Characterization of high intensity focused fields used in therapeutic ultrasound

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HOCHSCHULE MERSEBURG (FH)
University of Applied Sciences
FACHBEREICH INGENIEUR- UND NATURWISSENSCHAFTEN

gaMPT ULTRASONIC SOLUTIONS

PTB

K.-V. Jenderka, Hochschule Merseburg, Germany

M. Schultz, G. Dietrich, S. Sonntag,
GAMPT mbH, Merseburg, Germany

J. Haller, V. Wilkens, PTB, Braunschweig, Germany

Topics

- **Introduction to high intensity focused ultrasound therapy**
- **Measurement procedures and results**
  - **Acoustic output power**
  - **Sound pressure / wave form**
  - **Intensity distribution**
- **Summary**

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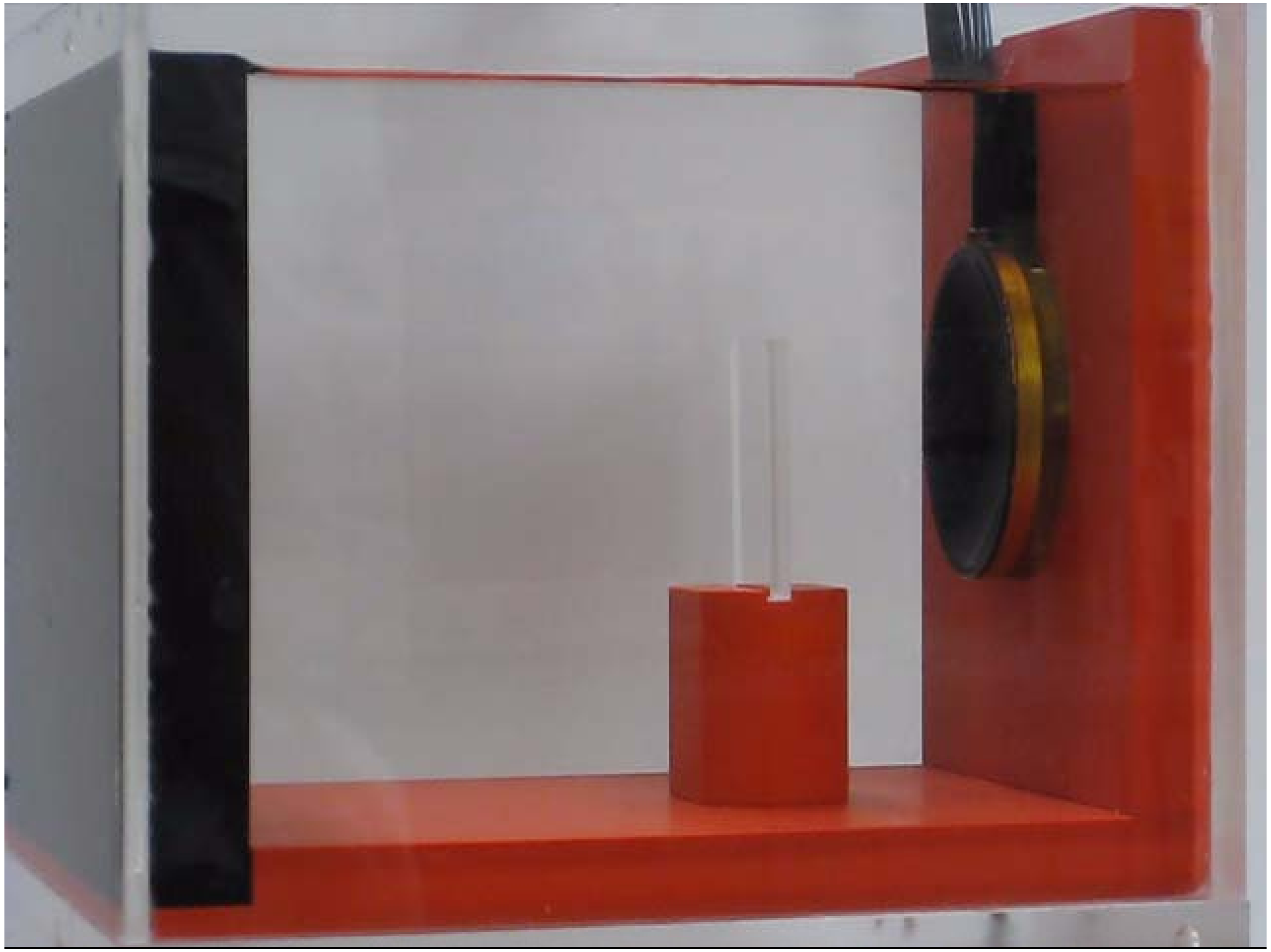
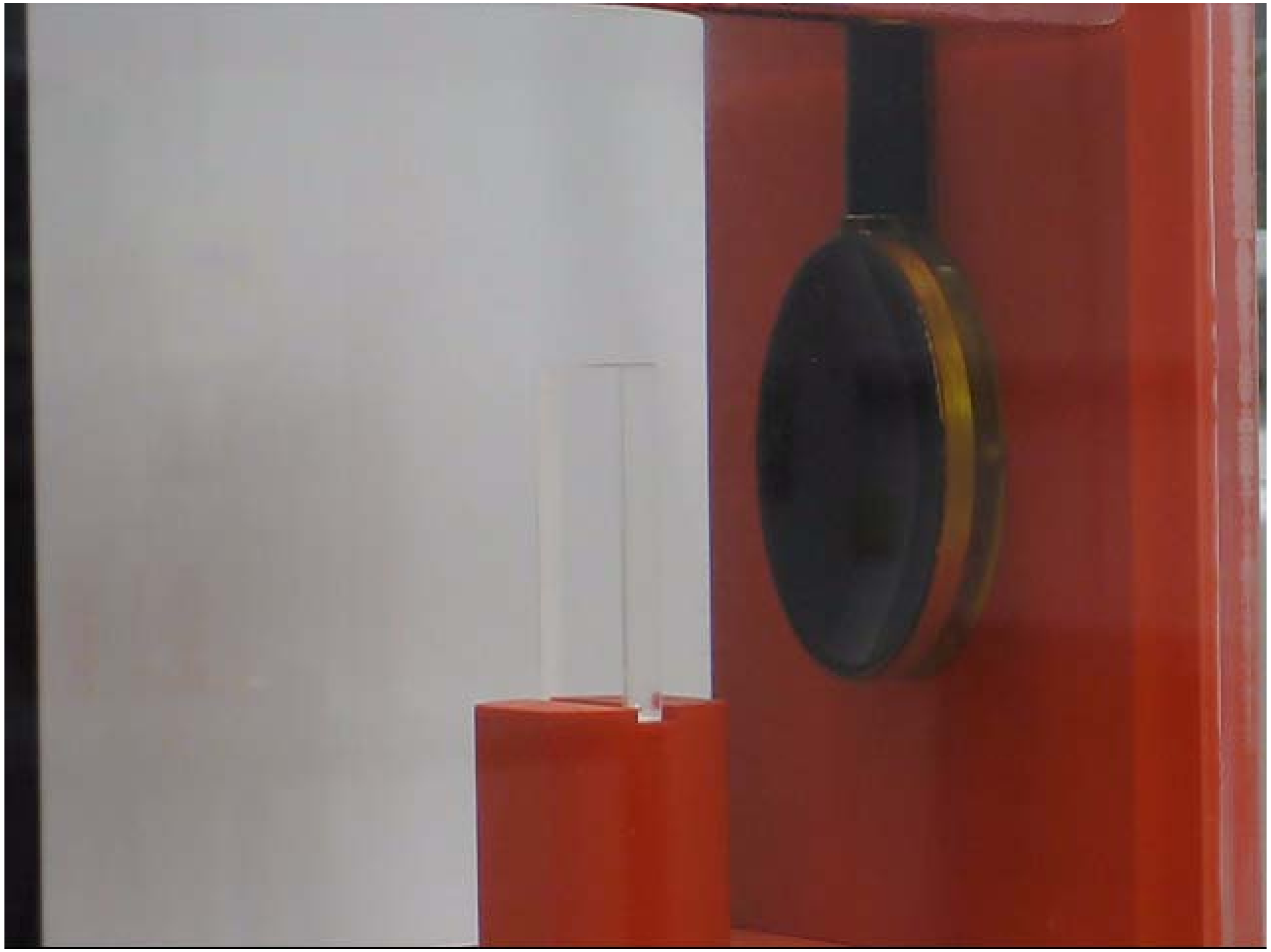
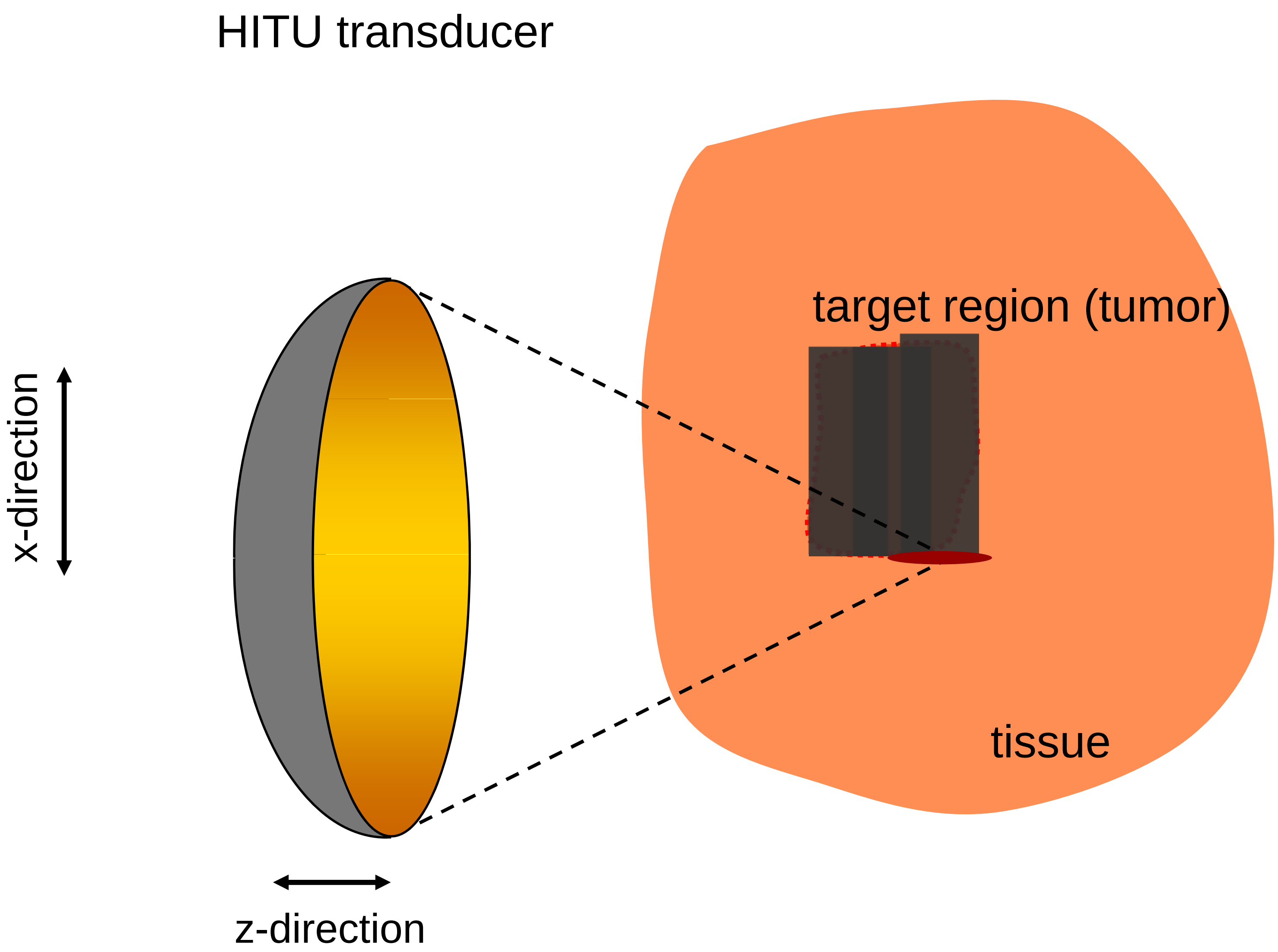
Ultrasound effects: Radiation force



Ultrasound effects:
Heating due to absorption



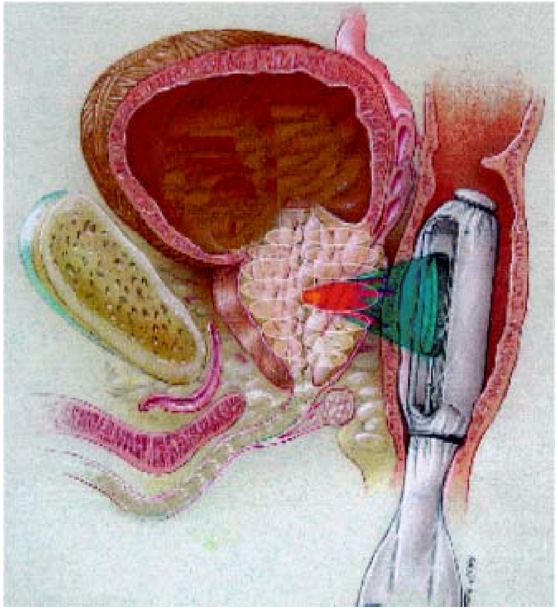
Tissue ablation with HITU



Clinical application of HITU

Therapeutic application:

- Tumor therapy (prostate, liver, breast, brain, …)
- Opening of the blood brain barrier (temporary)
- Thrombolysis
- Non-invasive sealing of blood vessels (Haemostasis)



→

Therapy relevant parameters:

- Power
- Intensity
- Peak pressure (p_+, p_-)

High power output measurements

Problems in HITU fields:

- **Thermal damage of the sensor or target**
- **Damage by cavitation**
- **Shielding by cavitation bubbles**

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Measurement of acoustic output power

Standard:
Power measurement with the Radiation force balance

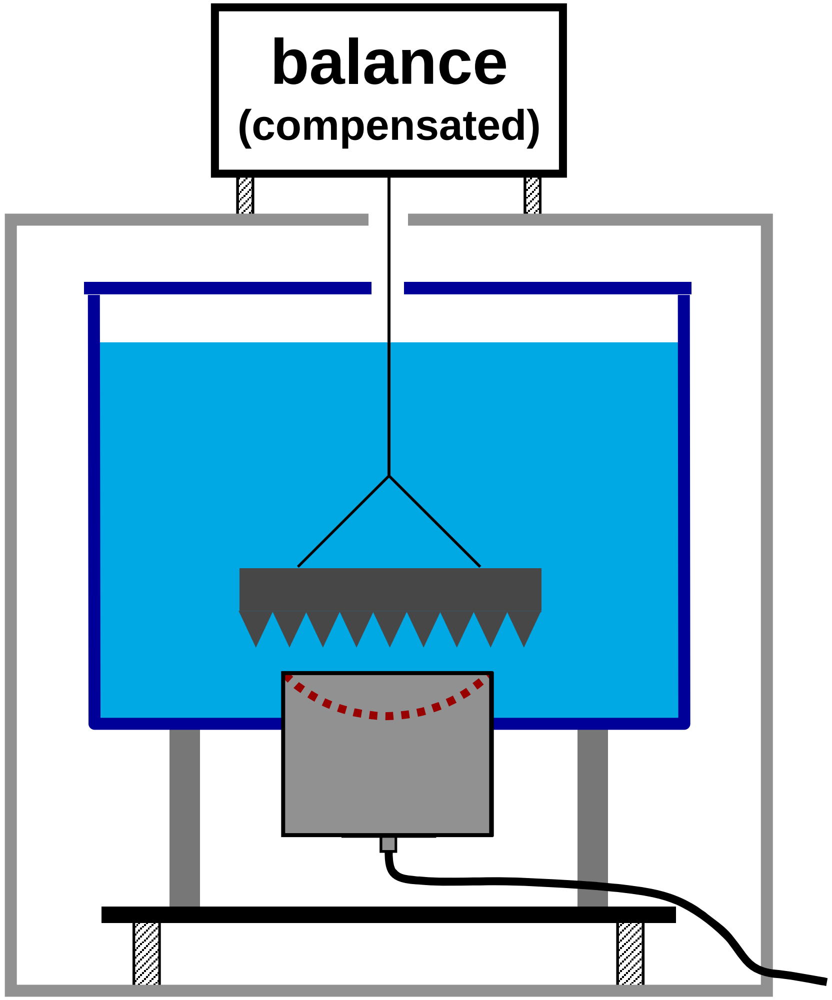
Plane wave front:

$$P = c\,F$$

Focused wave front:

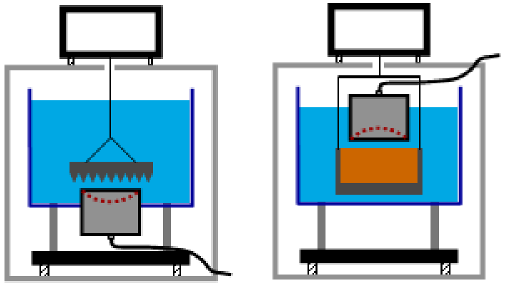
$$P = c\,F\,\frac{2}{(1+\cos\gamma)}$$

(γ – focus half-angle)

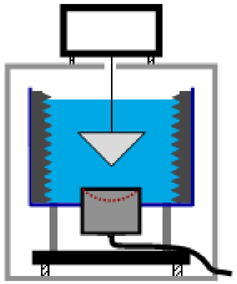


Results inter-laboratory key comparison

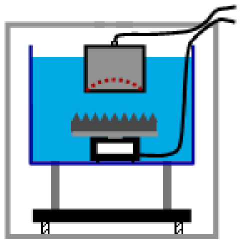
Lab 1 und 4



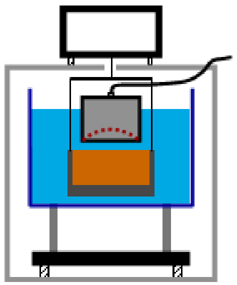
Lab 2



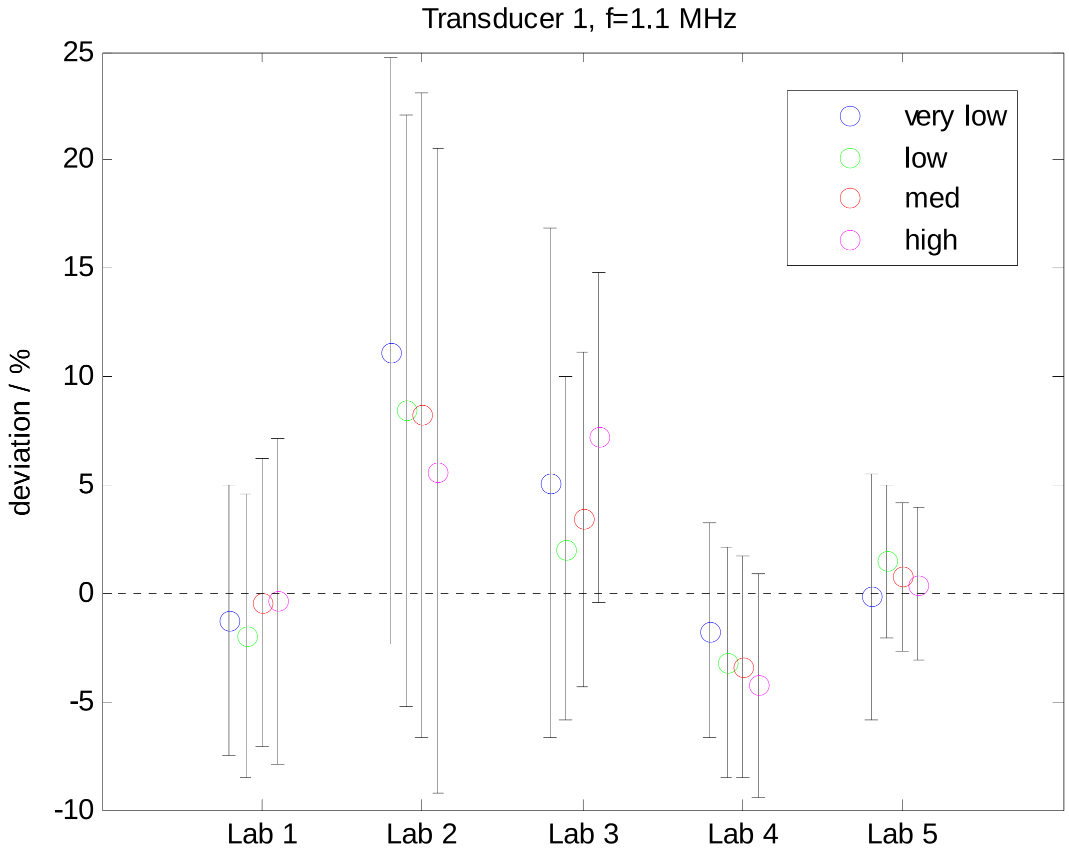
Lab 3



Lab 5



Degree of equivalence with key comparison reference value



K V Jenderka, G Durando, B Karaböce, S Rajagopal, A Shaw
J. Phys.: Conf. Ser. 279 (2011), 012015

Summary key comparison

- participant’s relative expanded uncertainties for the radiation conductance at the various combinations of transducer type, frequency and excitation level range from 4.5 % to 15.2 %
- degrees of equivalence with the reference level can generally be considered satisfactory (majority of deviations below 5 %, except measurements using RFB with reflecting target – max. 15 % deviation)
- the use of reflecting targets in strong focusing fields is not recommended

Report available at:
http://www.ptb.de/EURAMET-JRP7/document/document03.pdf

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Field characterization

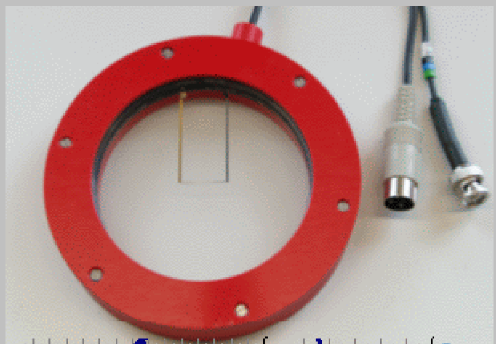
Special requirements for HITU fields:

focus size	Ø=1mm – 3mm
Peak pressure *p*	up to 50 MPa
Heating rate d*T*/dt	10 K/s and more

→ **Sensor: small and robust, withstanding pressure, cavitation and temperature**

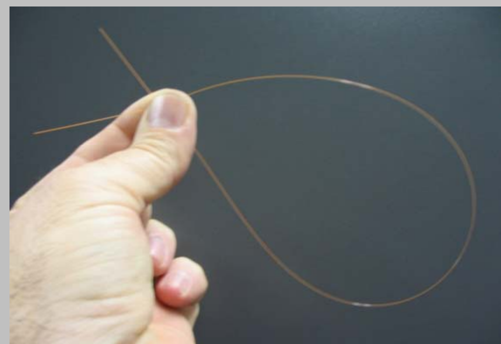
Approaches with different hydrophone types:

membrane hydrophone

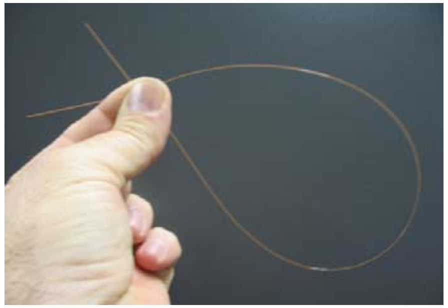


needle hydrophone

fiber sensor



Fiber-optic displacement sensor (I)



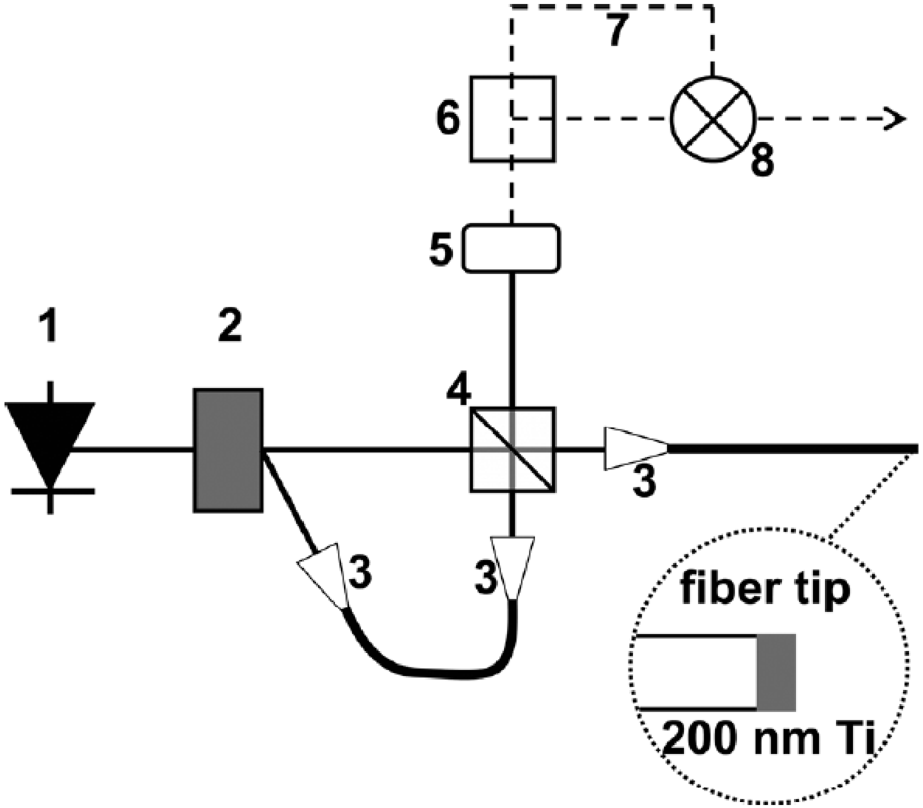
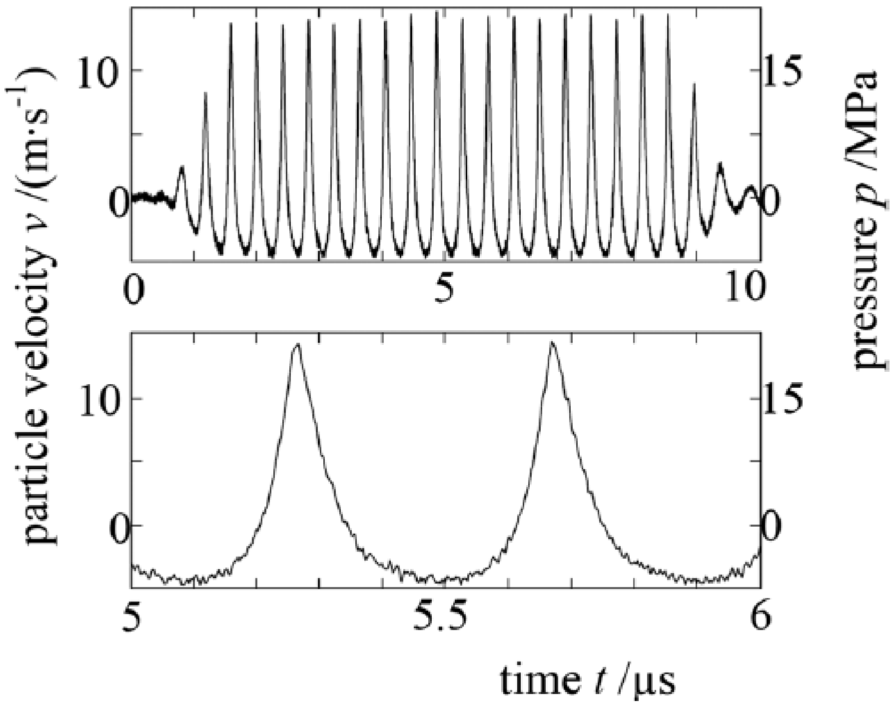
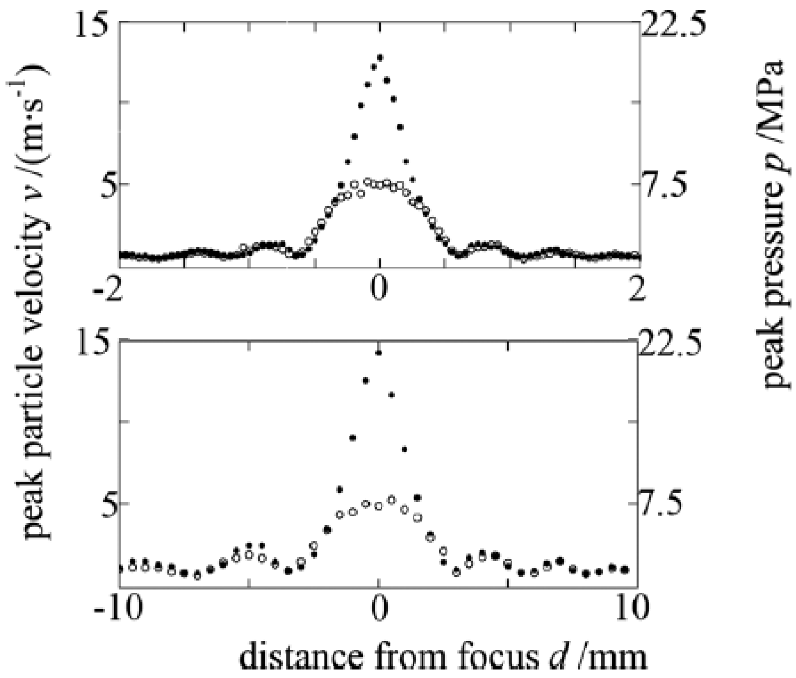


FIG. 1. Heterodyne interferometric setup for the displacement sensor. 1, laser diode; 2, AOM; 3, fiber coupler; 4, beam splitter; 5, photo diode; 6, 50:50 splitter; 7, delay line; 8, mixer. The discriminator consists of parts 6-8. A ring phase modulator in the measuring arm and polarization controllers in both arms are not depicted.

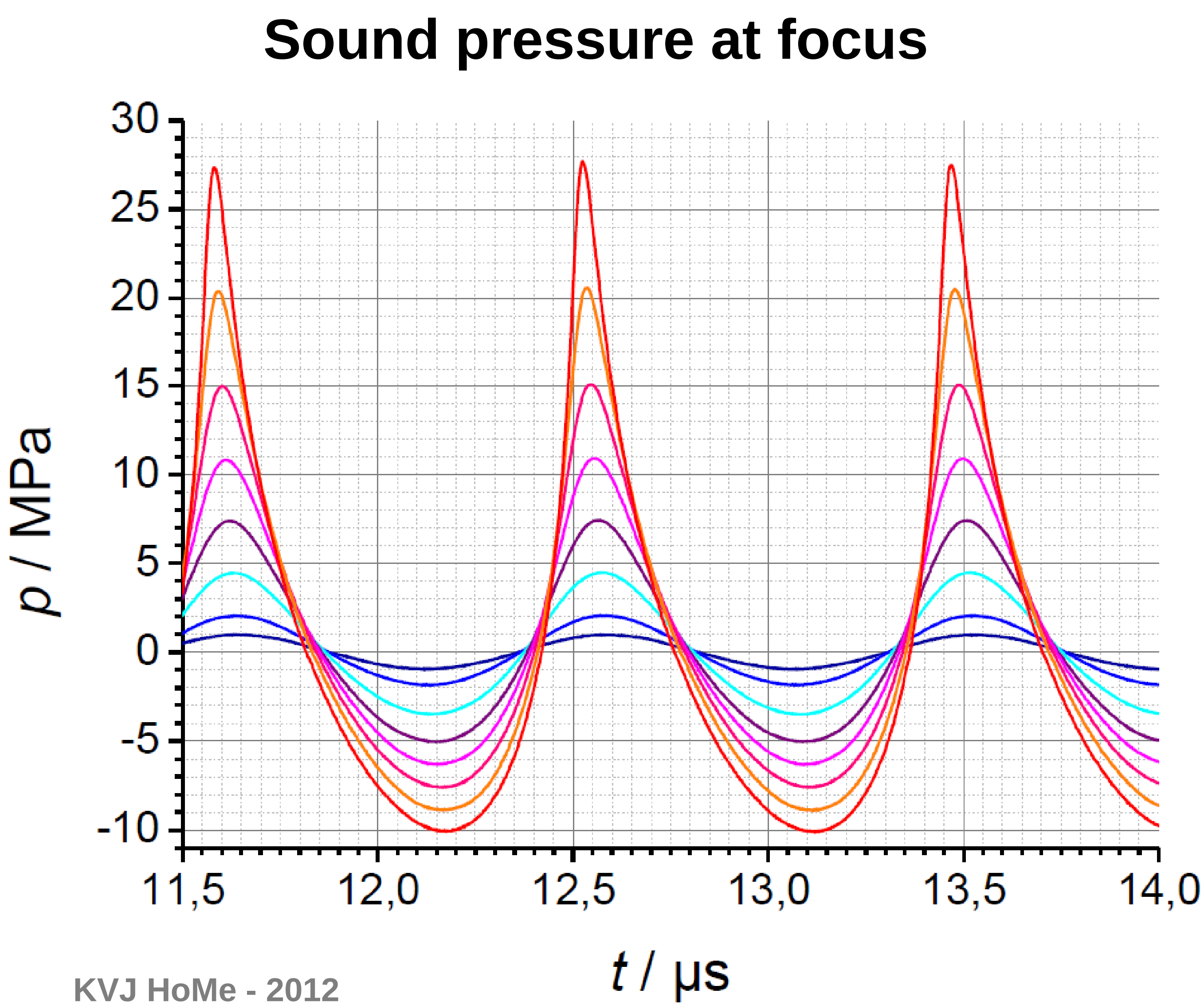
J Haller, V Wilkens, K V Jenderka, C Koch
J. Acoust. Soc. Am.,129(6), 3676 (2011)

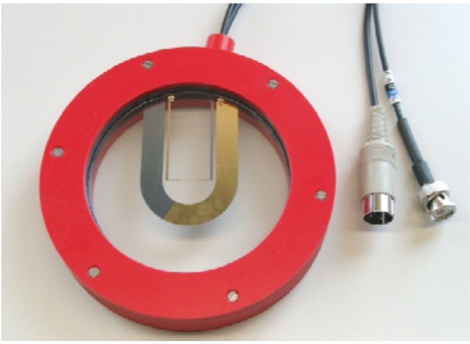
Fiber-optic displacement sensor (II)





Membrane hydrophone (I)

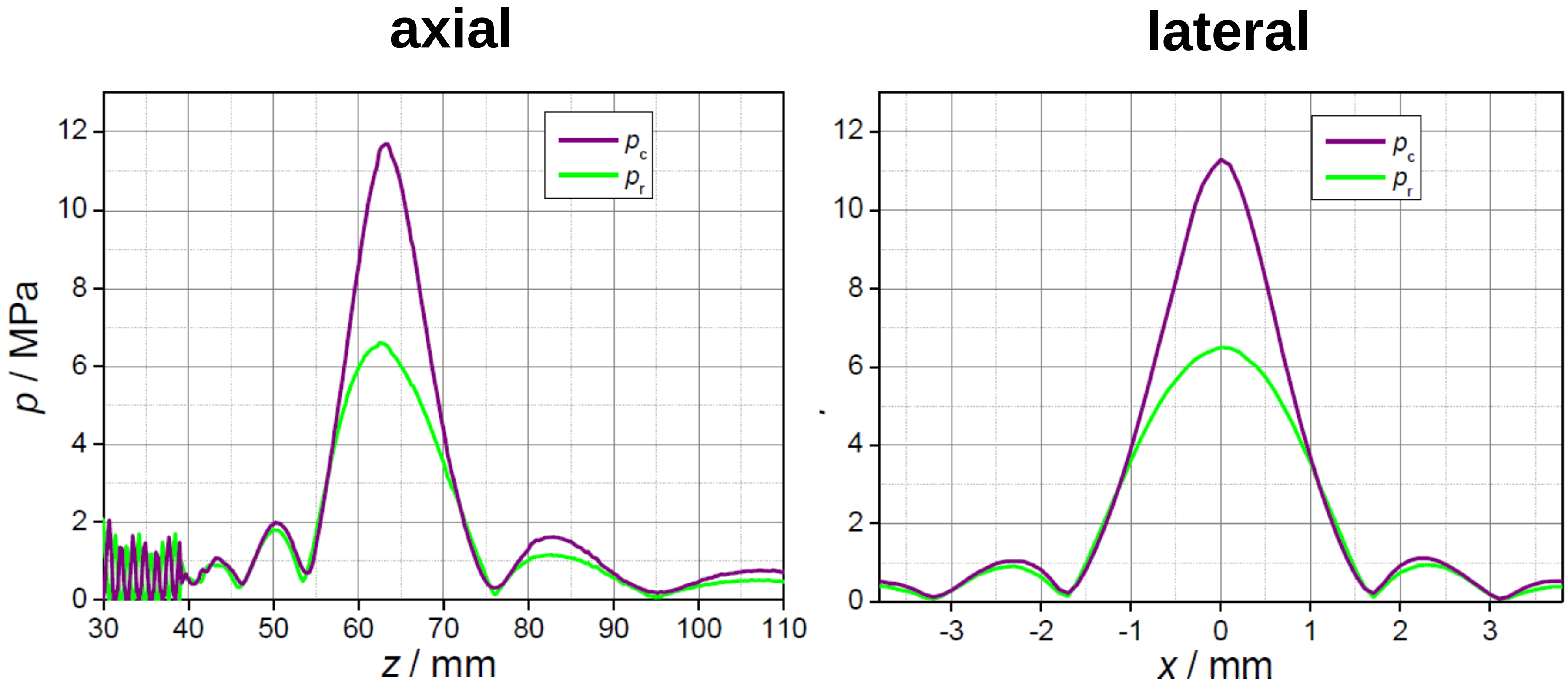




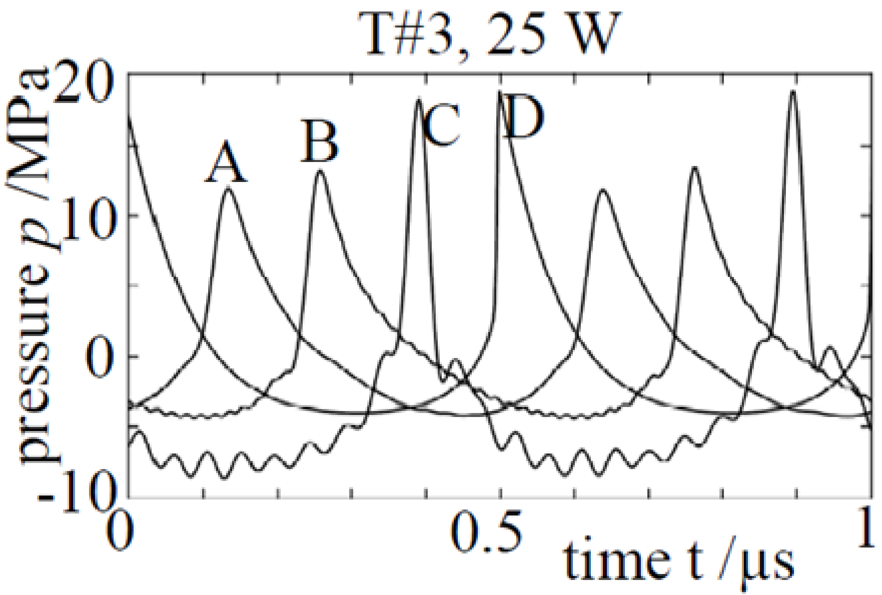
Sonic Concepts
H-101 (Ø 64 mm)
f = 1.06 MHz

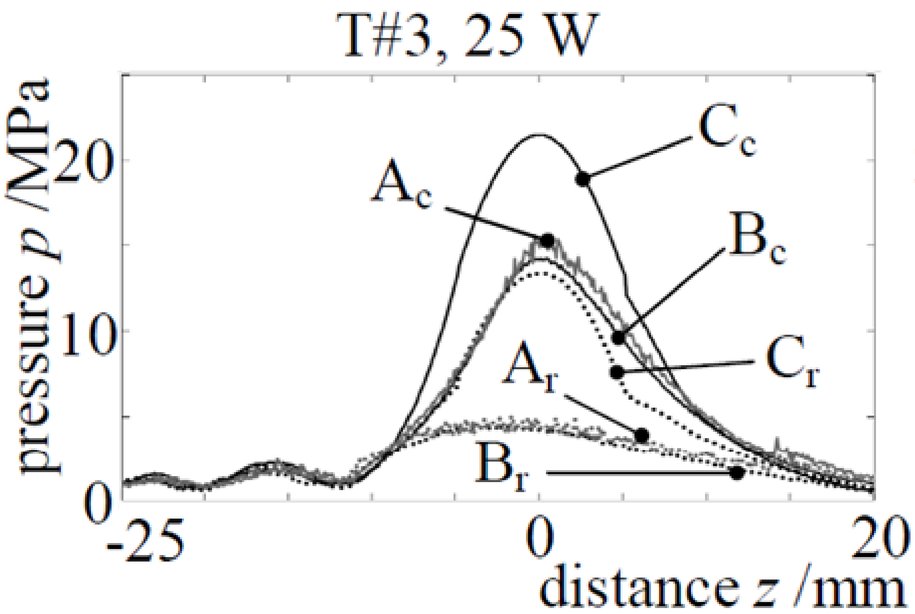
Membrane hydrophone (I)

Beam profile at focus



Comparison of sensor/hydrophone types



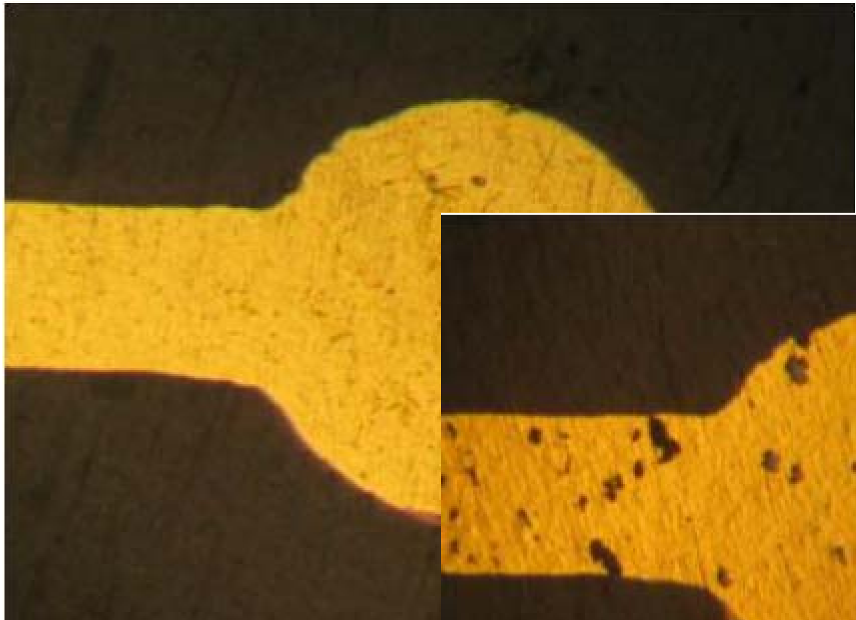


A: Fiber-optic displacement sensor (PTB)
B: Membrane hydrophone (NPL-Precision Acousics, with layer)
C: Needle hydrophone (Onda HNA-0400)
D: Simulation („HIFU Simulator‘, J. Soneson, FDA)

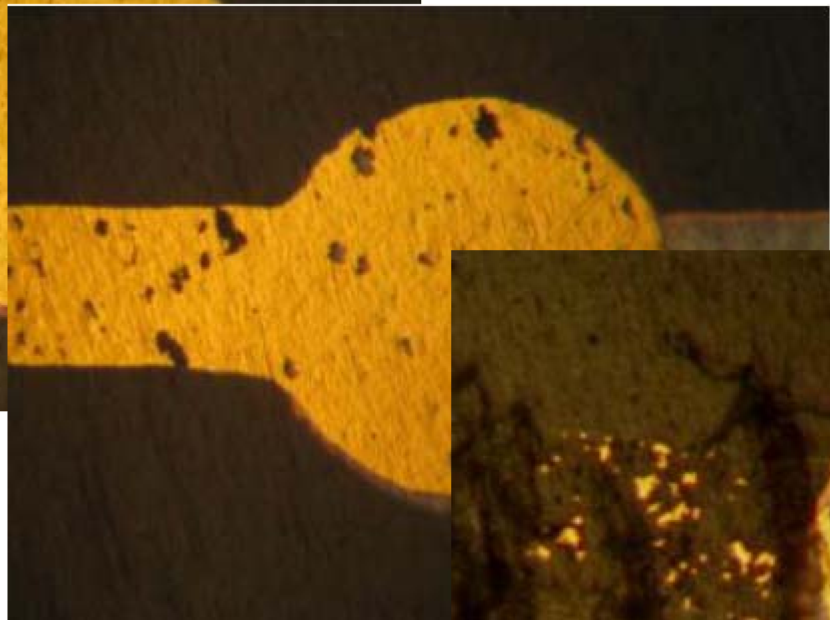
J. Haller, K.-V. Jenderka, G. Durando, A. Shaw : A comparative evaluation of three hydrophones and a numerical model in high intensity focused ultrasound fields. J. Acoust. Soc. Am., 131(2), 1121 (2012)

Problem: Cavitation (I)

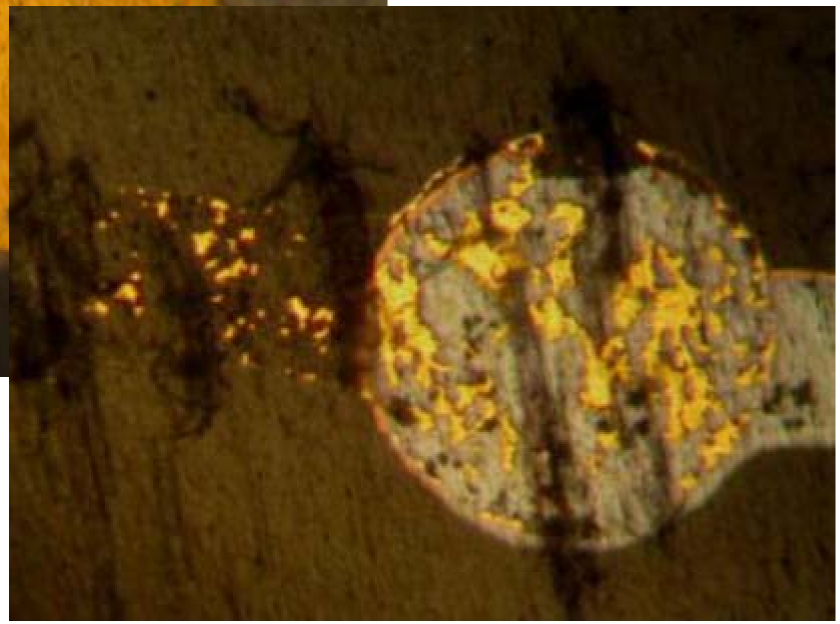
Membrane hydrophone without protecting layer



original

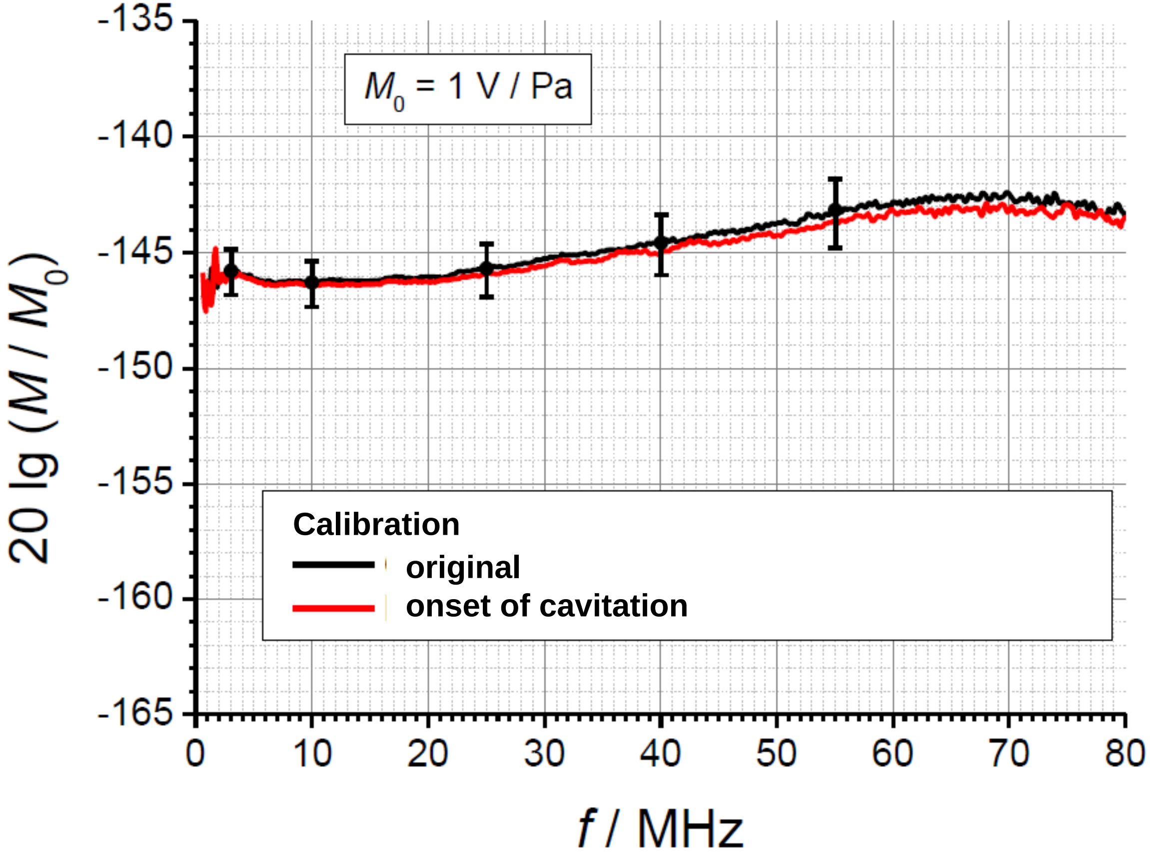


onset of cavitation

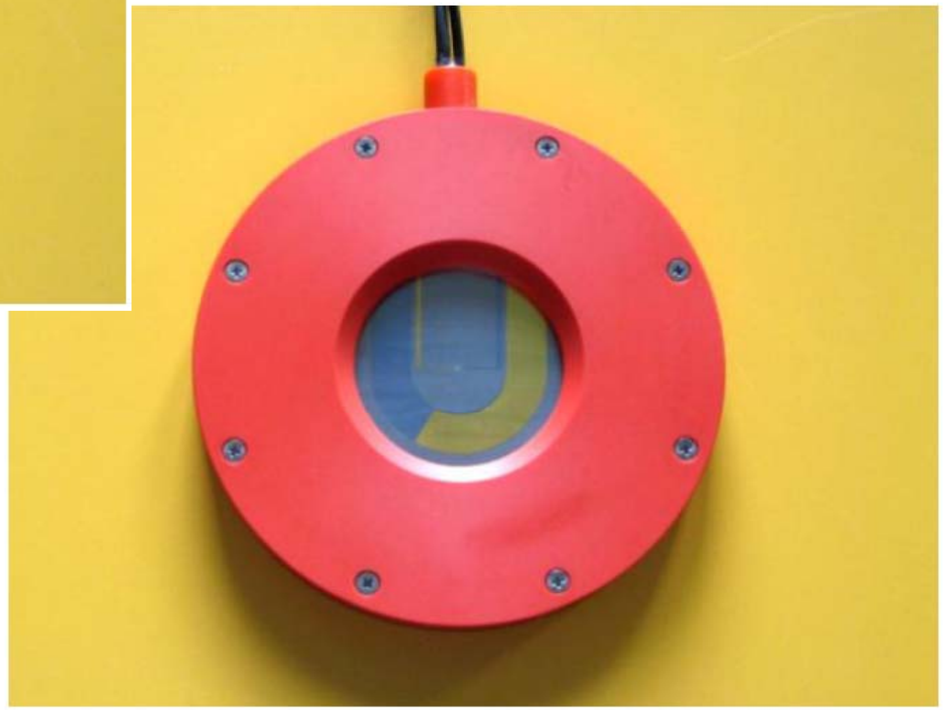


continuating cavitation

Problem: Cavitation (II)

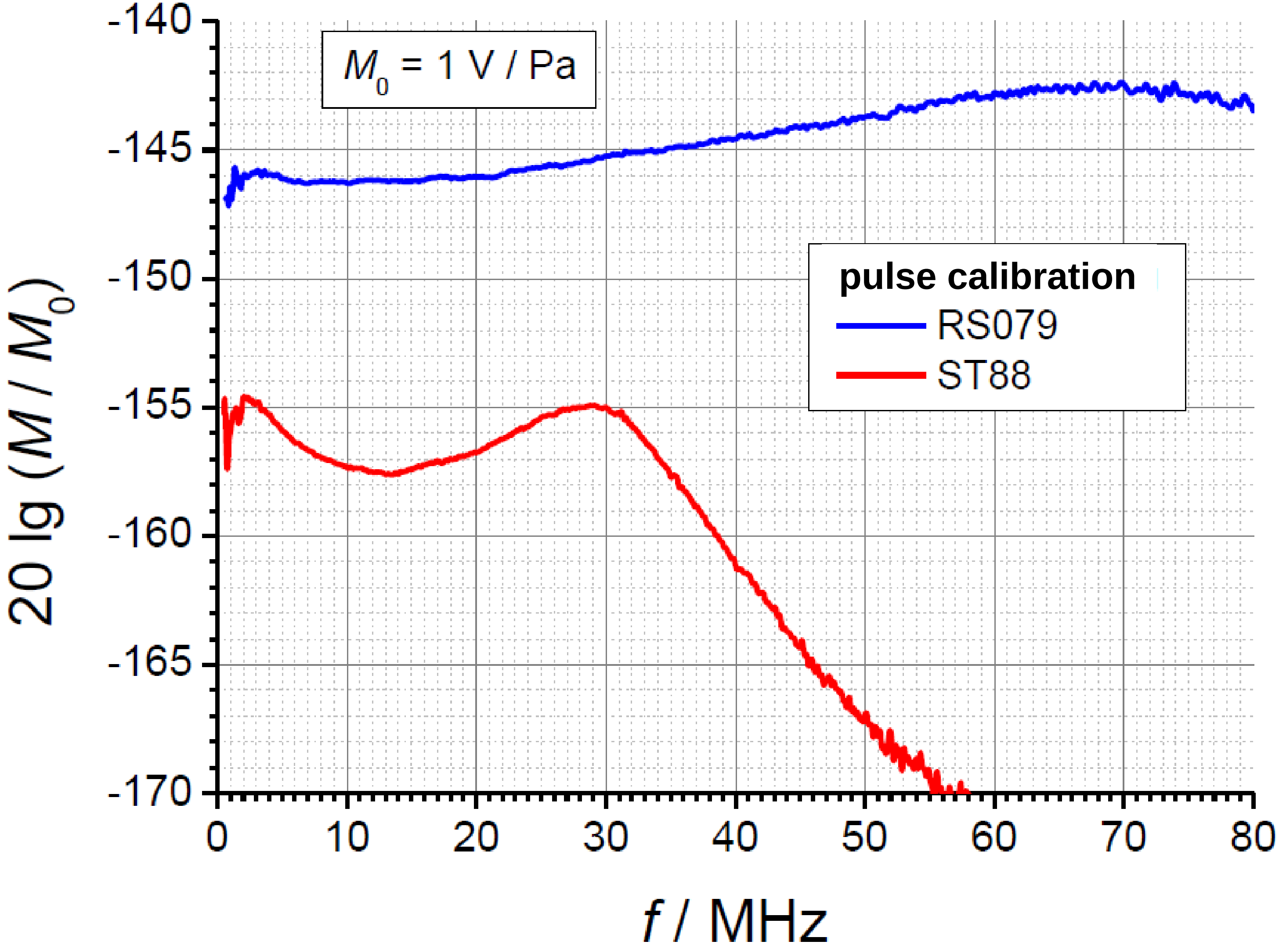


Protection with stainless steel foil (10 µm)



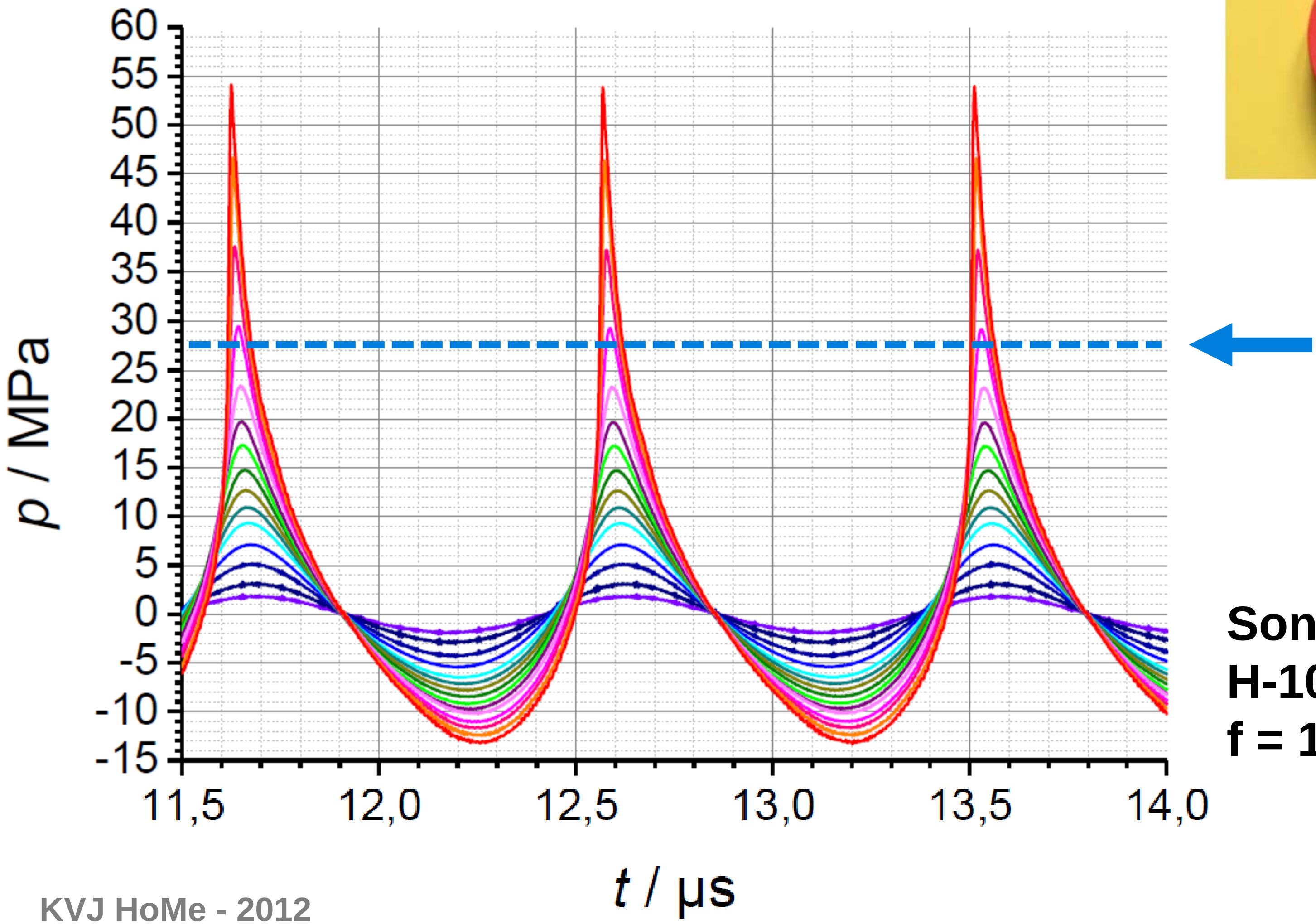
→ **Decrease of sensitivity and band width**

Comparison of transfer functions



Laminated membrane hydrophone

sound pressure at focus



„native“ membrane hydrophone

Sonic Concepts
H-101 (Ø 64 mm)
f = 1.06 MHz

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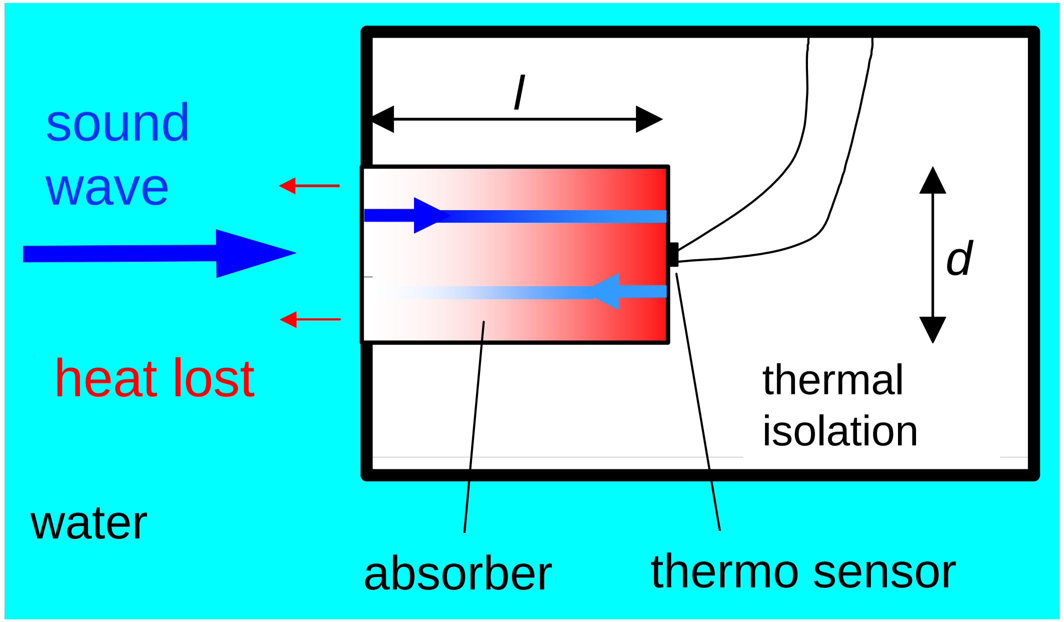
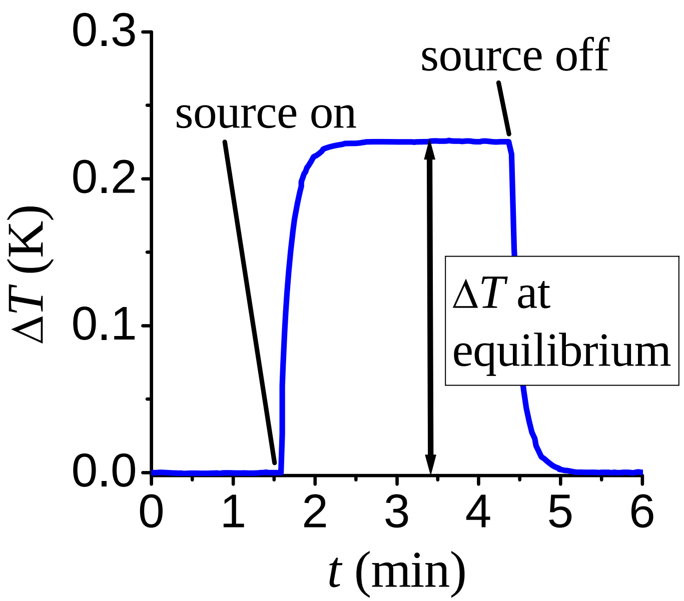
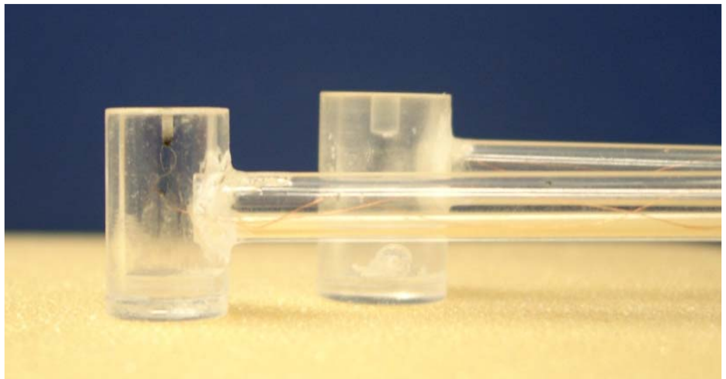
Thermo-acoustic sensors: Principle





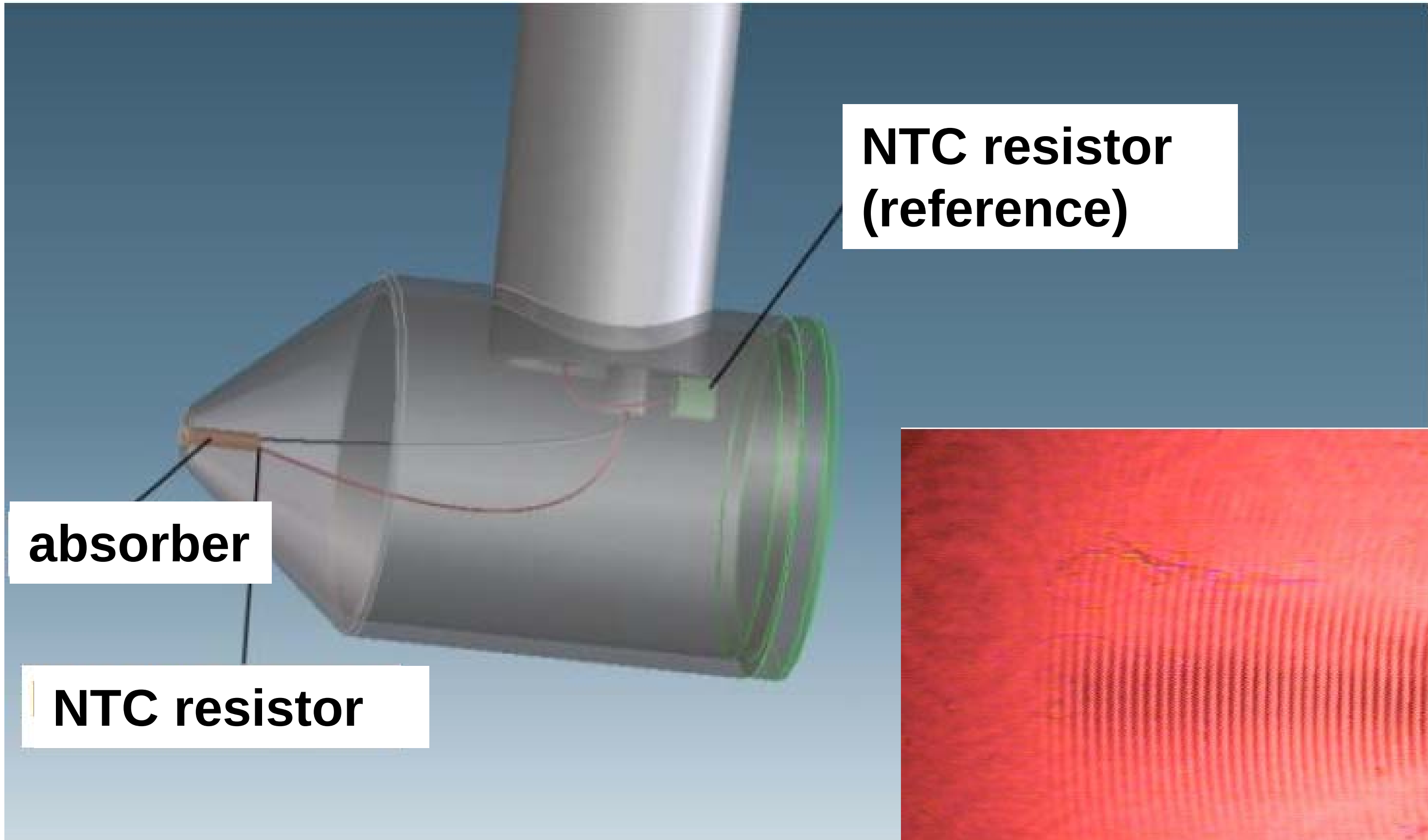


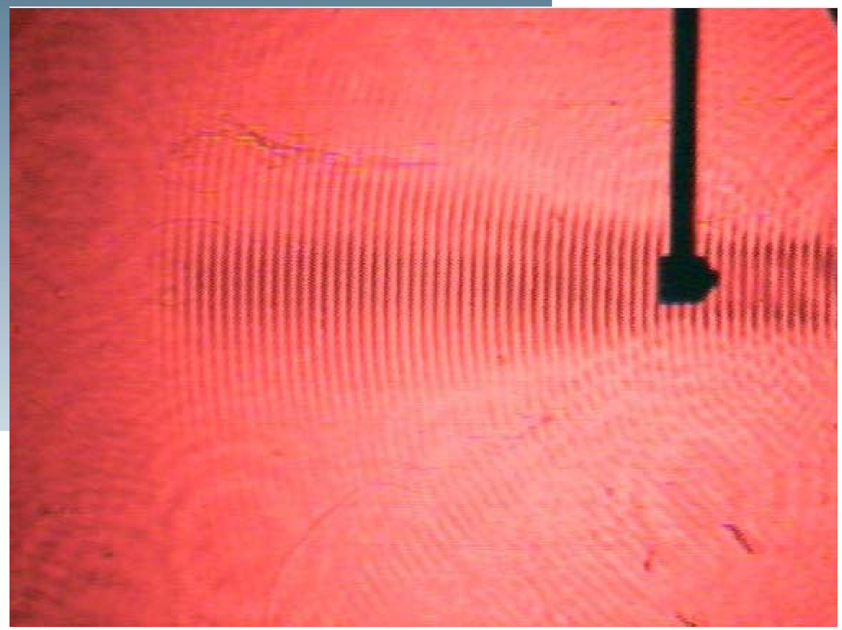
Prototypes (diagnostic fields)

V. Wilkens, Meas. Sci. Technol., 2010

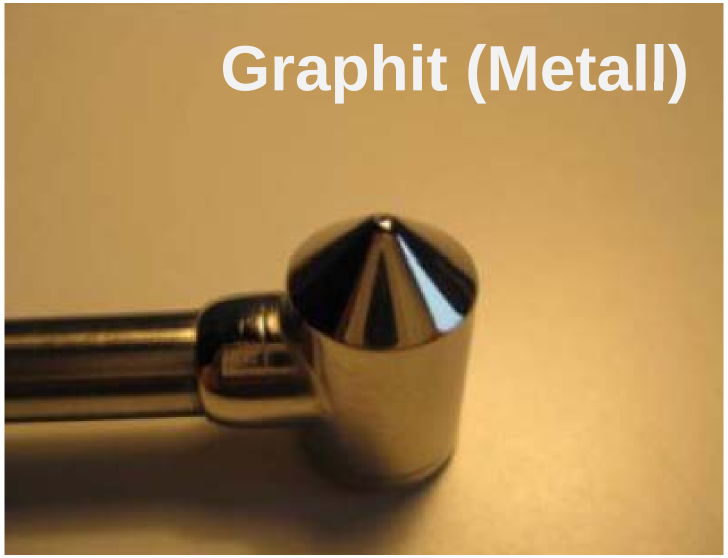
Inherent averaging over time

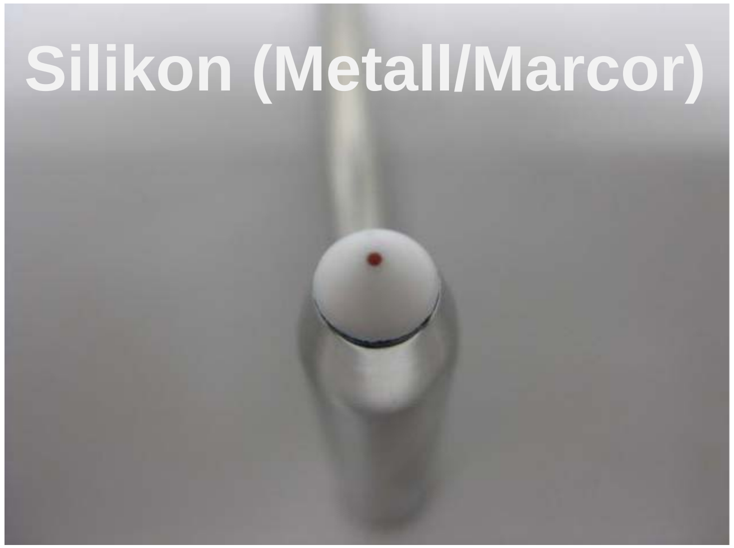
Sensor modification for HITU fields





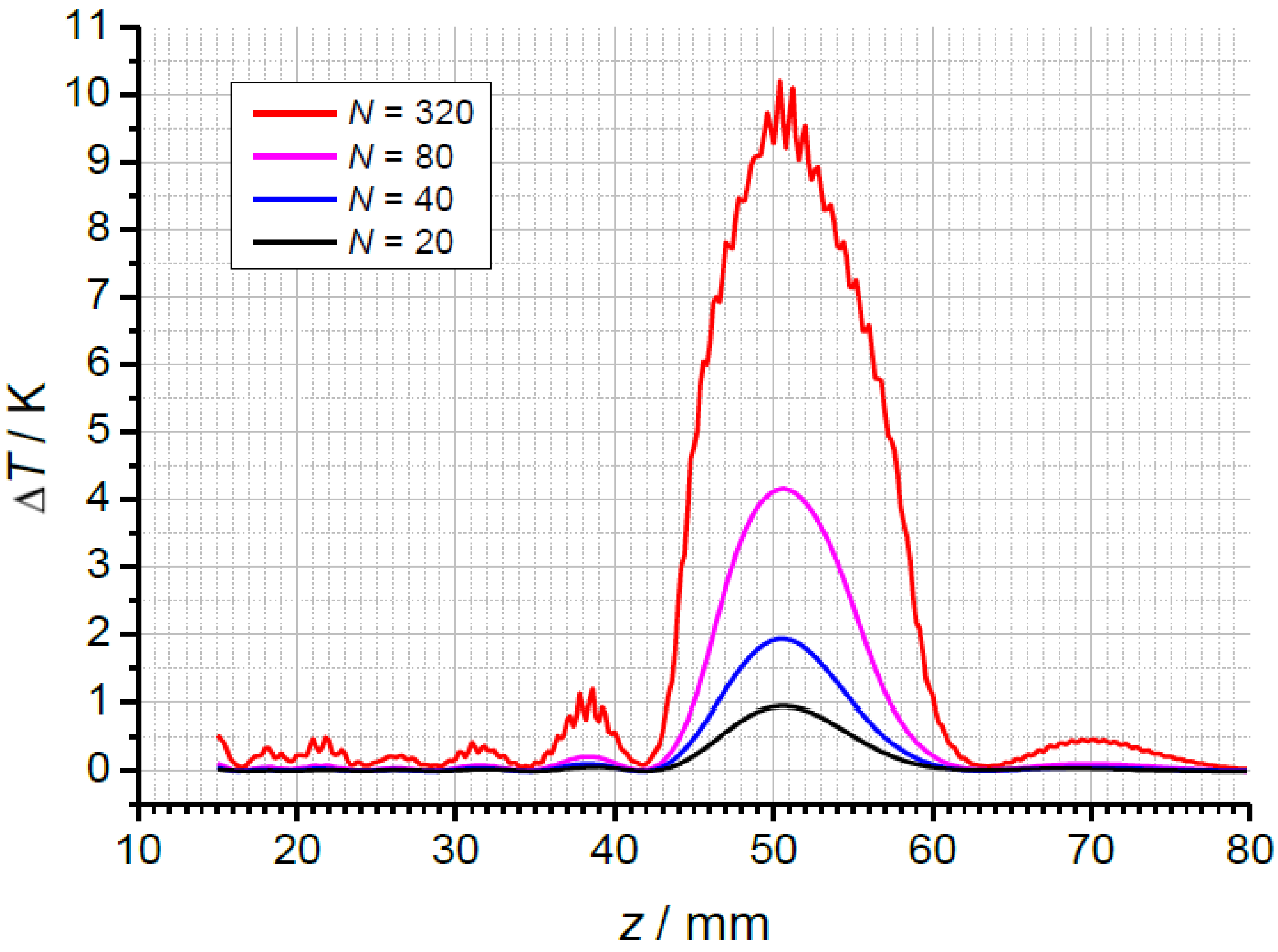
Variation of absorber and housing materials





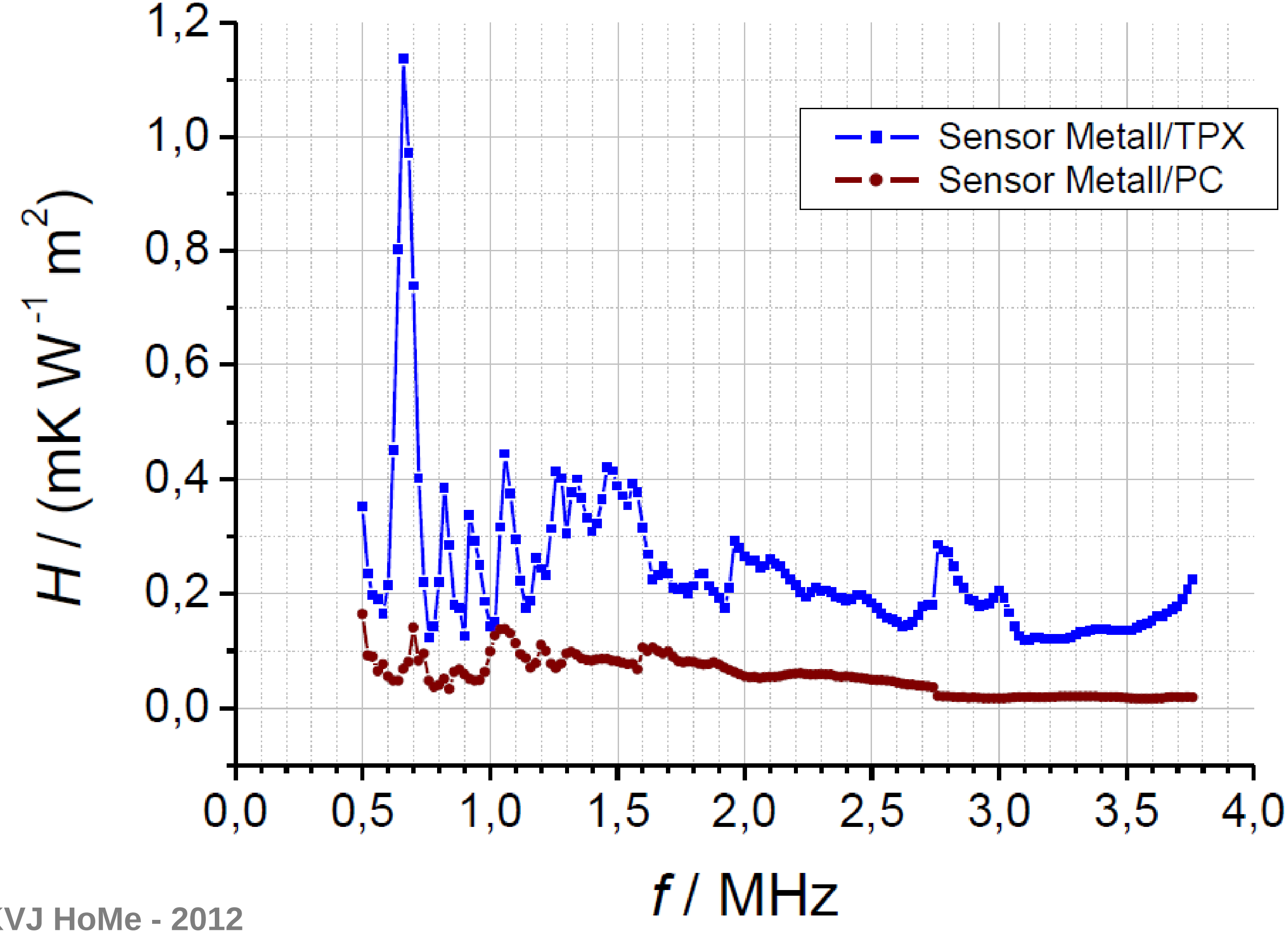
Axial intensity profile in dependence on burst length

(Temperature raw data)



Calibration of intensity sensors

Temperature intensity transfer function



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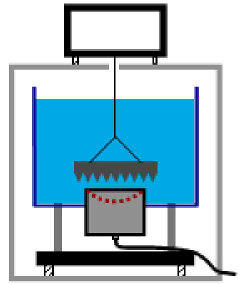
Summary

- **Reliable measurement of temporal averaged total acoustic output power up to 500 W is possible (Uncertainty (*k*=2) 4.5 %)**
- **The HITU hydrophone(*) is usable up to peak pressures of p_c= 55 MPa and p_r=12.8 MPa**
- **Thermo acoustic intensity sensors(*) acquire the intensity profiles of HITU fields with high reliability (in the current state up to 25 W acoustic power)**
- **General problem: Cavitation**



(*) Manufacturing and distribution: http://www.gampt.de