Nanosensoren voor én met ongehoord geluid

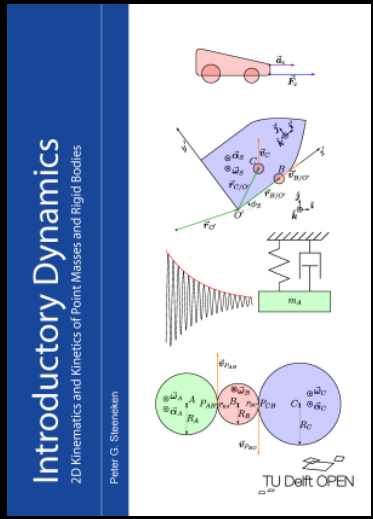
Peter Steeneken
TU Delft

WND conferentie
Noordwijkerhout, 14-12-2024

Van middelbare school tot professor

- Maartenscollege Groningen/Haren (1986-1992)
- Elisabethtown College USA (1992-1993)
- RuG (1993-2002)
- Industrie: Philips Natlab & NXP (2002-2017)
- TU Delft (2013-2024)

  - Groep Dynamics of Micro&Nanosystems
  - Dynamica: 900 1e jaars BSc. WB
  - Physics for ME: 250 1e jaars MSc. WB

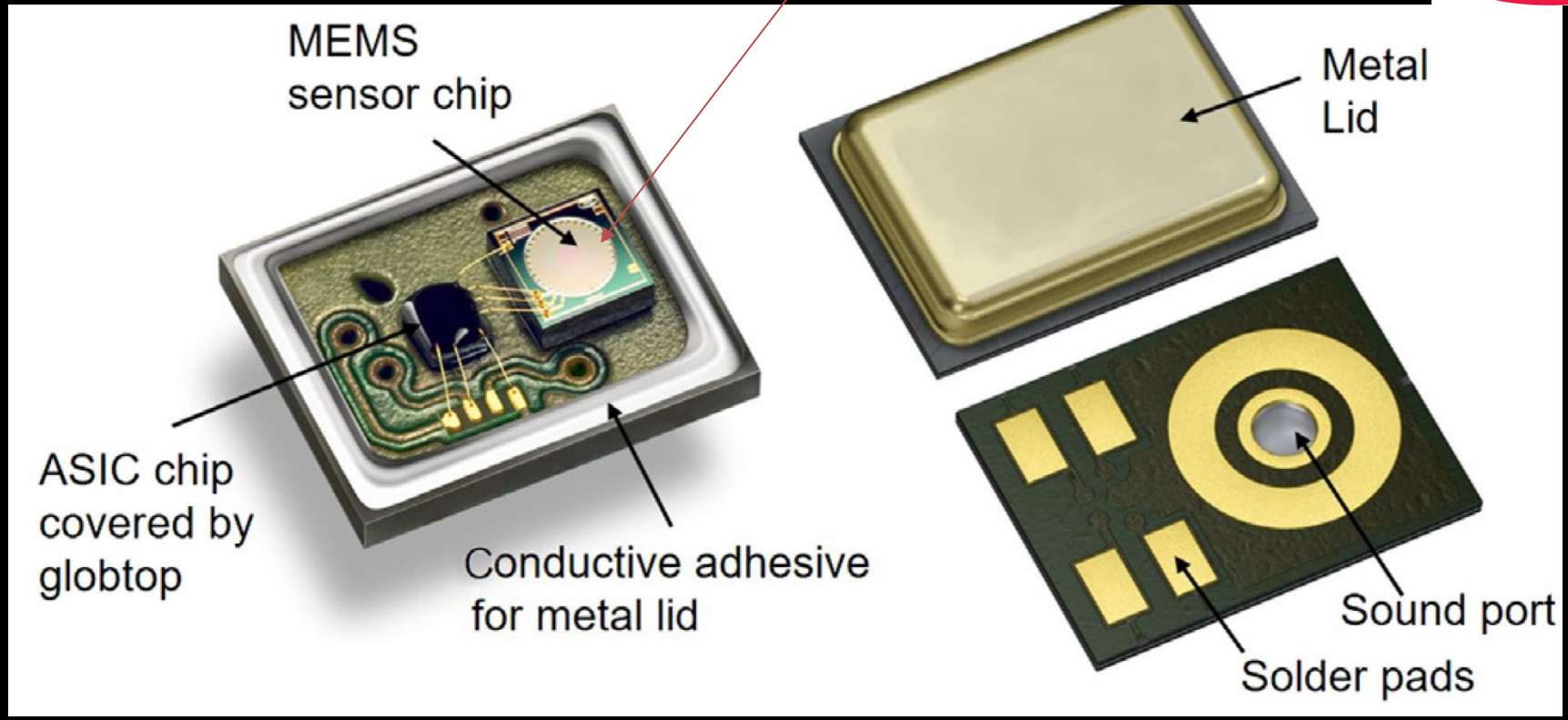


https://textbooks.open.tudelft.nl/textbooks/catalog/book/83

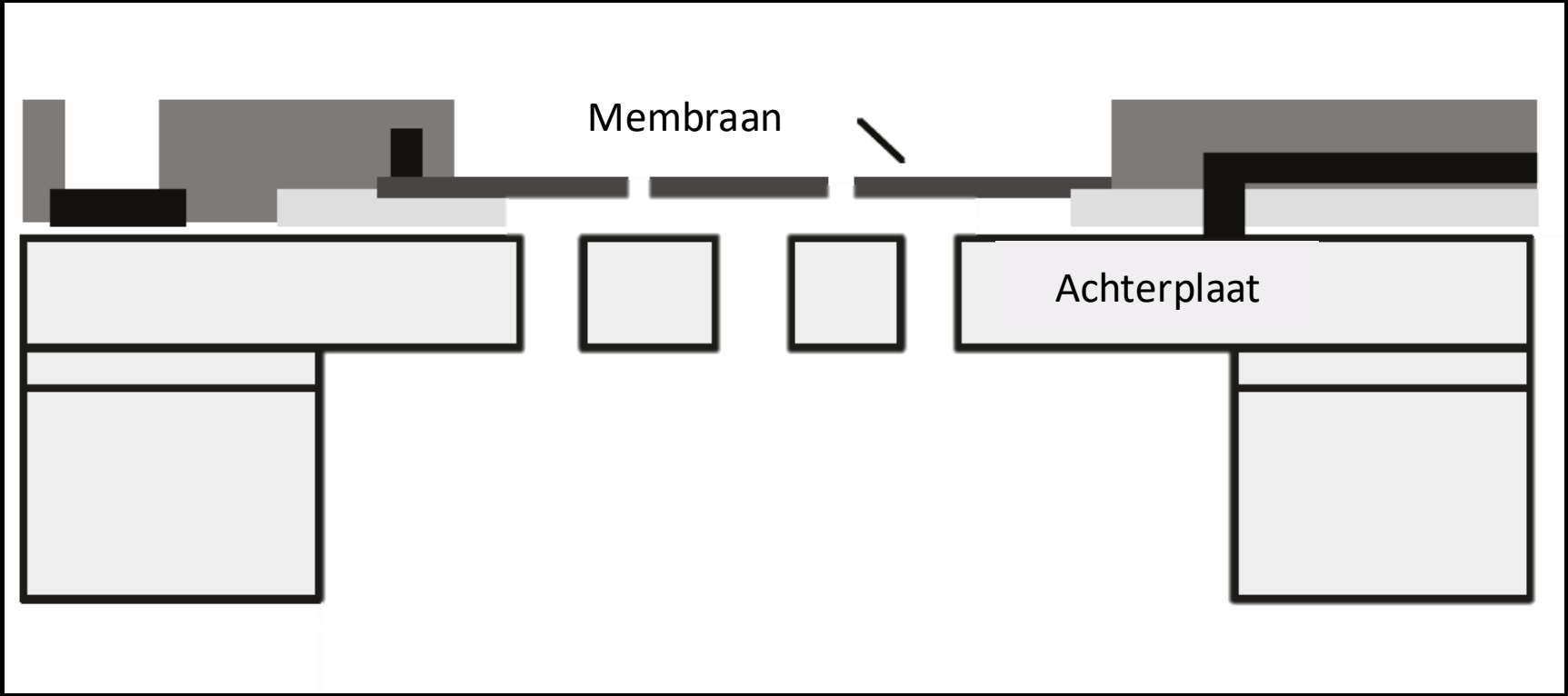
Nanosensoren en geluid

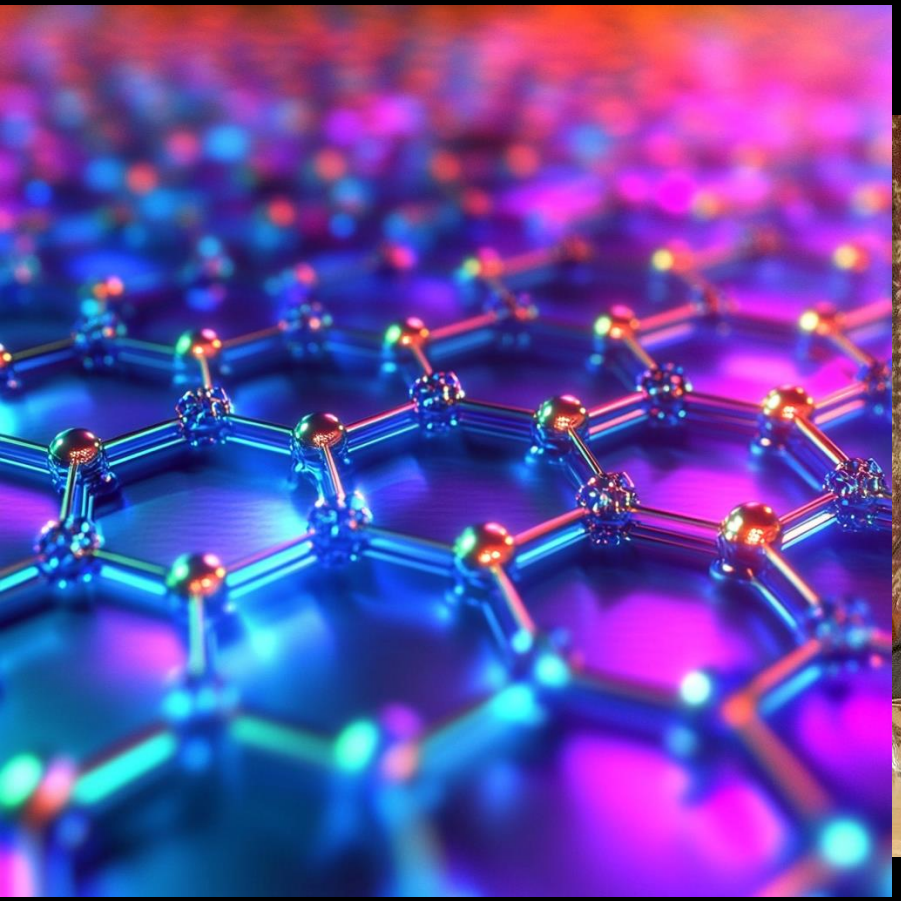
- Geluid meten met nanomembranen
- Nanomembranen meten met geluid
- Ongehoord geluid in de (micro)biologie
- Akoestiek op de nanoschaal bij ultrahoge frequentie
- Akoestische levitatie

Gevoeliger microfoons

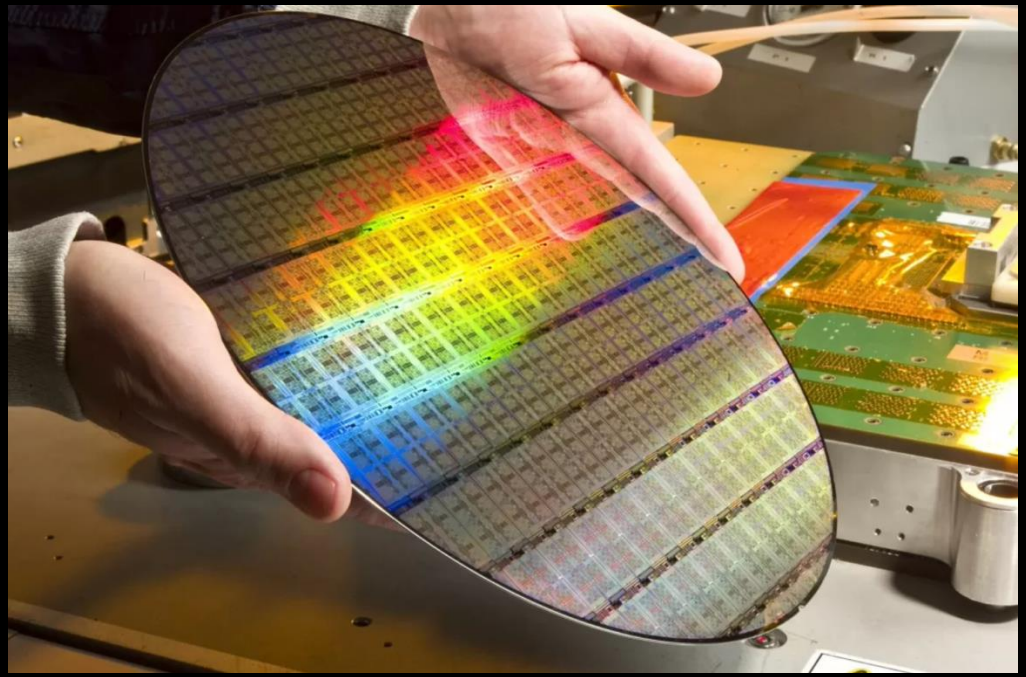


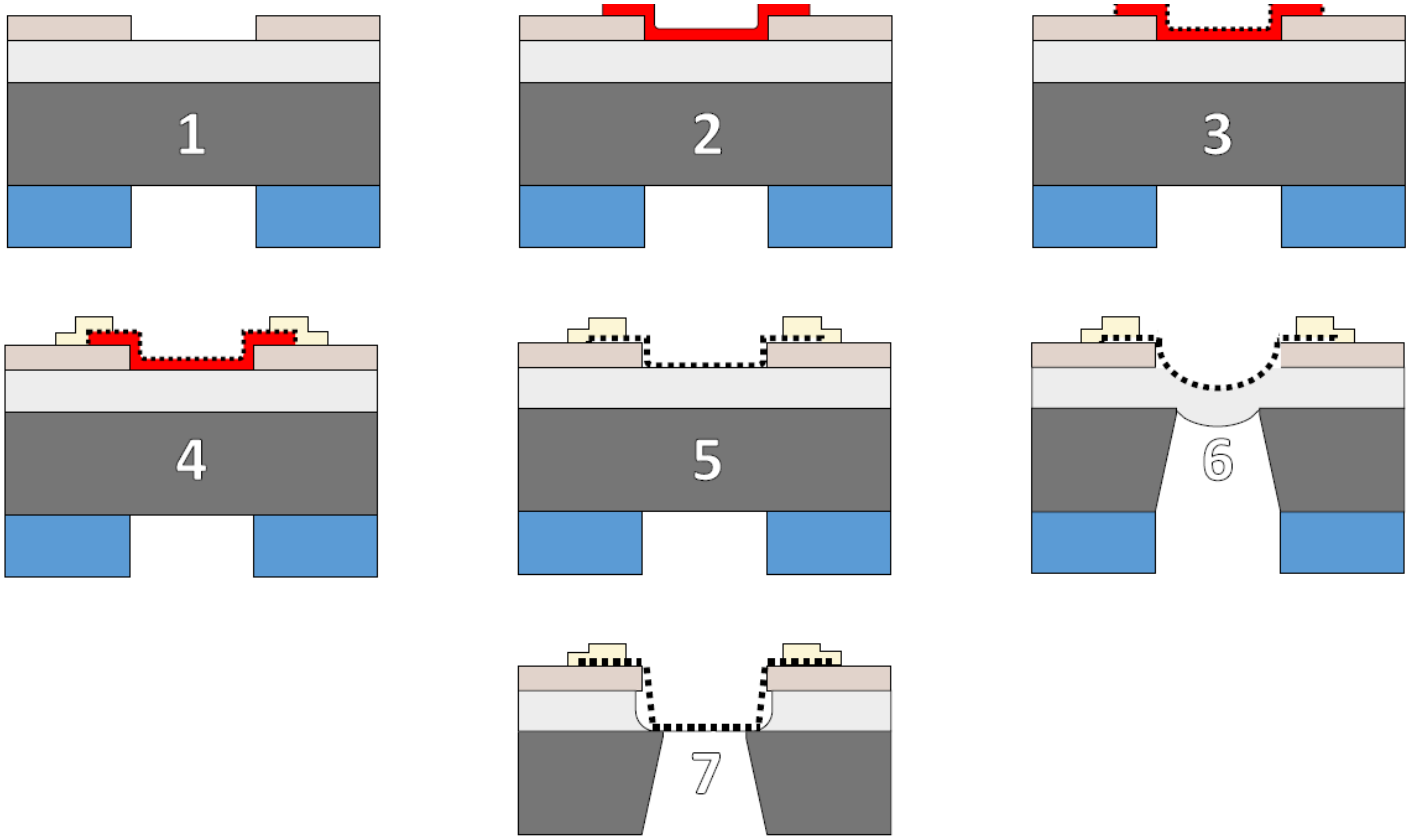
Dunnere membranen

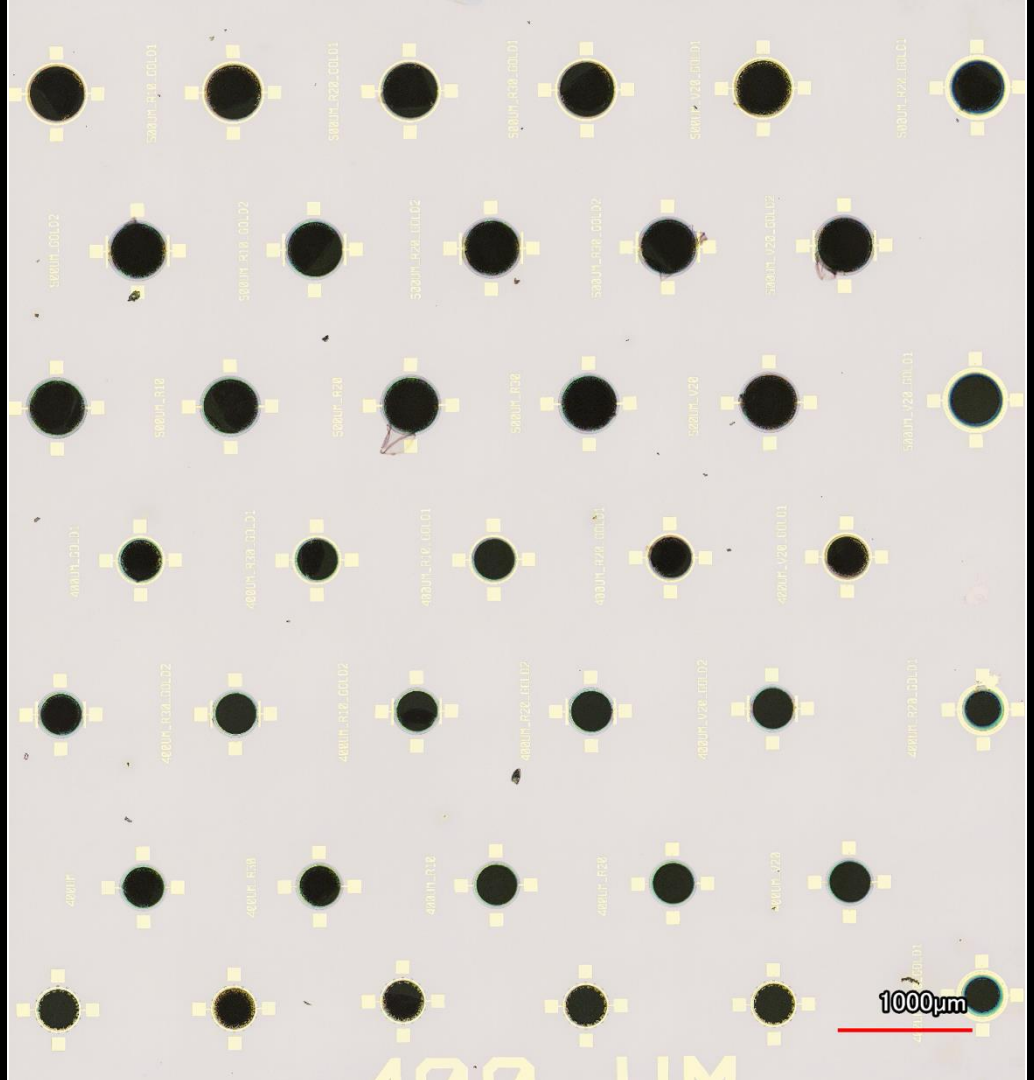


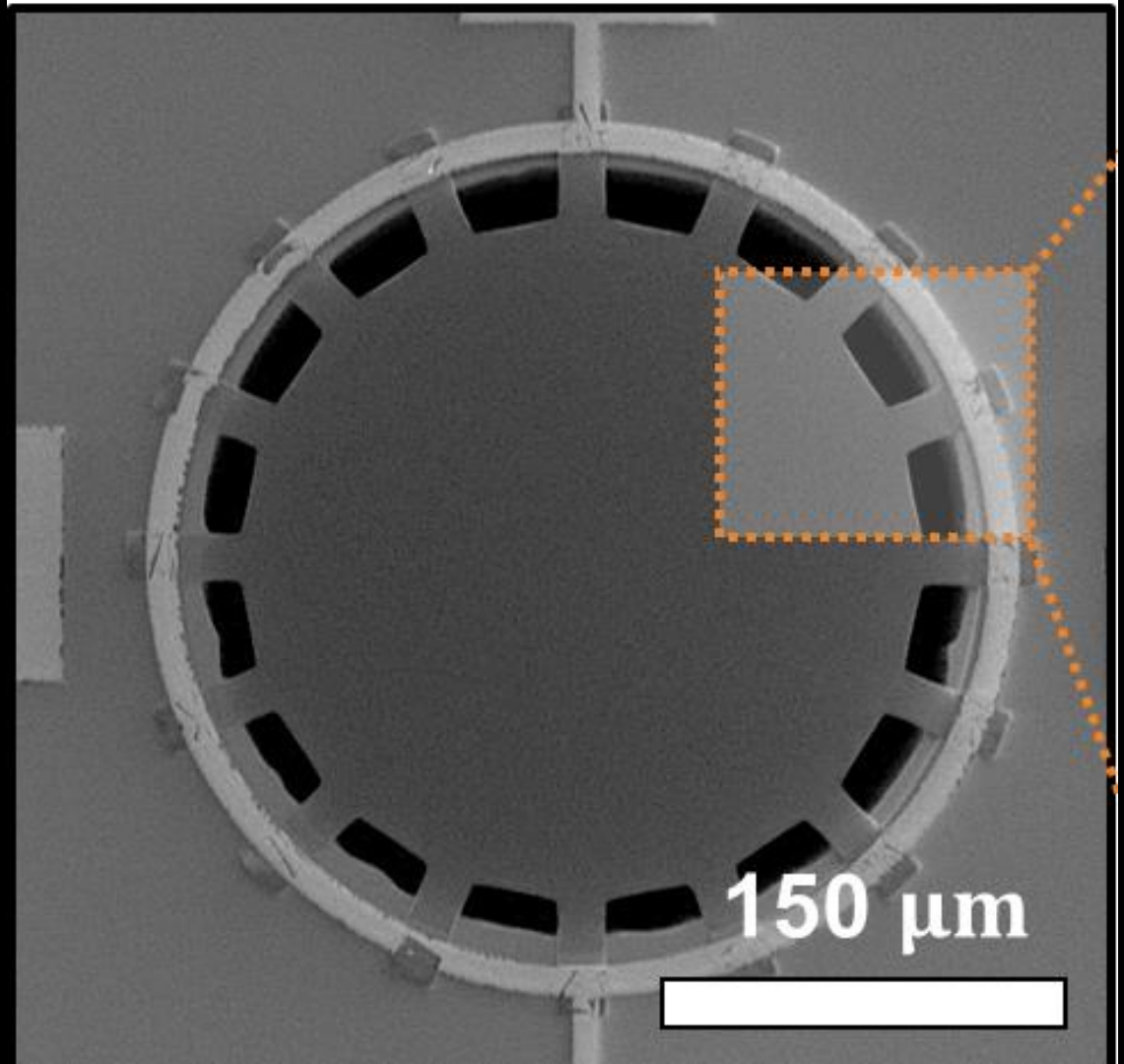



ANDRE GEIM
KUNGL VETENSKAPS AKADEMIEN




1
2
3
4
5
6
7
Si
Thermal SiO_2
LPCVD low-stress SiN_x
PECVD TEOS
Mo
ML-Graphene
Cr/Au


1000µm

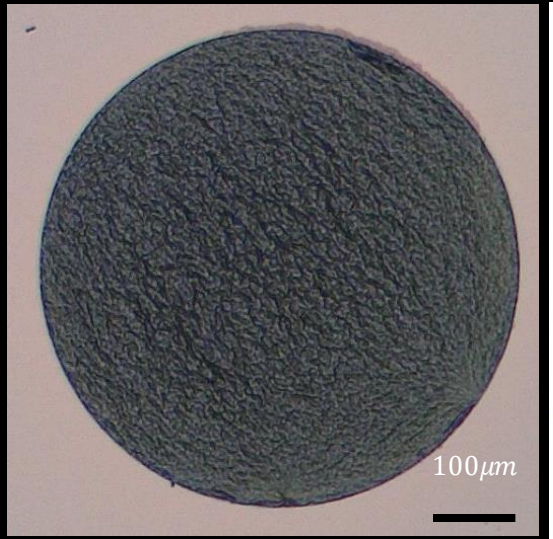


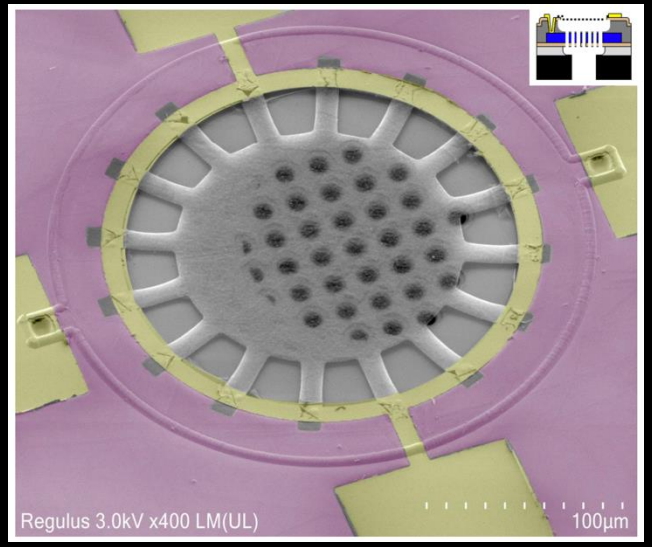
Else Kooi Laboratory

GRAPHENE FLAGSHIP

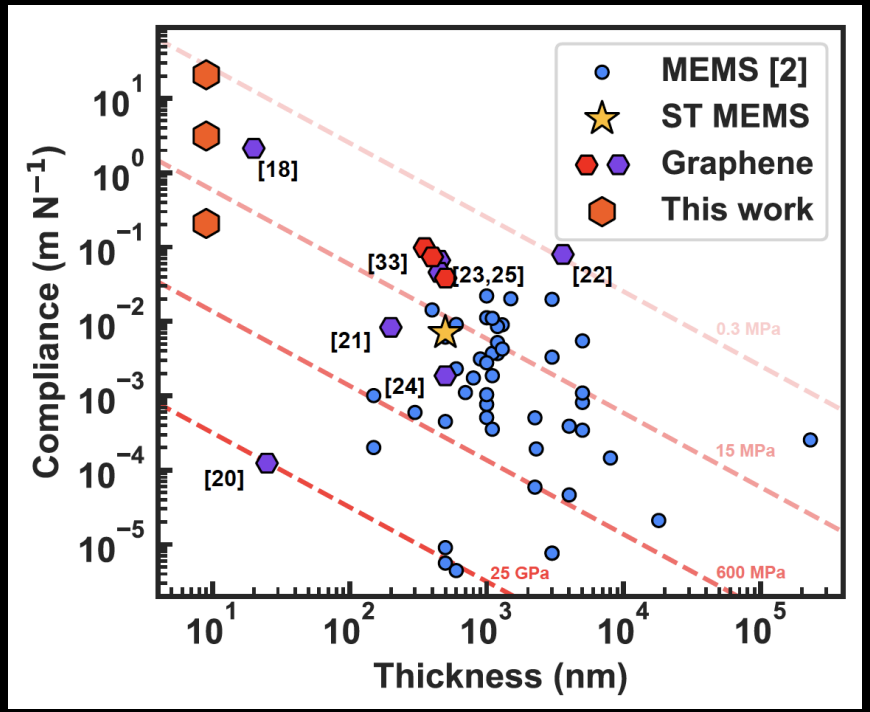
Grafeen microfoons

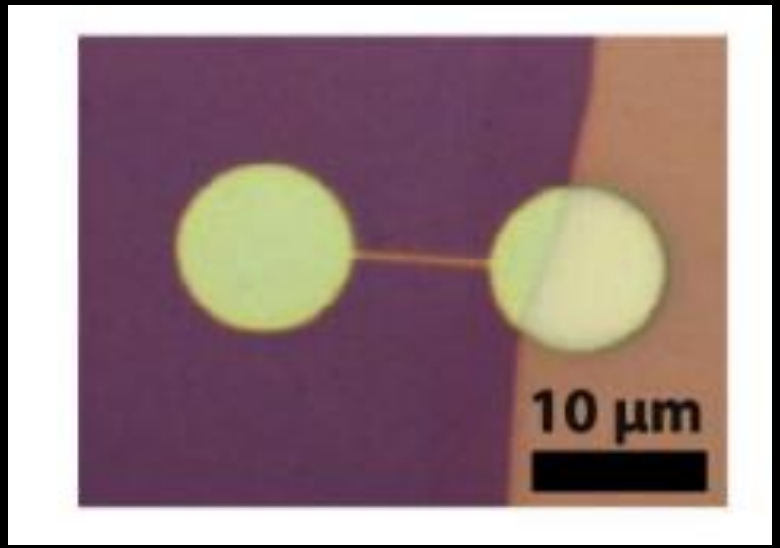
Pezone et al. Microsystems & Nanoengineering (2024) 10:27
Baglioni et al., Nanoscale 15 (13), 6343-6352





De meest gevoelige en kleinste microfoons

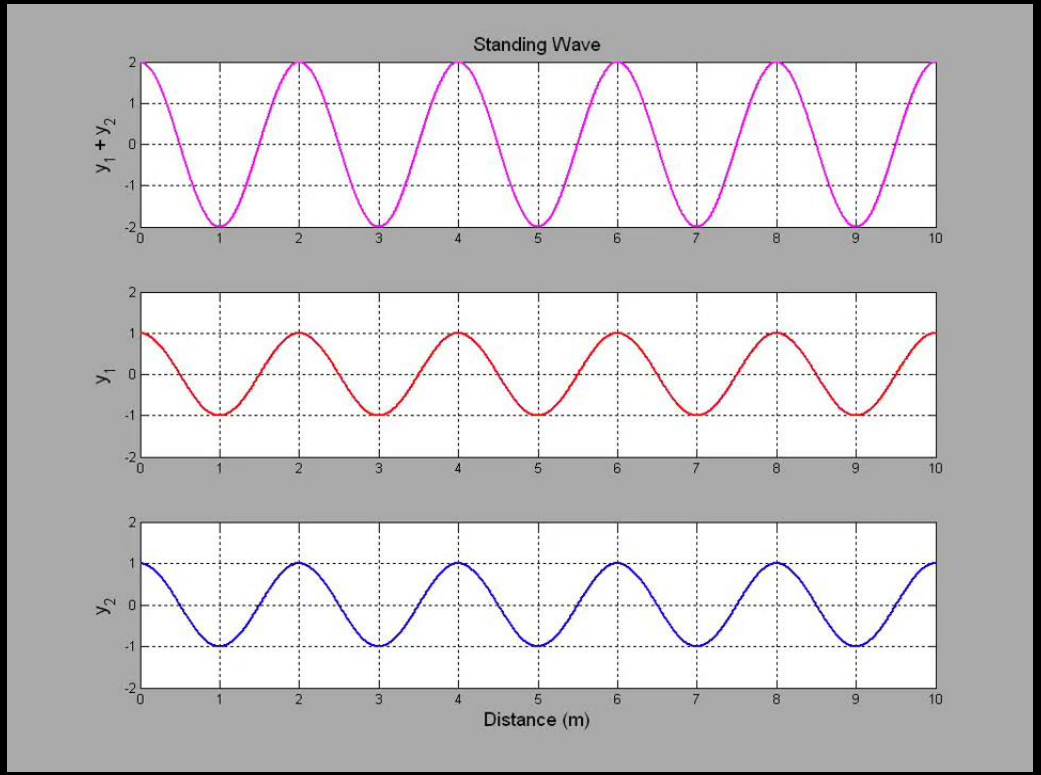




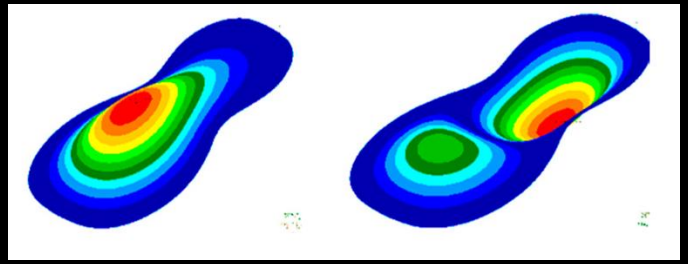
Abrahams, Marnix P., et al. "The graphene squeeze-film microphone." *Nano Letters* (2024).

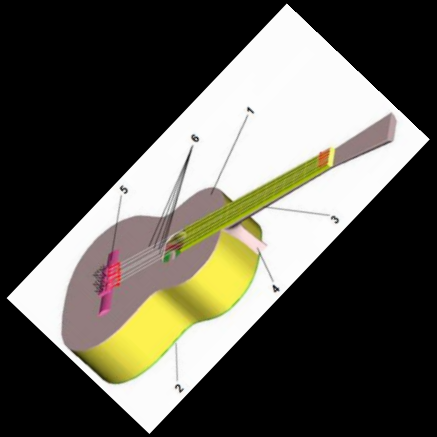
Nanomembranen meten met geluid

Geluid en staande golven



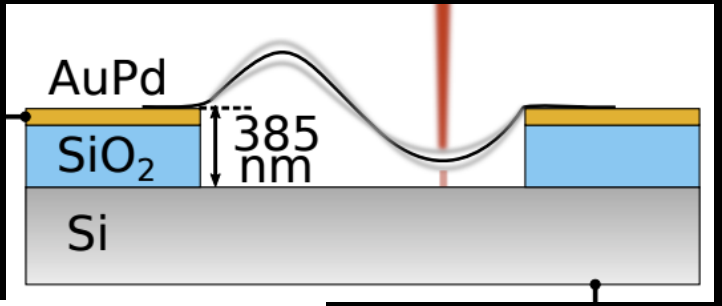
Resonantiemodes

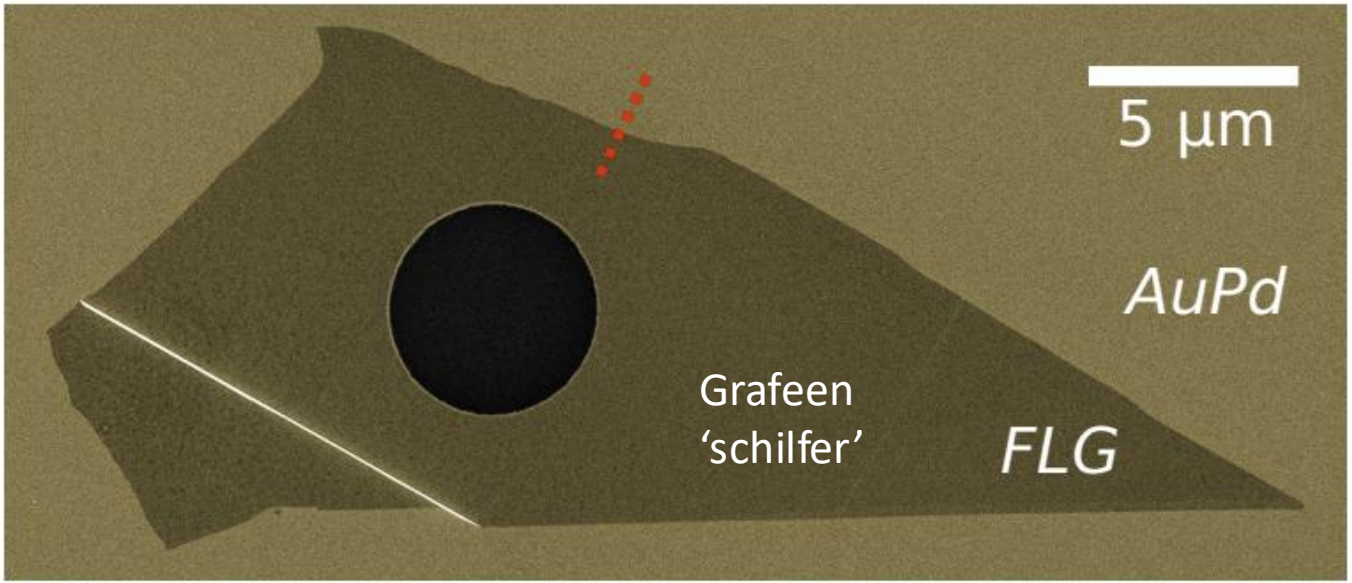




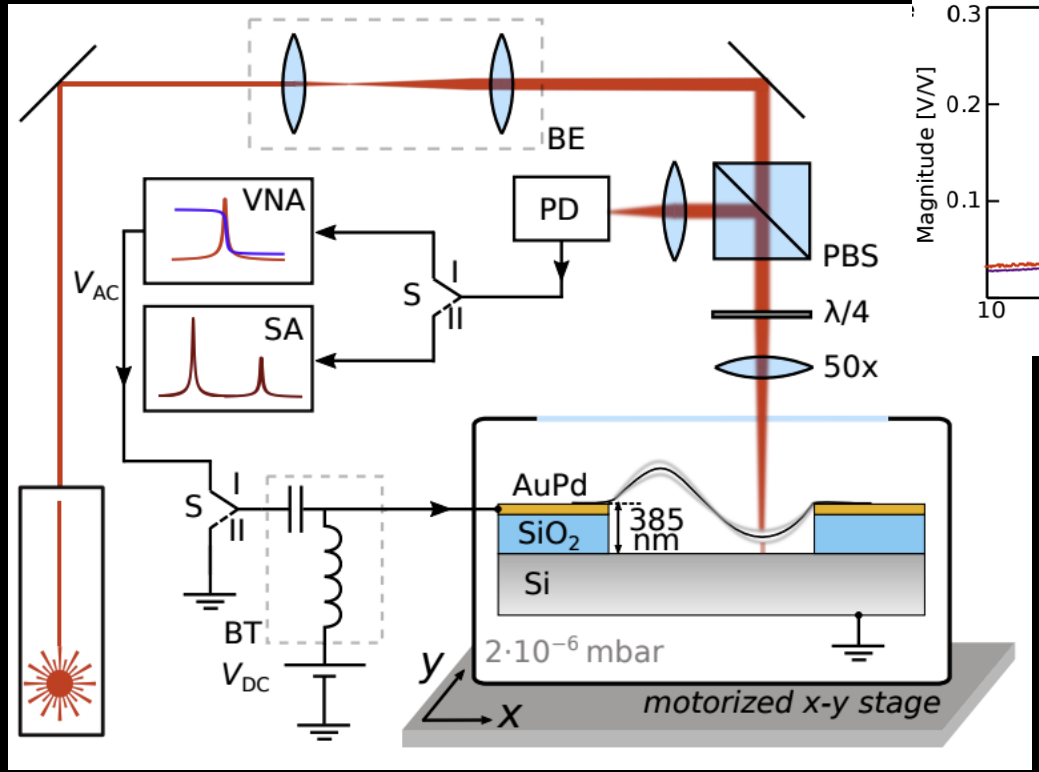
Stanciu et al., https://www.mdpi.com/2073-8994/11/6/727

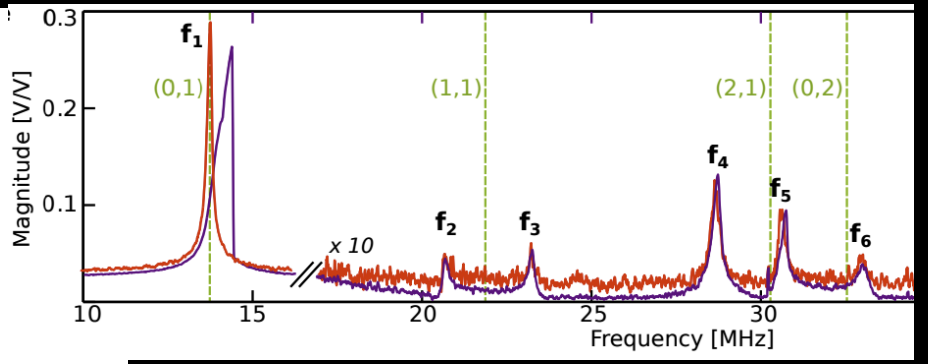
Grafeen nanotrommel





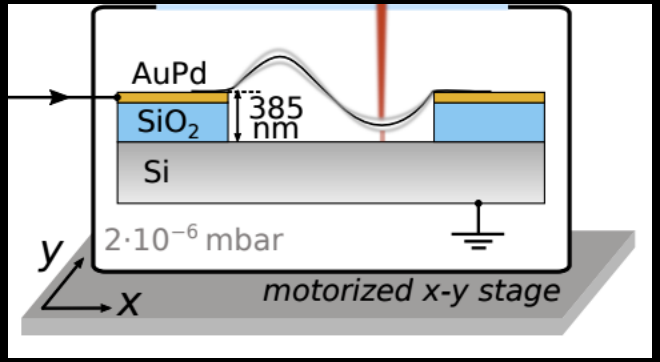
MHz resonantie meten met laser

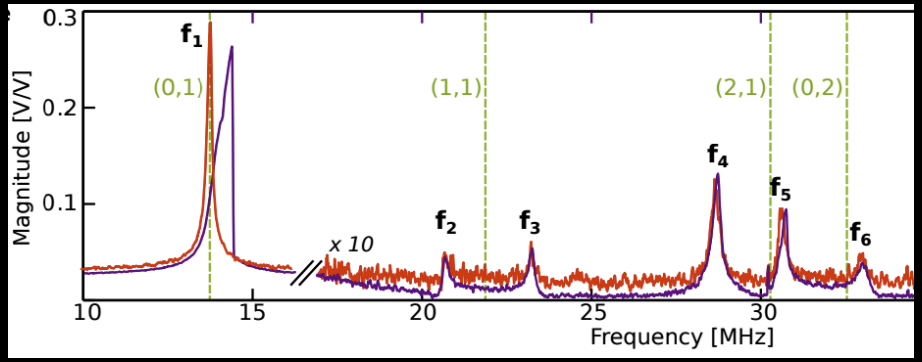


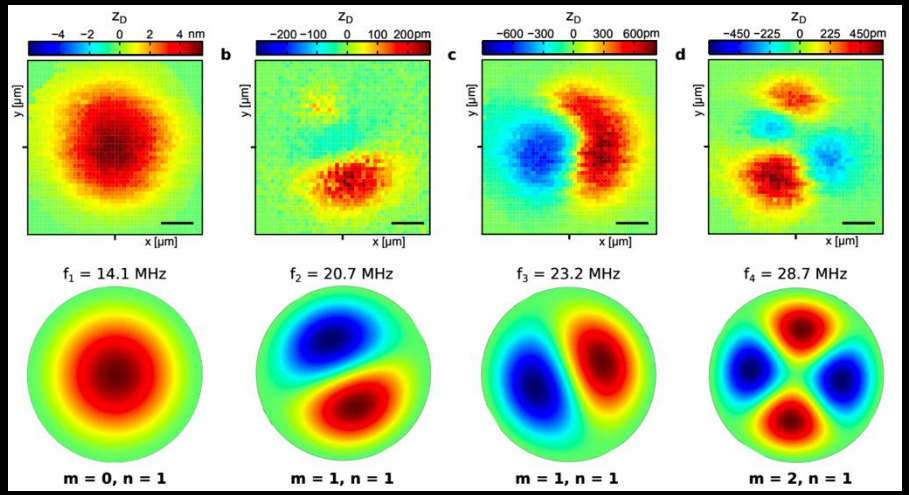


Resonantiepieken

Staande MHz geluidsgolven meten met laser

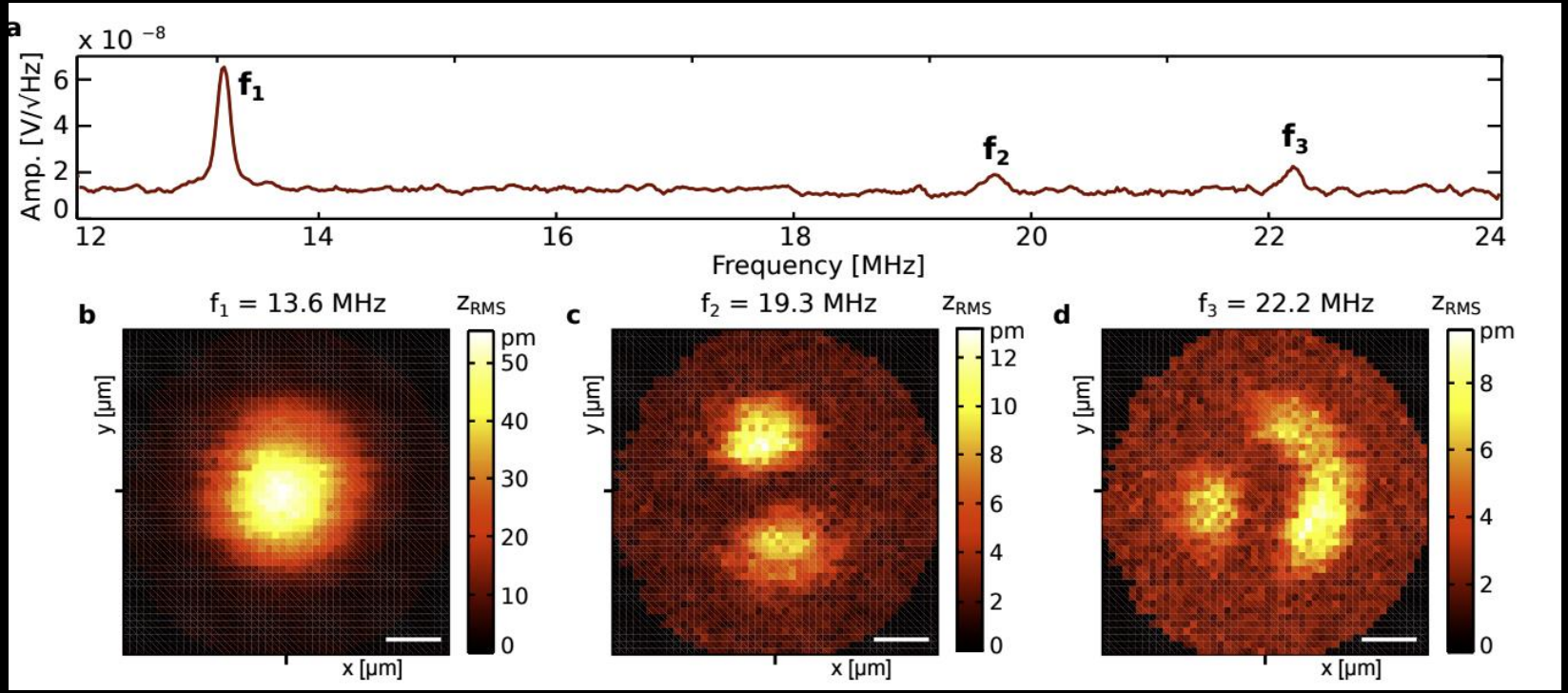




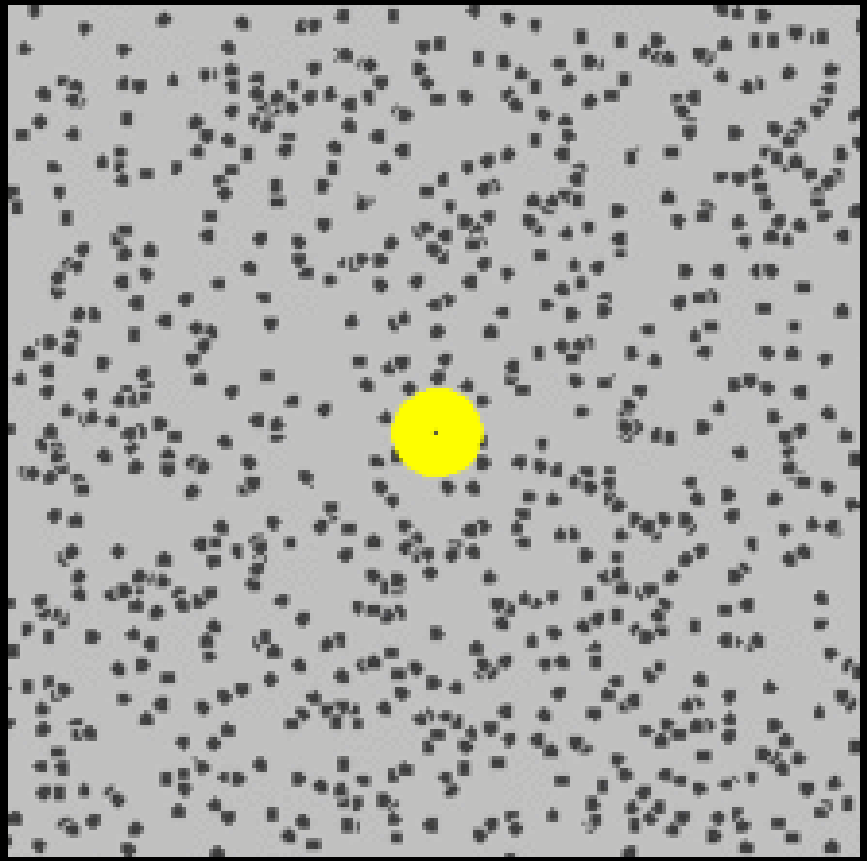


Resonantiemodes

Geluid van de stilte (sound of silence)



Brownse beweging

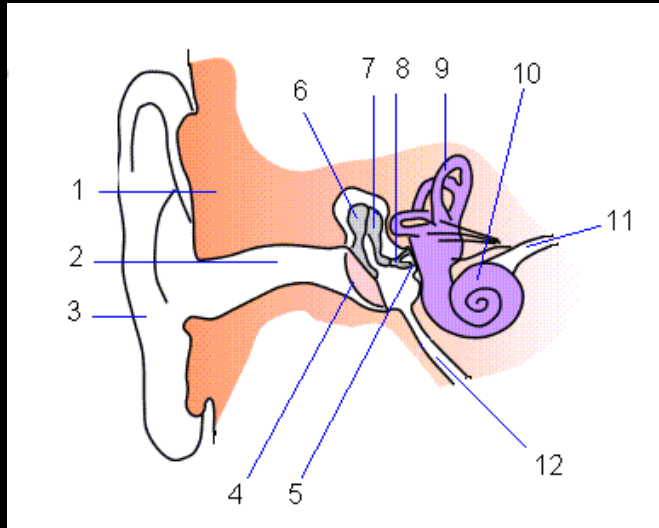


Gehoordrempel en Brownse beweging

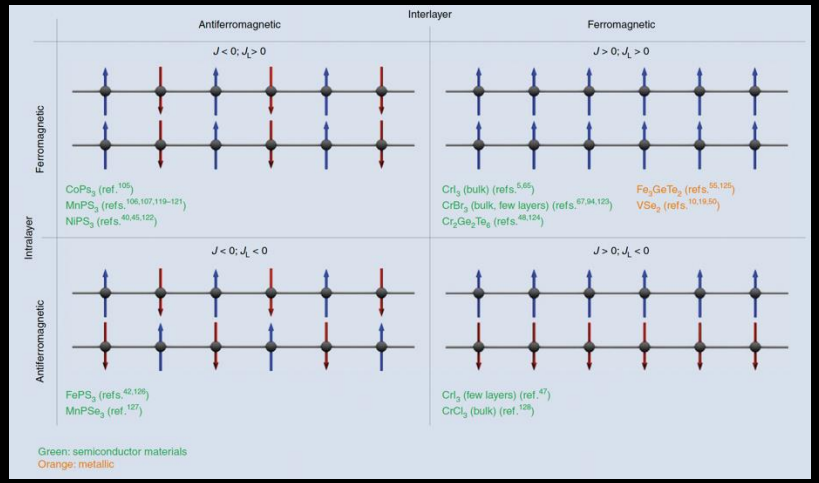
- Kunnen we Brownse beweging horen?
- Met ons oor niet, maar met grafeen wel

Ongehoorde natuurkunde!

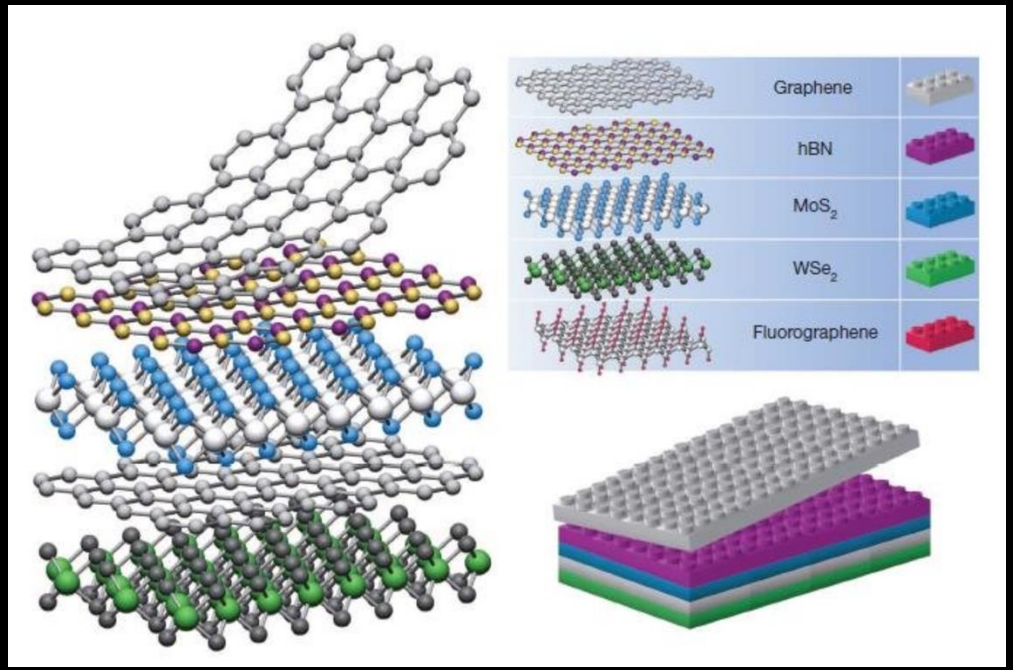
‘What is silence? Therefore, what is sound? Elliott H. Berger J. Acoust. Soc. Am. 155, 3604–3605 (2024)



Magnetische 2D materialen

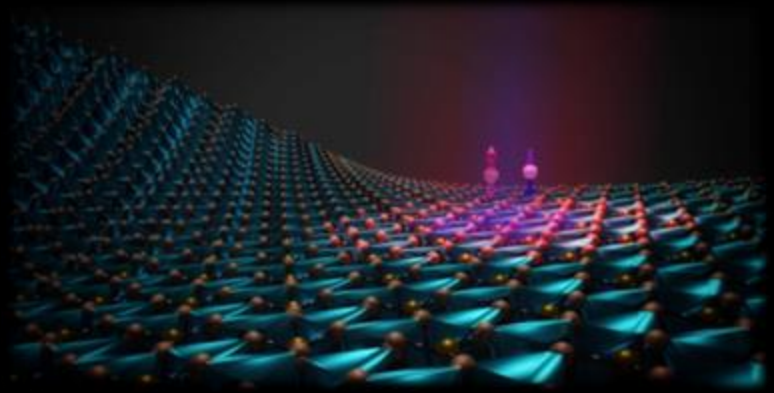


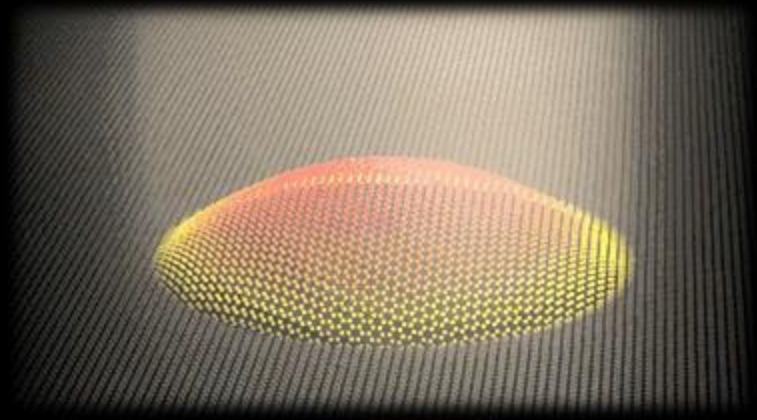
Gibertini et al., Nature Nano 2019

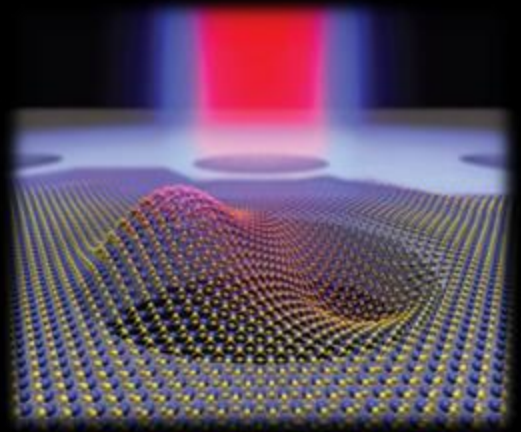


*Geim, A., Grigorieva, I. Van der Waals heterostructures. Nature **499**, 419–425 (2013).*

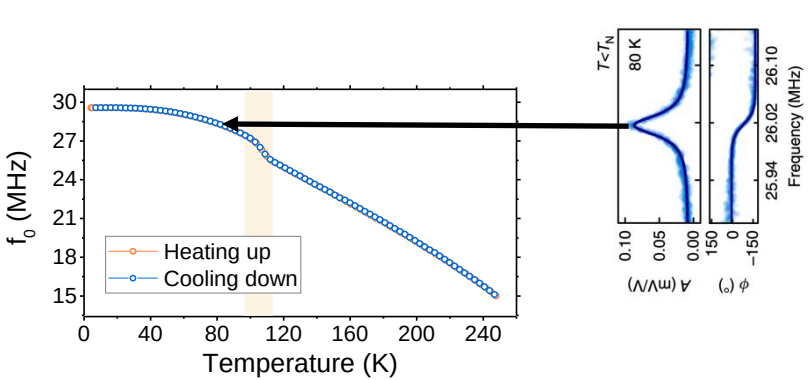
Magnetische 2D materialen

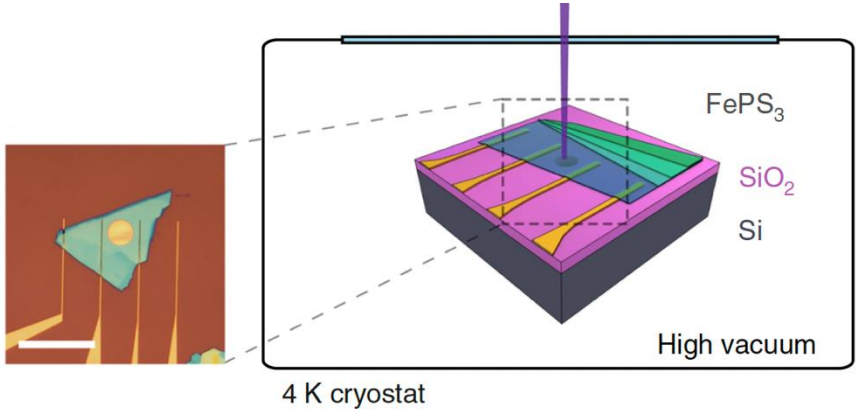


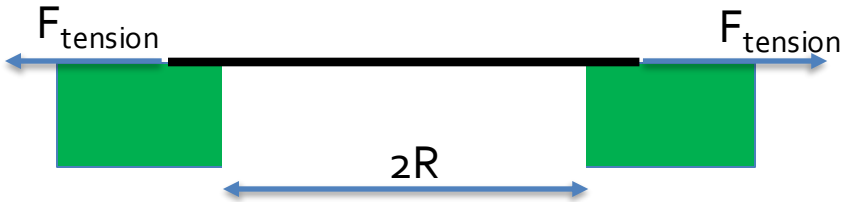




Temperatuur afhankelijke resonanties f_o

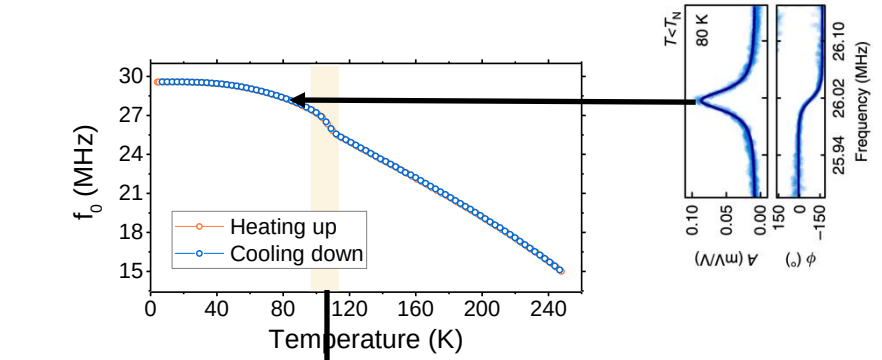




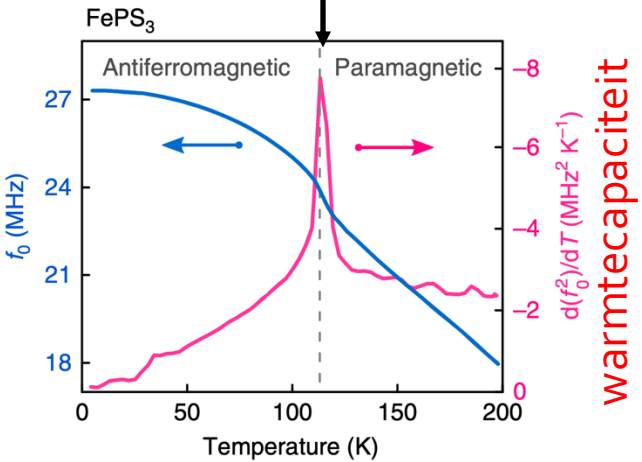


Als het membraan afkoelt trekt het zich strak als een gitaarsnaar

Magnetisme meten met geluidsfrequentie f_0

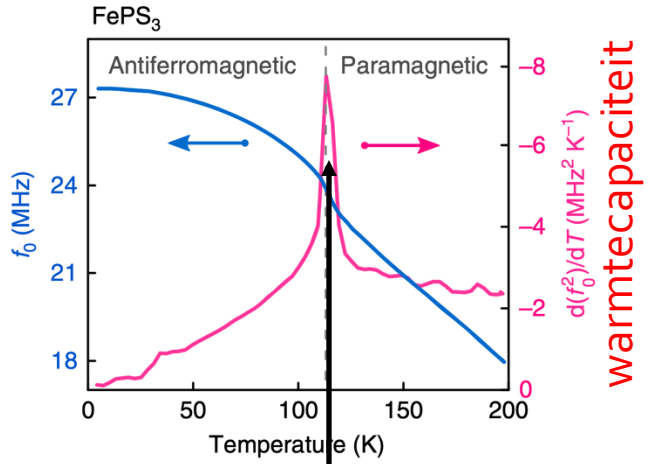


Afgeleide naar T



warmtecapaciteit

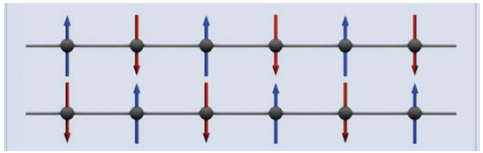
Magnetisme meten met geluidsfrequentie f_0



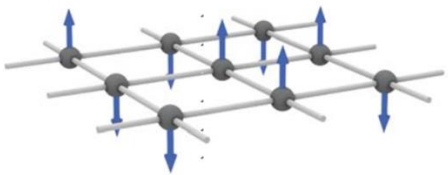
Antiferromagnetisch geordend

Faseovergang

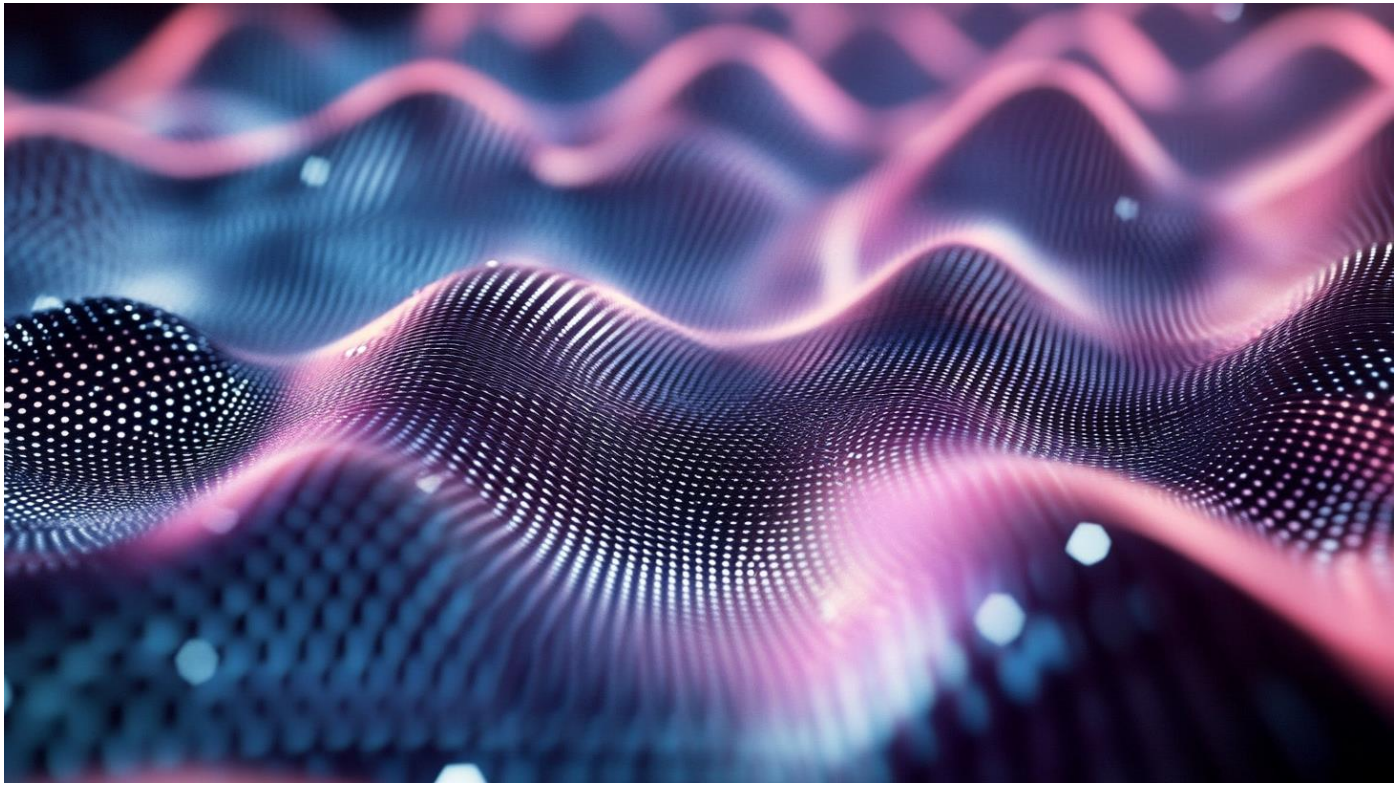
Paramagnetisch willekeurig



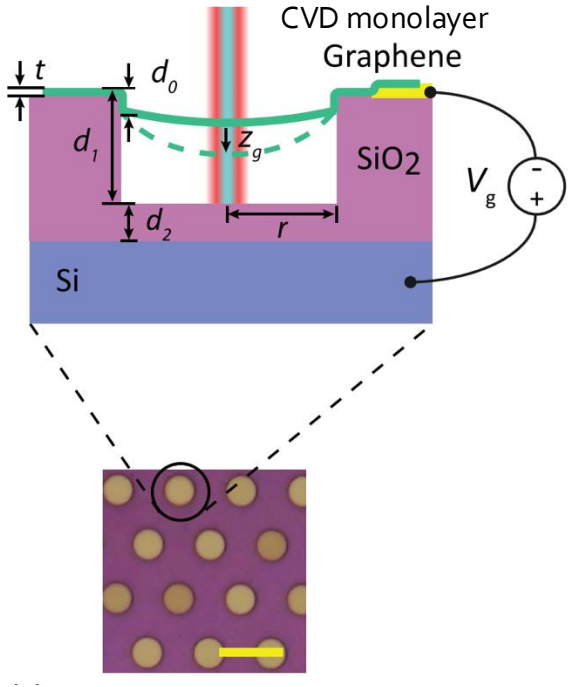
Smelten van het spinrooster kost veel energie: Hoge warmtecapaciteit

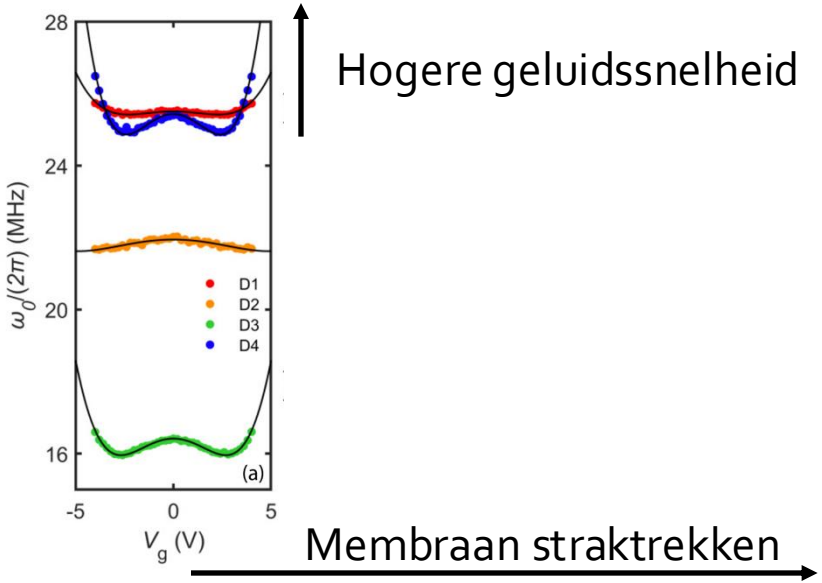


Geluidssnelheid in grafeen



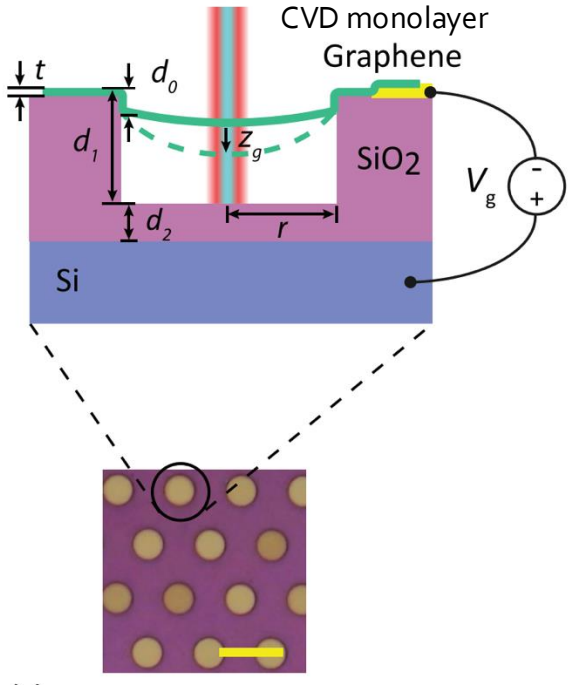
Geluidssnelheid verhogen door opspannen

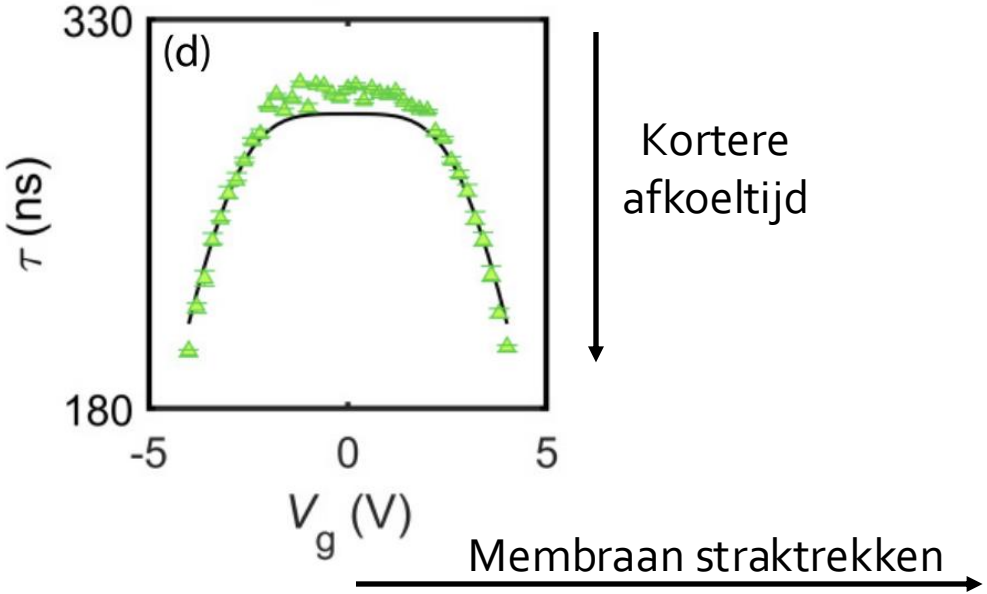




Liu, H.,…, Steeneken, Verbiest, et al. "Tuning heat transport in graphene by tension." *Physical Review B* 108.8 (2023): L081401.

Warmtegeleiding ook sneller!

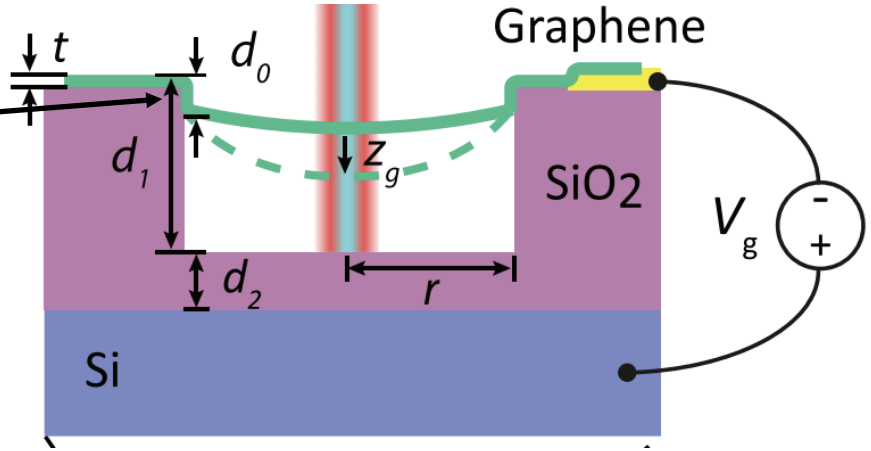




Liu, H.,…, Steeneken, Verbiest, et al. "Tuning heat transport in graphene by tension." *Physical Review B* 108.8 (2023): L081401.

Waarom warmtegeleiding hoger?

Hogere warmtegeleiding
door gladtrekken randen grafeen



Ongehoord geluid in de (micro)biologie

Sound tracks:

1. Rups
2. Plant
3. Vis
4. Bacterie

A

B

C

D

Ongehoorde biologie

A

2. Plant

B

1. Rups

C

4. Bacterie

D

3. Vis

Talking catfish (meerval)

The evolutionary origins of ritualized acoustic signals in caterpillars

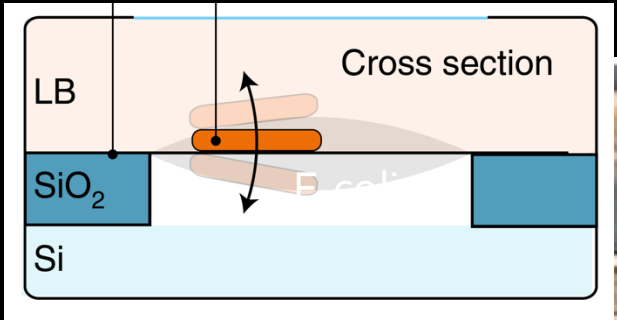
Nature Communications **1**, Article number: 4 (2010)

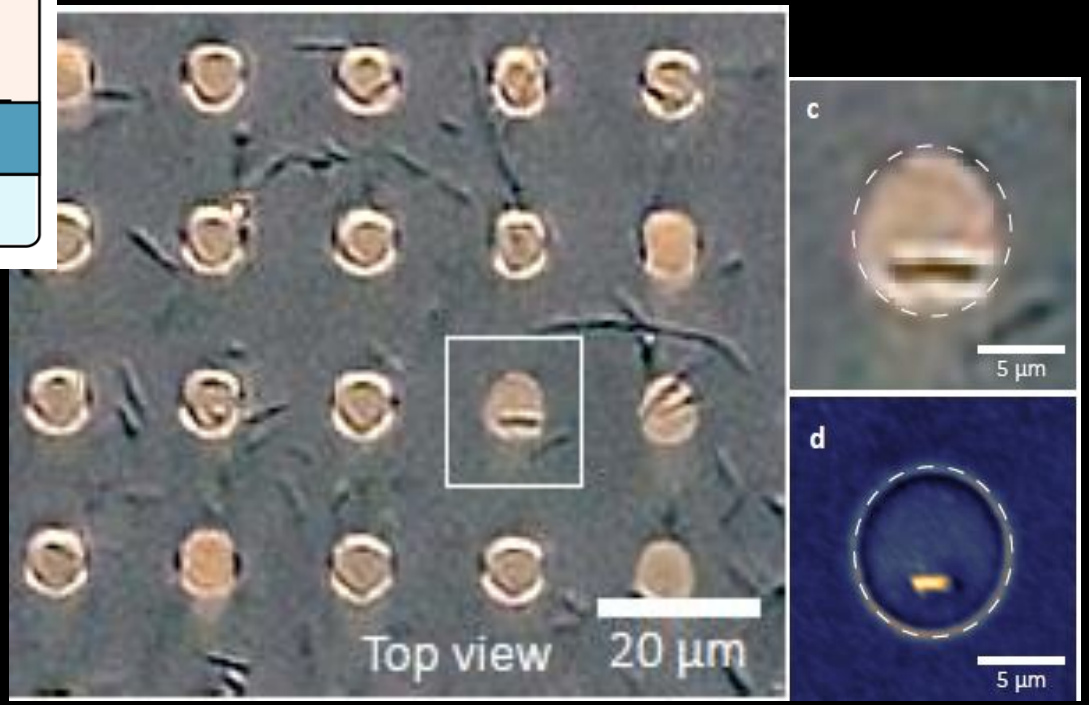
https://www.nature.com/articles/ncomms1002

Ecological Informatics 74 (2023) 101953

FishSounds Version 1.0: A website for the compilation of fish sound production information and recordings

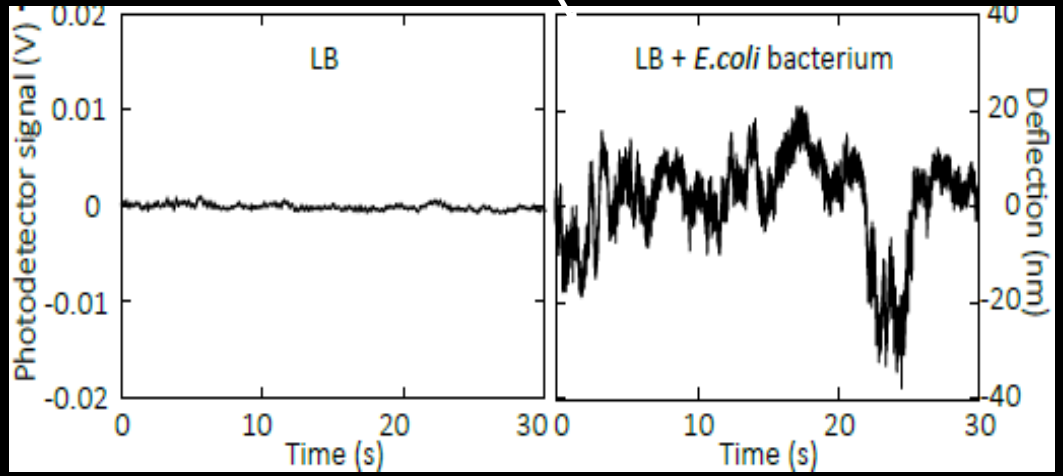
Naar bacteriën luisteren met grafeen 'microfoon'

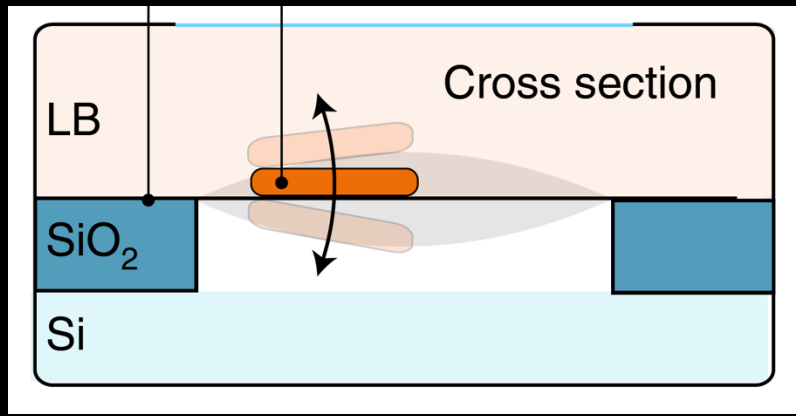




Antibiotica testen: luisteren of ze bacteriën doden

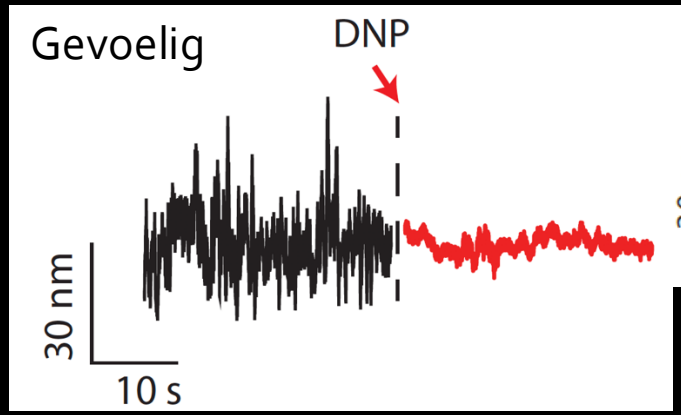
Bacterie op nanotrommel

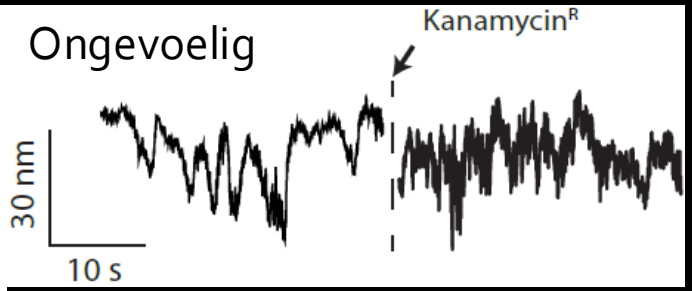


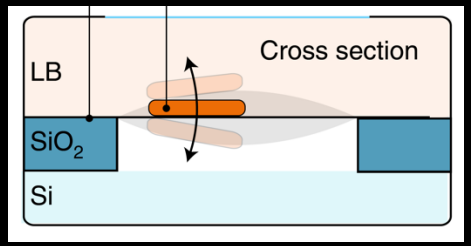


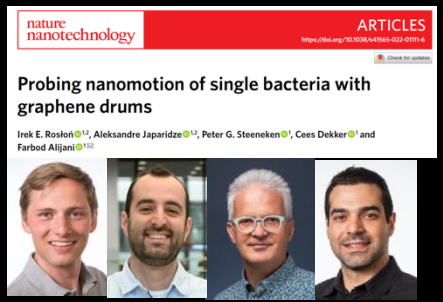
Antibiotica testen: luisteren of ze bacteriën doden

Antibiotica toedienen

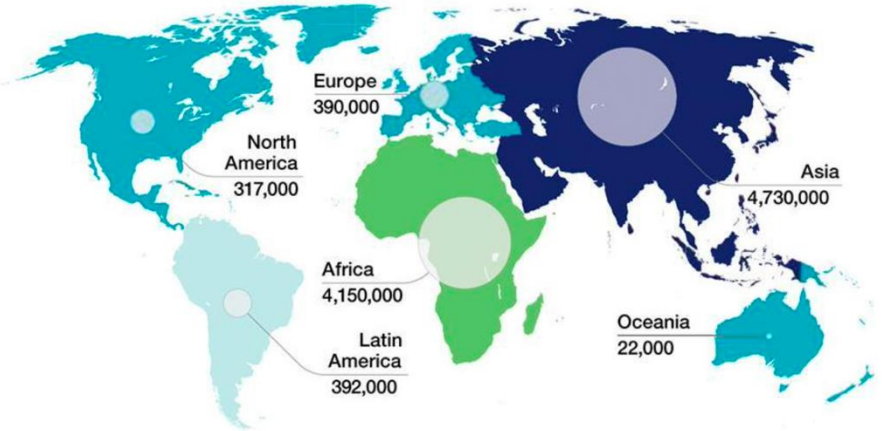








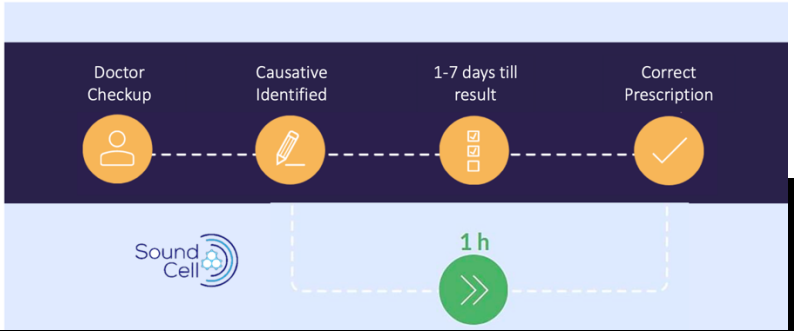
THE PROBLEM: 5M death due to antibiotic resistance



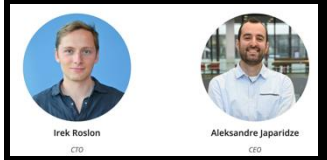
> $300 Billion loss to global economy

The Review On Antimicrobial Resistance O'Neill (2016)

THE SOLUTION: rapid Antibiotic Susceptibility Tests (AST)



Sound Cell

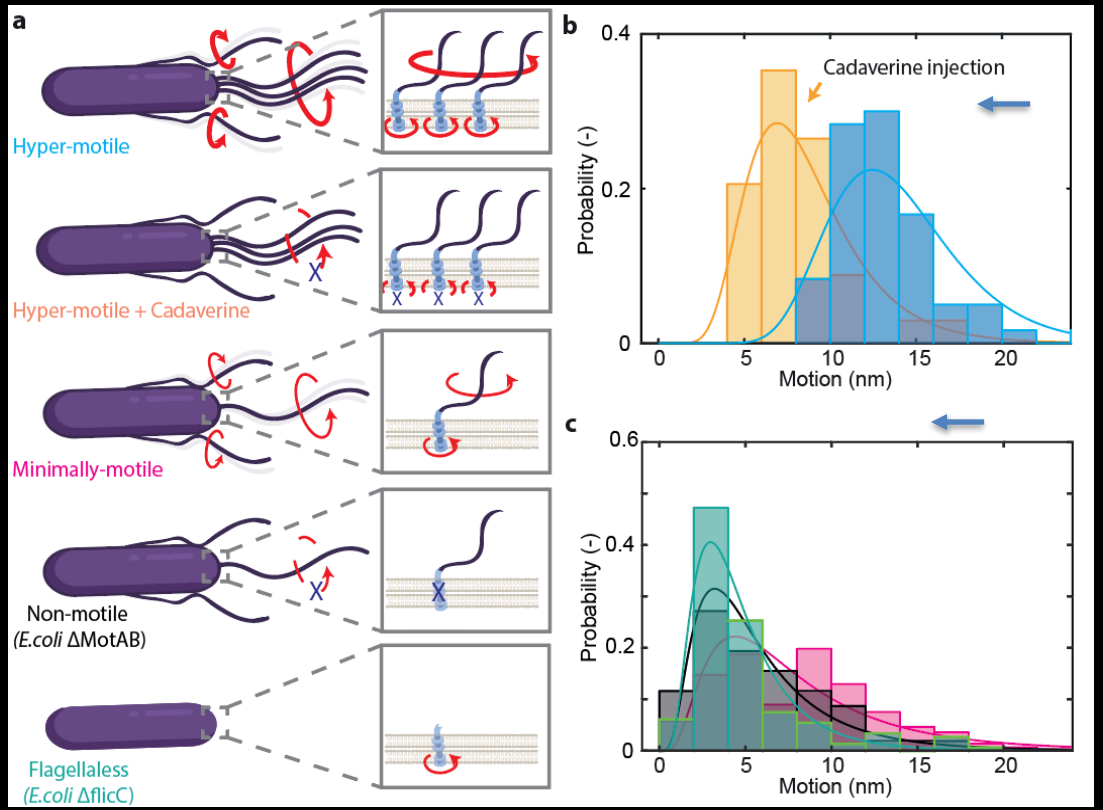


Farbod Alijani, Aleksandre Japaridze, Irek Roslon

SoundCell.nl

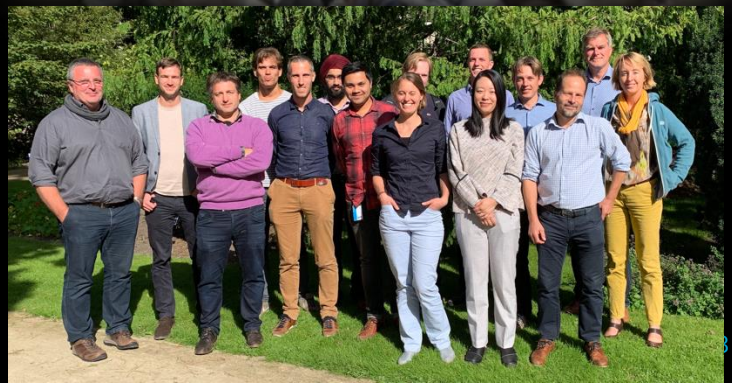
Hoe maken bacteriën geluid?

- Flagella?
- Rotors?
- Anders?



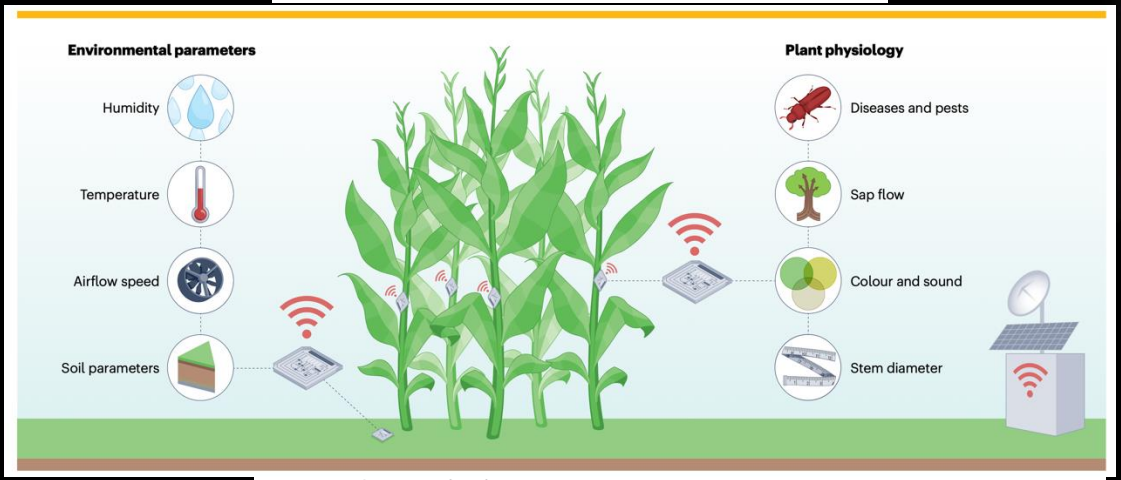
4TU Plantenna project
Sensoren klimaat en tuinbouw

4TU.Plantenna



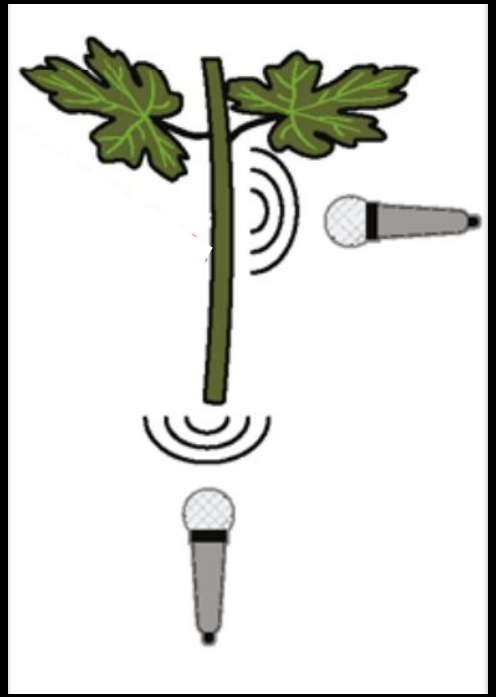
Sensors in agriculture: towards an Internet of Plants

Peter G. Steeneken, Elias Kaiser, Gerard J. Verbiest & Marie-Claire ten Veldhuis



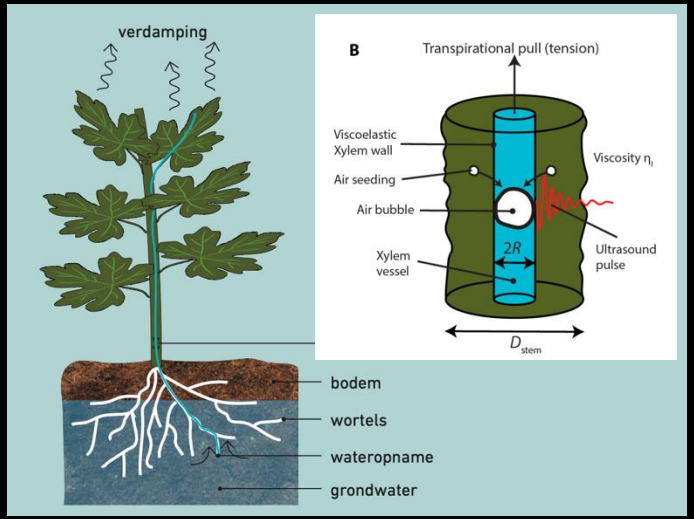
nature reviews methods primers (2023) 3:60 | 1

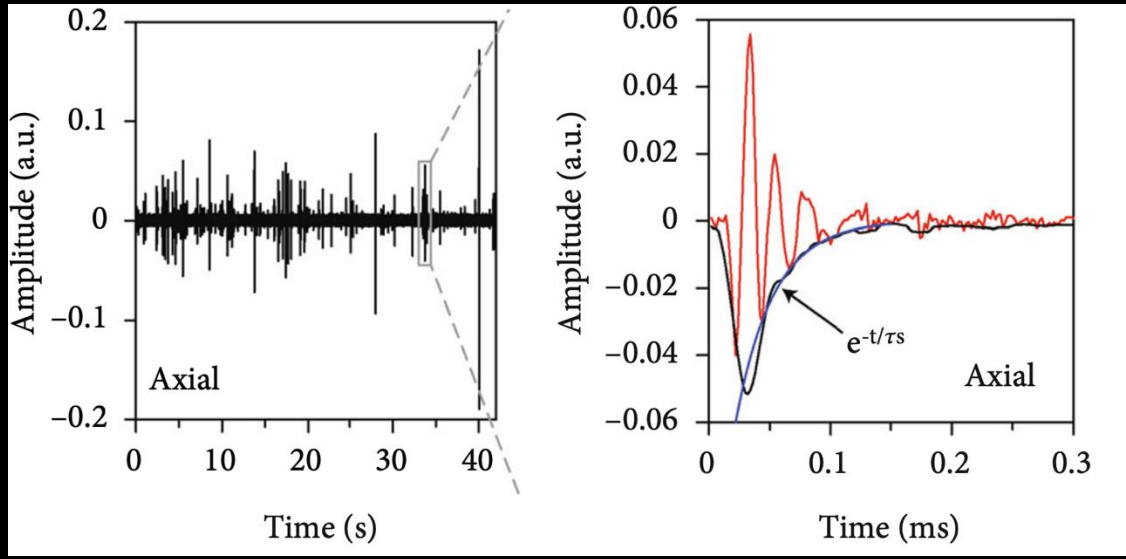
Luisteren naar planten



https://www.ntvn.nl/media/files/Luisteren_naar_planten_def.pdf

Luisteren naar planten





AAAS
Research
Volume 2022, Article ID 9790438

Satadal Dutta
Elias Kaiser
Gerard Verbiest

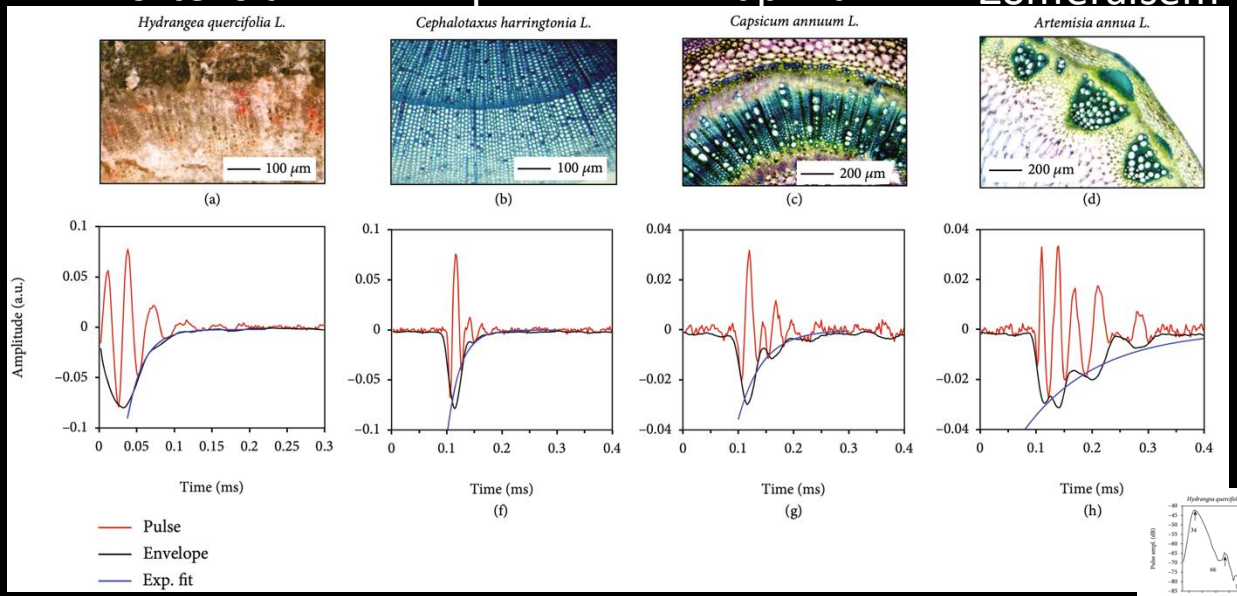
Wat vertellen de planten ons?

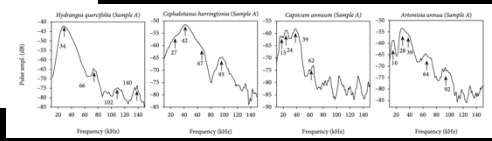
Hortensia

Knoptaxus

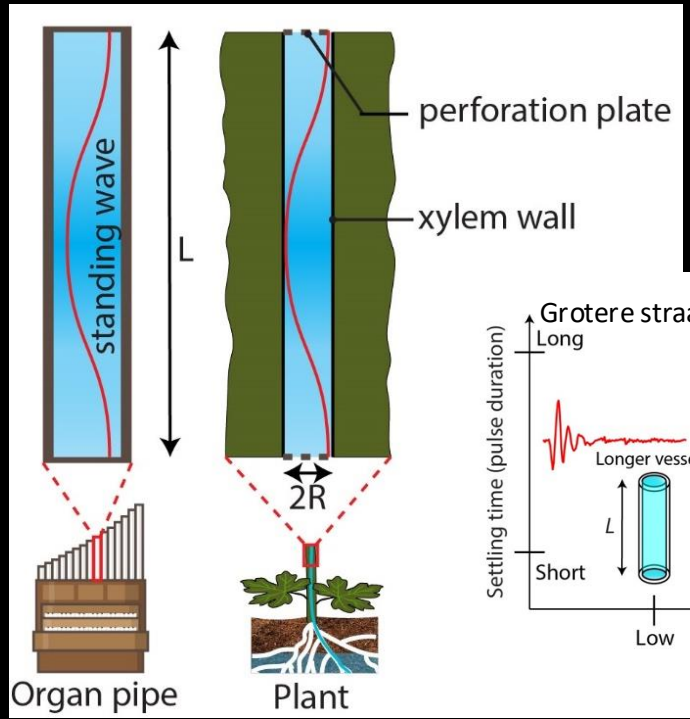
Paprika

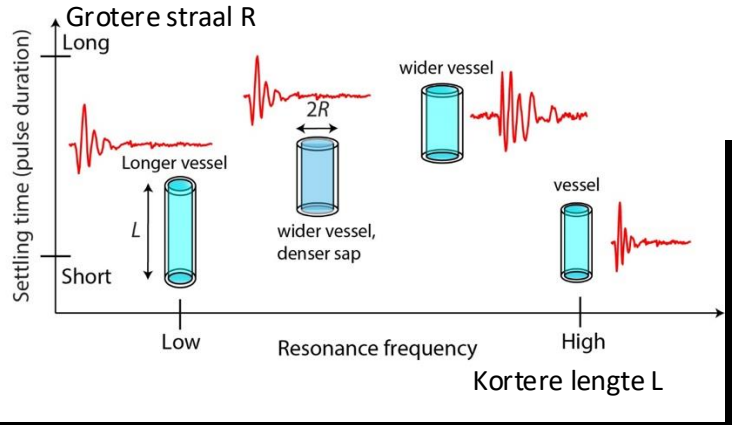
Zomeralsem

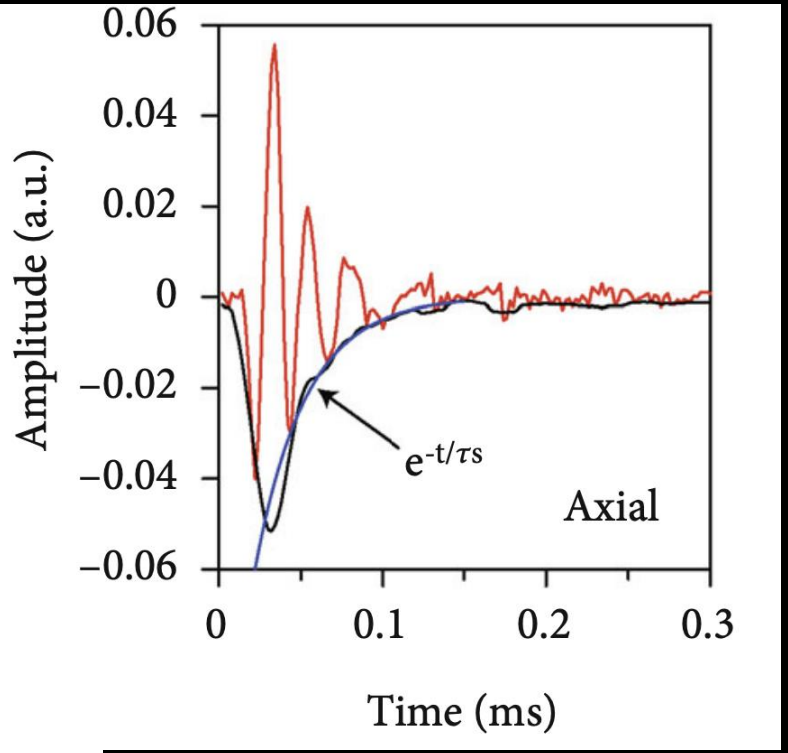




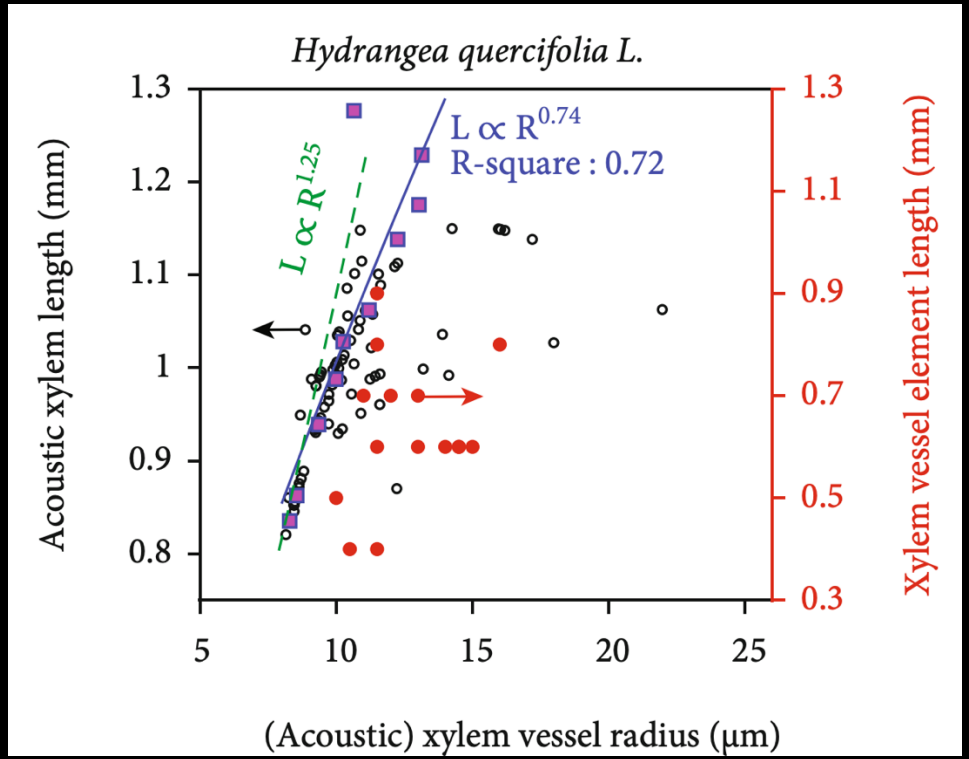
Orgelpijp model



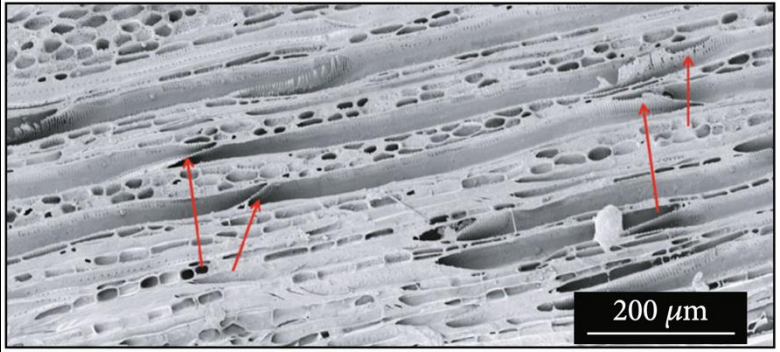




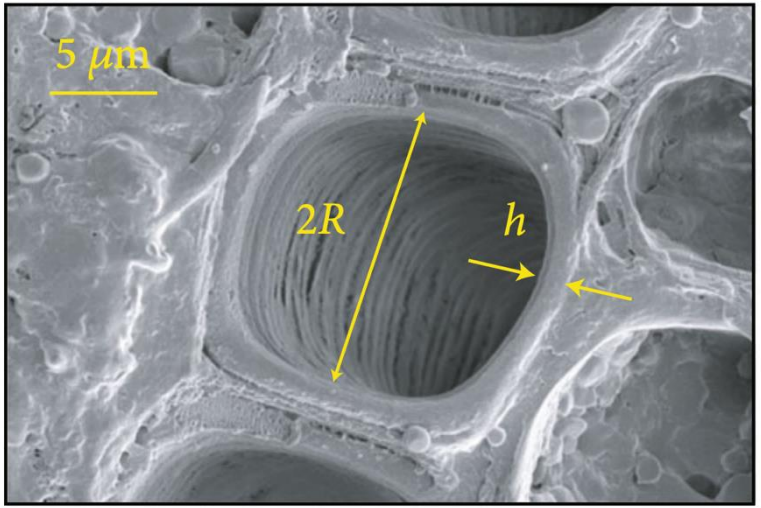
Xyleem vaten



Cryo-SEM (Longitudinal section)

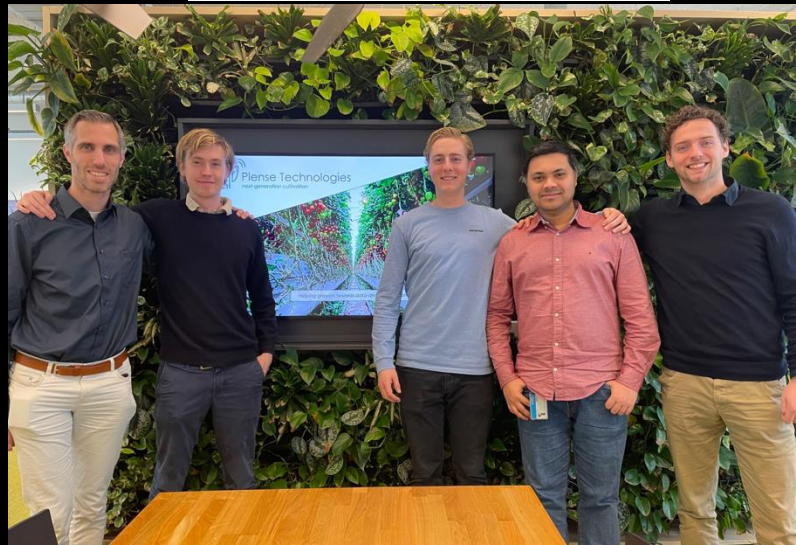


Cryo-SEM (Cross-section)



Plense: ultrageluid in tuinbouw

www.plense.tech



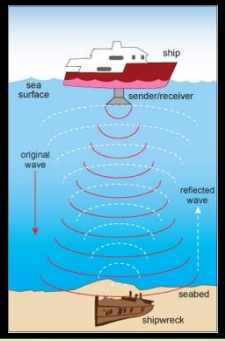
Akoestiek op de nanoschaal bij ultrahoge frequenties

G.J. Verbiest

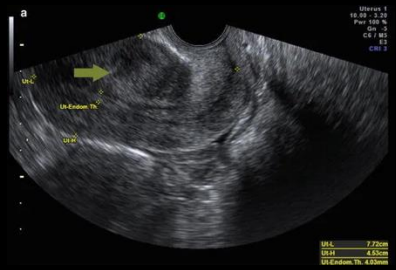
Akoestische beeldvorming

Voordeel: 3D + horen door ondoorzichtbare lagen

Sonar

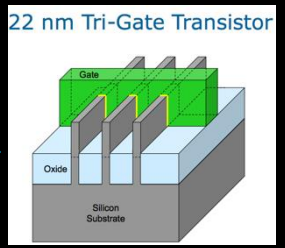


Sono/echografie



Grens ~1 µm

Semicon



Large

1 m

1 mm

miniaturisatie 10 µm

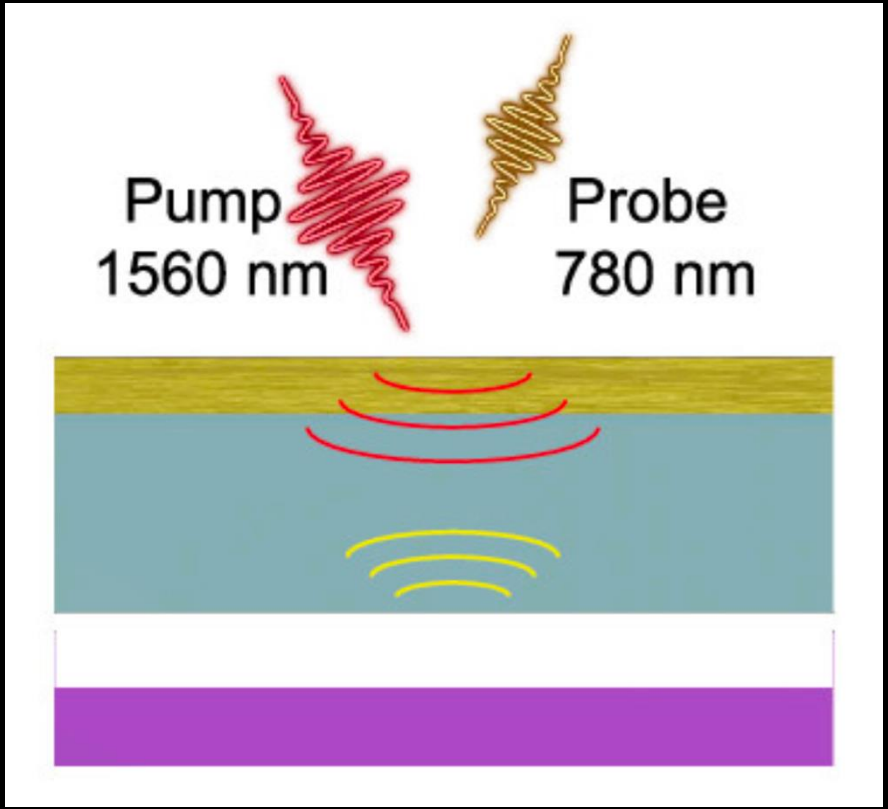
Small

Pijpleidingen

Akoestische microscoop

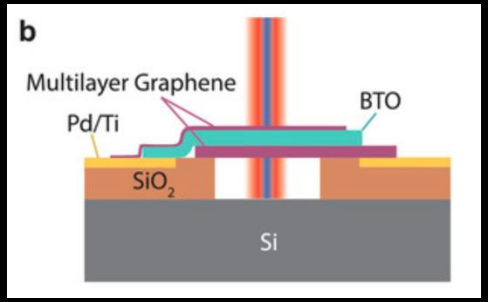
?

Nano akoestiek echo met gepulste lasers



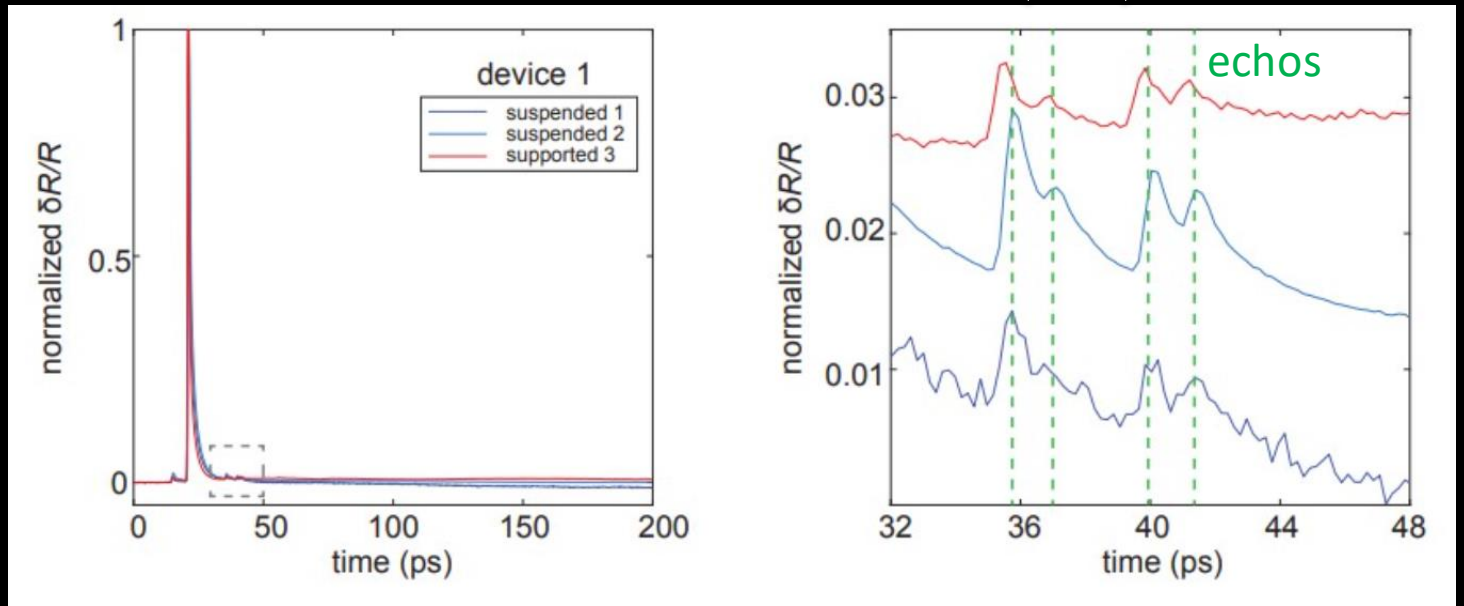
Nano akoestiek

Lee, Martin, et al.
Advanced Materials 34.44
(2022): 2204630.



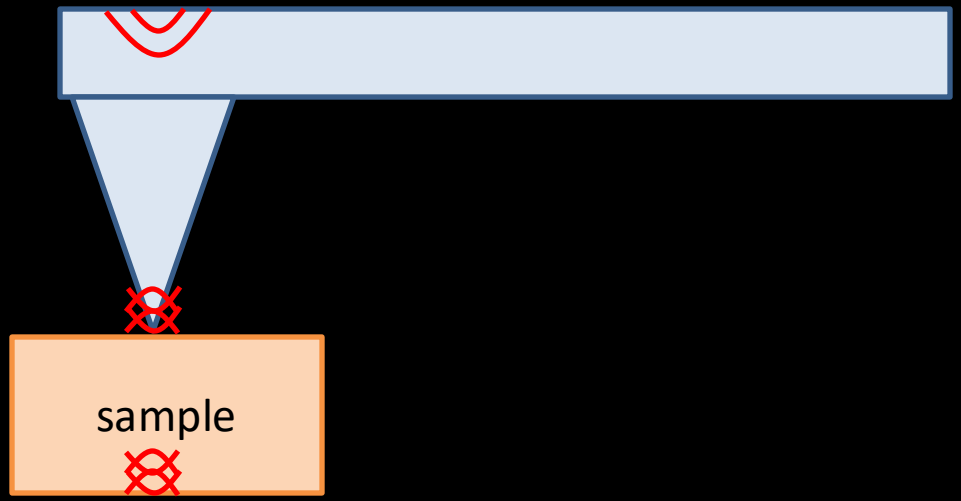
V_{geluid}=6500 m/s

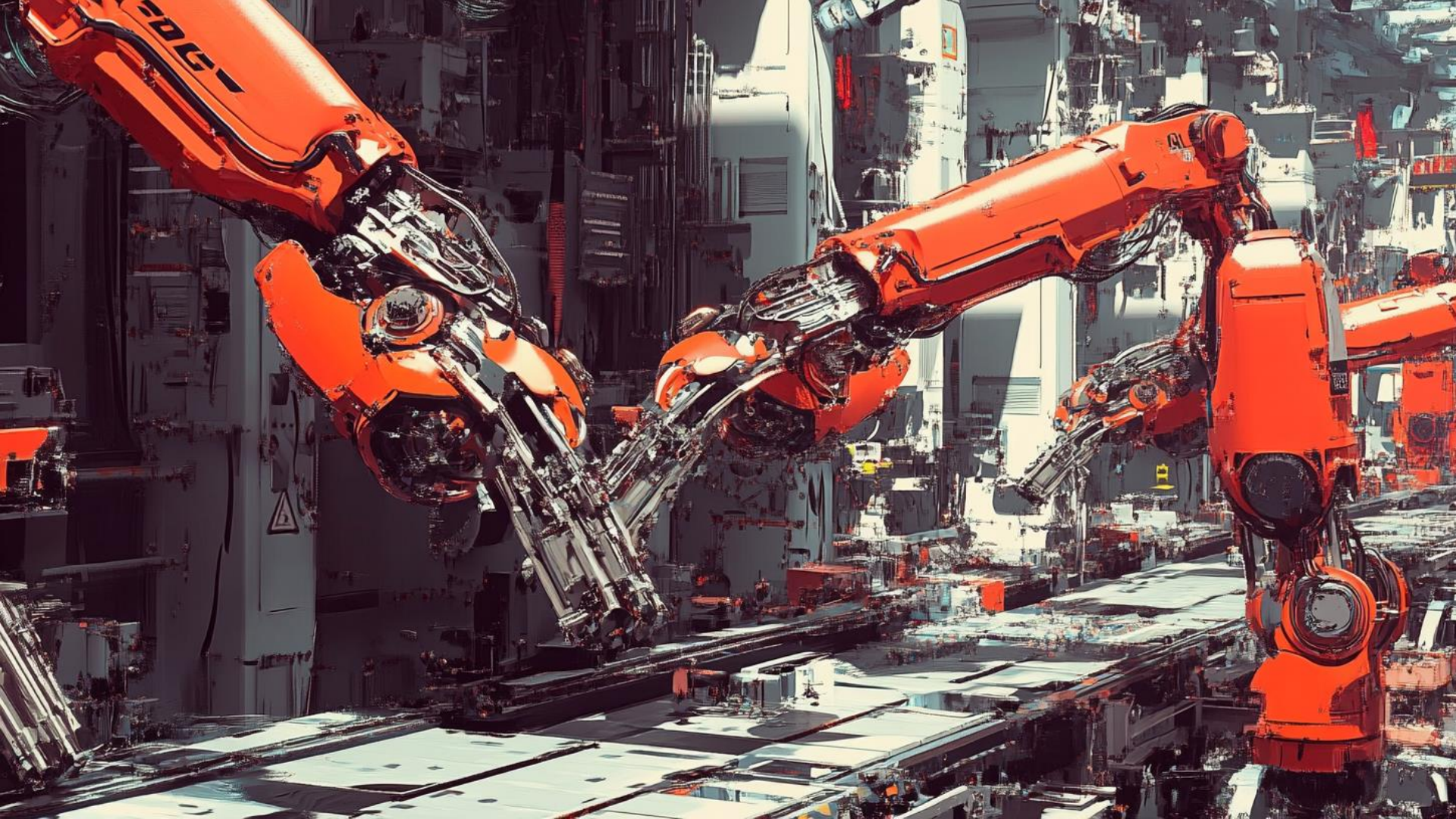
4.3 picoseconde echo: 14.7 nm, 233 GHz



Volgende stap: akoestische AFM echografie

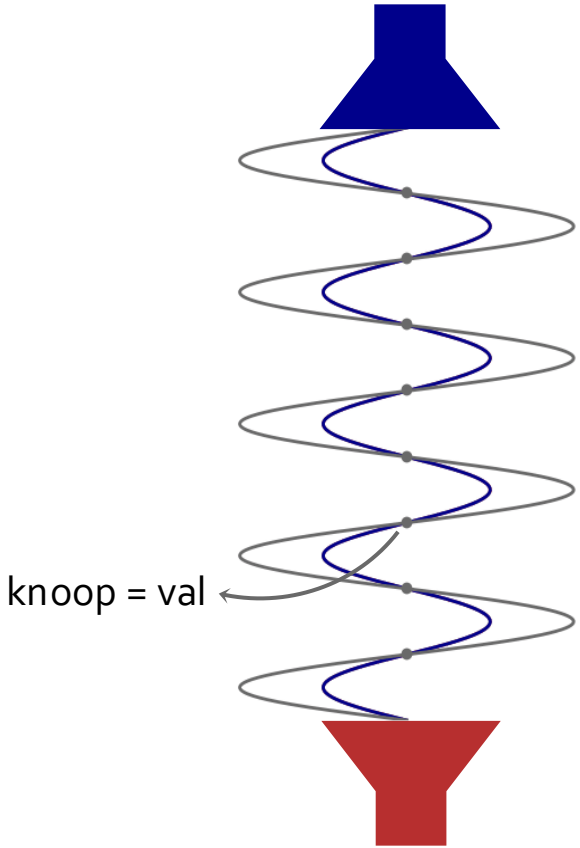
- Femtoseconde lasers (<100 fs)





Akoestische levitatie

Frederike
Wörtche
PhD

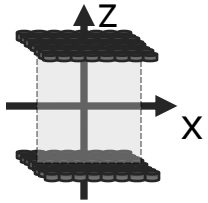


Levitatie drukveld

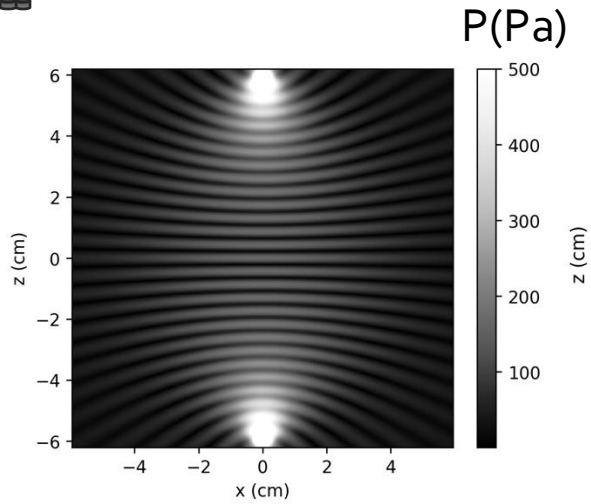
- Hogere druk = hogere kracht

Akoestische levitatie

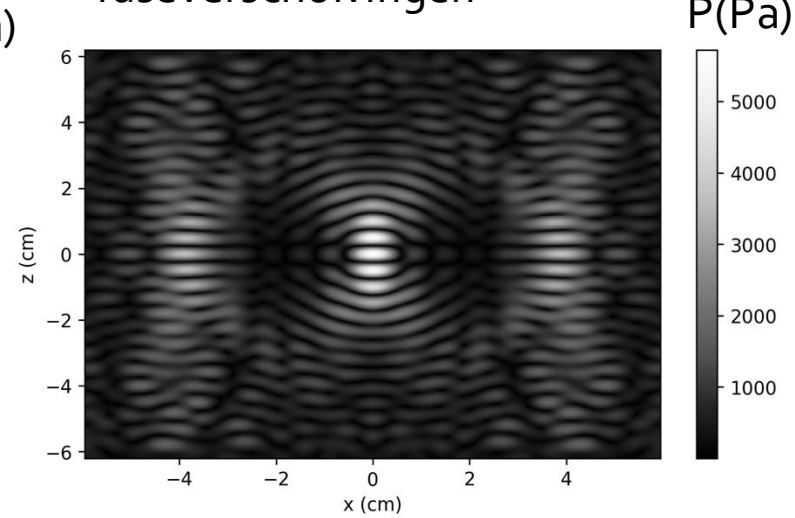
Akoestische levitator : Rooster van ultrageluid generatoren



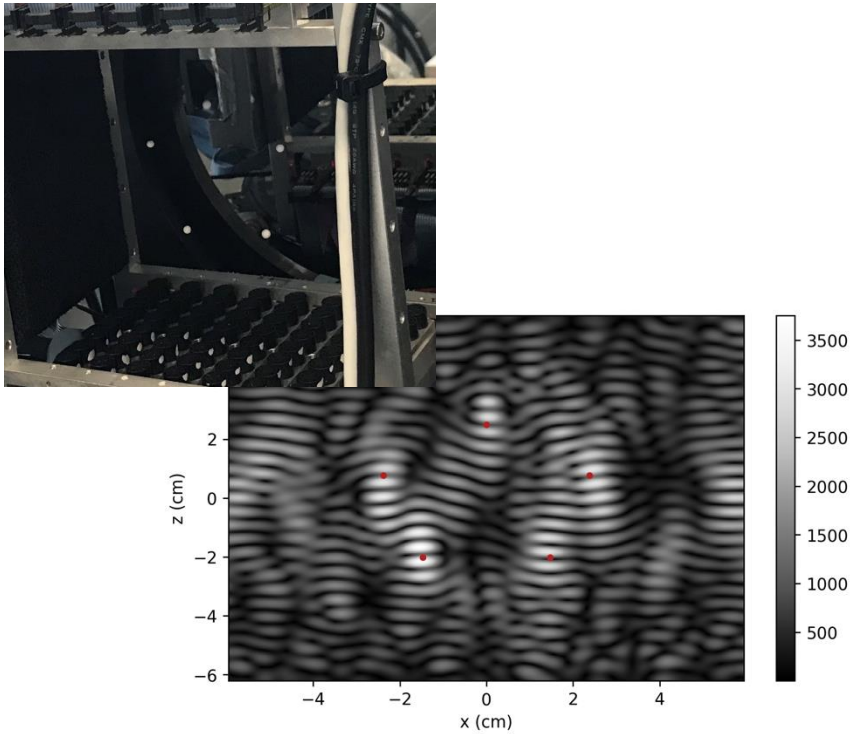
Drukveld
2 generatoren



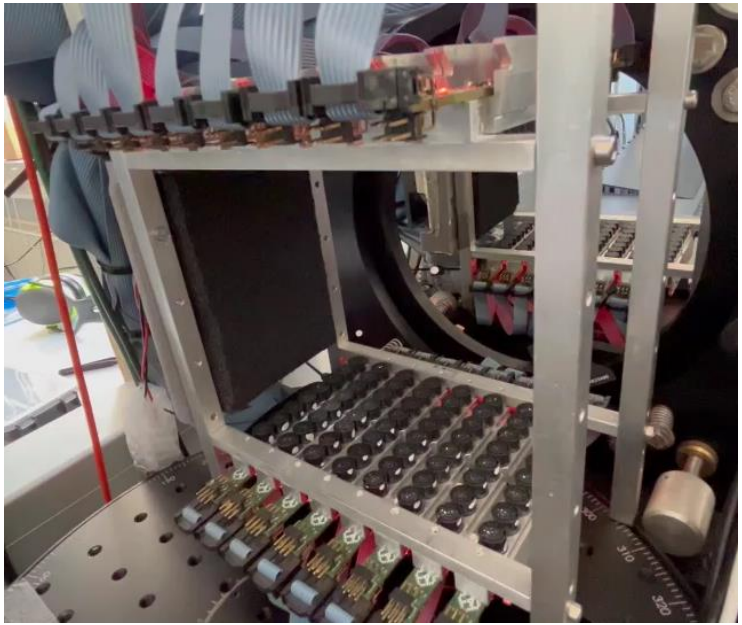
Drukveld rooster met
geoptimaliseerde
faseverschuivingen

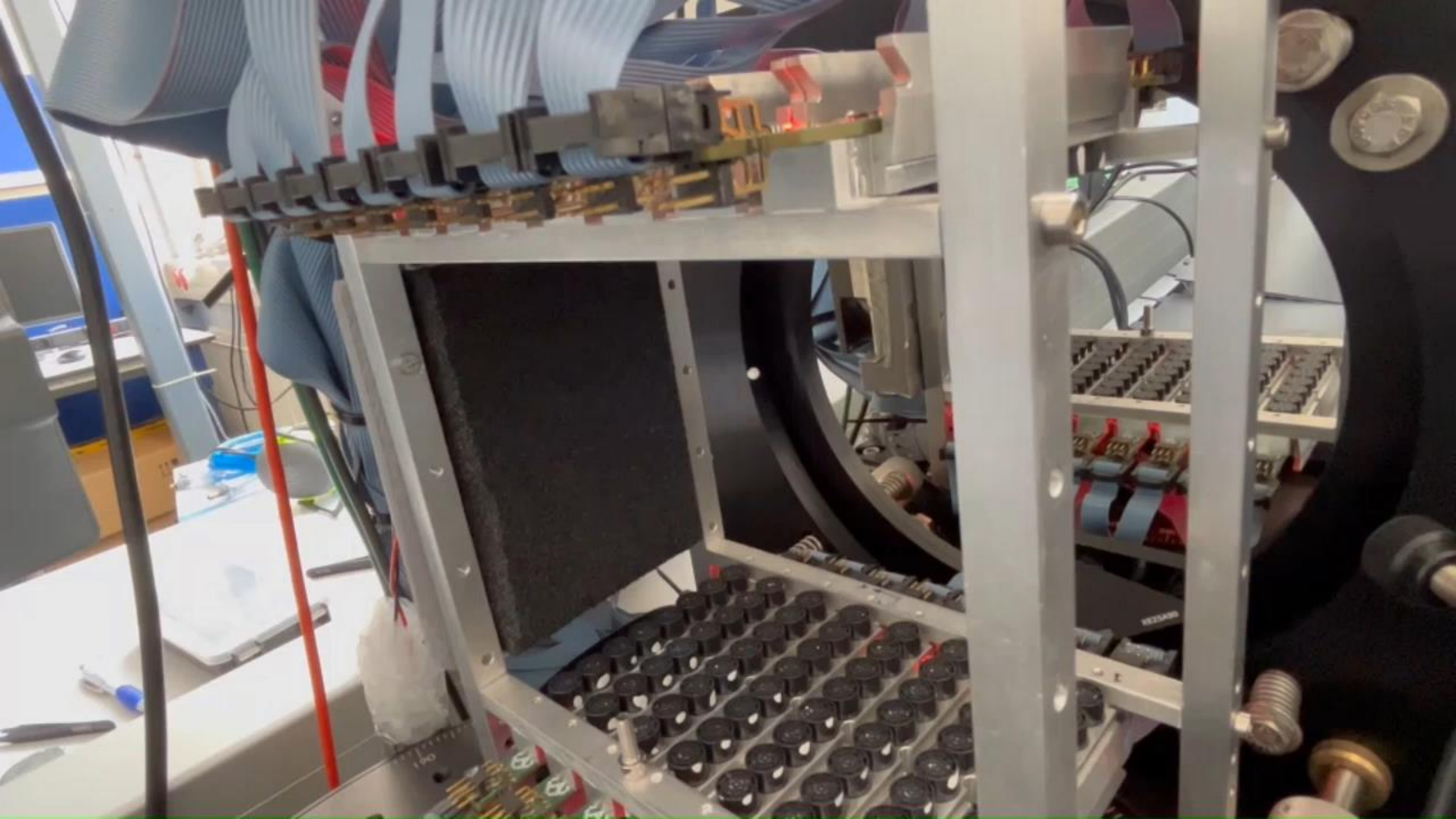


Meerdere deeltjes leviteren

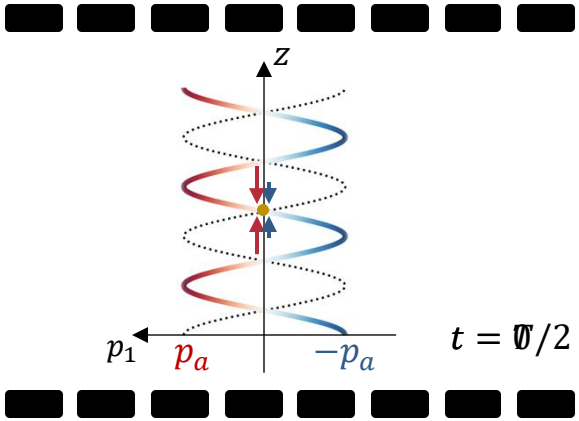


Objecten bewegen





Hoe werkt ultrageluid levitatie nou echt?

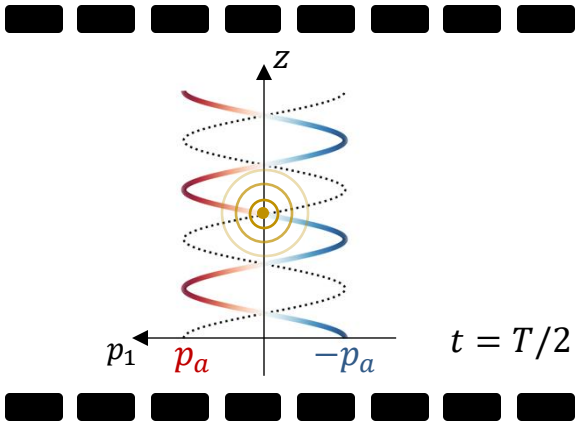


Drukveld staande golf:

$$p_1 = p_a \cos(\omega t)$$

⇒ gemiddelde druk en kracht is nul?

Niet lineaire termen voor akoestische levitatie



Drukveld staande golf:

$$p_1 = p_a \cos(\omega t)$$

Berekende levitatiekracht wordt:

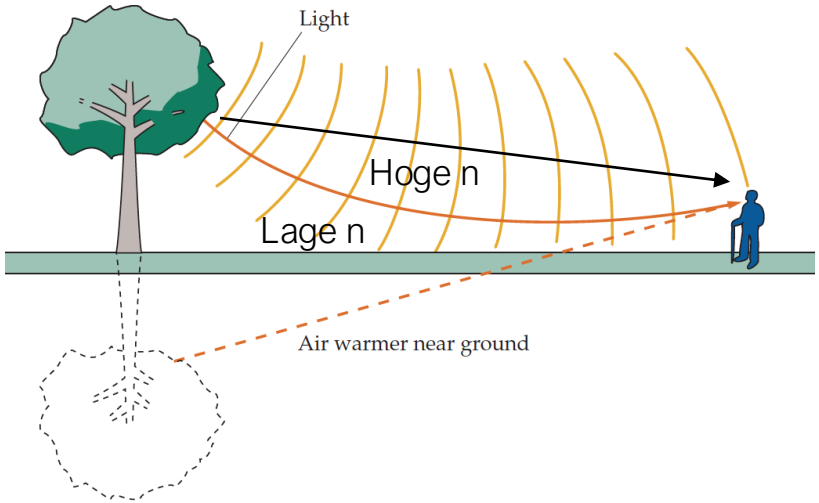
$$\boldsymbol{F}^{\mathrm{rad}} = -\int_{\partial\Omega} \mathrm{d}a \left\{ \left[\frac{1}{2}\kappa_0 \langle p_1^2 \rangle - \frac{1}{2}\rho_0 \langle v_1^2 \rangle \right] \boldsymbol{n} \right.$$

drukveld

luchtstroomveld

Geluidsvelden zien met schlieren

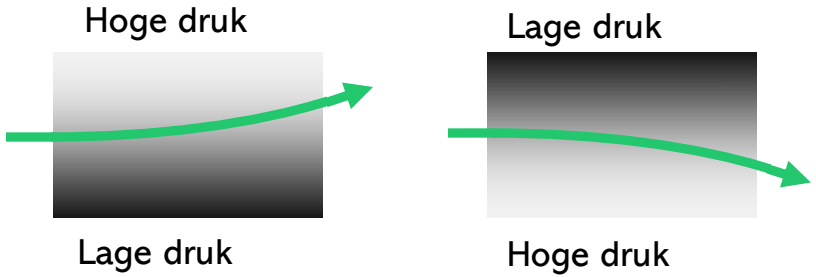
Licht wordt afgebogen als brekingsindex *n* varieert

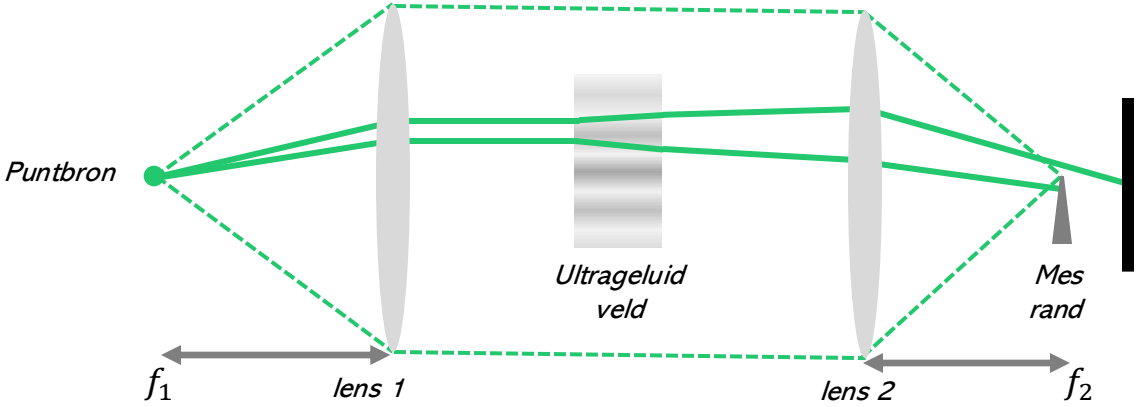


Luchtspiegeling

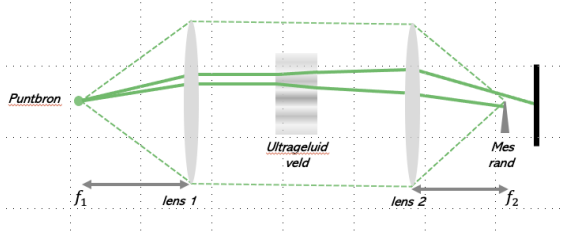
Geluid zien door afbuiging licht

Luchtdrukgradient $p \rightarrow$ Gradient in $n \rightarrow$ buigt licht





Geluid zien: schlieren techniek



Mirror d = 100mm

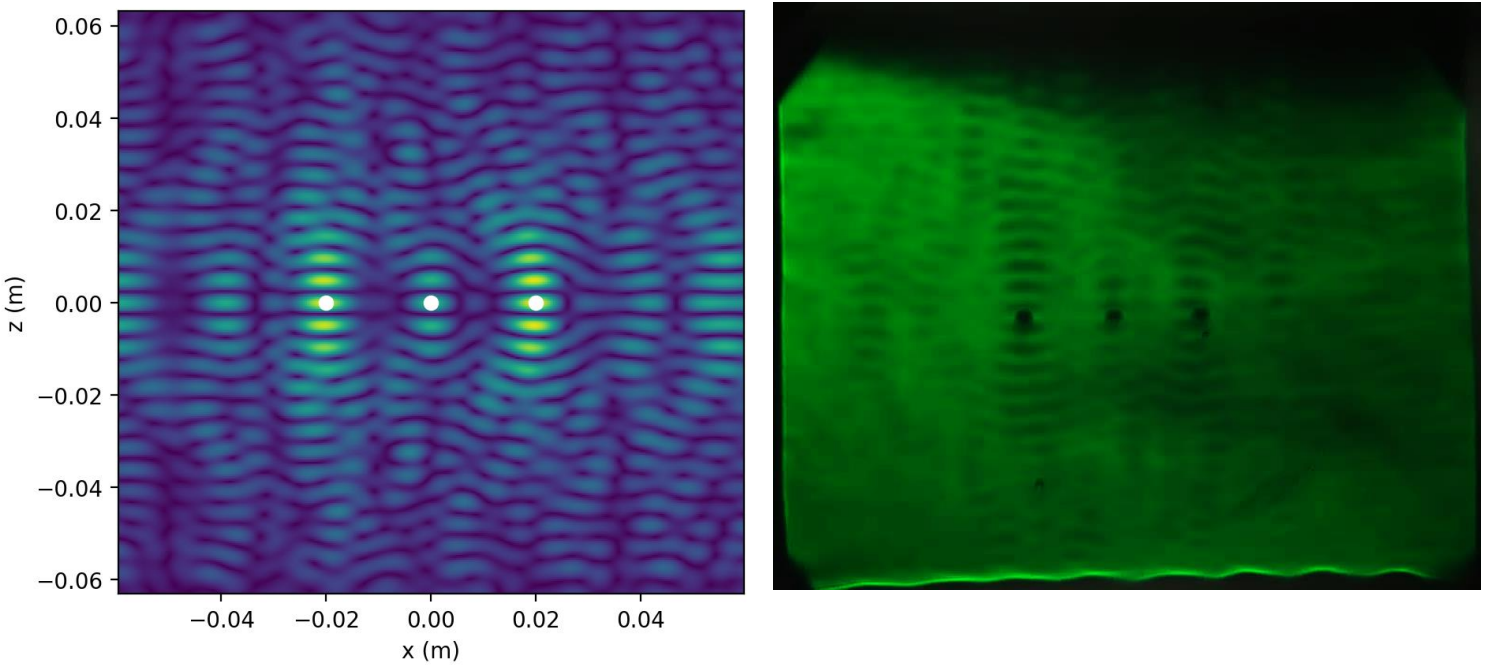
Acoustic levitator

Spherical mirror d=203.2mm

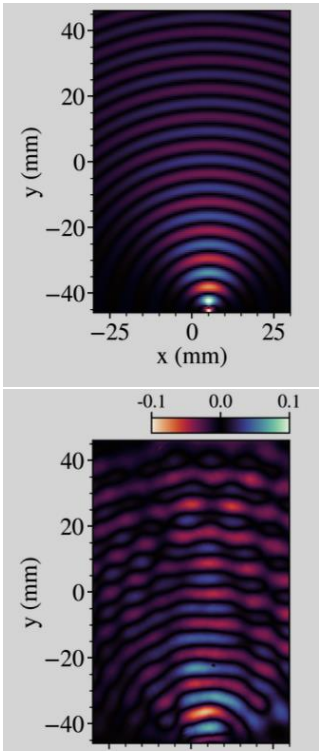
Camera

Geluid zien: schlieren techniek

Drie vallen



Puntbron



https://phyphox.org

PhyPhoX - Lab op je mobieltje

Dr. Gerard J. Verbiest @ TU Delft
PhyPhoX ambassadeur NL

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Met dank aan:

- Maurits Houmes
- Makars Siskins
- Hanqing Liu
- Gabriele Baglioni
- Roberto Pezone
- Robin Dolleman
- Ruben Guis
- Martin Lee
- Dejan Davidovikj
- Gerard Verbiest
- Sten Vollebregt
- Yaroslav Blanter
- Eugenio Coronado
- Herre van der Zant
- Frederike Wörtche
- Vincent Bos
- Martijn Mooiweer
- Jasper Wesseling
- DMN group
- En veel anderen

GRAPHENE FLAGSHIP

NWO Netherlands Organisation for Scientific Research


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