Résonateurs nanomécaniques: les virus aussi veulent pouvoir surveiller leur poids

S. Hentz - C. Masselon
Mass sensing over 30 orders of magnitude
Current Mass Spectrometry

- Fastest growing analytical technique in the past two decades
- Ubiquitous systems in biology labs, entered clinical area

- Measures mass to charge ratio
- Identifies species by their Molecular Mass
Mass sensing over 30 orders of magnitude

- Mass is not specific
- Single cat sensing
- Does not require ionization

Objects have molecular mass
- Ensemble average
- Requires ionization

Mass Spectrometry

- pg
- fg
- ag
- zg
- yg

- TDa
- GDa
- MDa
- kDa
- Da
Nanoelectromechanical Systems

Late 90’s examples

On-chip transduction?
Real-world applications?

Craighed, Science 2000
NEMS resonators

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]
NEMS mass sensing

\[ f = \frac{1}{2\pi} \sqrt{\frac{k}{m + \Delta m}} \]

Mass sensitivity:

\[ \frac{\partial f}{\partial m_p} \sim - \frac{f_0}{2M_0} \propto L^{-4} \]

Limit of detection

\[ \delta m_p \sim 2M_0 \frac{\partial f}{f_0} \propto L^{3/2} \]

Race for the smallest mass with NEMS

2004: 1ag

Craighead group, Cornell, APL 2004

2008: <1zg

Bockrath group
Zettl group
Bachtold group

2012: 1yg

Bachtold group, Nature Nano 2012
NEMS Mass Spectrometry

Collaboration between

- a Mass Spec lab
- a NEMS lab

Christophe Masselon

Watt balance
Analytical balance
Precision µbalance

Acoust. wave
Quartz µbalance

NEMS
CD MS
Native MS

Mass Spectrometry

T kg g mg µg ng pg fg ag zg yg

TDa GDa MDa kDa Da
Large Scale Integration silicon NEMS

- Monocrystalline silicon
- Electrostatic actuation
- Piezoresistive detection
- 100nm * 10µm typical
- 10 – 100 MHz
- 100’s kDa mass resolution
NEMS in conventional MS architectures

- 1 particle in $10^{13}$ detected
- Acquisition time: 1 month


- Metallic particles only
- Demonstration of Mass Spectrometry of neutral particles

Sage et al. Nature Comms 2015

+ R. Morel
High efficiency charge-independent NEMS-MS architecture

Nebulization source
- ElectroSpray
- Surface Acoustic Wave

Aerodynamic focusing

NEMS mass sensing

Atmospheric pressure
Low vacuum
High vacuum

US Patent application US20140250980 A1
The system

a.k.a. “the beast”

(in Nanobio)
Surface Acoustic Wave Nebulization

Atmospheric pressure
Surface Acoustic Wave Nebulization

• Sample solution is nebulized by ultrasonic waves
• 5-10 µm avg droplet diameter
• Softer than ESI
• High collection efficiency

Atmospheric pressure

Nebulization source

Or

Surface Acoustic Wave

ElectroSpray

Aerodynamic focusing

Low vacuum
Nanoparticle focusing using an aerodynamic lens

Gas flow lines

Particle trajectories

NEMS detector

Nebulization source
- ElectroSpray
- Surface Acoustic Wave

Aerodynamic focusing

NEMS mass sensing

Atmospheric pressure

Low vacuum

High vacuum
Increasing capture area with arrays of NEMS

Array of 20 NEMS

Sage, E., et al submitted
Towards measuring the mass of 25 nm coated fluorescent nanoparticles

Polystyrene core

Fluorescent coating

350 particles in 60mn

Mass (10^{-18} grams)
A FIRST LARGE SCALE NEMS PROCESSOR

Array of 20 NEMS

→ Embedding electronics on-chip: CMOS co-integration

Array of 1000 NEMS
1024 NEMS processor

+ E. Rolland, C. Tabone, W. Ludurczak, J. Munoz Gamarra, S. Dagher, P. Mattei...
Large scale optomechanics

Light is fast! → up to GHz resonance frequencies
Light is sensitive! → down to $10^{-17}$ m

Single particle mass sensing on-going
Acknowledgements

C. Masselon
S. Dominguez
A-K Starck
H. Muhammad

Ariel Brenac
R. Morel

S. Fostner
M. Defoort
A. Holovchenko
T. Alava
G. Jourdan
M. Gely
M. Sansa
M. Hermouet
L. Banniard

A. Fafin, G. Scherrer, W. Ludurczak, G. Billiot, P. Villard, G. Gourlat, L. Hutin,
Jose-Luis Munoz, G. Usai, E. Rolland, C. Tabone, C. Plantier...