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Development of MEMS type sensors dedicated to real-time measurement of mass concentration in aerosols

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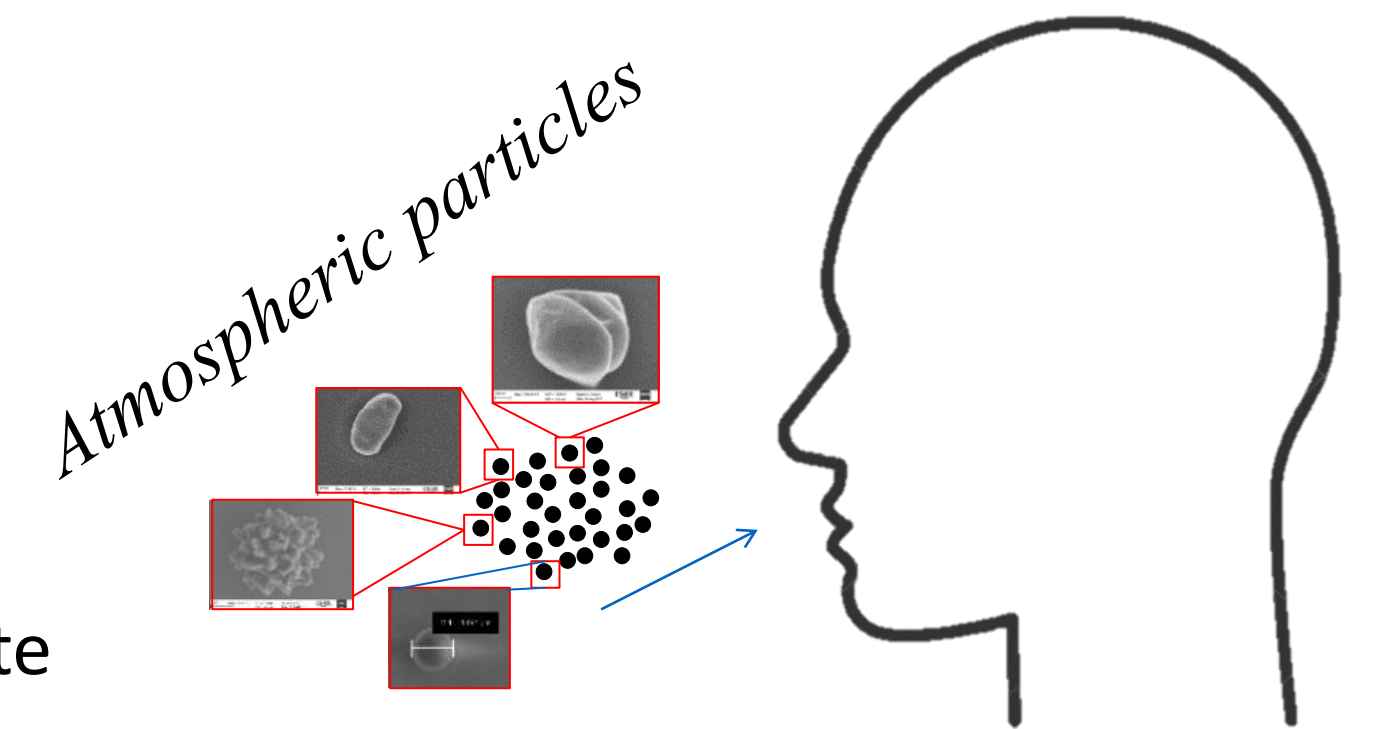
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Introduction

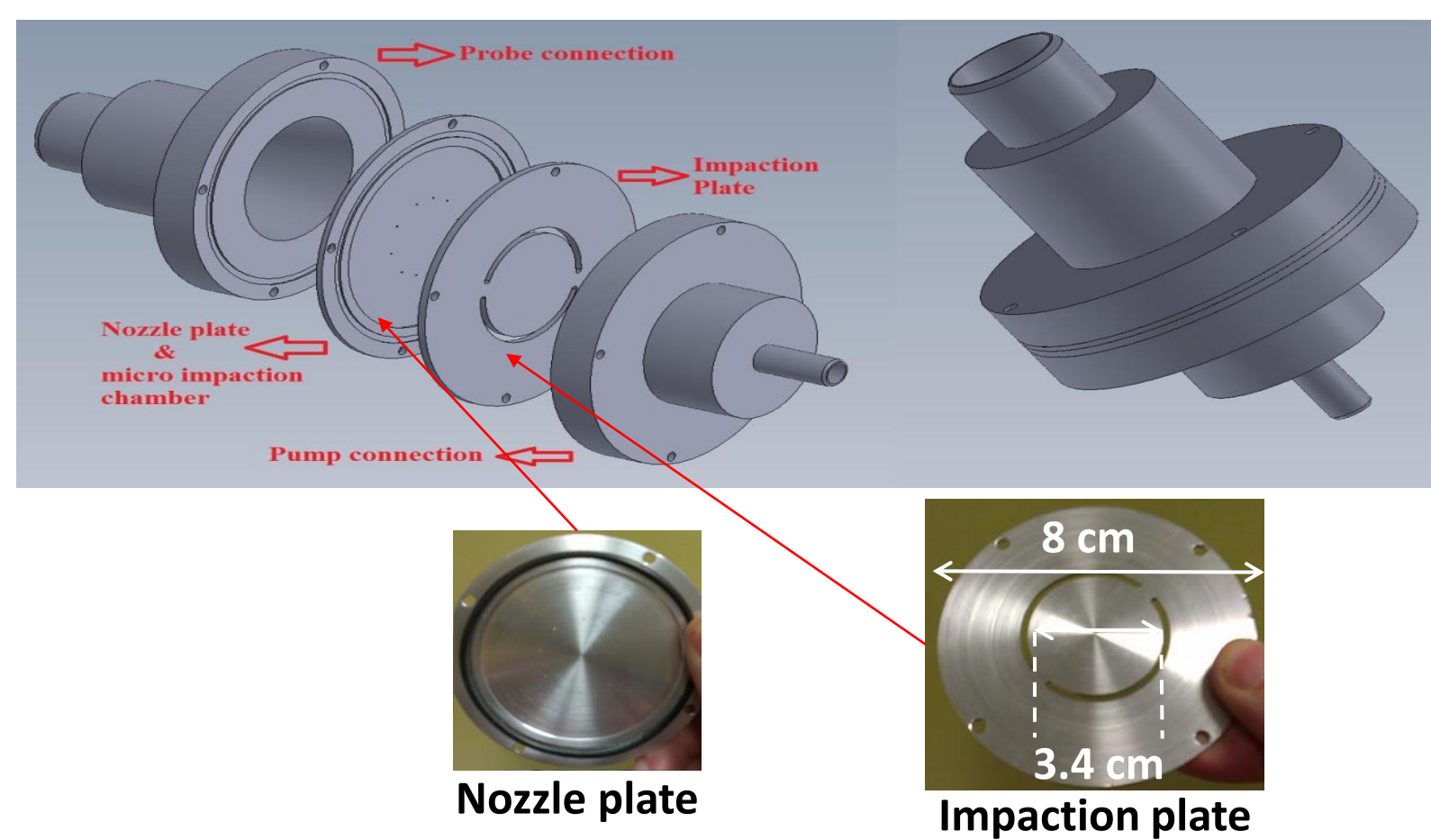
Since 2013, the International Agency for Research on Cancer has classified atmospheric pollution and the particles that compose it as compounds "definitely carcinogenic for humans" which can have harmful short and long-term effects on the body

Commonly used systems are limited because of their large size, their significant sampling times or their costs. Thus, one of the major ways of improvement of these systems is towards **their miniaturization**.

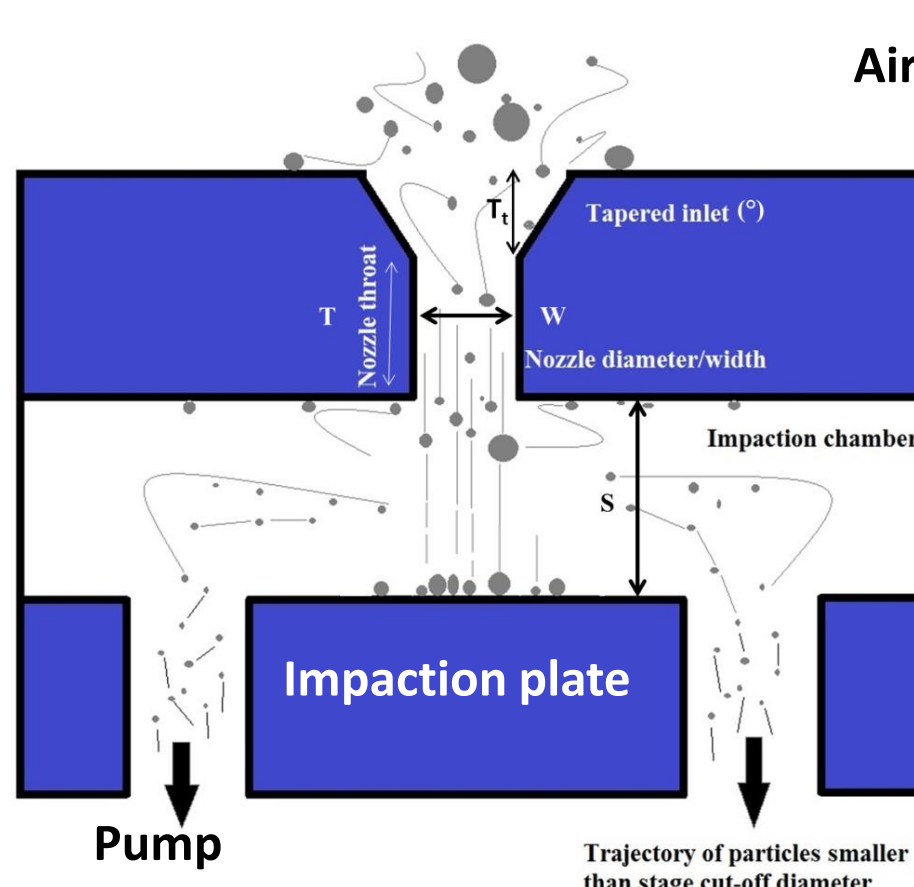
This study couples an **airborne particle sampling method** with a **sub- μm air gap resonant bulk mode MEMS mass sensor** as an appropriate option for a real-time aerosol monitoring system.



Airborne particle sampling design



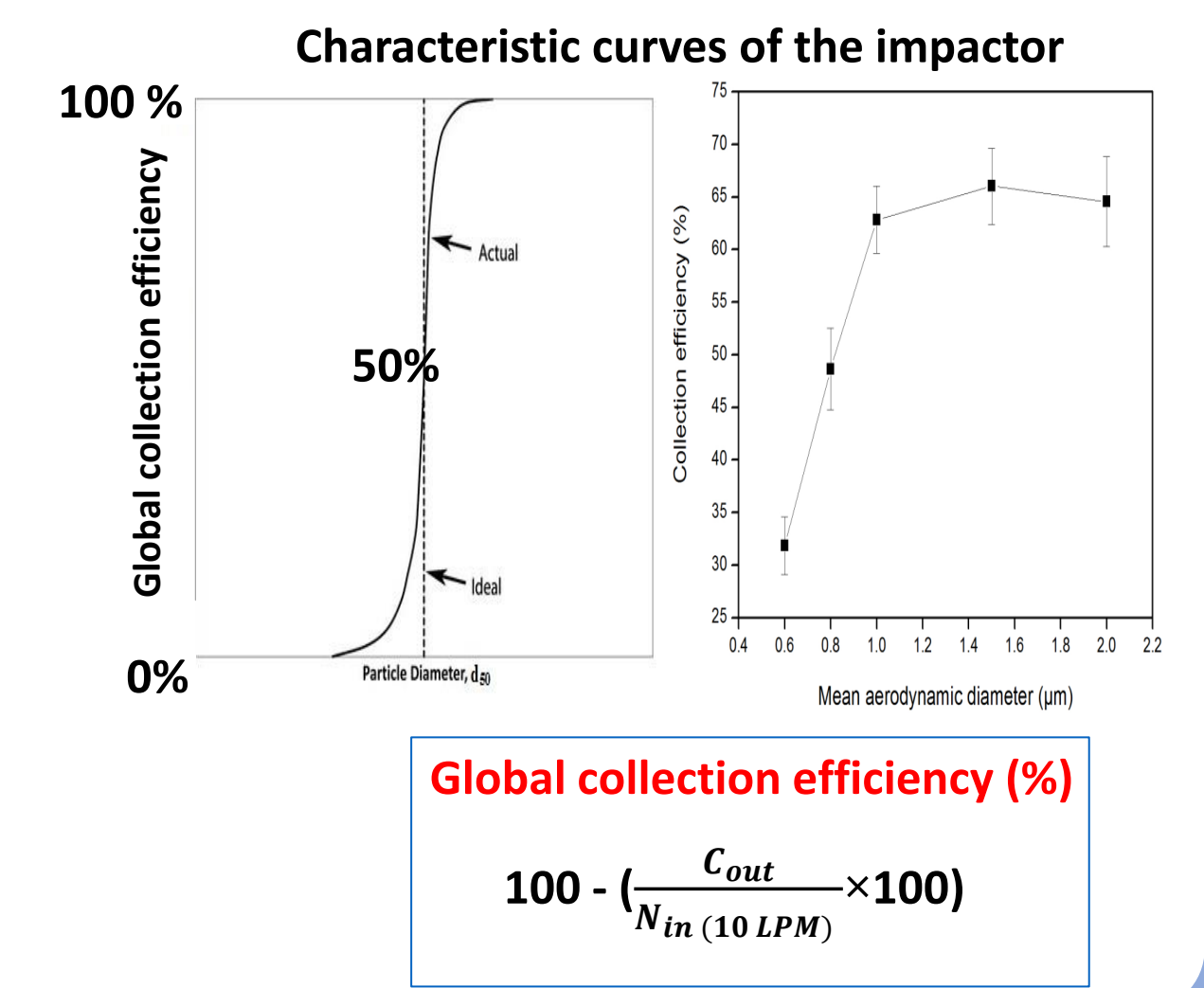
Flow of particles inside the impaction



$d_{50} = \sqrt{\frac{9W\mu St_{50}}{\rho_p C}}$
 $Re = \frac{\rho W V_0}{\mu}$

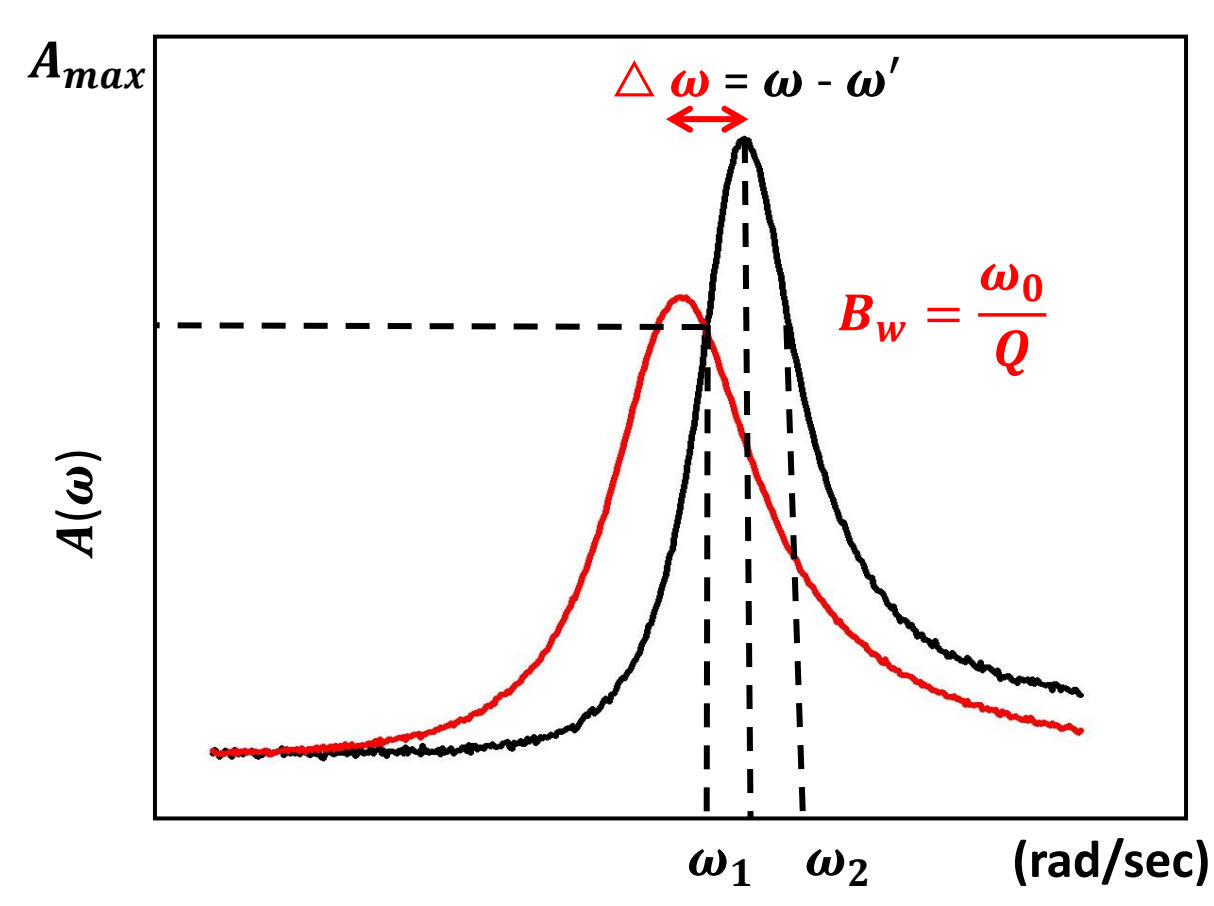
St₅₀ → Stokes number
V₀ → Average particle velocity
 ρ_p → Particle density
 d_{50} → Cut-off diameter
 μ → Air viscosity
C → Cunningham slip correction
Re → Reynolds Number

Distance between the impaction plate and nozzles (S)	1000 μm
Nozzle diameter (W)	500 μm
Number of nozzles (n)	10
Flow rate (Q)	10 LPM
Reynolds number (Re)	2825
Theoretical cut-off diameter (d_{50})	0.39 μm



MEMS sensor principle

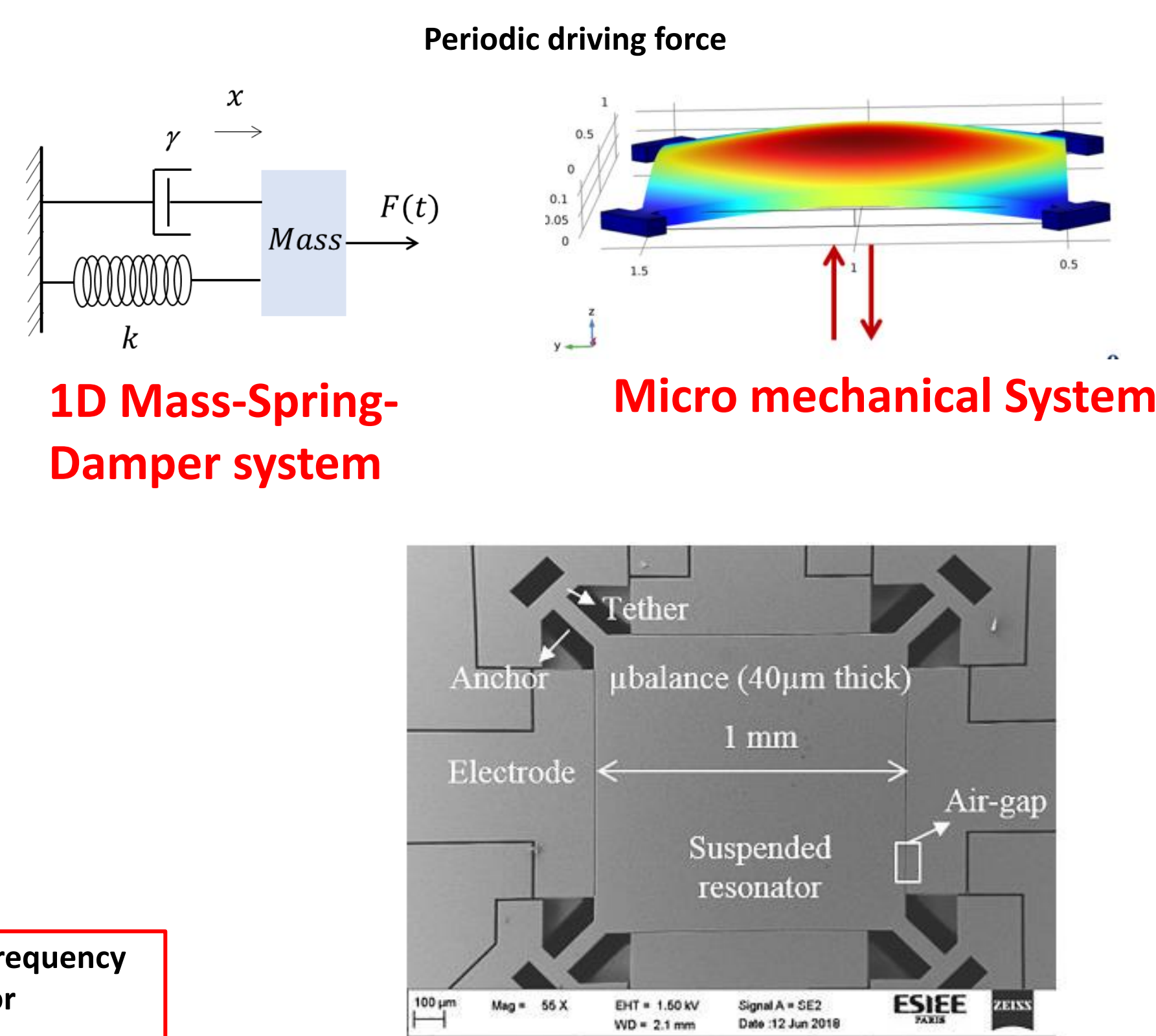
Main parameters in MEMS resonators: **Q, f₀** transduction



$$\omega' = \sqrt{\frac{K_{eff}}{M_{eff} + \delta M_{eff}}}$$

$$\omega = \sqrt{\frac{K_{eff}}{M_{eff}}}$$

High performance MEMS → High Resonance frequency
High Quality factor



MEMS manufacture process

Si₃N₄ 110nm (green) and Poly Si 1.4 μm (pink)

Device (0.005-0.01 Ωcm^{-2}) (40 \pm 1 μm)
Handle 300 μm , Highly resistive
Oxide 2 μm

538.4 nm, 332 nm, 614.7 nm, 403.8 nm, 1.277 μm

Measurement principle

Impaction (1096 ± 463) # = (0.5 ± 0.2) ng

Before impaction: f_0
After impaction: f_1

$$\frac{\Delta f}{\Delta m} = -\frac{f_0}{2m_{eff}}$$

Δf , frequency shift
 Δm , added mass
 f_0 , unloaded sensor resonance frequency
 m_{eff} , effective mass of MEMS sensor

Mass calibration experiment

Experimental mass sensitivity of device 3

Impactation 1 (167±135) Hz/ng
Impactation 2 (81±39) Hz/ng

Theoretical mass sensitivity

$$\frac{\delta m}{2m_{eff}} = 44.3 \text{ Hz/ng}$$

k = 2	Calculated mass from particle counting	Measured mass (Δm)	Number of counted particles (1 μm)	Resonance shift (Δf)
Impactation 1	(0.45±0.19) ng	(1.71±1.18) ng	(1096±463) #	(75±52) Hz
Impactation 2	(1.8±0.6) ng	(3.31±1.16) ng	(4400±1400) #	(145±51) Hz

Best-fit line defines the experimental sensitivity of the sensors as (53±33) Hz/ng

Conclusions

- The impactor and the MEMS-type mass sensors have been successfully designed, fabricated, characterized and the sensors integrated into the impactor developed.
- The mass of the impacted particles is estimated by shifting the resonance frequency of the MEMS. The sensitivity is estimated at (53±33) Hz/ng which agrees with the theoretical sensitivity of (44 Hz/ng).
- The proposed solution aims to obtain a micro-sensor allowing real-time monitoring while respecting regulatory directives and standards.

Future works

- Improvement of the sensitivity by modifying the surface structure.
- Development of the electrical measurement allowing the real-time monitoring
- Integration of the electrical part into the impactor system, in order to increase the reproducibility of the measurement.