Novel Design of Multi-Layered Resonator Sensor For Detection of Atomic Oxygen

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M.Sc. thesis project

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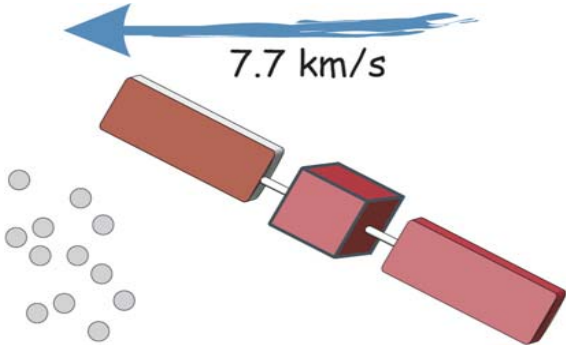
Prepared for the ***6th ESA Round Table on Micro & Nano Technologies for Space Applications***
ESA/ESTEC Noordwijk, The Netherlands , October 8-12 2007

Why is it important to measure Atomic Oxygen?



- Due to its atomic form and its impact velocity, oxygen is responsible for significant erosion and degradation of satellites.

- Acquire a better understanding of the atmospheric chemical reactions in the mesosphere and lower thermosphere.

Goal: achieve continuous monitoring of Atomic Oxygen

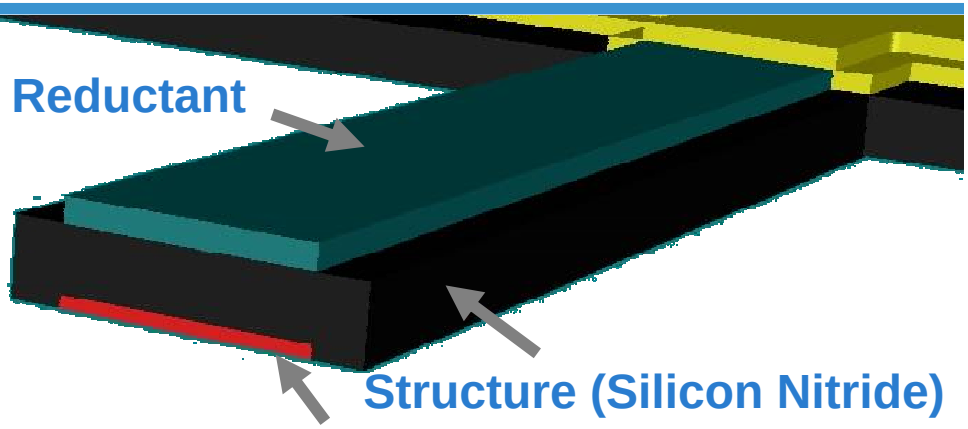
How has this been done until now?

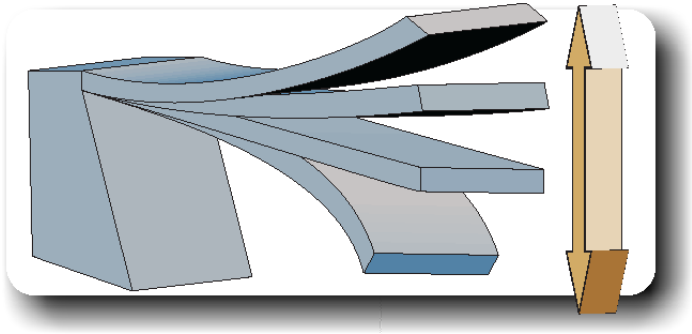
- *Witness samples*
  - *Put an object in orbit and retrieve it after some time*
- *Mass spectrometers*
  - *Measure bended trajectory according to mass/charge ratio*
- *Quartz Crystal Microbalances*
  - *Measure change in mass as a sample oxidizes*
- *Actinometers*
  - *Measure change in resistance as a sample oxidizes*
- *etc.*

Design.

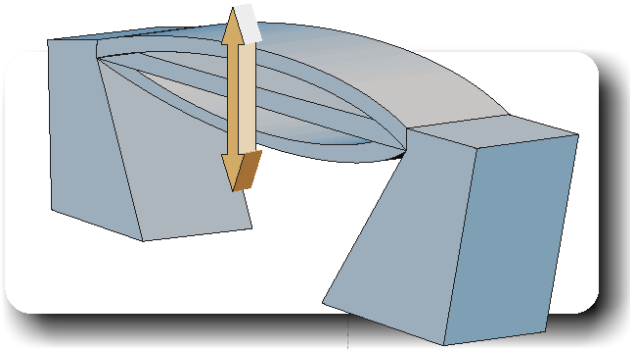
Our design:

- *Micro/nano resonators covered by an oxidizable reductant layer.*





Cantilever



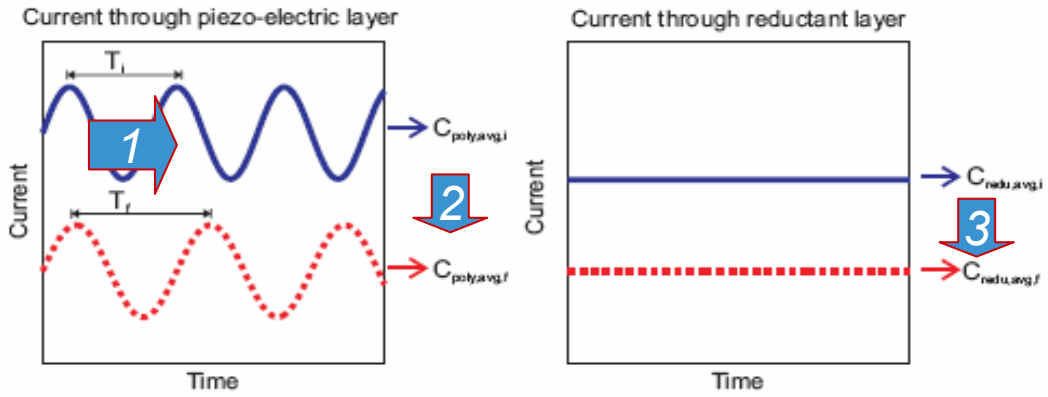
Bridge

Three simultaneous detection methods:

1. Dynamic osc. Change in mass and elastic modulus (due to oxidation) leads to a shift in oscillation frequency

2. Static bending Introduction of oxide layer leads to static bending

3. Actinometry Oxidation causes a change in the resistance of the reductant layer



Possibility of self **re-calibration**

Design. Dynamic operation

Resonant frequency of a cantilever:

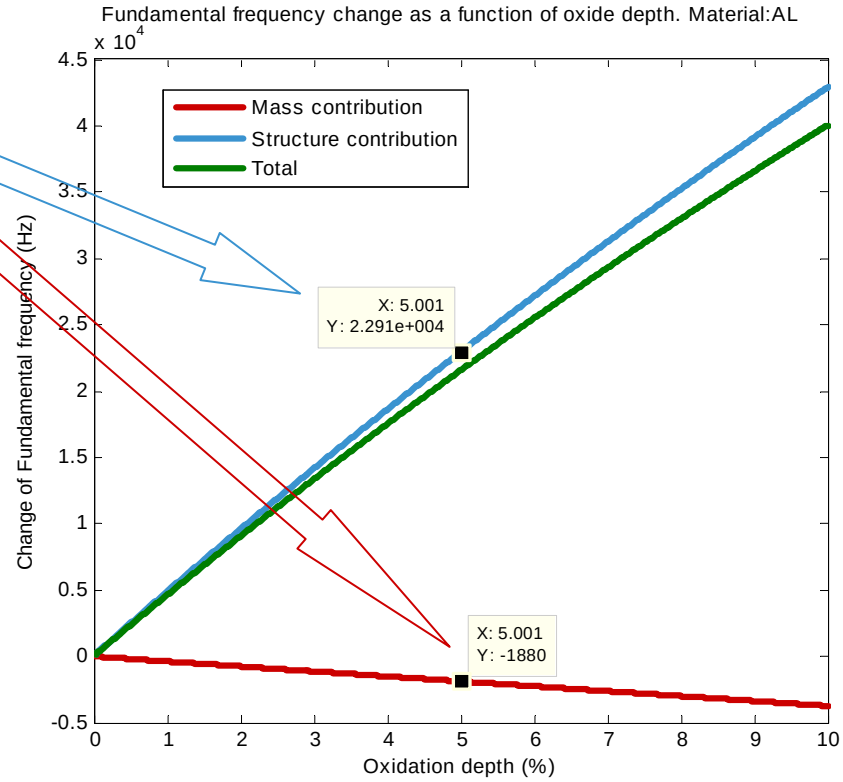
$$f_n = \frac{C_n^2}{4\sqrt{3}\pi}\sqrt{\frac{E}{\rho}}\frac{t}{L^2}$$

where:

- C_n: modal coefficients
- E: elastic modulus
- ρ: density
- t: thickness
- L: length

In this graph:

- cantilever
- aluminum reductant
- 10x20 um
- Layers:
  - 200nm polysilicon
  - 500nm silicon nitride
  - 200nm aluminum



Theoretical limit of sensitivity: $t_{ox} \sim 2 \times 10^{-10}$ m

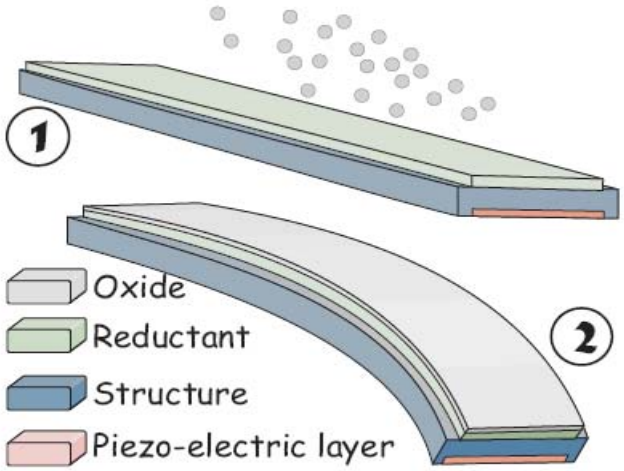
Taking a measurement every minute: $\Delta(\text{Flux}) \sim 2 \times 10^{9}$ atoms/cm^2·s

Design. Static operation

Expansion of reductant material as it oxidizes leads to bending

Stoney's equation:

$$\sigma = \frac{Et^2}{6R(1-\nu)t_{ox}}$$



where:

- *σ: stress (due to added layer)*
- *E: elastic modulus*
- *R: radius of curvature*
- *t: thickness*
- *t_{ox}: oxidation thickness*
- *v: poisson ratio*

Theoretical limit of sensitivity: t_{ox} ~ 8 x 10^{-12} m

Taking a measurement every minute: Δ(Flux) ~ 2 x 10^5 atoms/cm^2·s

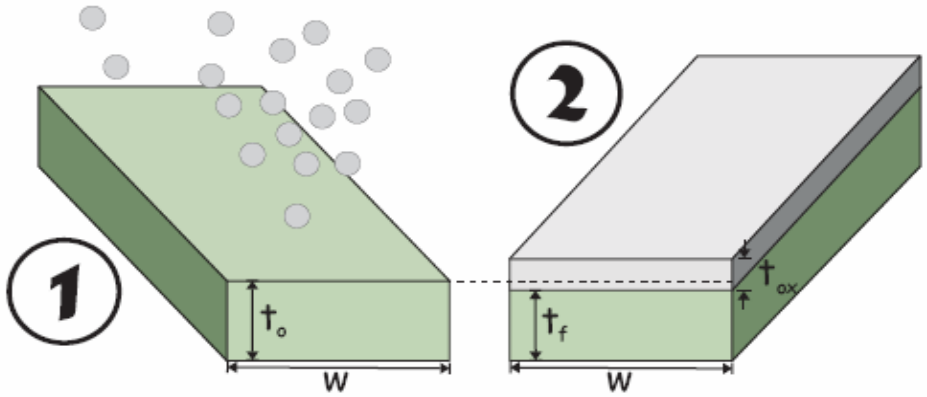
Design. Actinometry

The resistance of the reductant increases as it is replaced by a non conductive oxide.

$$t_{ox} = t_0 \left(1 - \frac{R_0}{R}\right) PBR$$

where:

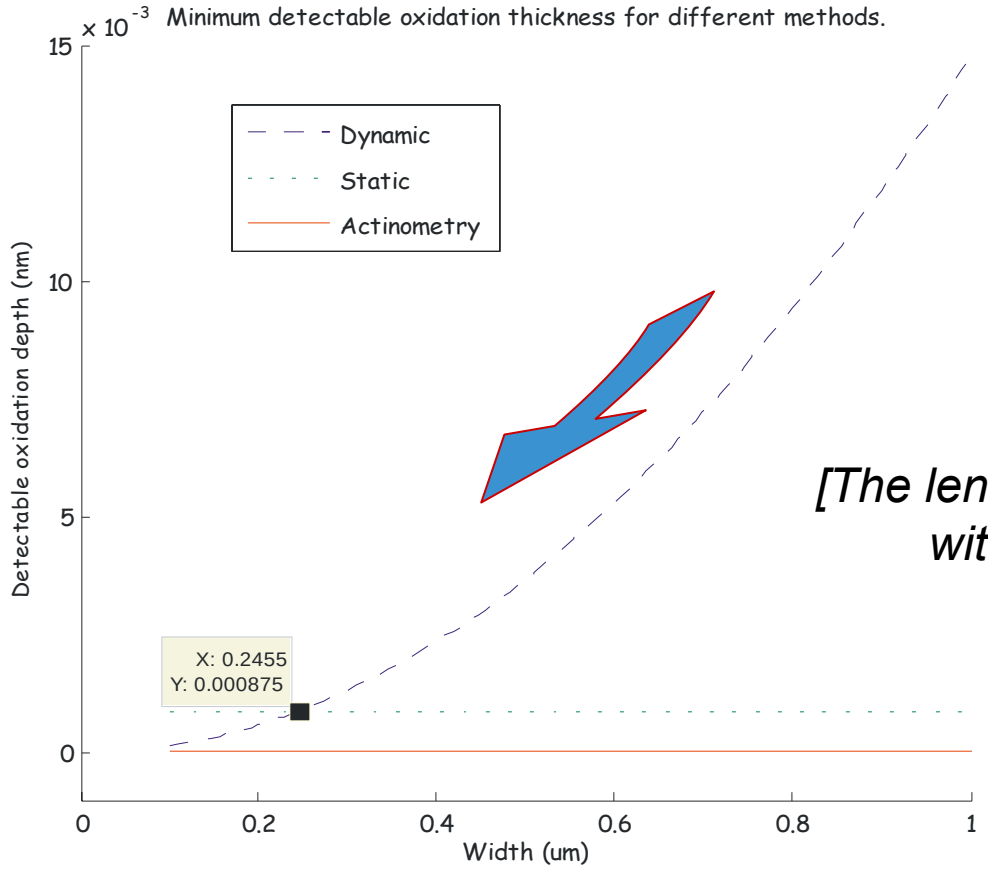
- *PBR: Pilling-Bedworth ratio*
- *R_o: original resistance*
- *R: final resistance*
- *t_o: original thickness*
- *t_{ox}: oxidation thickness*



Theoretical limit of sensitivity: t_{ox} ~ 2 x 10^{-14} m

Taking a measurement every minute: Δ(Flux) ~ 20 atoms/cm^2·s

Design. Optimization



[The length scales down with the width]

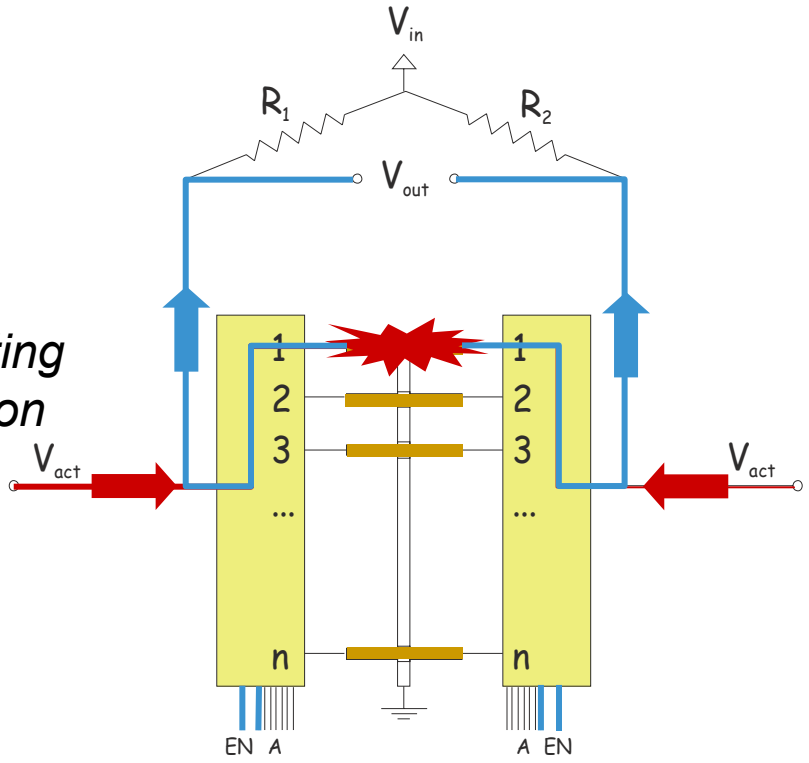
Dynamic sensitivity ↑ *as dimensions* ↓

System. Operation

Large array of resonators

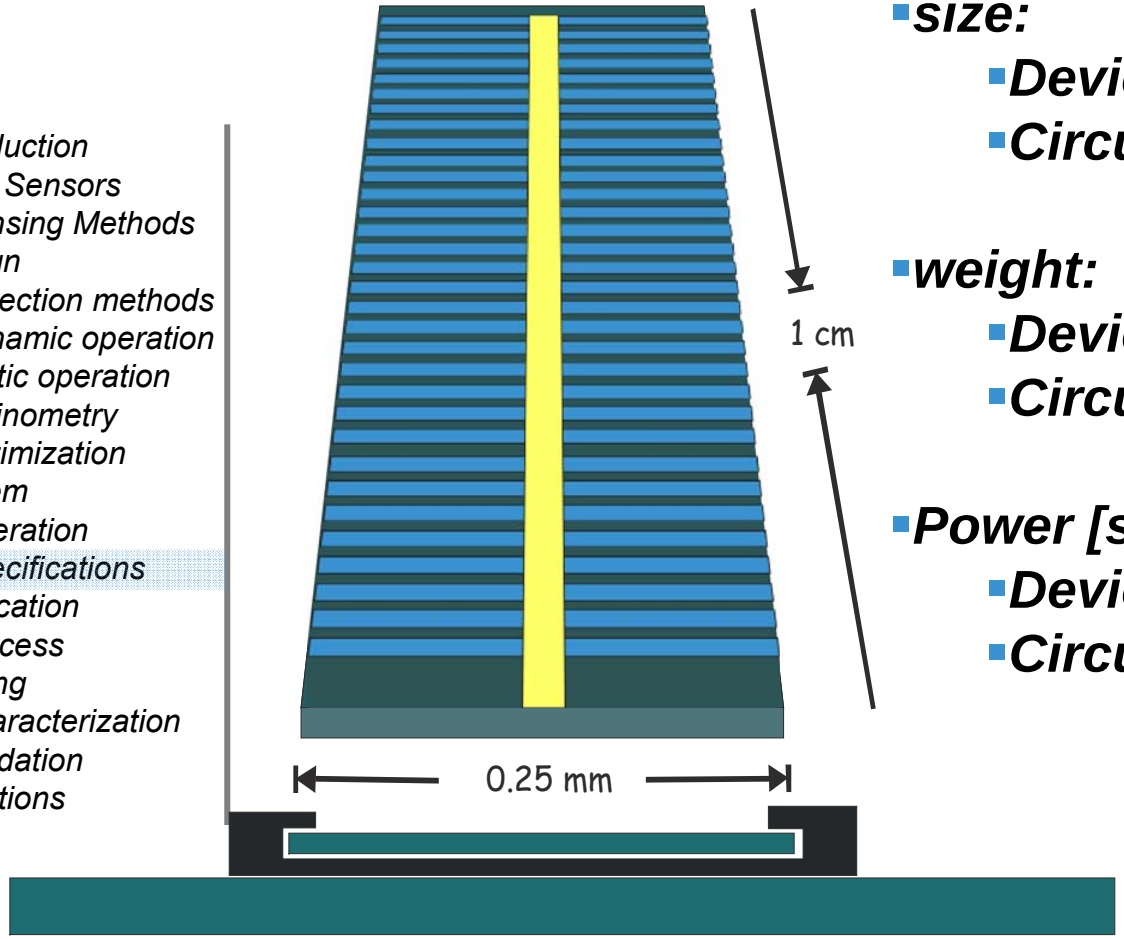
Activate devices as measurements are requested

1. *Enable circuitry*
2. *Activate a resonator by heating and removing oxide protection (gold)*
3. *Make measurement*
4. *Disable circuitry*



System. Specifications

100 bridges

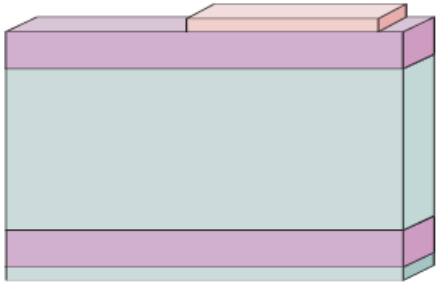


- ***size:***
  - ***Device: 2.5 mm²***
  - ***Circuitry: ~10 cm²***
- ***weight:***
  - ***Device: 3 mg***
  - ***Circuitry: 0.5 g***
- ***Power [shutdown]:***
  - ***Device: ~0.5 mW [50 µW]***
  - ***Circuitry: ~10 mW [0.1 µW]***

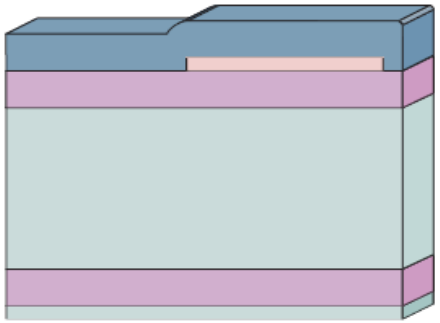
Fabrication. Process

- Starting silicon wafer
- 500 nm oxide deposition
- 200nm LPCVD polysilicon

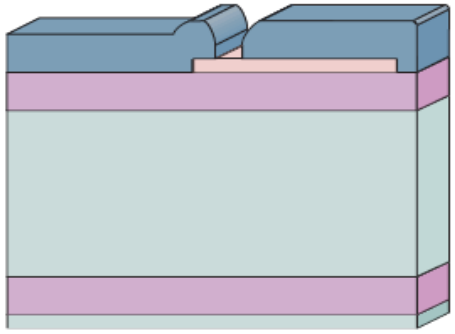
- ~4 x 10^{15} Boron doping in front



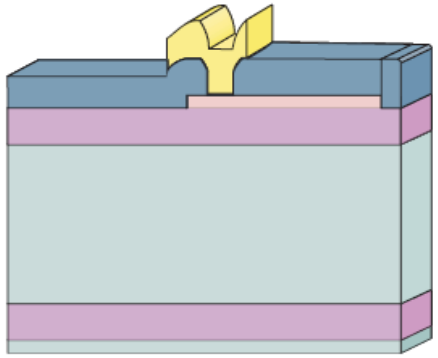
- Piezo-define (RIE)



- 500 nm LPCVD nitride

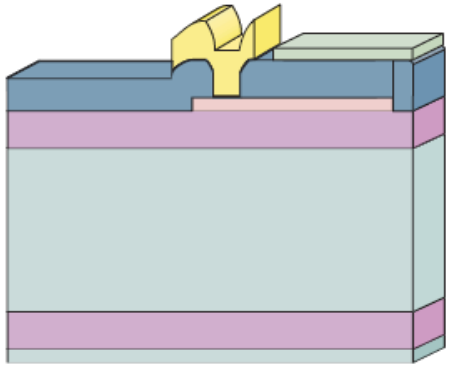


- Nitride define (RIE)

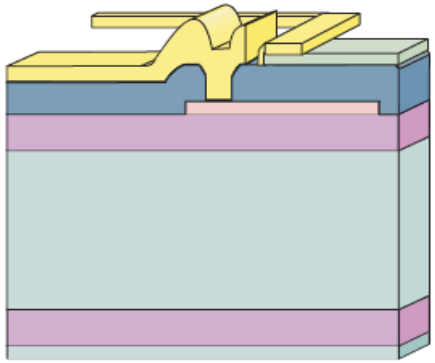


- 500 nm metal deposition (Gold contacts)
- Lift-off

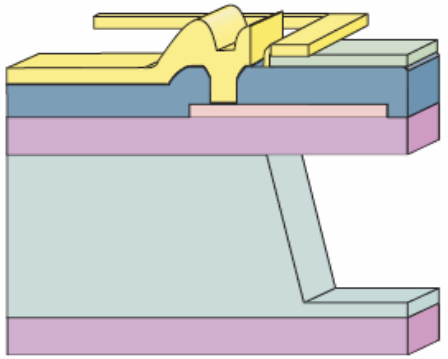
Fabrication. Process



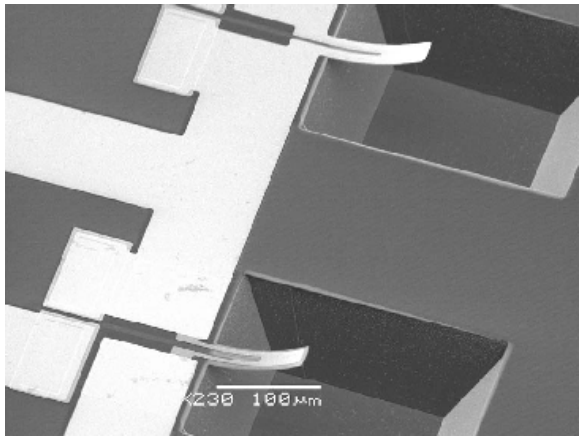
- 200 nm metal deposition (Redu)
- Lift-off

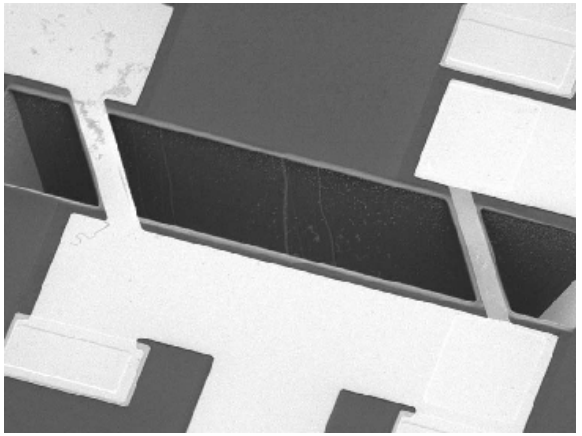


- 200 nm metal deposition (Gold)
- Lift-off

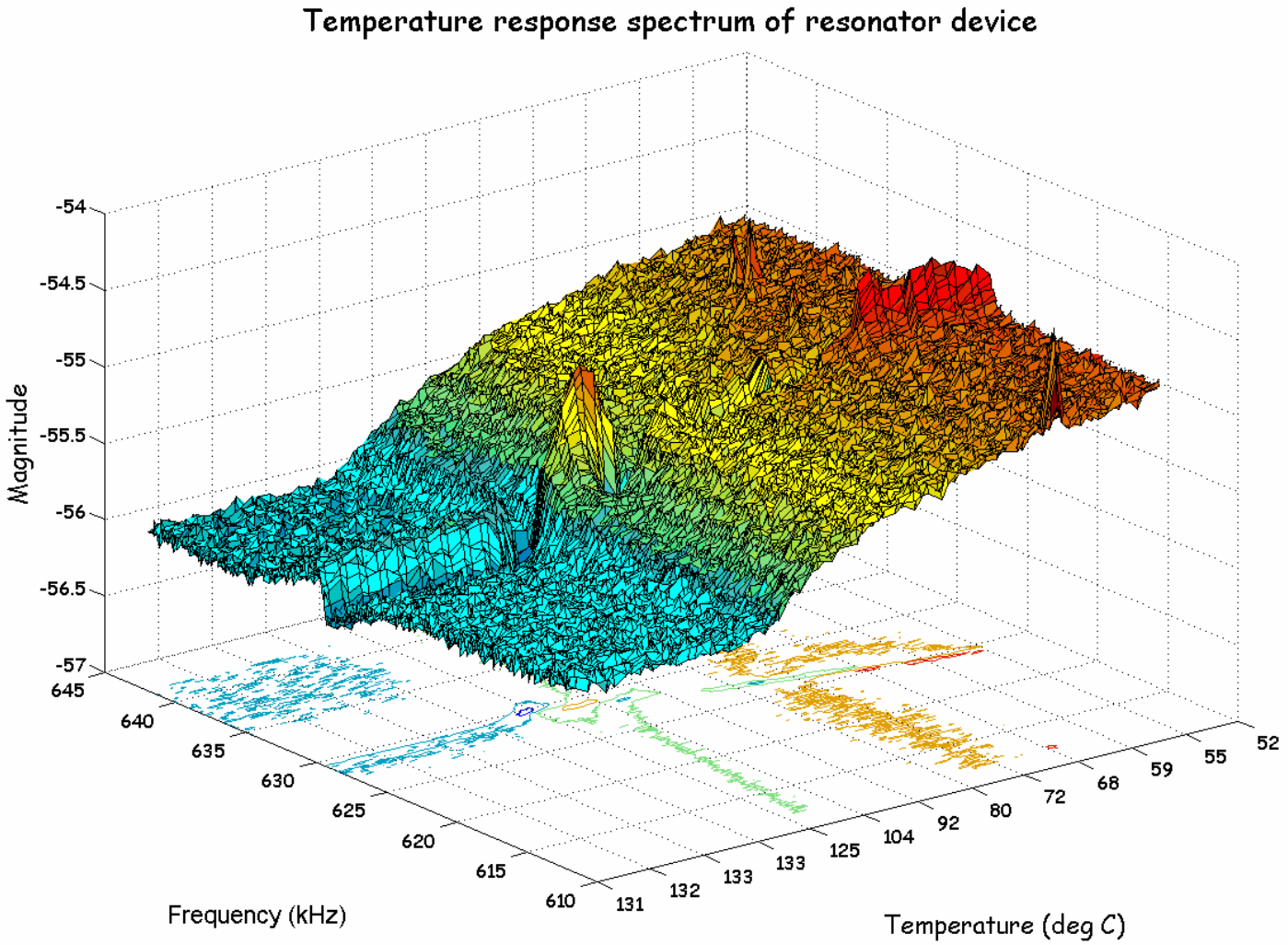


- KOH etch from the front

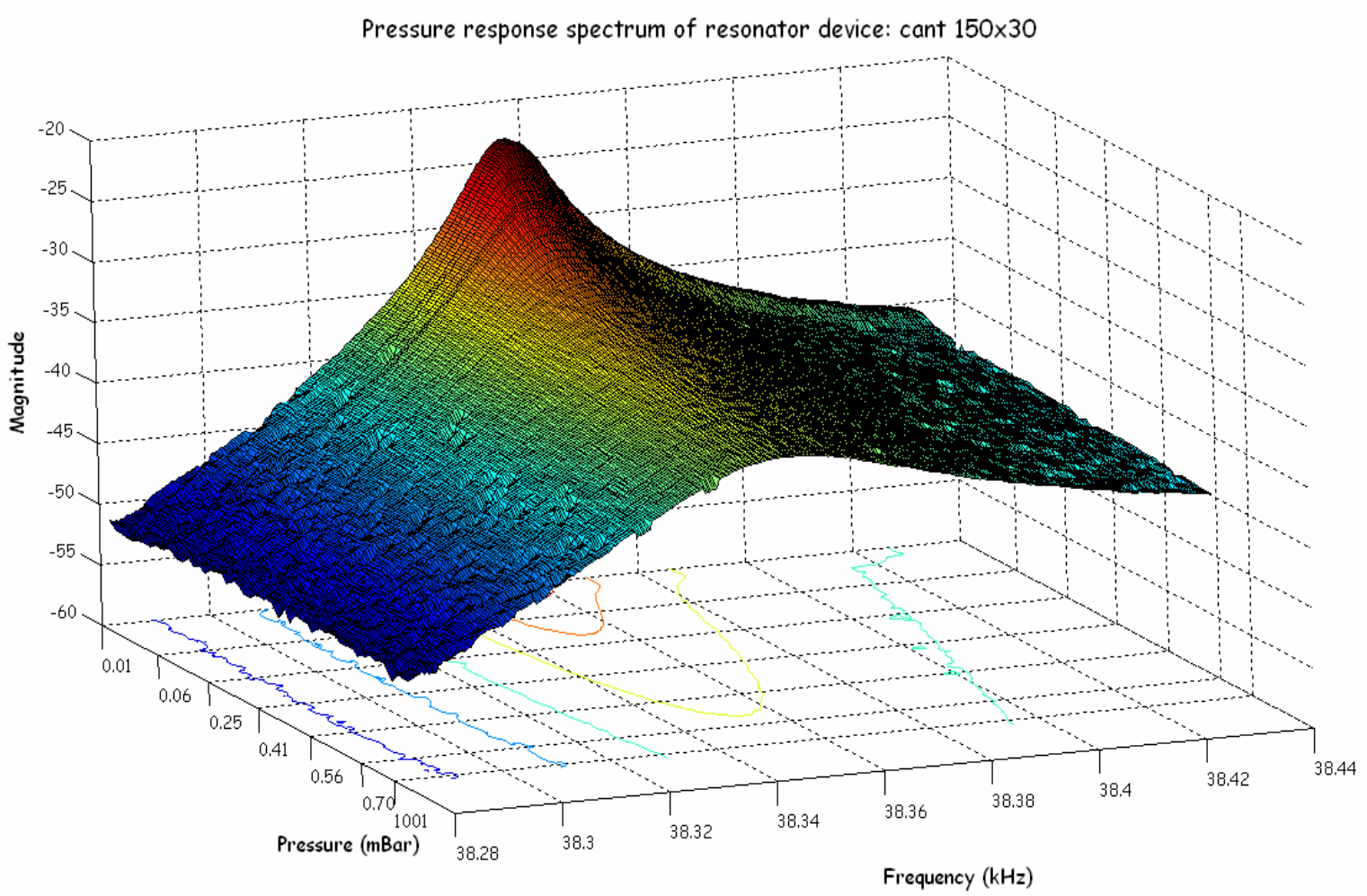




Device: bridge 30x150 μm²

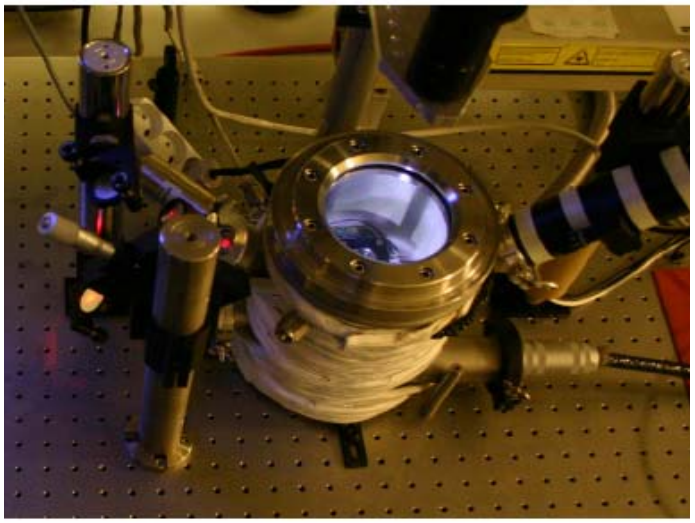


Device: cantilever 30x150 µm

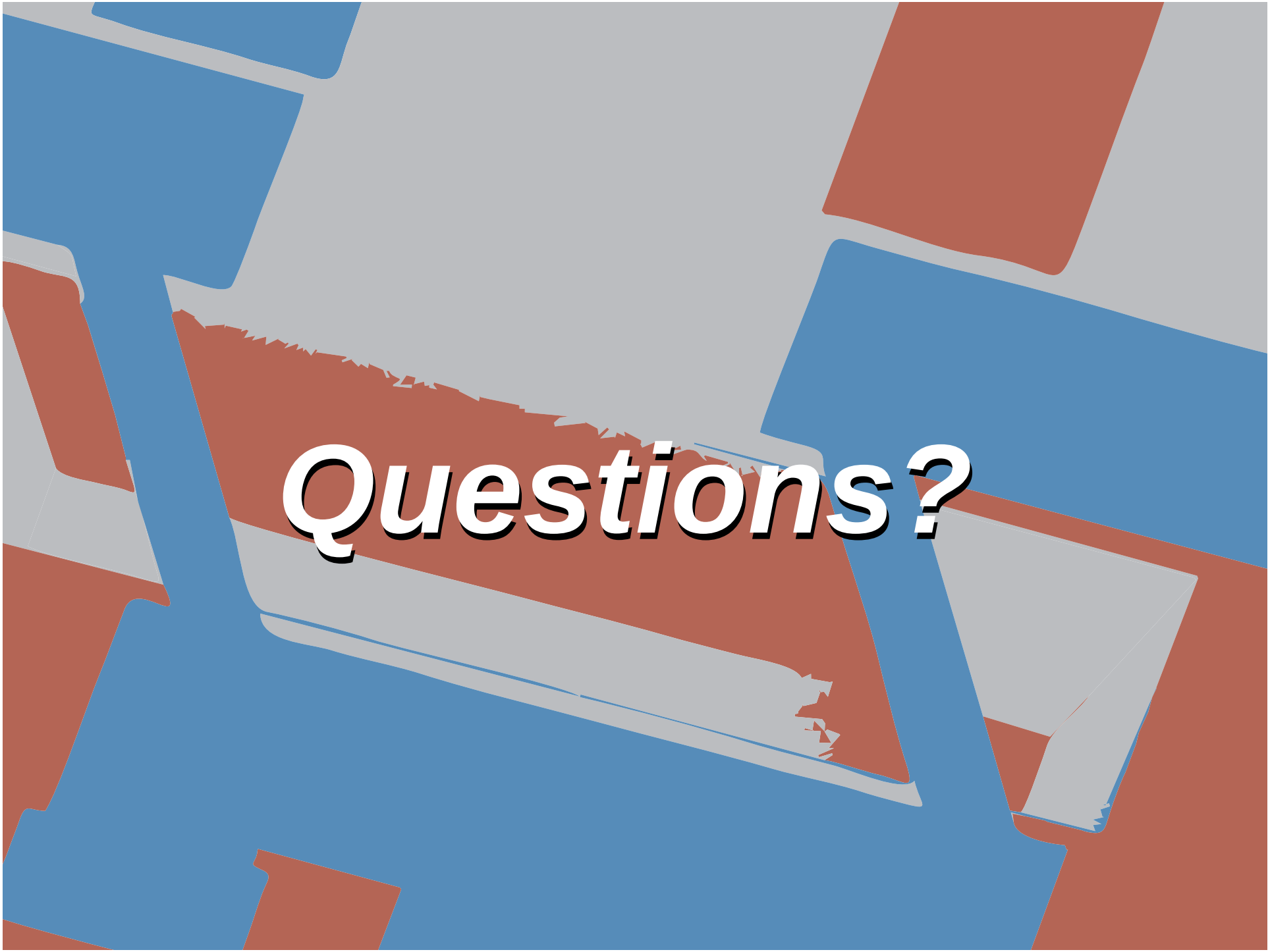


Testing. Oxidation

Oxidization was attempted with temperature regulated vacuum chamber



- *800 mBar of pure oxygen introduced in the chamber and heated up to 120 °C. 8 hour soak.*
- *results cannot conclusively support that oxidization occurred*
- *A better experimental setup will be required to proceed*


Questions?