Reliability of RF-MEMS

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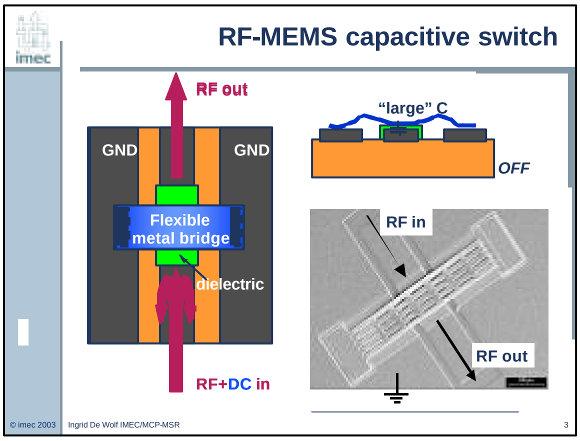
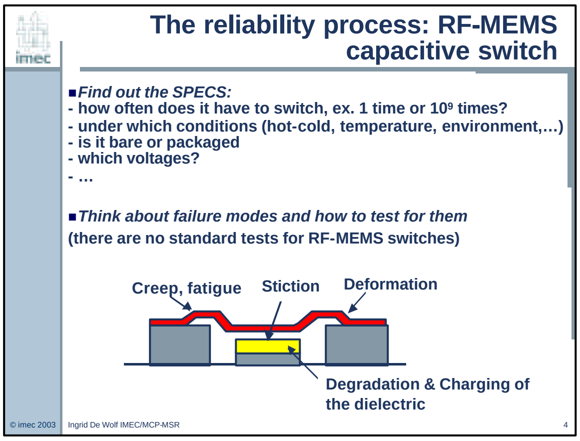
SEEDS FOR TOMORROW'S WORLD

Outline

- RF-MEMS capacitive switch
- The reliability process
- Techniques:
  - *ELT*
  - *MOPS*
  - *VAP*
- Stiction
- 0-level packaging
- Conclusions



RF-MEMS capacitive switch



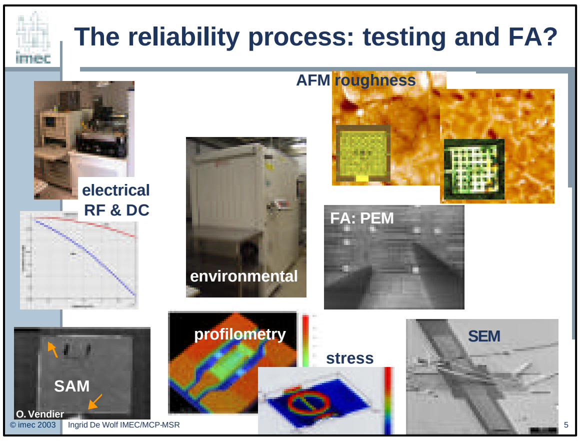
The reliability process: RF-MEMS capacitive switch

- *Find out the SPECS:*

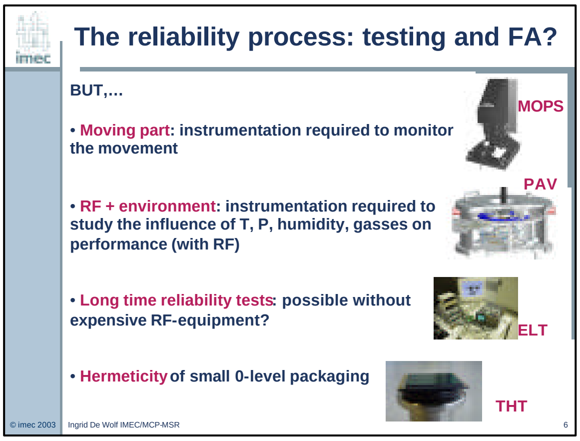
- how often does it have to switch, ex. 1 time or 10^9 times?
- under which conditions (hot-cold, temperature, environment,…)
- is it bare or packaged
- which voltages?
- …

- *Think about failure modes and how to test for them*

(there are no standard tests for RF-MEMS switches)



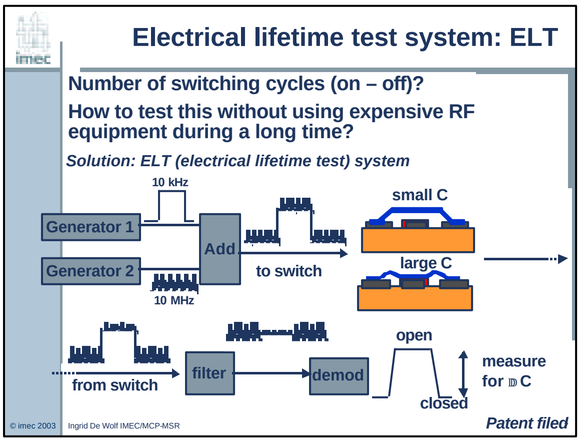
The reliability process: testing and FA?



The reliability process: testing and FA?

BUT,…

- **Moving part**: instrumentation required to monitor the movement
- **RF + environment**: instrumentation required to study the influence of T, P, humidity, gasses on performance (with RF)
- **Long time reliability tests**: possible without expensive RF-equipment?
- **Hermeticity** of small 0-level packaging



Electrical lifetime test system: ELT

Number of switching cycles (on – off)?

How to test this without using expensive RF equipment during a long time?

Solution: ELT (electrical lifetime test) system

Patent filed

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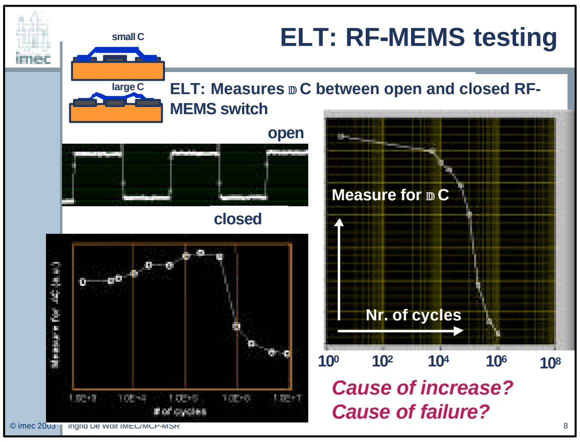

ELT: RF-MEMS testing

ELT: Measures ⅅC between open and closed RF-MEMS switch

Cause of increase?

Cause of failure?

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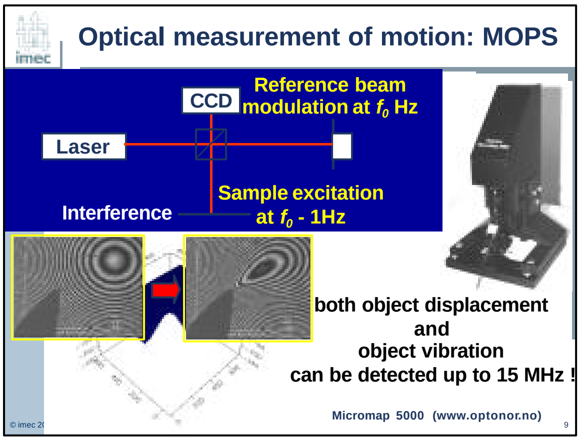

Optical measurement of motion: MOPS

Reference beam modulation at f_0 Hz

Sample excitation at f_0 - 1Hz

both object displacement and object vibration can be detected up to 15 MHz !

Micromap 5000 (www.optonor.no)

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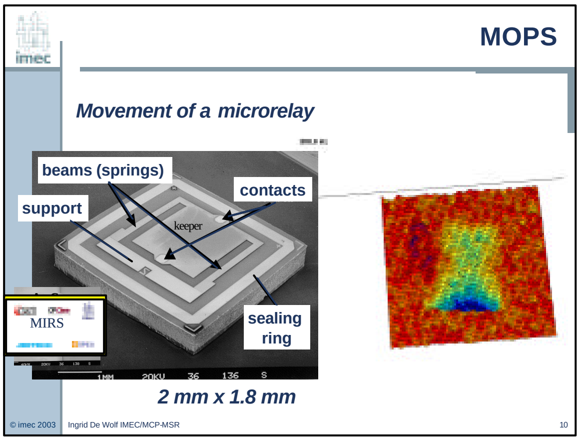

MOPS

Movement of a microrelay

2 mm x 1.8 mm

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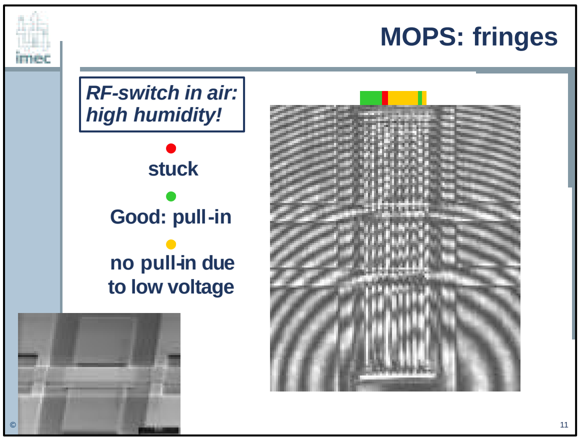

MOPS: fringes

RF-switch in air: high humidity!

- 🔴 **stuck**
- 🟢 **Good: pull-in**
- 🟡 **no pull-in due to low voltage**

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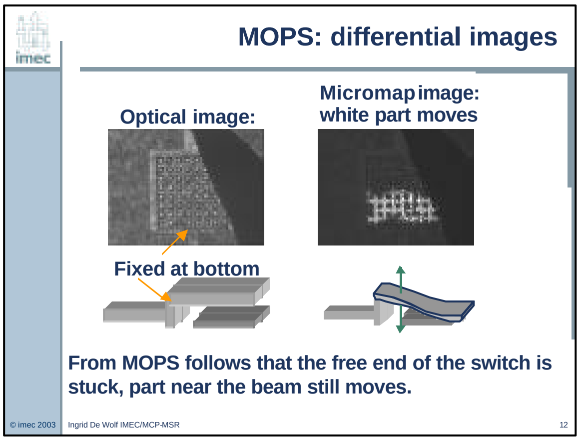

MOPS: differential images

From MOPS follows that the free end of the switch is stuck, part near the beam still moves.

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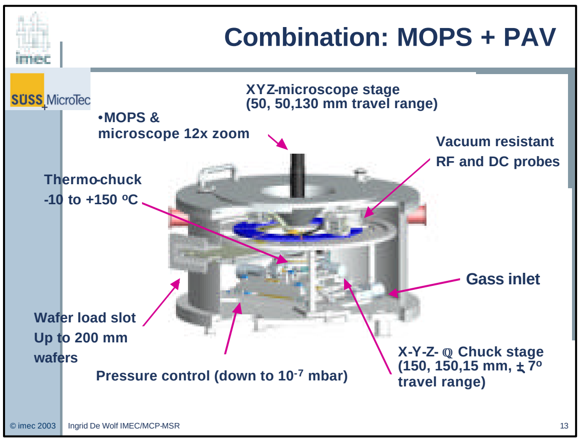


Combination: MOPS + PAV

XYZ-microscope stage
(50, 50,130 mm travel range)

•MOPS &
microscope 12x zoom

Vacuum resistant
RF and DC probes

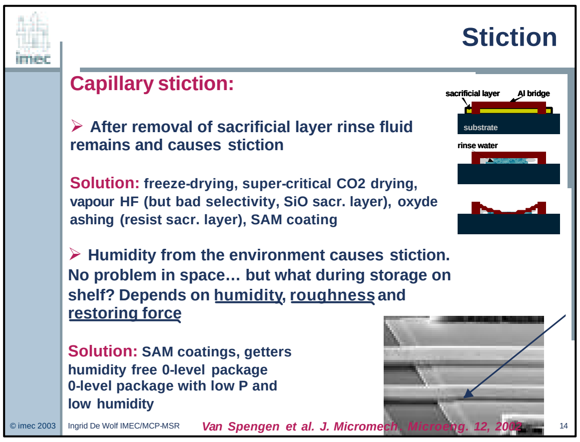
Thermo-chuck
-10 to +150 ºC

Gass inlet

Wafer load slot
Up to 200 mm
wafers

Pressure control (down to 10^{-7} mbar)

X-Y-Z- φ Chuck stage
(150, 150,15 mm, ± 7º
travel range)



Stiction

Capillary stiction:

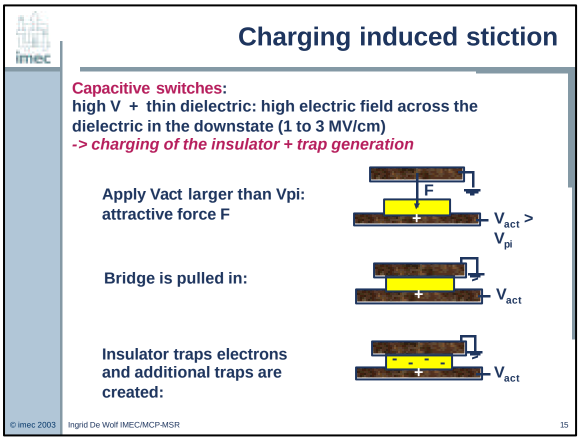
➢ After removal of sacrificial layer rinse fluid remains and causes stiction

Solution: freeze-drying, super-critical CO2 drying, vapour HF (but bad selectivity, SiO sacr. layer), oxyde ashing (resist sacr. layer), SAM coating

➢ Humidity from the environment causes stiction. No problem in space… but what during storage on shelf? Depends on humidity, roughness and restoring force

Solution: SAM coatings, getters
humidity free 0-level package
0-level package with low P and
low humidity

Van Spengen et al. J. Micromech. Microeng. 12, 2002



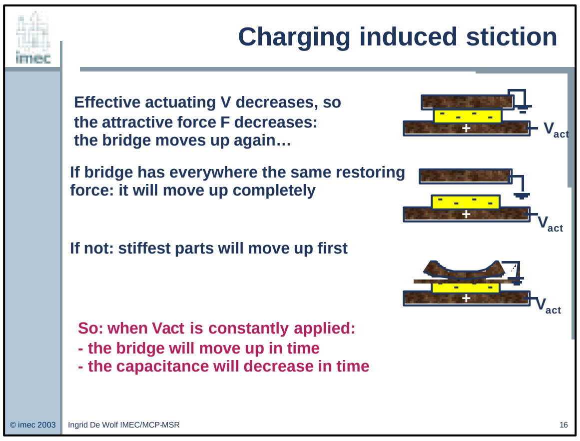
Charging induced stiction

Capacitive switches:
high V + thin dielectric: high electric field across the dielectric in the downstate (1 to 3 MV/cm)
-> charging of the insulator + trap generation

Apply Vact larger than Vpi:
attractive force F

Bridge is pulled in:

Insulator traps electrons and additional traps are created:



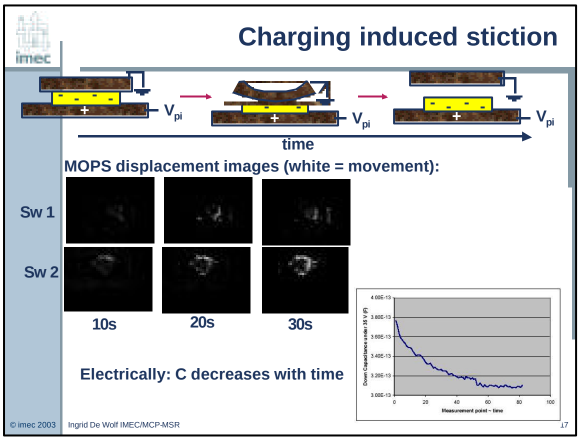
Charging induced stiction

Effective actuating V decreases, so the attractive force F decreases: the bridge moves up again…

If bridge has everywhere the same restoring force: it will move up completely

If not: stiffest parts will move up first

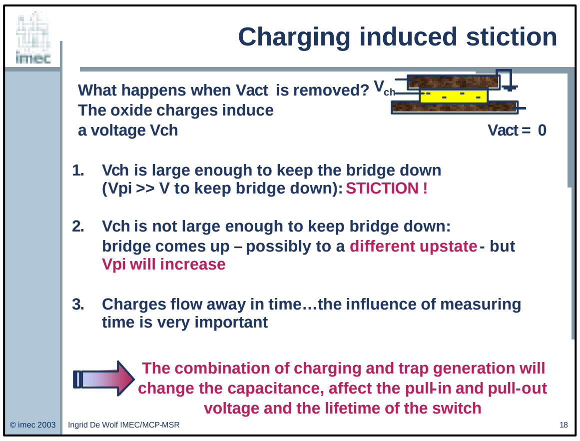
So: when Vact is constantly applied:
- the bridge will move up in time
- the capacitance will decrease in time



Charging induced stiction

MOPS displacement images (white = movement):

Electrically: C decreases with time

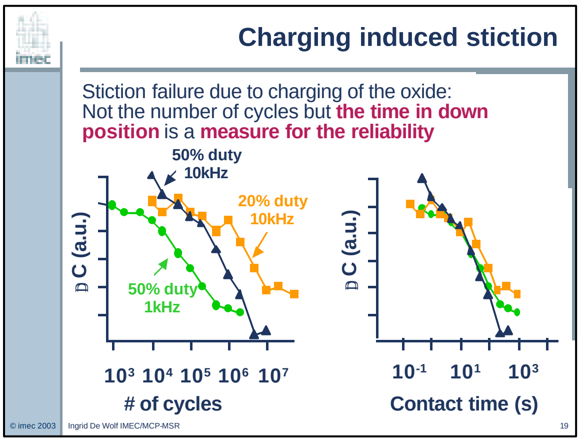


Charging induced stiction

What happens when Vact is removed? The oxide charges induce a voltage Vch

1. Vch is large enough to keep the bridge down (Vpi >> V to keep bridge down): STICTION !
2. Vch is not large enough to keep bridge down: bridge comes up – possibly to a different upstate - but Vpi will increase
3. Charges flow away in time…the influence of measuring time is very important

The combination of charging and trap generation will change the capacitance, affect the pull-in and pull-out voltage and the lifetime of the switch



Charging induced stiction

Stiction failure due to charging of the oxide:
Not the number of cycles but **the time in down position** is a **measure for the reliability**

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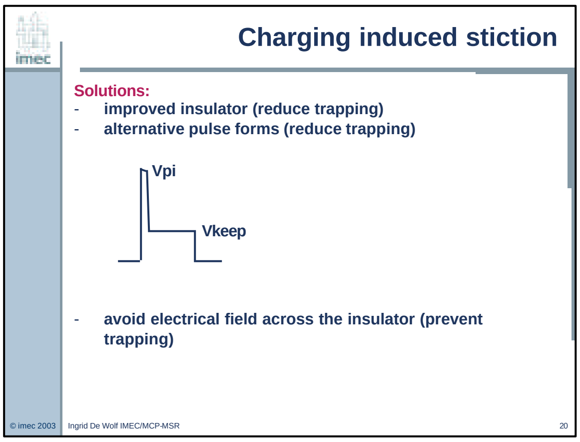

Charging induced stiction

Solutions:
- **improved insulator (reduce trapping)**
- **alternative pulse forms (reduce trapping)**

- **avoid electrical field across the insulator (prevent trapping)**

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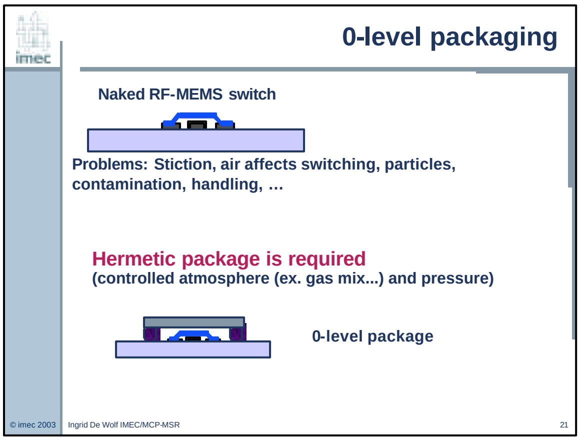

0-level packaging

Naked RF-MEMS switch

Problems: Stiction, air affects switching, particles, contamination, handling, …

Hermetic package is required
(controlled atmosphere (ex. gas mix...) and pressure)

0-level package

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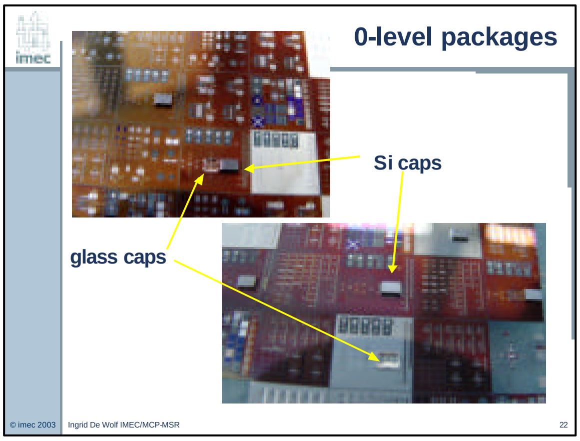

0-level packages

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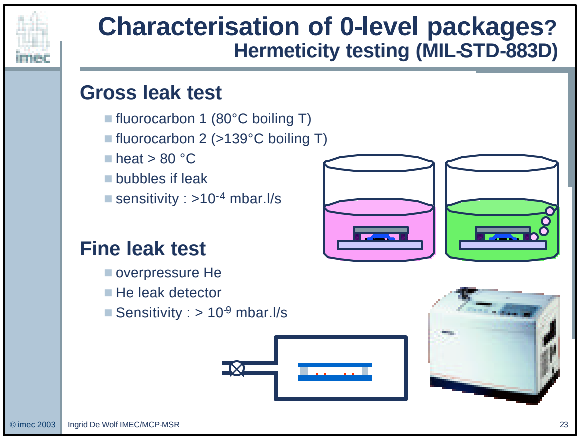

Characterisation of 0-level packages?

Hermeticity testing (MIL-STD-883D)

Gross leak test
- fluorocarbon 1 (80°C boiling T)
- fluorocarbon 2 (>139°C boiling T)
- heat > 80 °C
- bubbles if leak
- sensitivity : $>10^{-4}$ mbar.l/s

Fine leak test
- overpressure He
- He leak detector
- Sensitivity : $> 10^{-9}$ mbar.l/s

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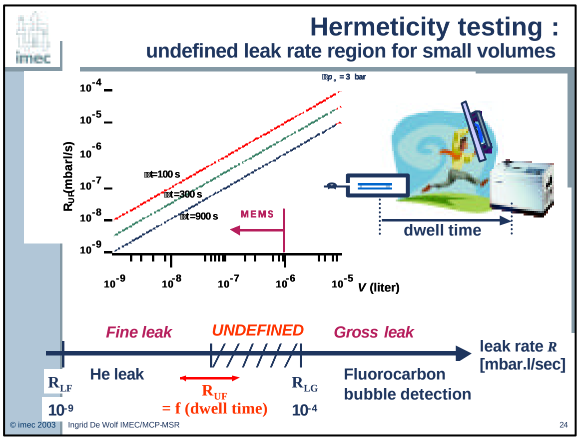

Hermeticity testing :

undefined leak rate region for small volumes

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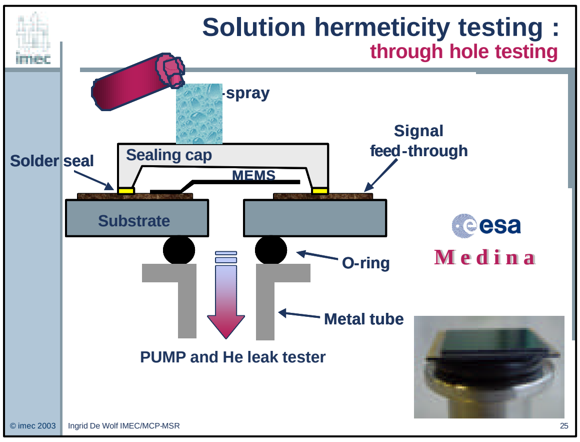

Solution hermeticity testing :
through hole testing

spray

Signal
feed-through

Solder seal

Sealing cap

MEMS

Substrate

O-ring

Metal tube

PUMP and He leak tester

esa
Medina

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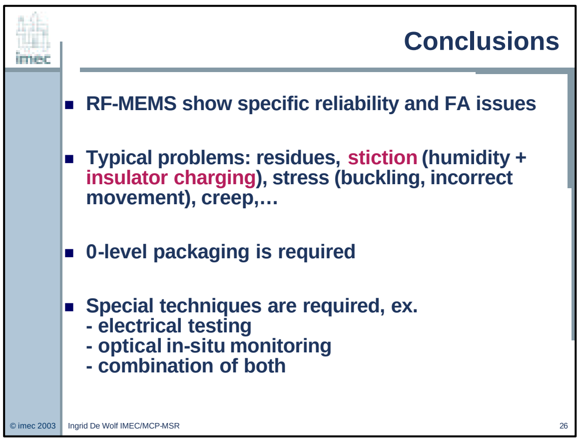

Conclusions

- RF-MEMS show specific reliability and FA issues
- Typical problems: residues, stiction (humidity + insulator charging), stress (buckling, incorrect movement), creep,…
- 0-level packaging is required
- Special techniques are required, ex.
  - electrical testing
  - optical in-situ monitoring
  - combination of both

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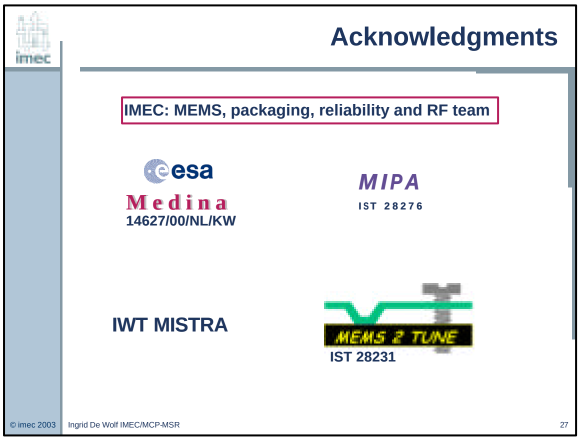

Acknowledgments

IMEC: MEMS, packaging, reliability and RF team

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