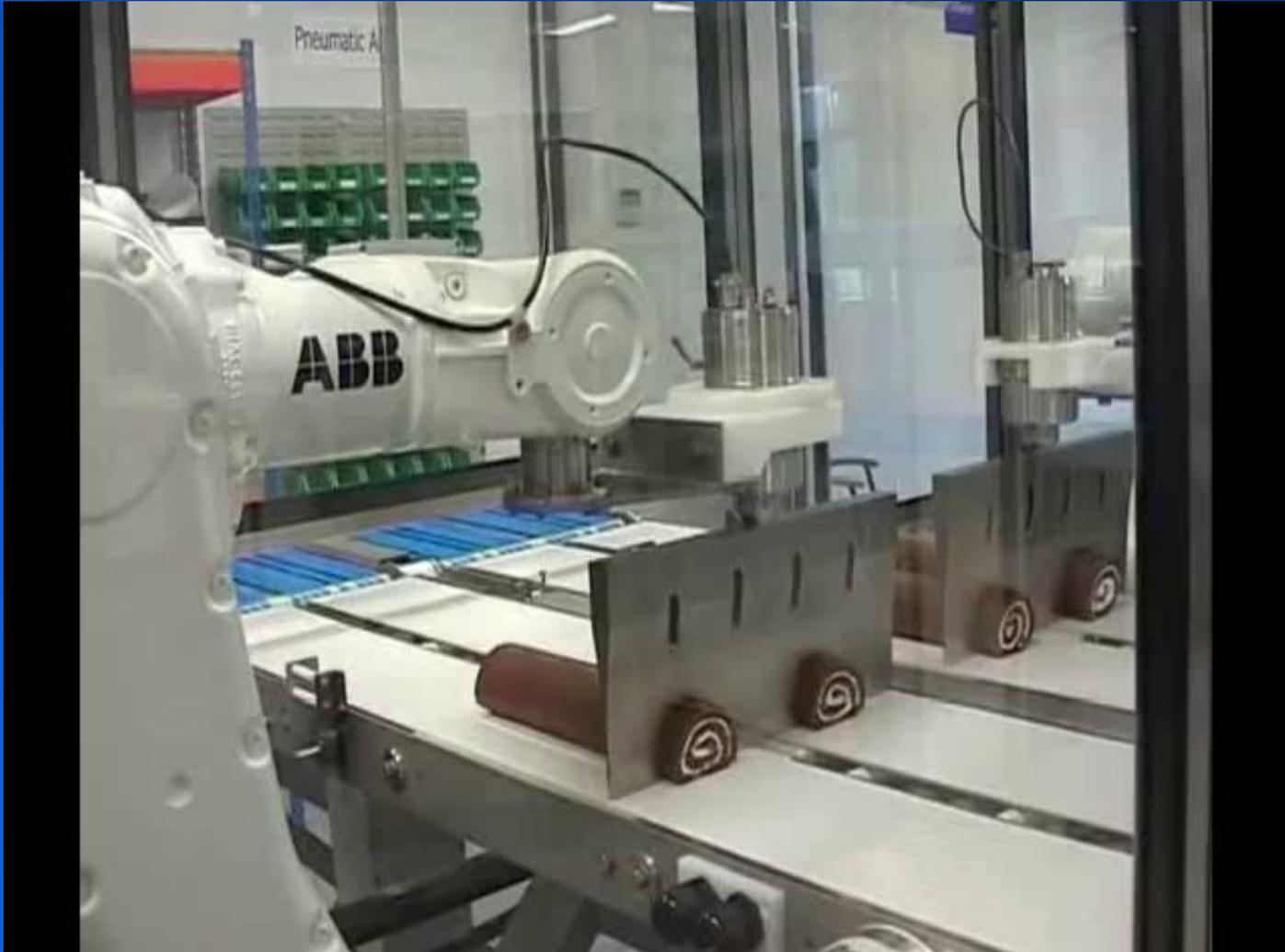


fonte: <https://www.youtube.com/watch?v=xreJsl8Dpsk>

Video: Horizontal ultrasonic sealing technology by Herrmann Ultrasonics

Corte com ultrassom

Corte com ultrassom



fonte: <https://www.youtube.com/watch?v=mcWFmIH3zWk>

Video: newtech – ultrasonic food cutting applications

Cavitação acústica e algumas aplicações interessantes

Cavitação acústica

- A cavitação pode ser definida como a formação de bolhas de ar ou vapor no interior de um líquido devido a uma redução de pressão



- O termo cavitação acústica pode designar as contrações e expansões de bolhas devido a uma pressão que oscila no tempo

Modelo matemático de cavitação acústica

$$f_0 = \frac{1}{2\pi} \sqrt{\left(3\gamma \frac{\left(P_0 + \frac{2\sigma}{R_0} \right)}{\rho_0 R_0^2} - \frac{2\sigma}{\rho_0 R_0^3} \right)}$$

Equação de Gilmore:

$$R \left(1 - \frac{U}{c} \right) \frac{d^2 R}{dt^2} + \frac{3}{2} \left(1 - \frac{U}{3c} \right) \left(\frac{dR}{dt} \right)^2 - \left(1 + \frac{U}{c} \right) H - \frac{U}{c} \left(1 - \frac{U}{c} \right) R \frac{dH}{dR} = 0$$

Modelo matemático de cavitação acústica

Pressão acústica irradiada pela bolha:

$$p(r, t) = A \left[\frac{2}{m+1} + \frac{m-1}{m+1} \left(1 + \frac{m+1}{rc_0^2} G(t) \right)^{\frac{1}{2}} \right] - B$$

onde:

$$G(R, t) = R(t) \left[H(R, t) + \frac{U(t)^2}{2} \right]$$

Resultados do modelo

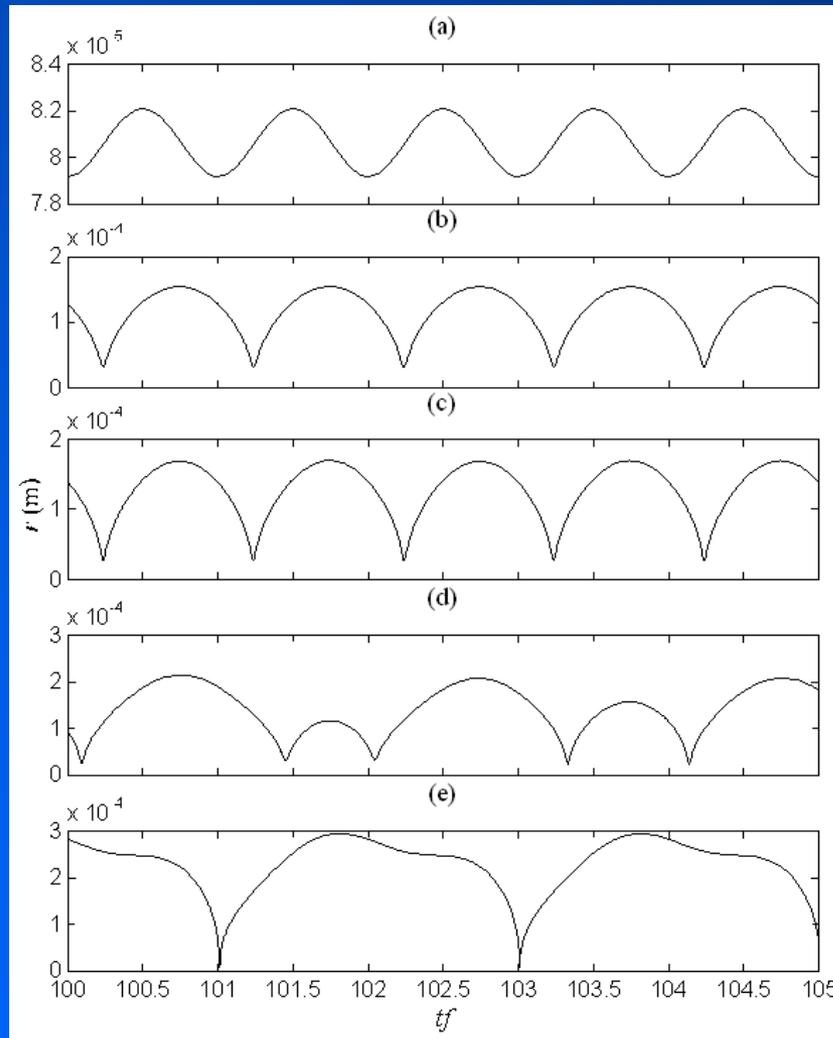
Raio da bolha em função do tempo:

$$P_{\infty} = P_0 - P_n \text{sen}(2\pi ft)$$

$$P_0 = 1 \text{ atm}$$

$$f = 40 \text{ kHz}$$

$$R_0 = 80,64 \text{ }\mu\text{m}$$



$$P_0 = 0,001 \text{ atm}$$

$$P_0 = 1 \text{ atm}$$

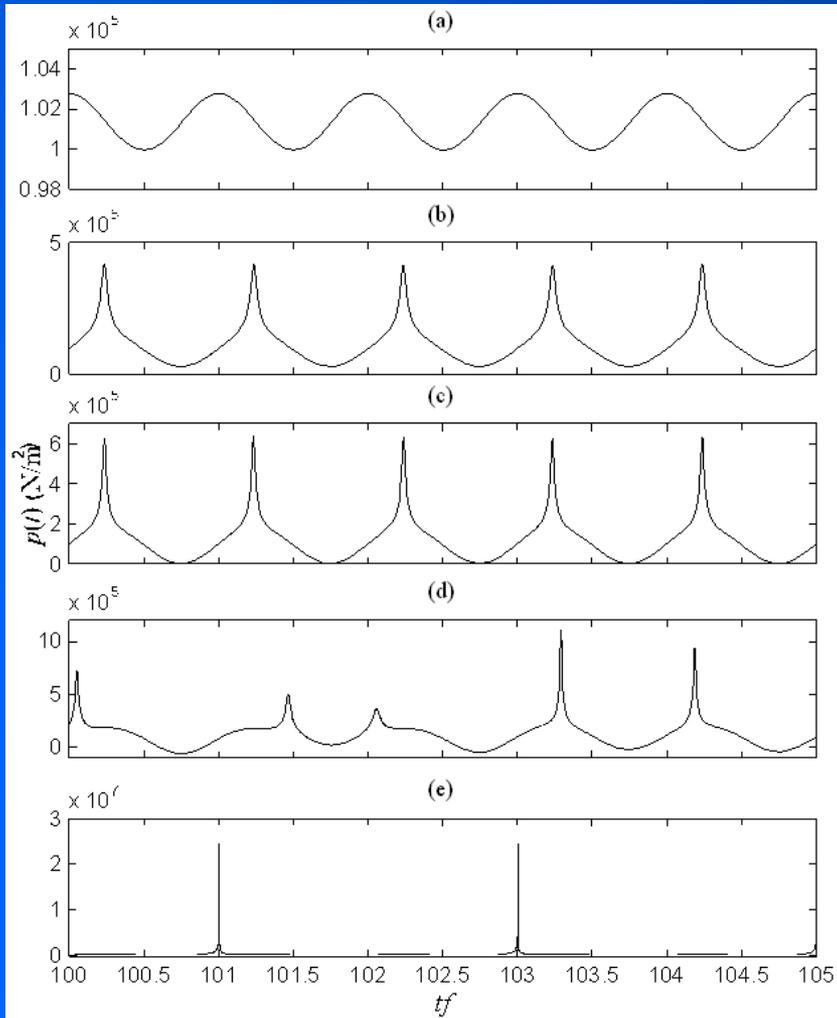
$$P_0 = 1,5 \text{ atm}$$

$$P_0 = 2 \text{ atm}$$

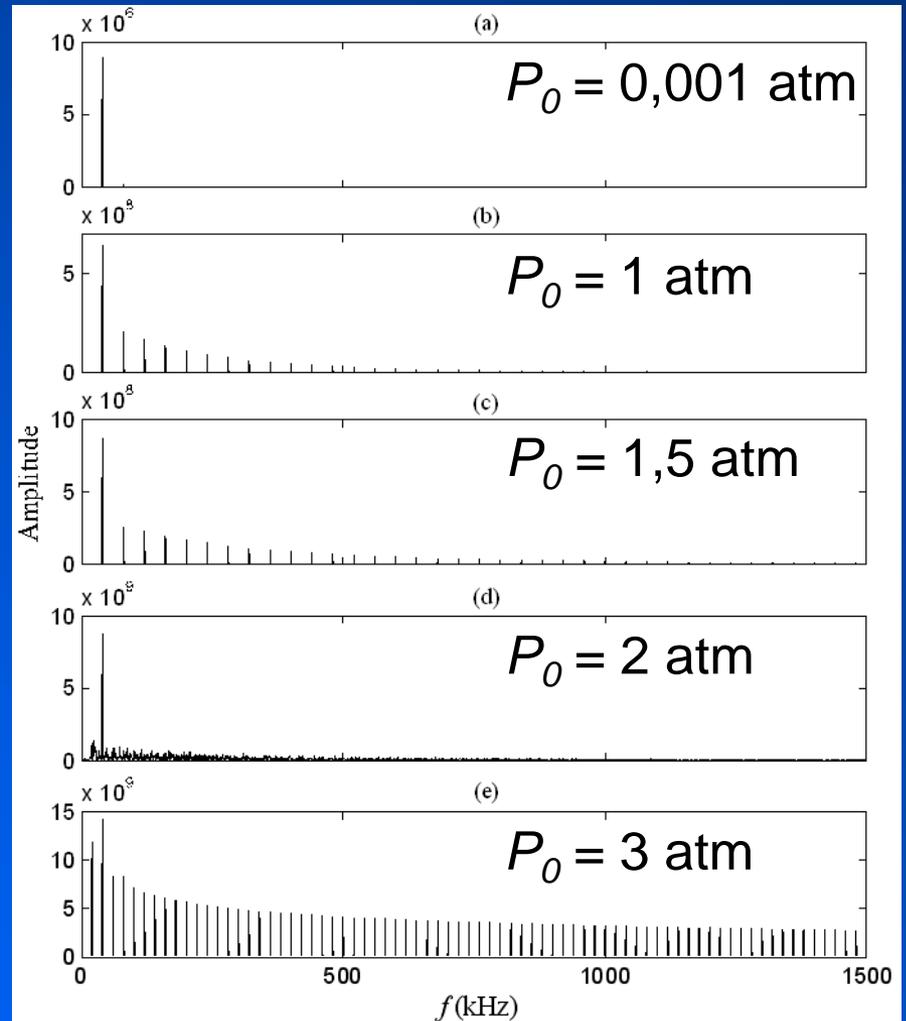
$$P_0 = 3 \text{ atm}$$

Resultados do modelo

Pressão irradiada pela bolha:

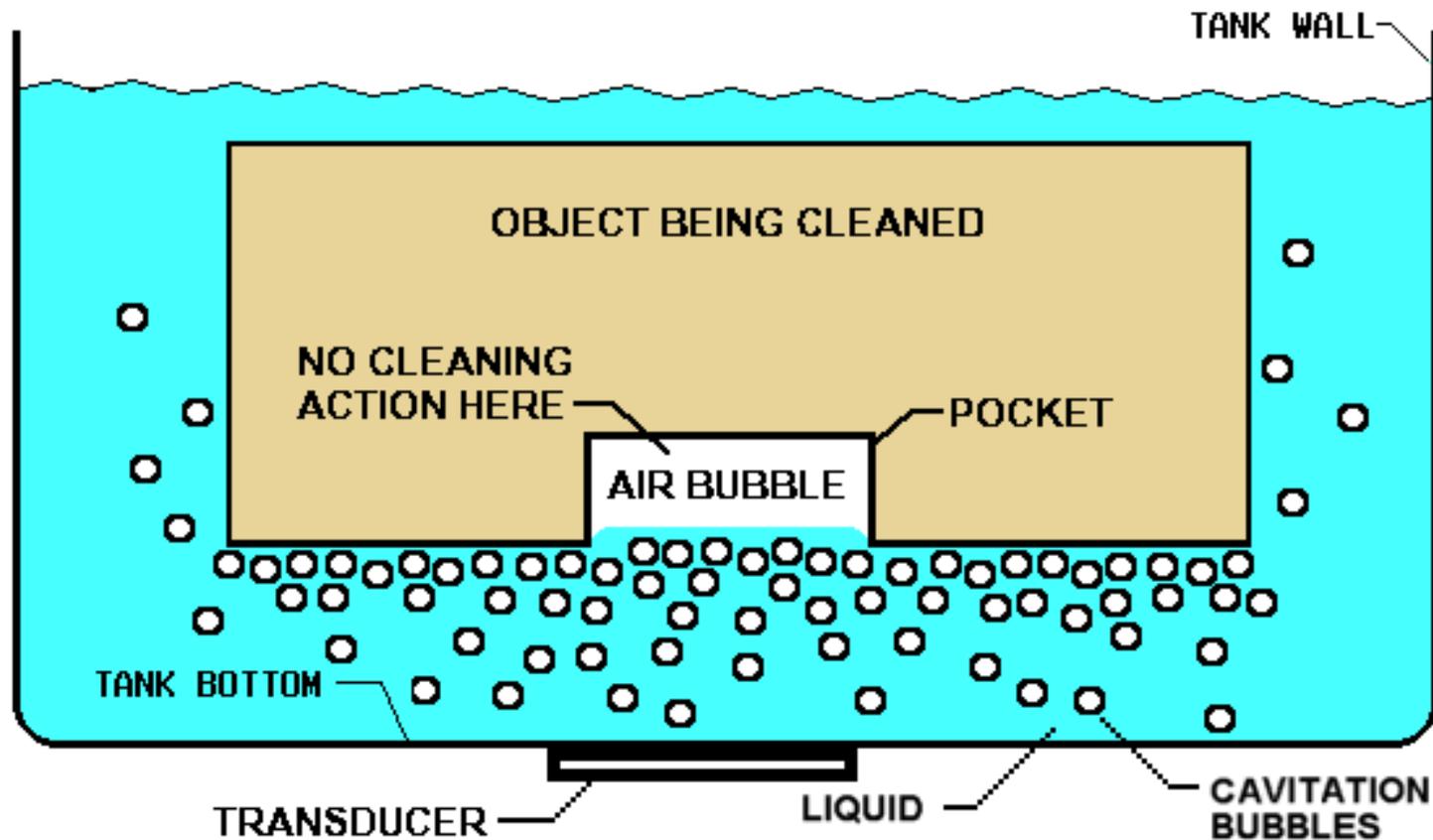


FFT da pressão irradiada:



Cavitação acústica:
Limpeza ultrassônica

Limpeza ultrassônica



ULTRASONIC POCKETING

S. BERLINER, III

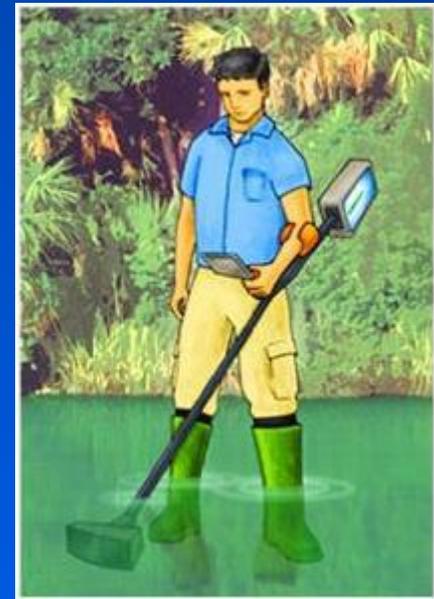
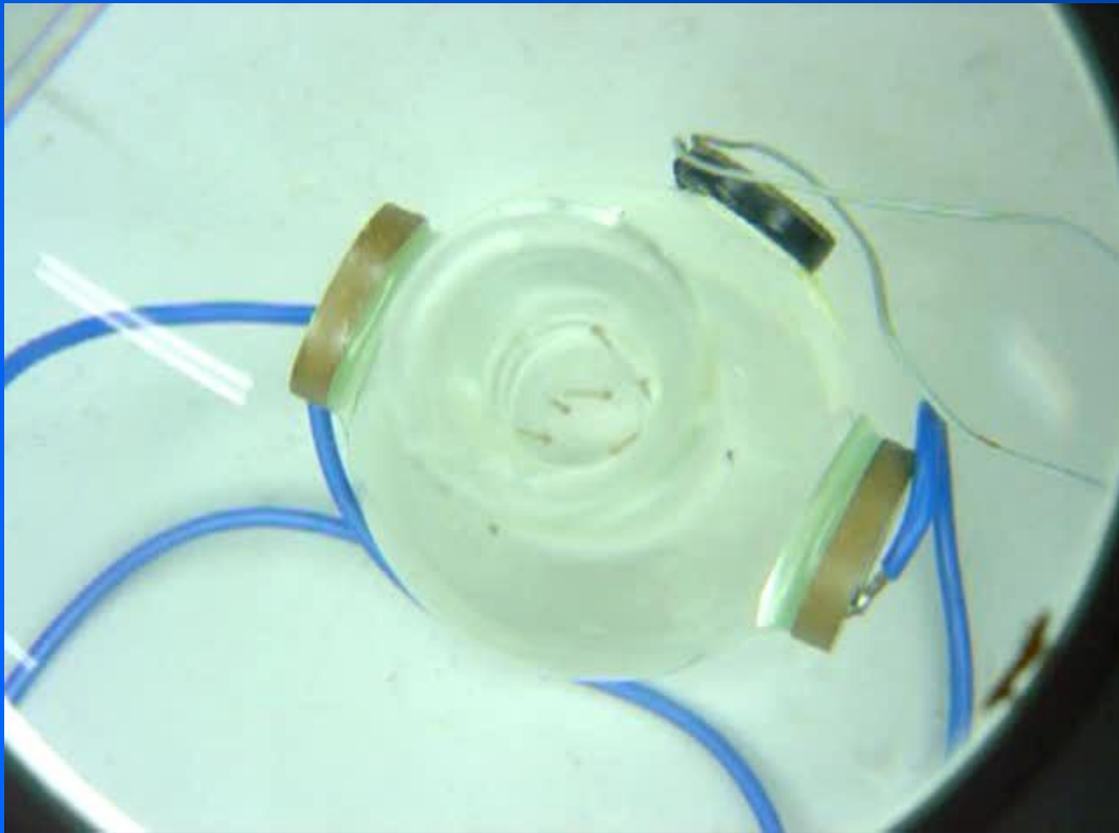
04 Mar 2010

fonte: <http://berliner-ultrasonics.org/us-clean.html>

**Cavitação acústica:
Controle de larvas de mosquito**

Cavitação acústica

- Controle de Larvas de Mosquito

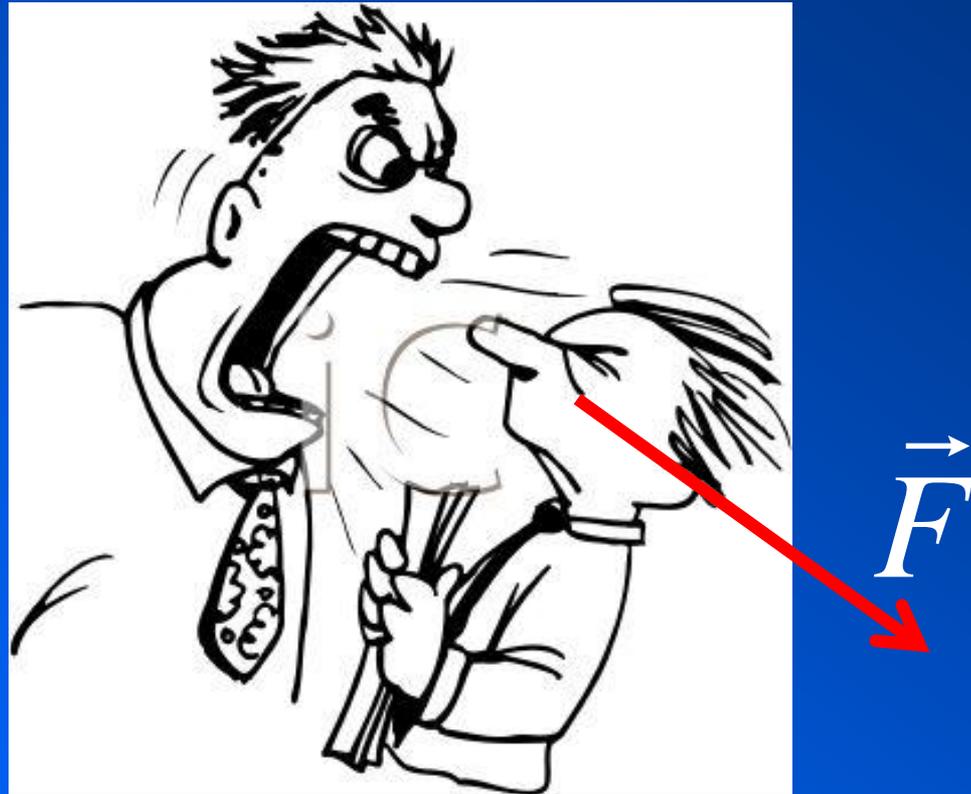


Força de radiação acústica

E

Levitação acústica

Força de radiação acústica

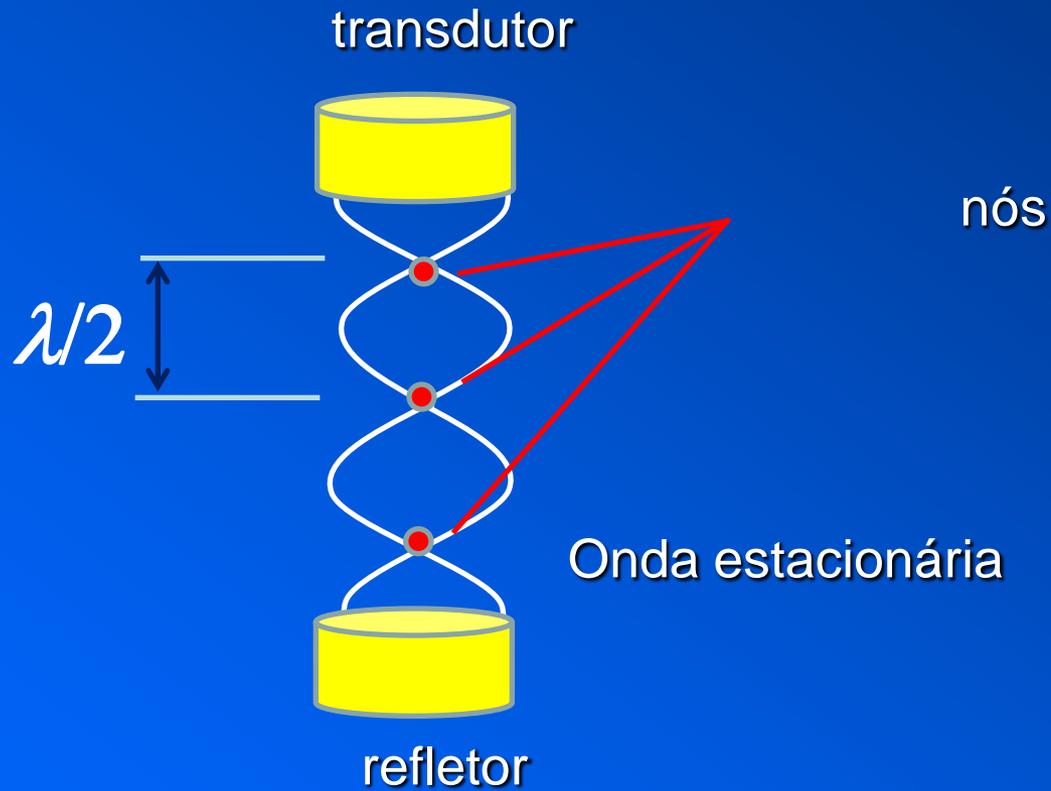


Levitação acústica



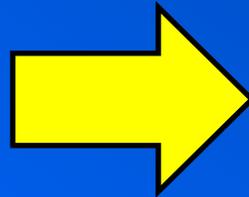
Princípio de funcionamento

Ondas estacionária



**Força de radiação acústica:
Teoria de Gor`kov**

Aproximar formiga por uma esfera ($R \ll \lambda$)



Teoria de Gor'kov

Potencial da força de radiação acústica:

$$U = 2\pi R^3 \left(\frac{\overline{p^2}}{3\rho_f c_f^2} f_1 - \frac{\rho_f \overline{u^2}}{2} f_2 \right) \quad F = -\nabla U$$

$$f_1 = 1 - \frac{\rho_f c_f^2}{\rho_s c_s^2} \quad f_2 = \frac{2(\rho_s - \rho_f)}{2\rho_s + \rho_f}$$

Para o caso $\rho_s \gg \rho_f$:

$$f_1 = 1 \quad ; \quad f_2 = 1$$

Teoria de Gor'kov

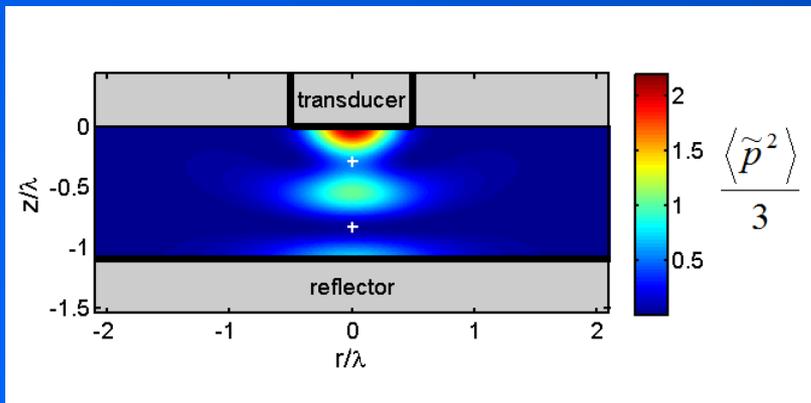
Potencial adimensional:

$$\tilde{U} = \frac{U}{2\pi R^3 \rho u_0^2} = \left(\frac{\langle \tilde{p}^2 \rangle}{3} - \frac{\langle \tilde{\mathbf{u}} \cdot \tilde{\mathbf{u}} \rangle}{2} \right)$$

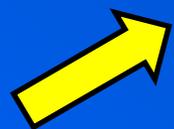
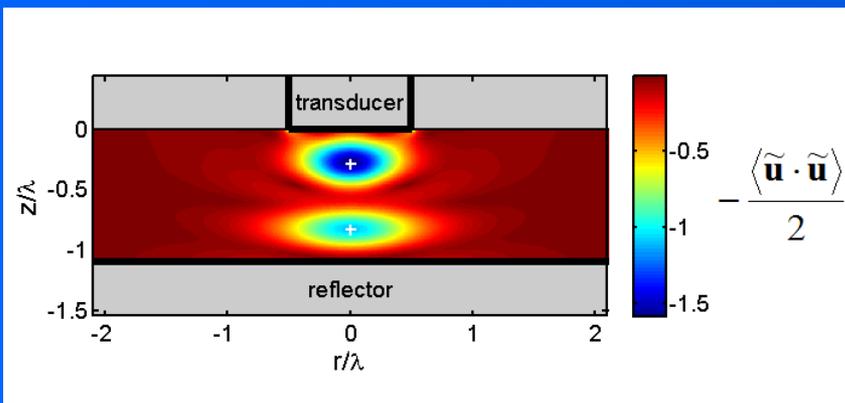
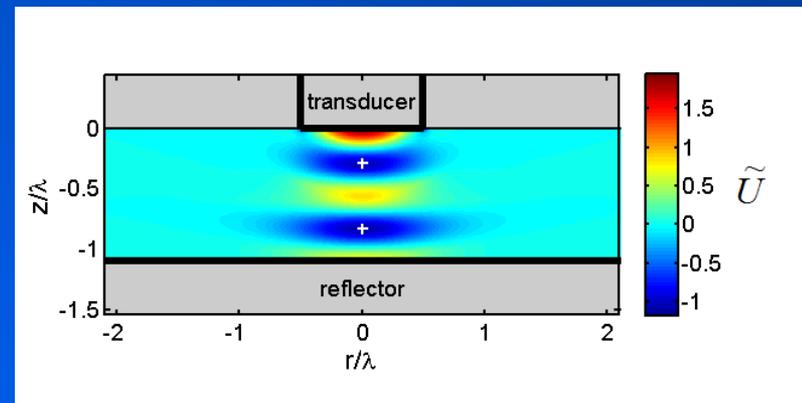
onde:

$$\tilde{p} = \frac{p}{\rho c u_0}$$

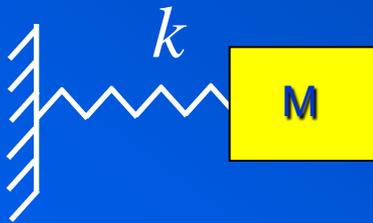
$$\tilde{\mathbf{u}} = \frac{\mathbf{u}}{u_0}$$



Potencial da força de radiação acústica:

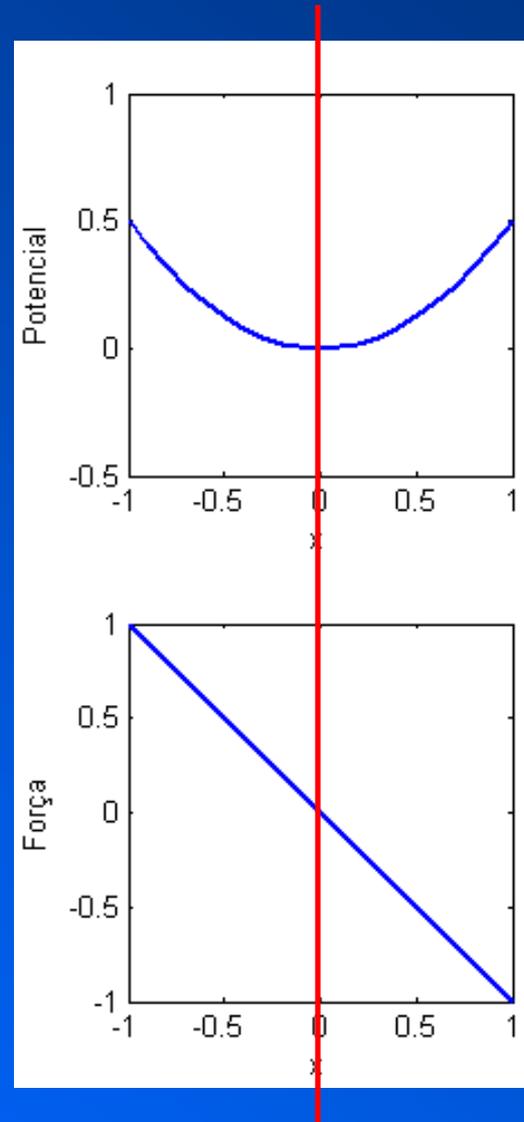


Potencial de uma mola

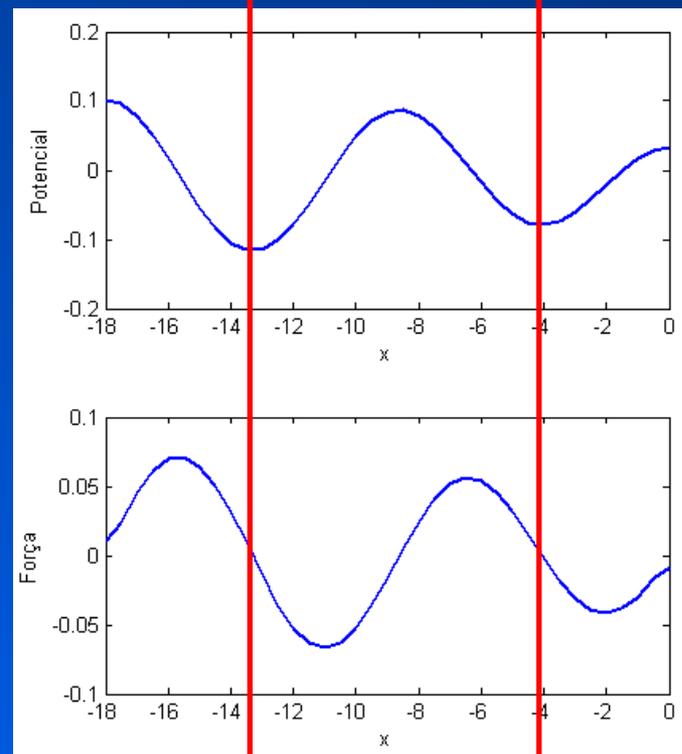
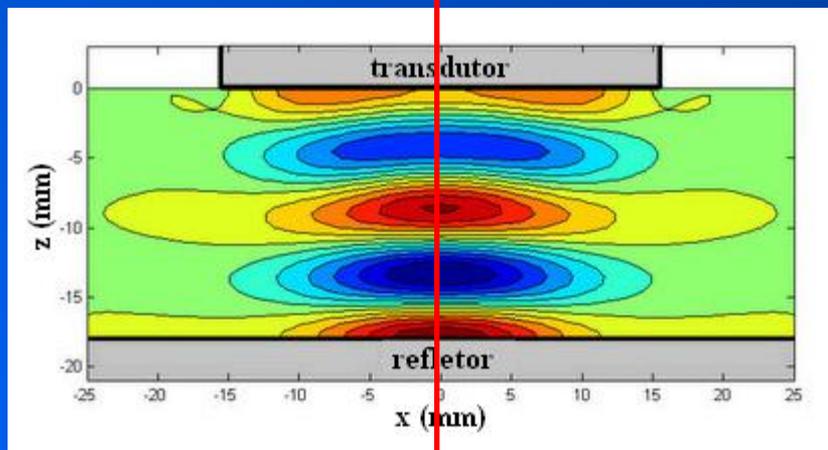


$$U = \frac{1}{2} kx^2$$

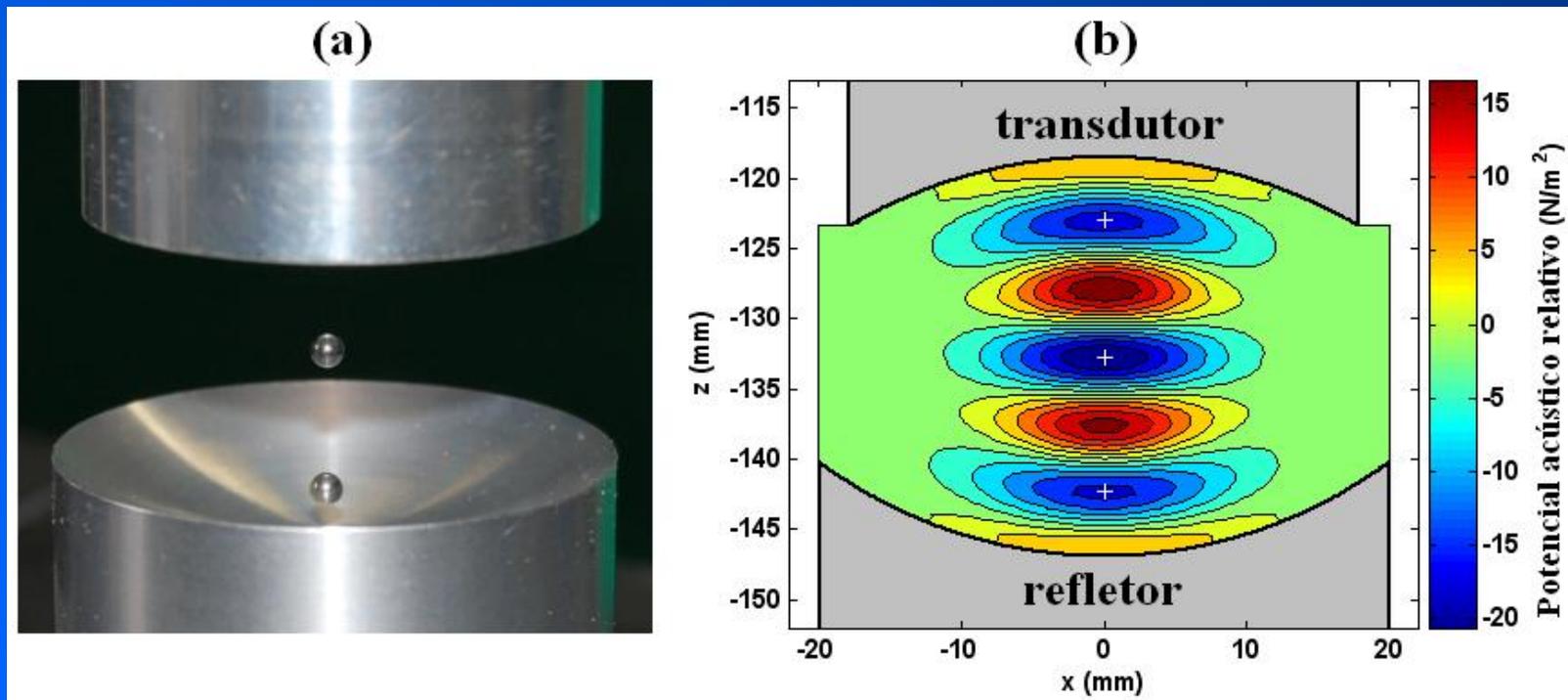
$$F = -\frac{dU}{dx} = -kx$$



Potencial da força de radiação acústica

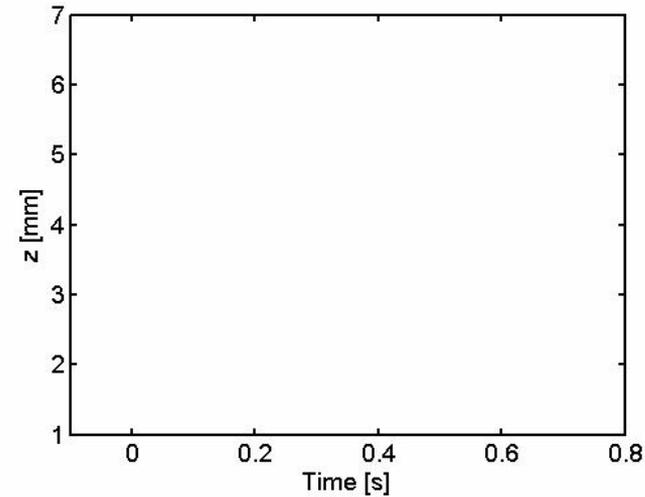
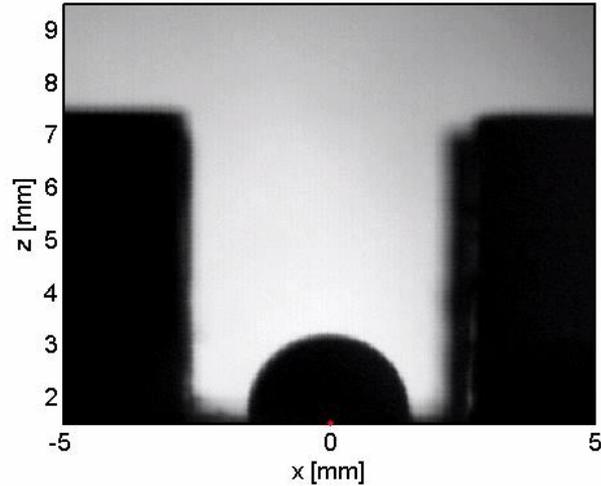


Levitação Acústica



fonte: IEEE TUFFC, 2010, 57(2), 469-479

Posição da esfera em função do tempo

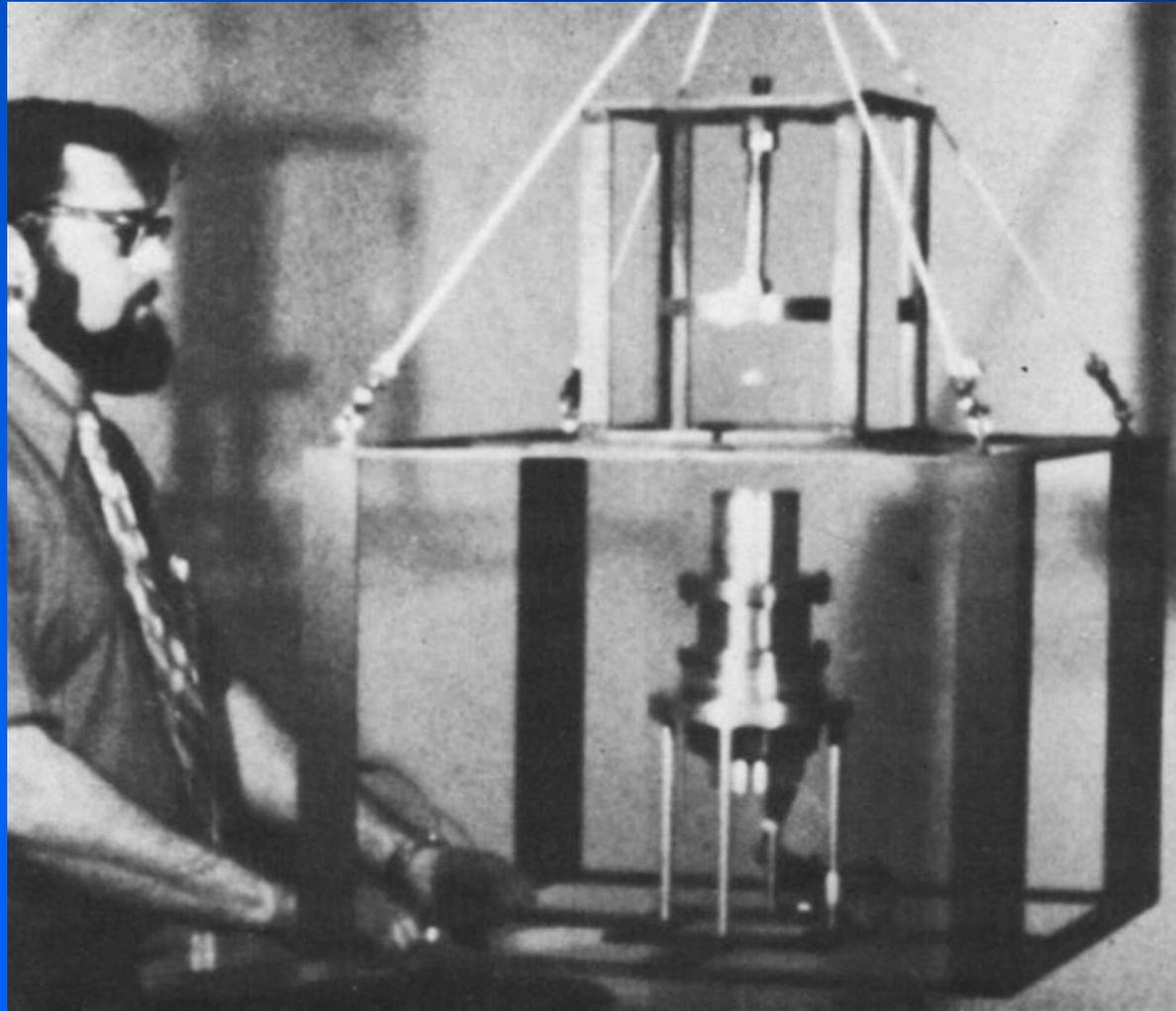


fonte: J. Appl. Phys., 2014, 116(18), 184903

Exemplos de levitadores acústicos e algumas aplicações

1975: Whymark (U.S.A)

fonte: Ultrasonics, 1975, 13, 251-261



$f = 20.000 \text{ Hz}$

2006: Xie e Wei (China)



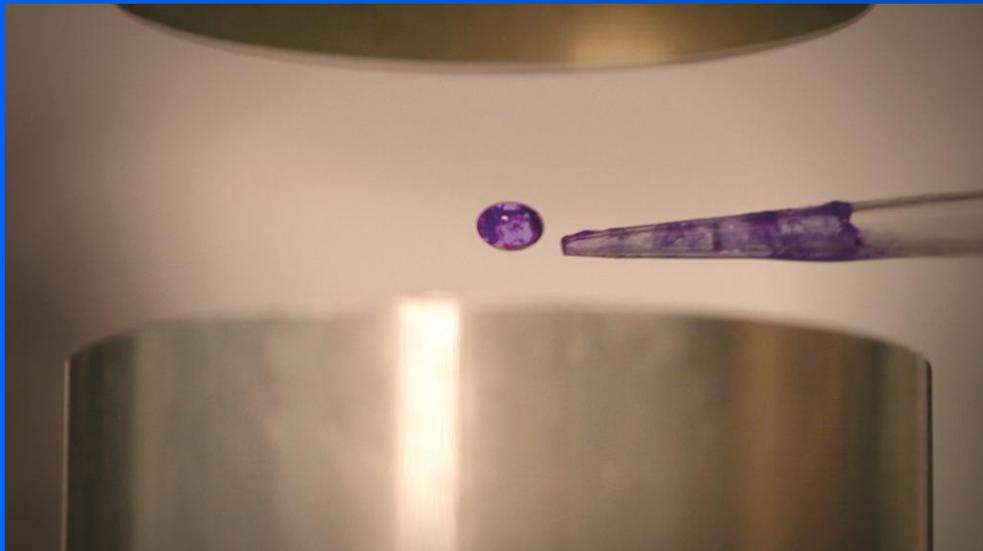
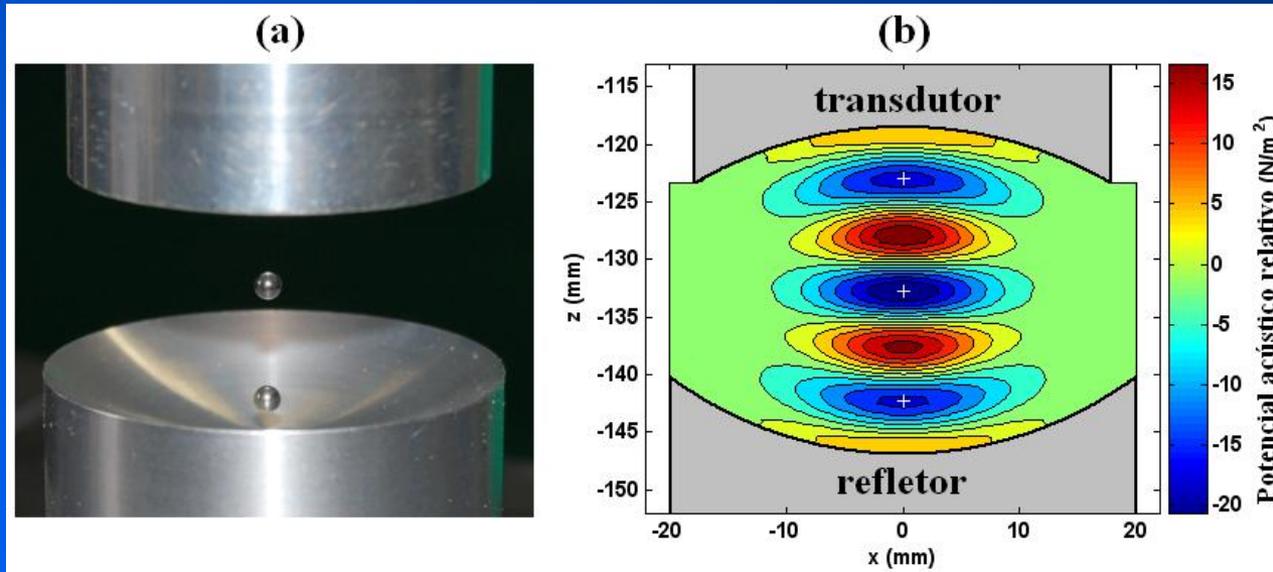
Levitação acústica de insetos

$$f = 16.700 \text{ Hz}$$

fonte: Appl. Phys. Lett., 2006, 89(21), 214102

2010: Andrade e coautores (Brasil)

fonte: IEEE TUFFC, 2010, 57(2), 469-479



$f = 20.340$ Hz

2012: Benmore e coautores (E.U.A)

fonte: <https://www.youtube.com/watch?v=669AcEBpdsY>

Video: Acoustic levitation

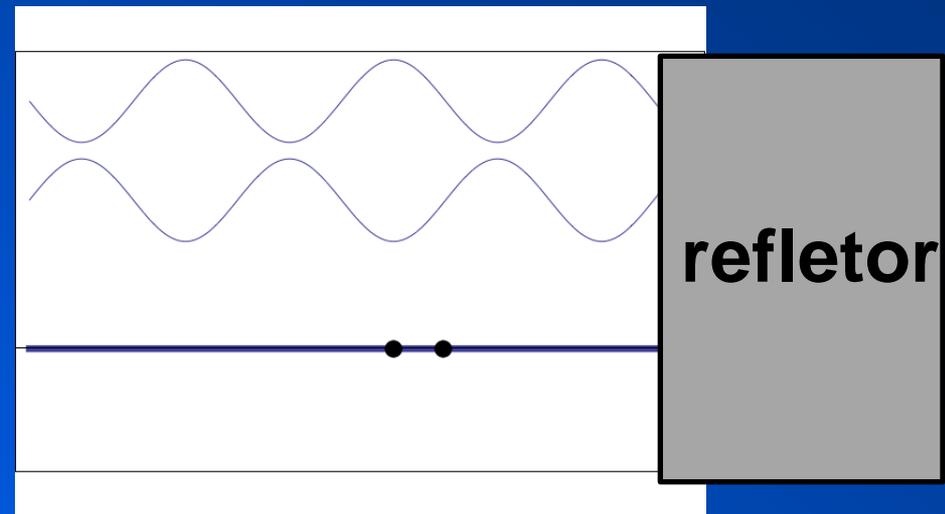
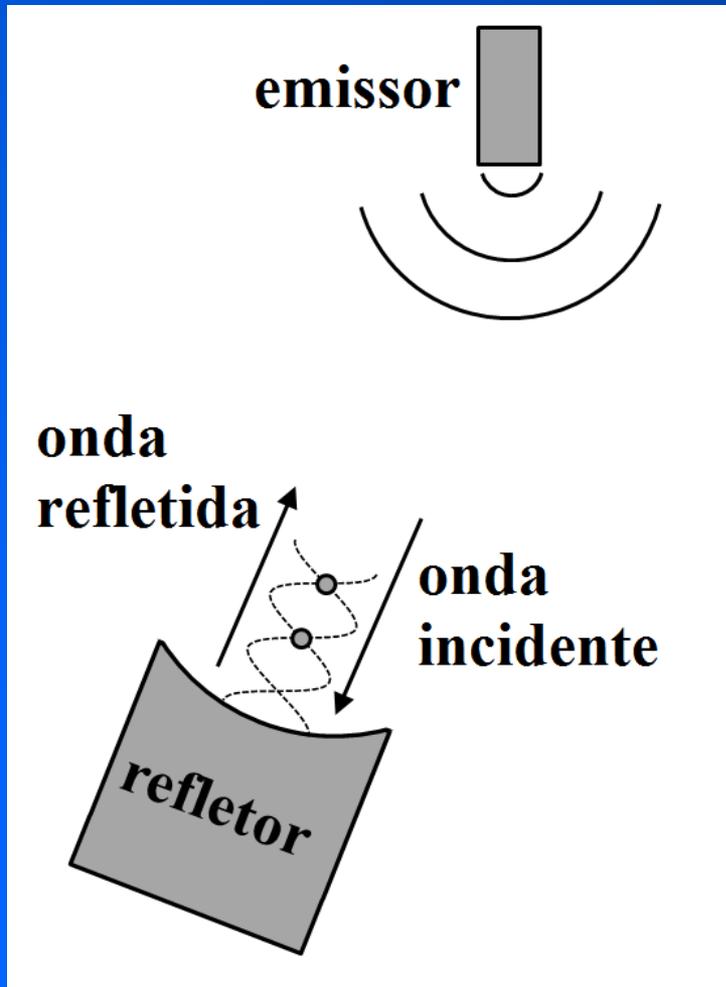


**Levitação acústica de
gotas (fármacos)**

$f = 22.000$ Hz

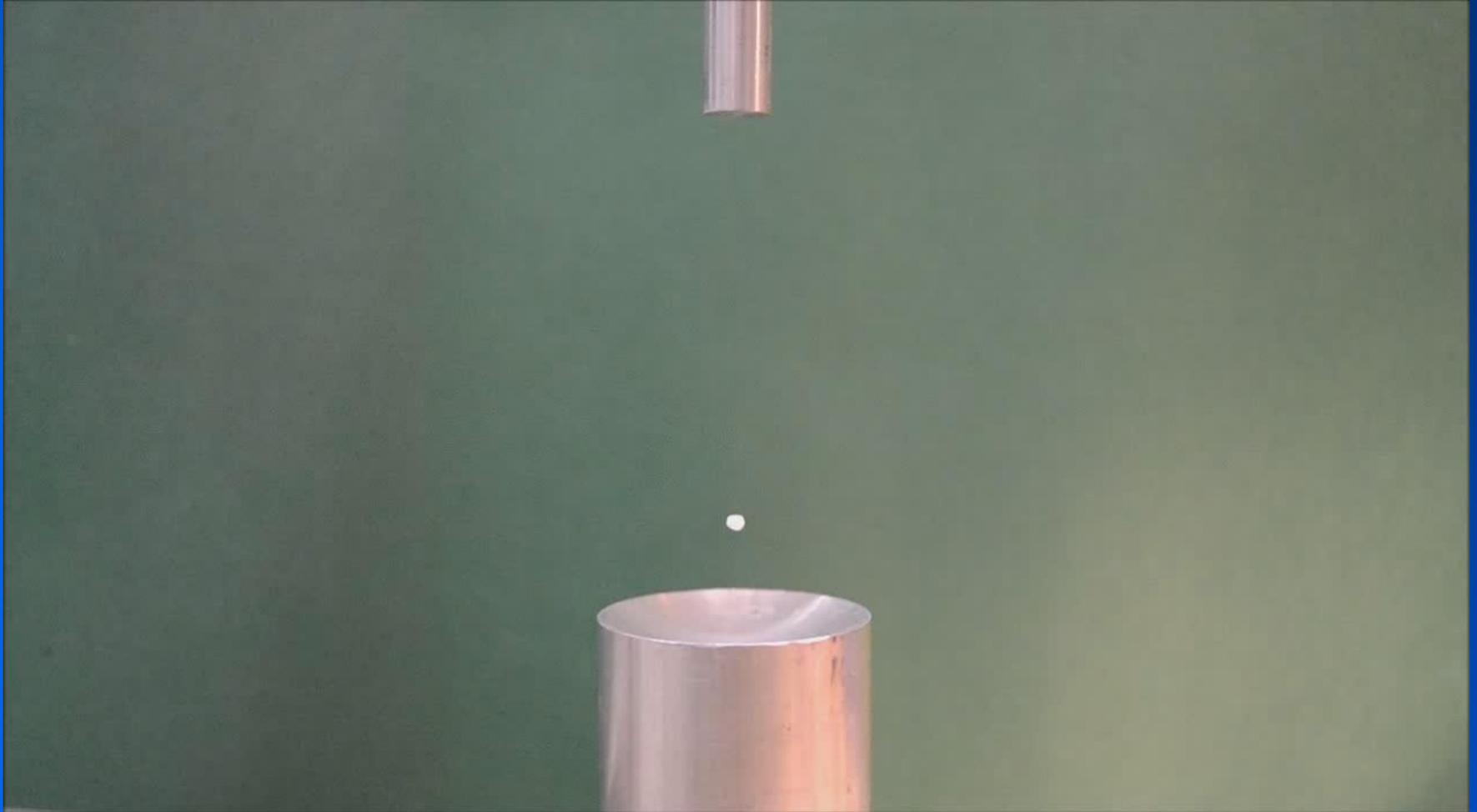
2015: Andrade e coautores (Brasil)

Levitador não ressonante



$$f = 23.700 \text{ Hz}$$

2015: Andrade e coautores (Brasil)

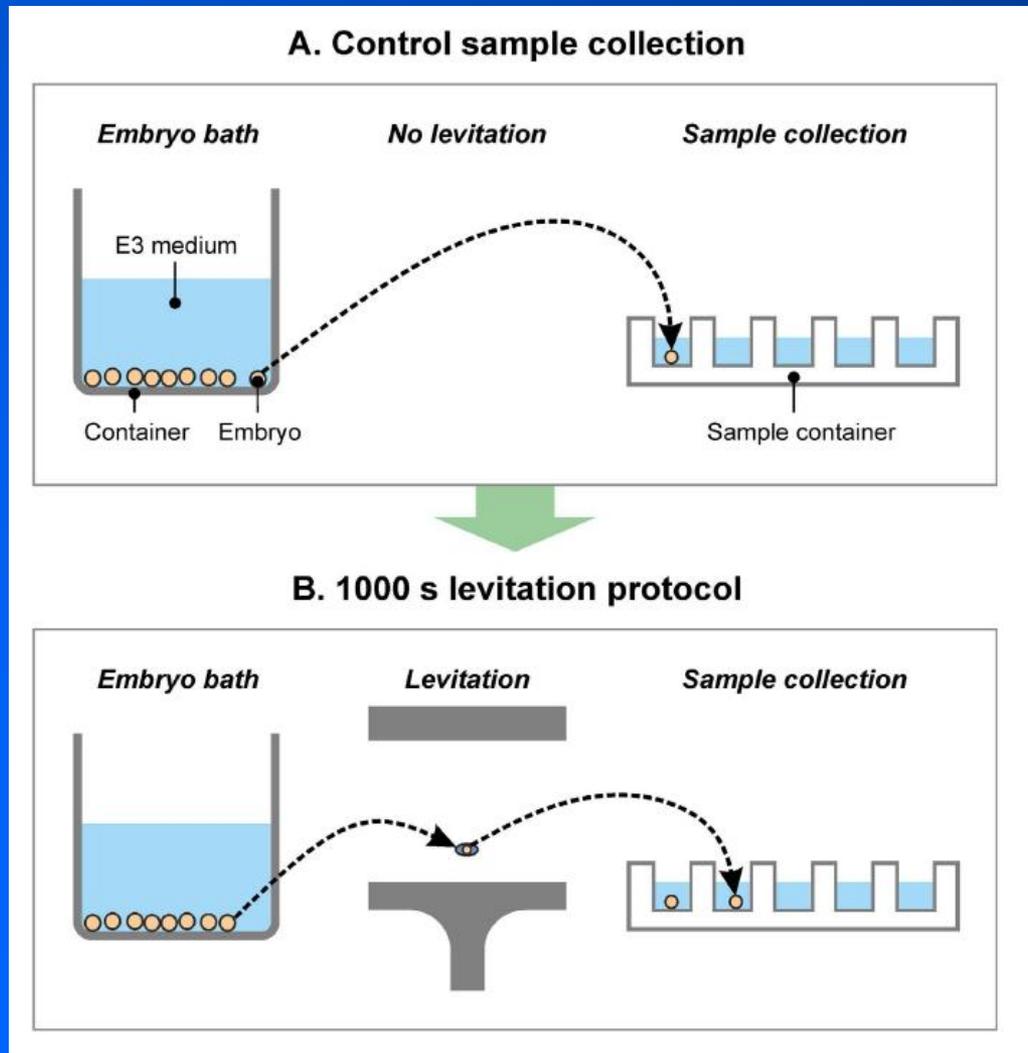


fonte: Appl. Phys. Lett., 2015, 106(1), 014101

2015: Sundvik e coautores (Finlândia)

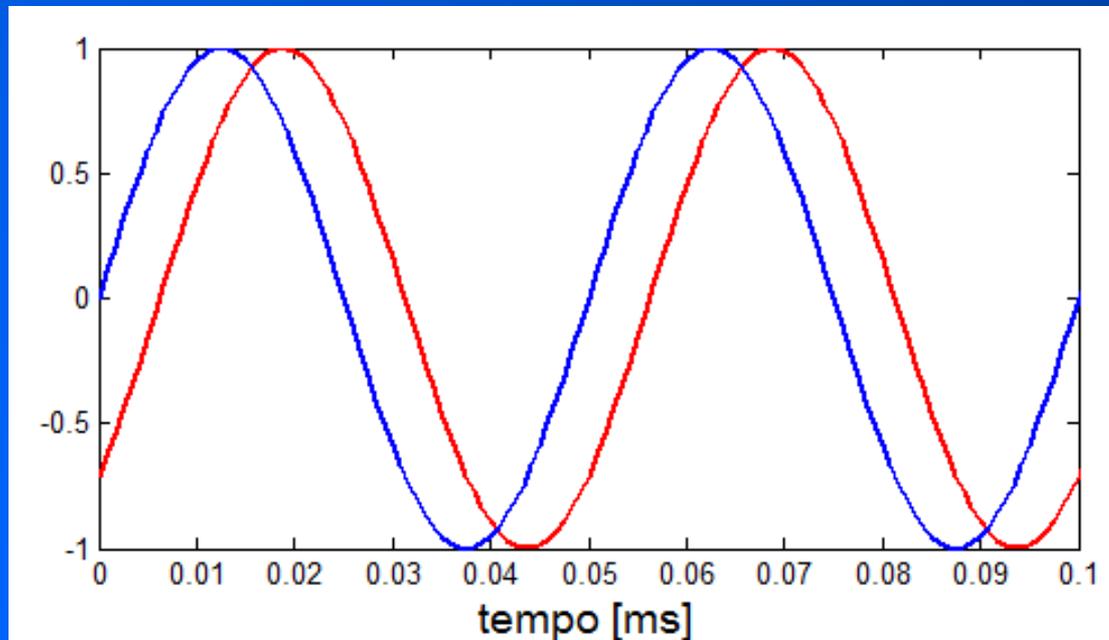
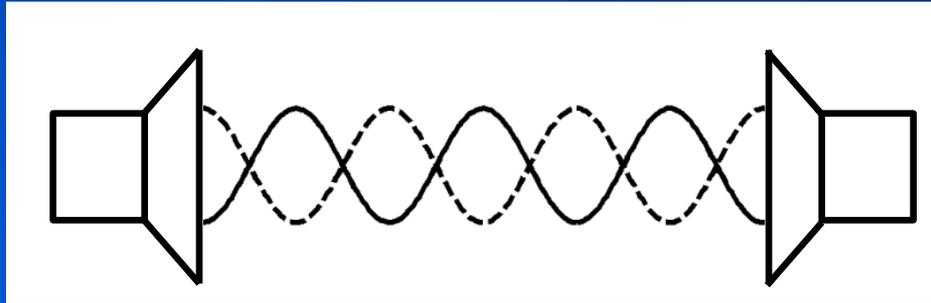
Levitação de embrião de peixe-zebra

$f = 35.200 \text{ Hz}$

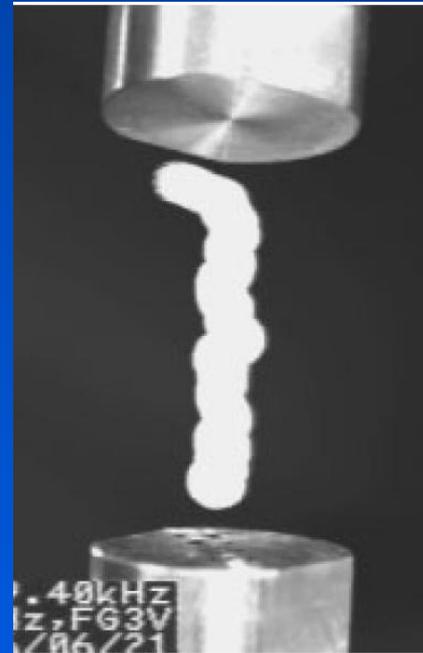
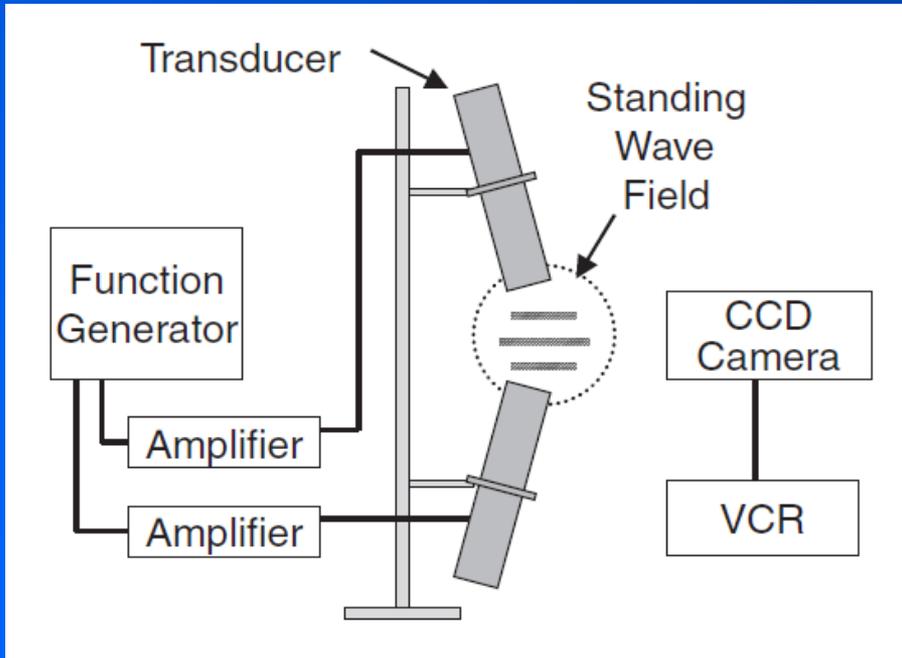


**Exemplos de levitadores acústicos
capazes de manipular as partículas**

Manipulação de partículas



2007: Kozuka e coautores (Japão)



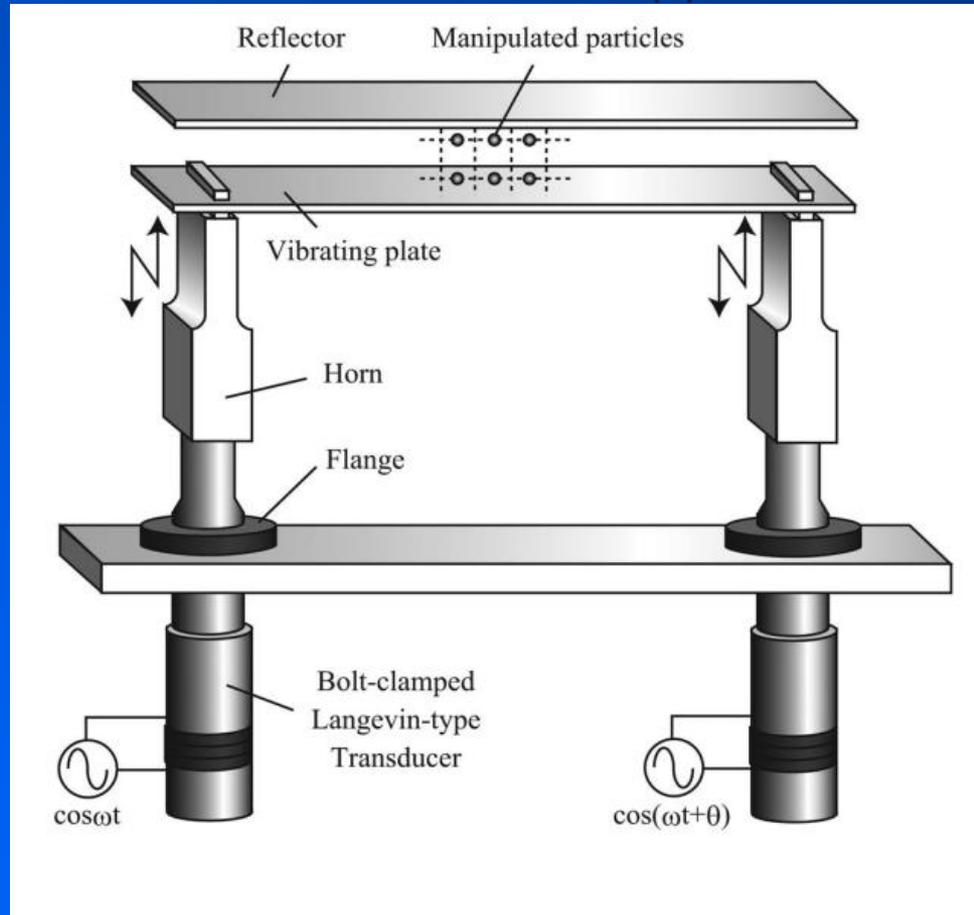
fonte: Jpn. J. Appl. Phys., 2007, vol. 46, 7b, 4948-4950

2 transdutores

$f = 39.200 \text{ Hz}$

2010: Koyama e Nakamura (Japão)

fonte: IEEE TUFFC, 2010, 57(5), 1152-1159



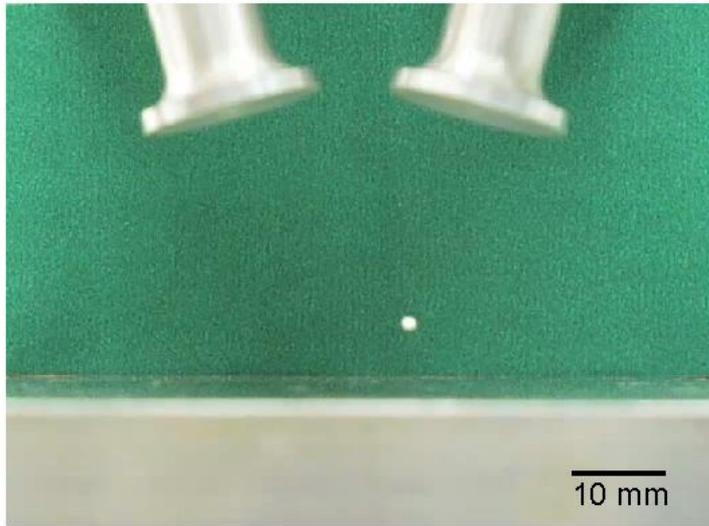
2 transdutores

$f = 22.500 \text{ Hz}$

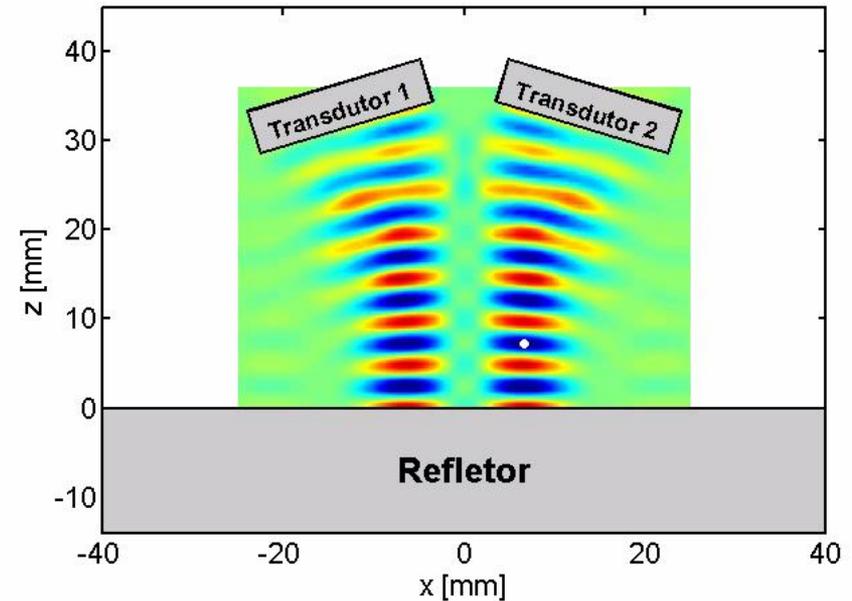
2011: Andrade e coautores (Brasil)

fonte: IEEE TUFFC, 2011, 58(8), 1674-1683

Experimental



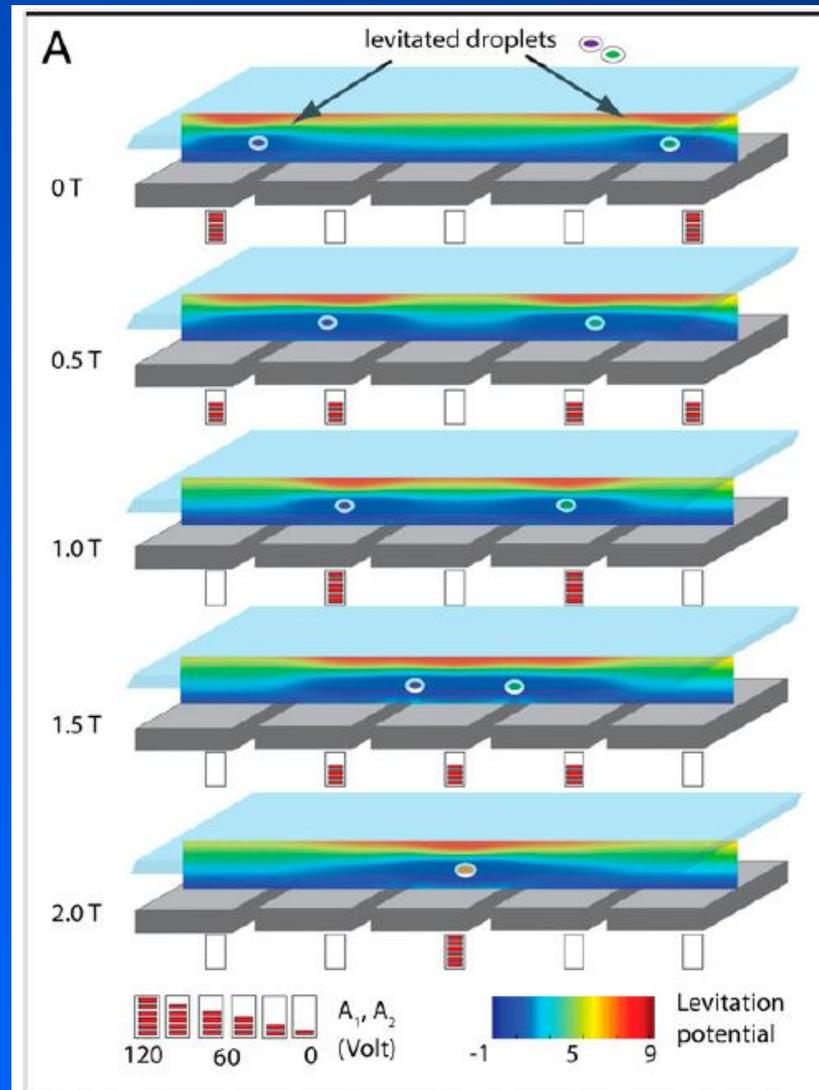
Simulado



2 transdutores

$f = 37.900$ Hz

2013: Foresti e coautores (Suíça)



fonte: PNAS, 2013, 110(31), 12549-12554

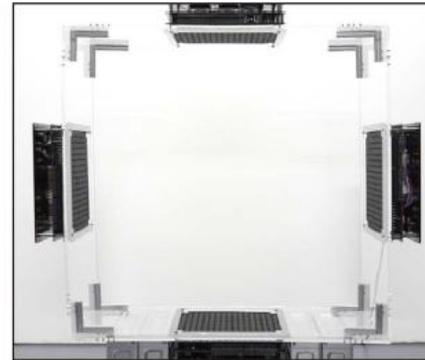
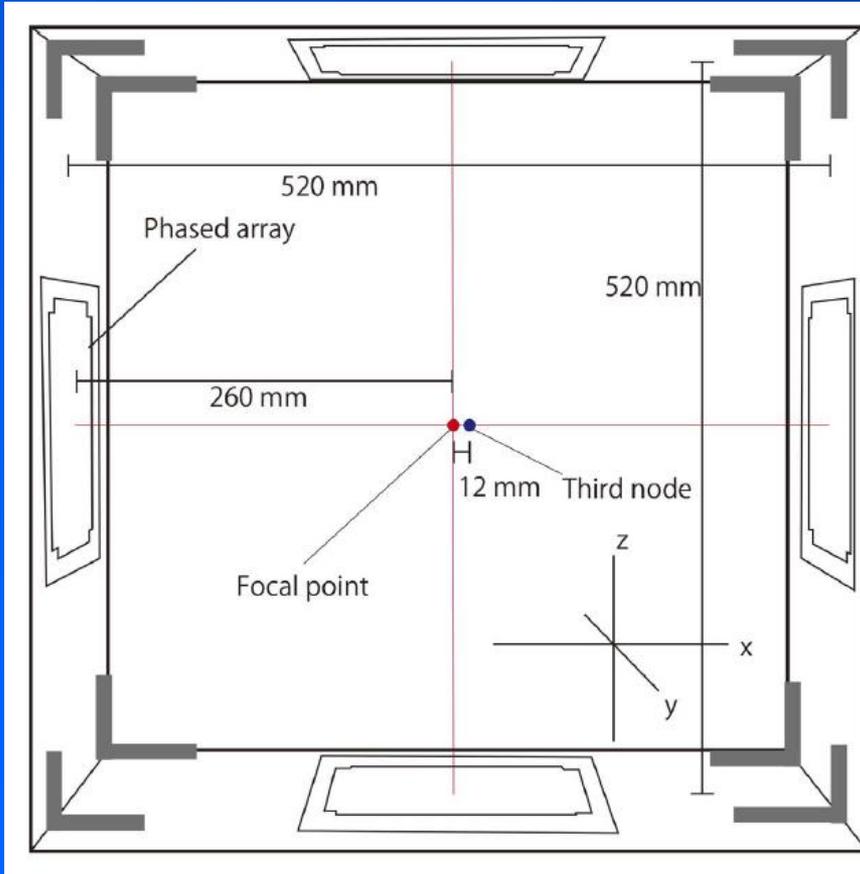
2013: Foresti e coautores (Suíça)



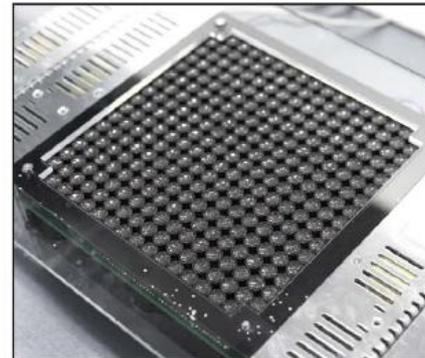
$f = 24.300 \text{ Hz}$

2013: Ochiai e coautores (Japão)

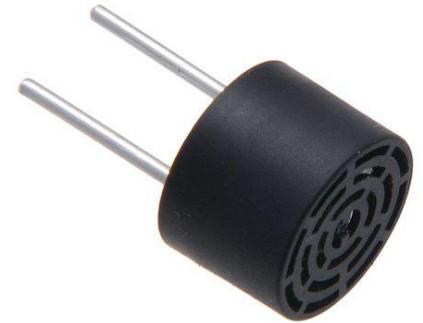
fonte: PloS one, 2014, 9(5), e97590



All devices



Ultrasound device at bottom



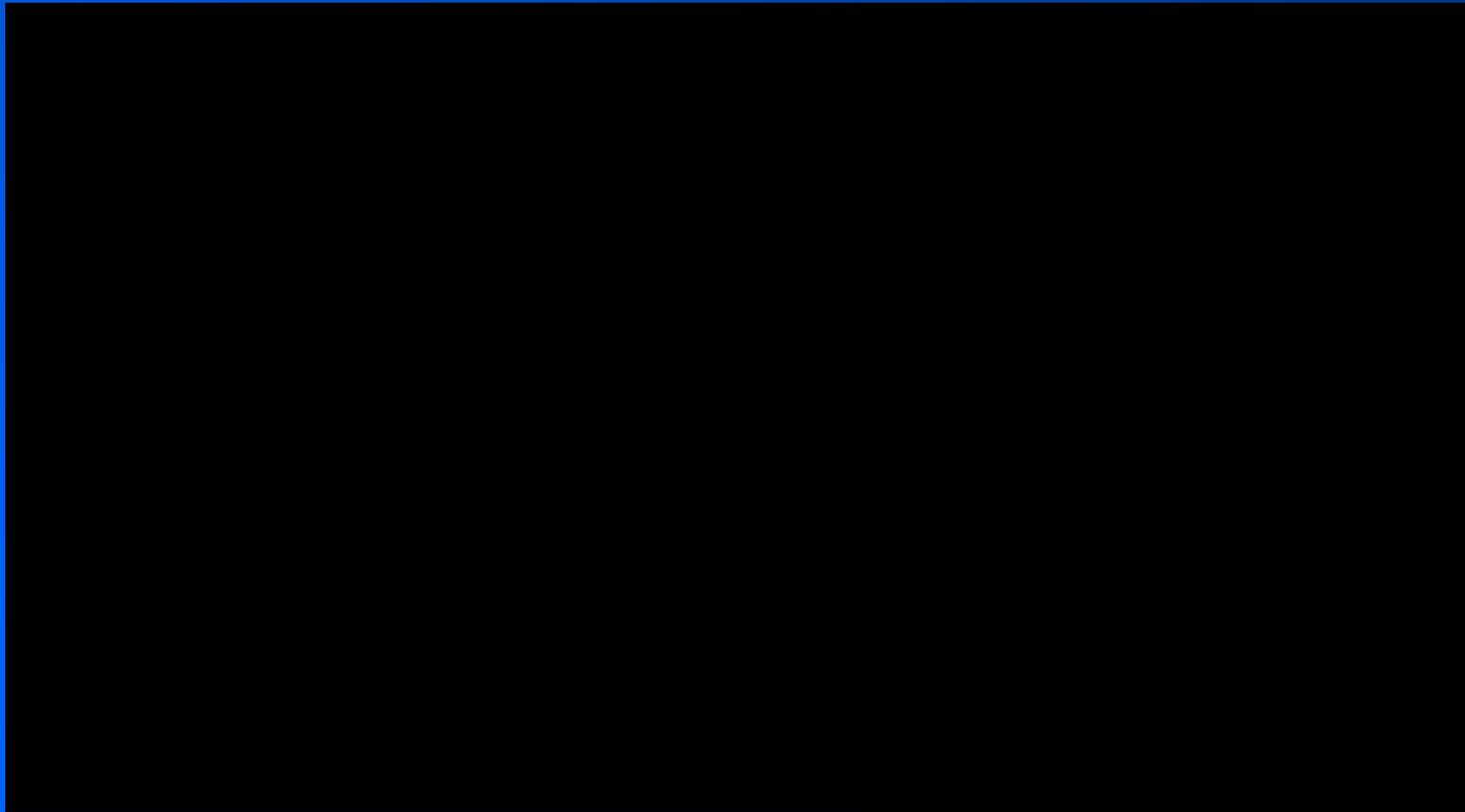
4 x 285 transdutores

$f = 40.000$ Hz

2013: Ochiai e coautores (Japão)

fonte: <https://www.youtube.com/watch?v=odJxJRAxdFU>

Video: Three-Dimensional Mid-Air Acoustic Manipulation [Acoustic levitation] (2014-)



4 x 285 transdutores

$f = 40.000$ Hz

“Levitação” em meios líquidos

Separação Acústica

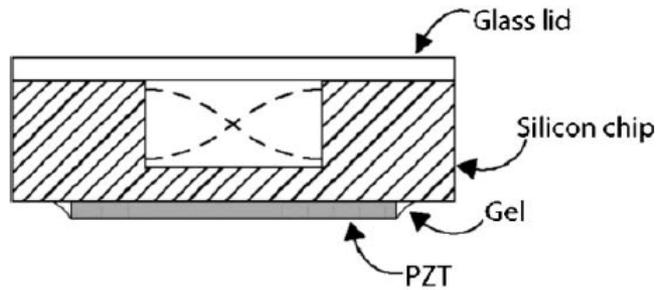


Fig. 5 Schematic cross-section of separation chip utilizing the Lund method. The silicon separation channel is sealed by a boron silica glass lid and is actuated from below using a piezoelectric ceramic.

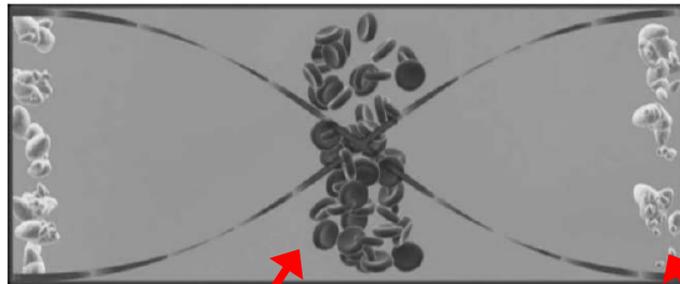


Fig. 6 Illustrated cross section (along the dashed line in Fig. 7) of a separation channel showing negative ϕ -factor particles (e.g. lipid particles) collected in the pressure antinodes by the side walls and positive ϕ -factor particles (i.e. red blood cells) in the pressure node.

glóbulos vermelhos

lipídio

fonte: Chem. Soc. Rev., 2007, 36, 492-506

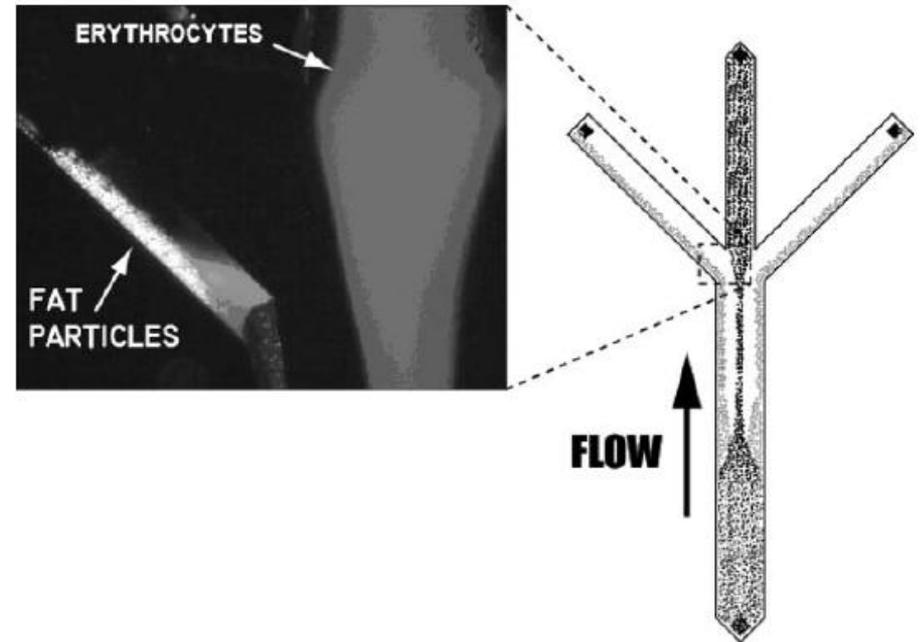
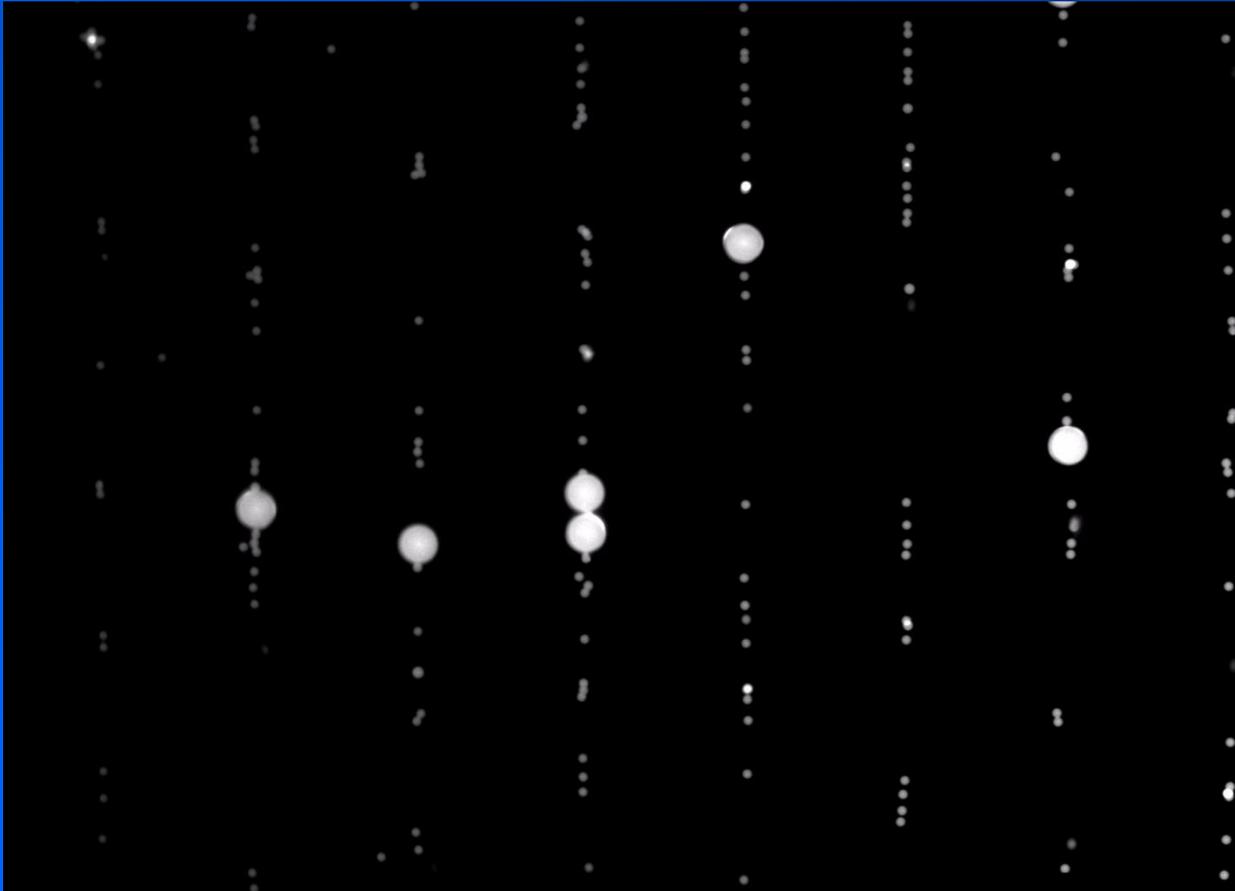


Fig. 15 Microscope image showing human lipid (fat) particles being separated from red blood cells (erythrocytes).

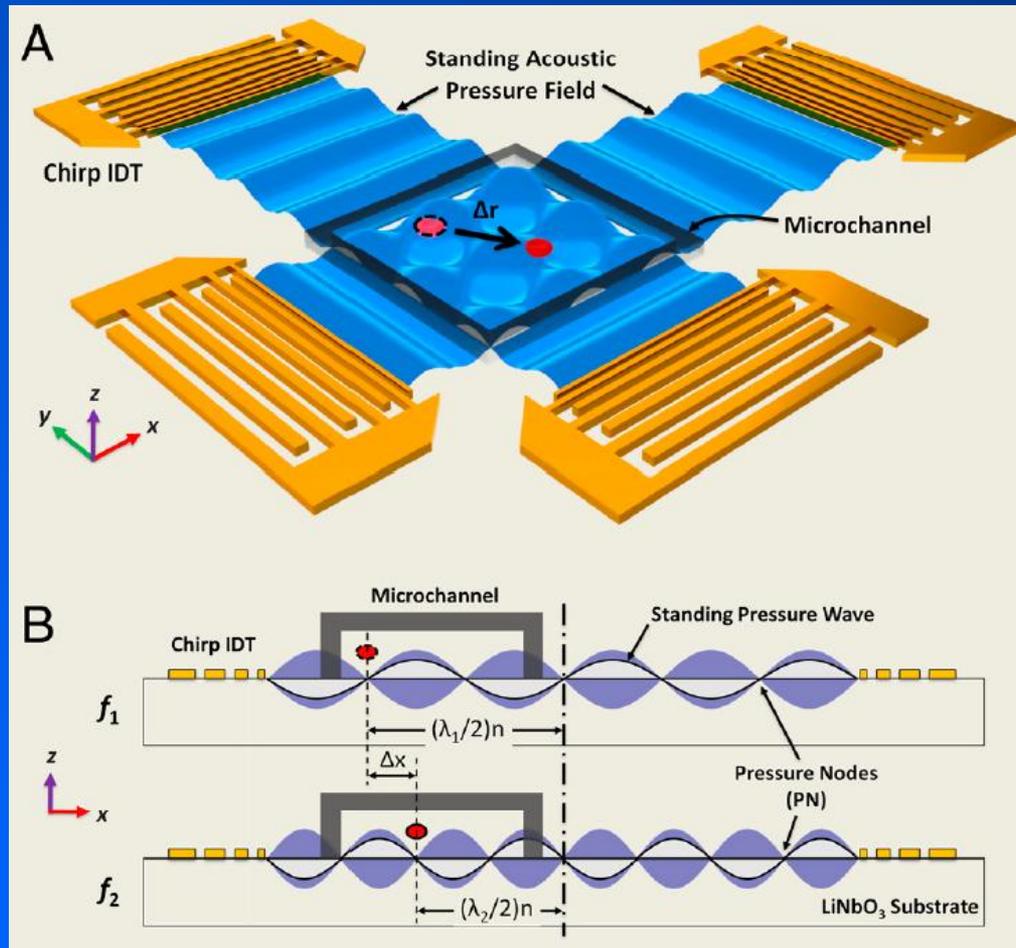
Separação Acústica

fonte: Lab Chip, 2015, 15(3), 802-810



2012: Ding e coautores (E.U.A)

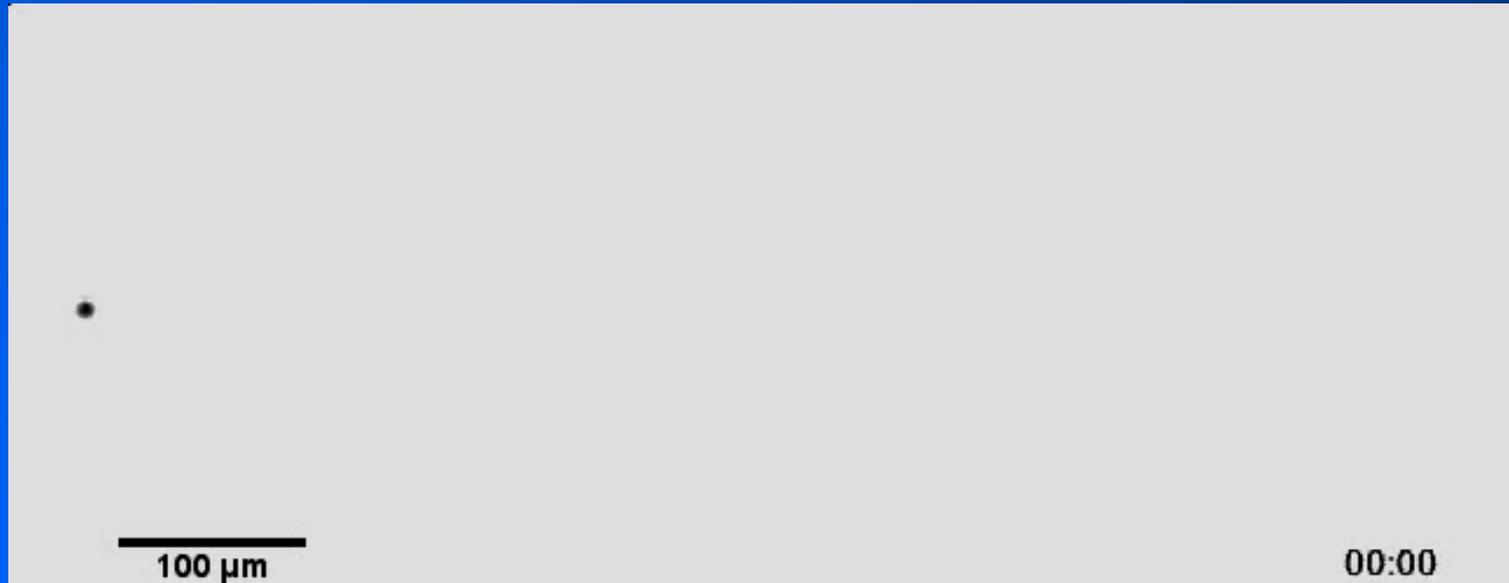
fonte: Proc. Natl. Acad. Sci. USA, 109(28), 11105-11109 (2012).



$$f = 18.500.000 \text{ Hz} - 37.000.000 \text{ Hz}$$

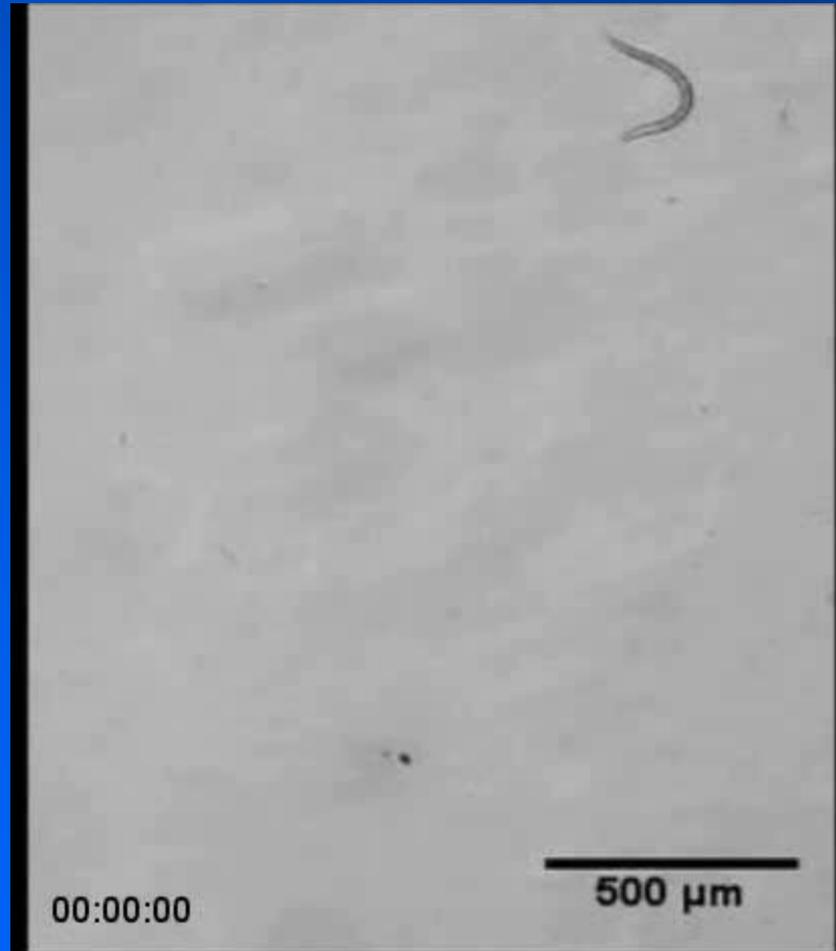
2012: Ding e coautores (E.U.A)

fonte: Proc. Natl. Acad. Sci. USA, 109(28), 11105-11109 (2012).



2012: Ding e coautores (E.U.A)

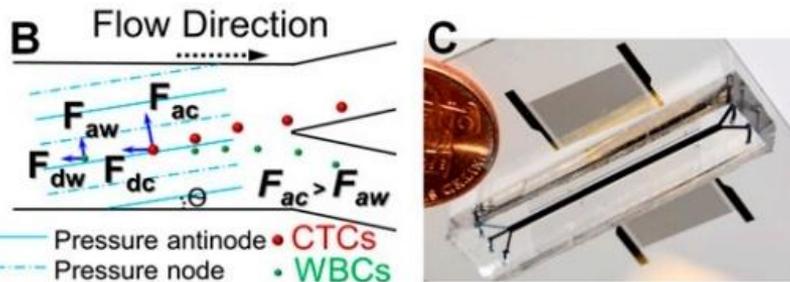
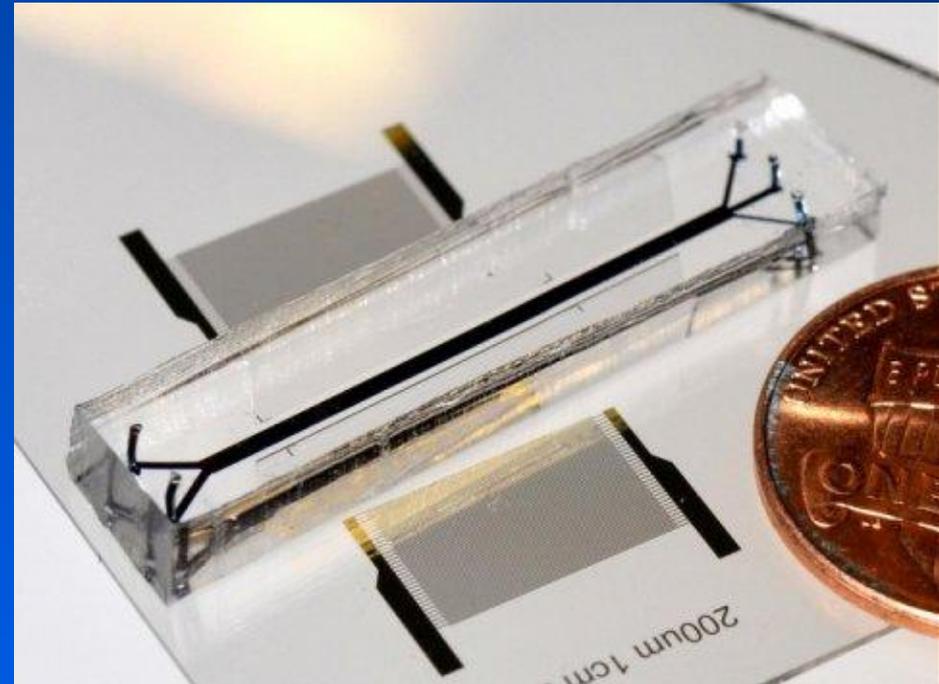
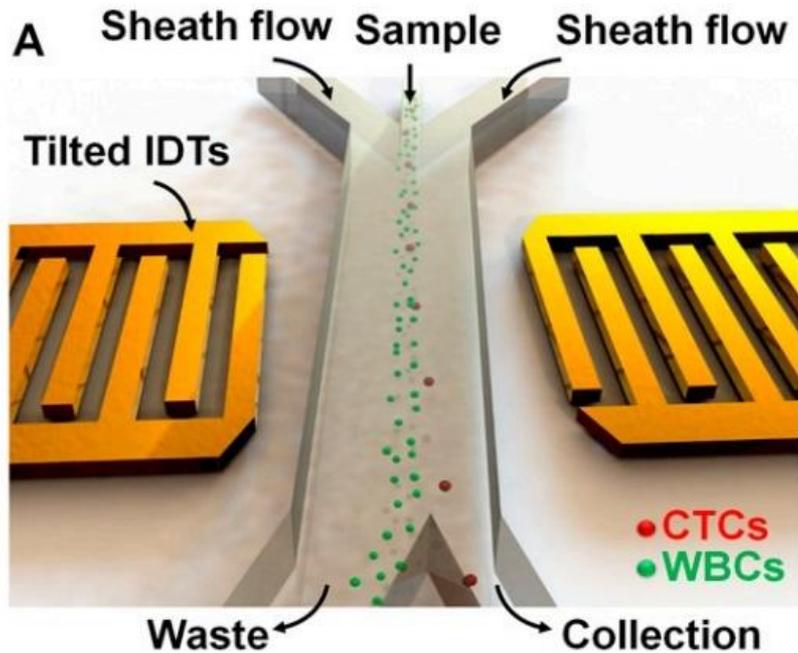
fonte: Proc. Natl. Acad. Sci. USA, 109(28), 11105-11109 (2012).



2015: Li e coautores (E.U.A)

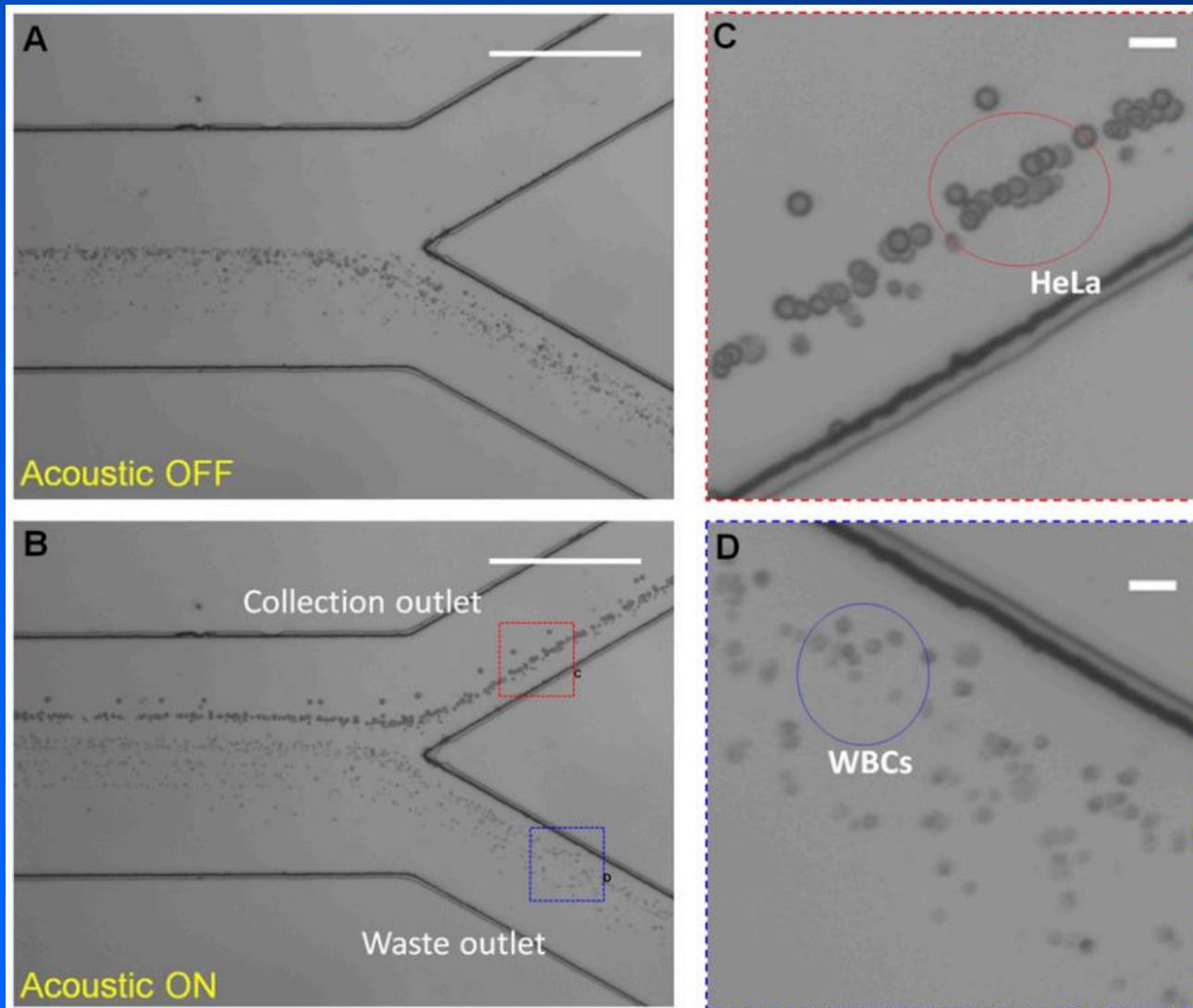
Separação de células com câncer

fonte: Proc. Natl. Acad. Sci. USA, 112(16), 4970-4975 (2015).



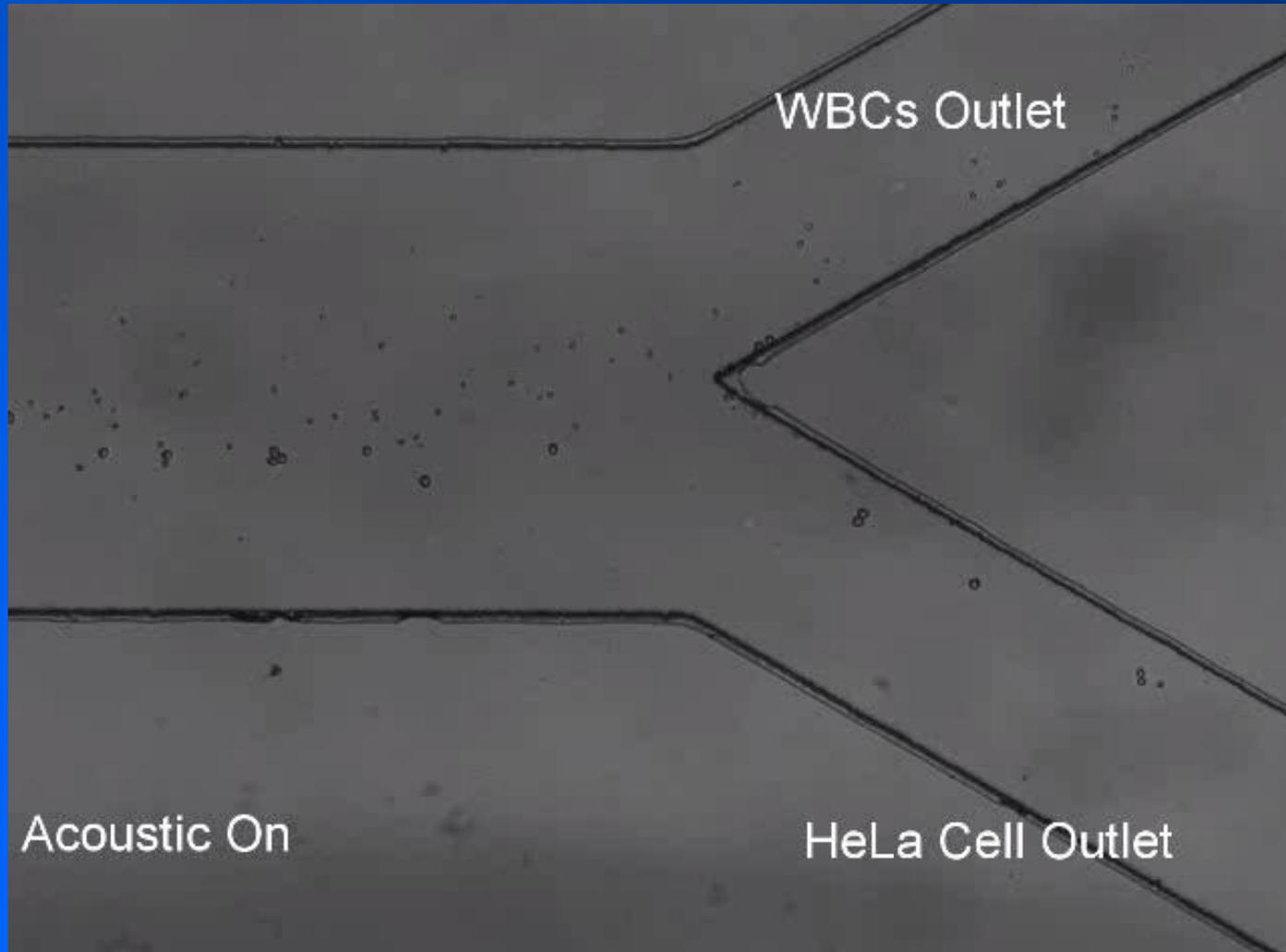
$$f = 19.573.000 \text{ Hz}$$

2015: Li e coautores (E.U.A)



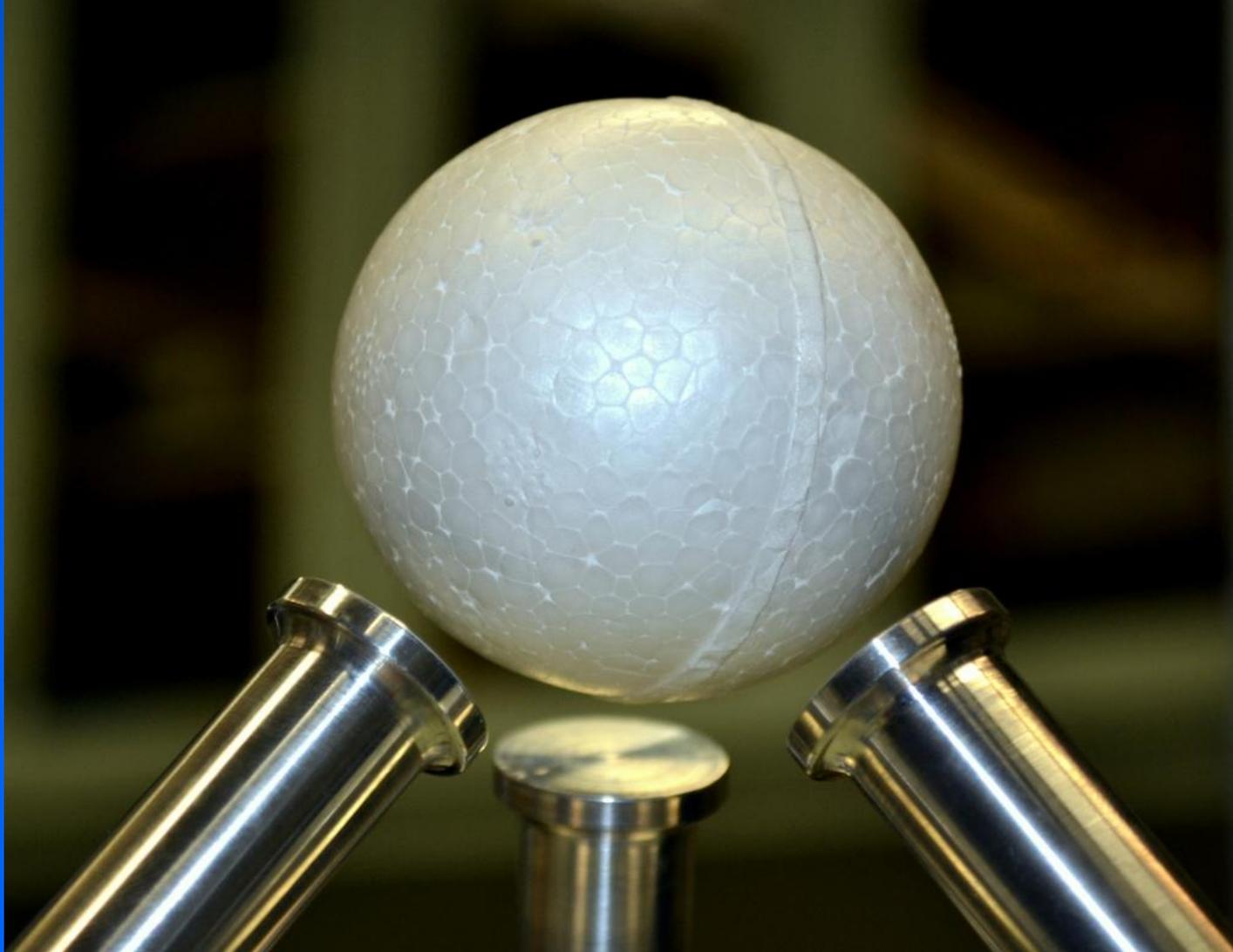
fonte: Proc. Natl. Acad. Sci. USA, 112(16), 4970-4975 (2015).

2015: Li e coautores (E.U.A)



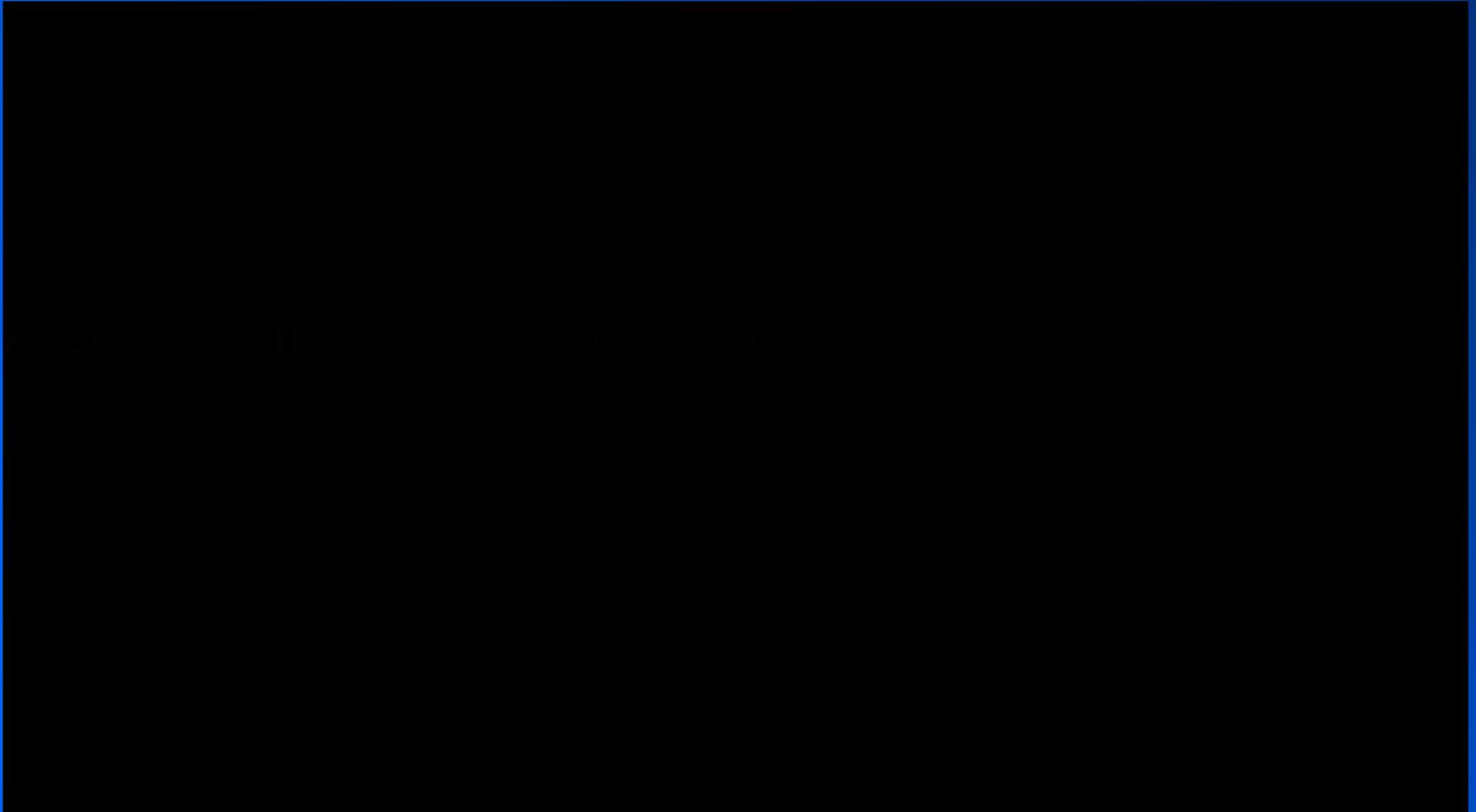
fonte: Proc. Natl. Acad. Sci. USA, 112(16), 4970-4975 (2015).

Levitação acústica: esfera grande



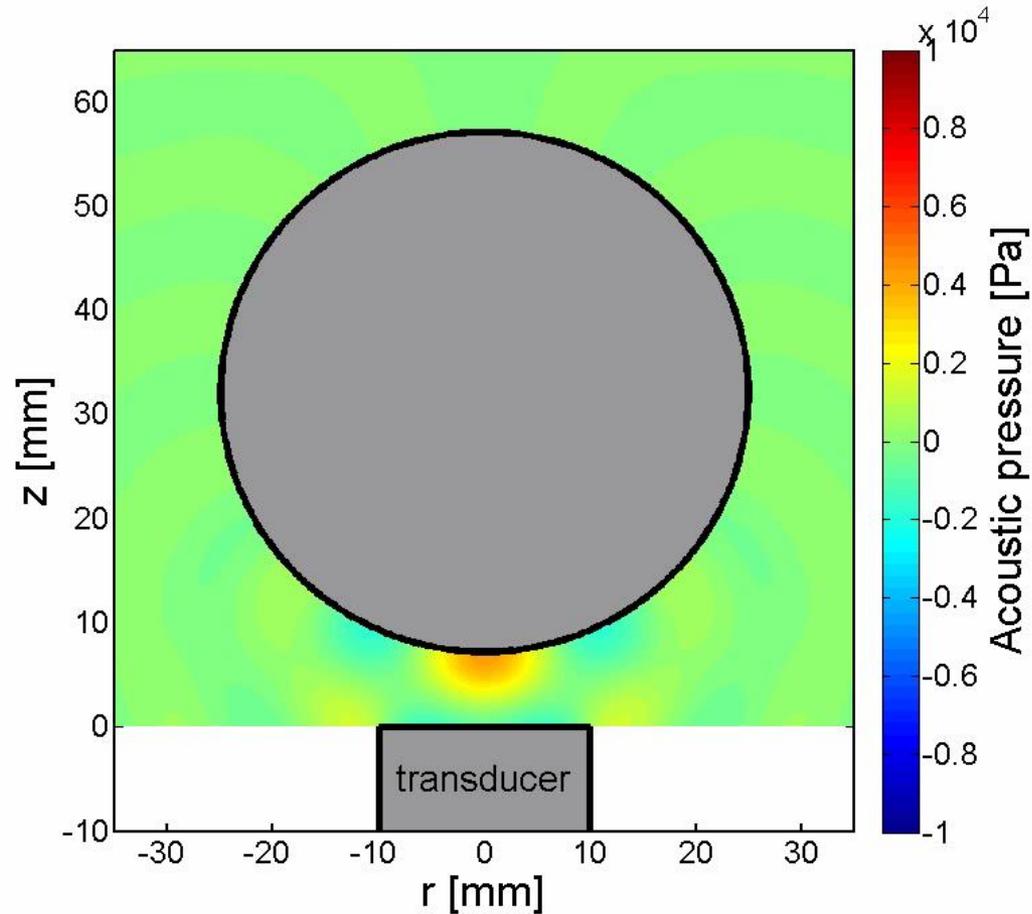
fonte: Appl. Phys. Lett., 2016, 109(4), 044101

Levitação acústica: esfera grande



fonte: Appl. Phys. Lett., 2016, 109(4), 044101

Levitação acústica: esfera grande



fonte: Appl. Phys. Lett., 2016, 109(4), 044101

Agradecimentos



Obrigado pela atenção !

Contato:

marcobrizzotti@gmail.com