Reliability improvements of an electrostatic energy harvester for TPMS

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TPMS

Valve mounted

Tire integrated

- Tire pressure monitoring system
  - Legislation driven market
- Transition from valve to tire → *intelligent tire*
  - All tire companies are developing intelligent tire solutions
    - Bridgestone, Pirelli, Continental, Goodyear,..
  - Added functionality besides pressure
    - Tire ID monitoring (ID, tire use (distance),..)
    - Safety improvements (coefficient of friction, tire wear,...)

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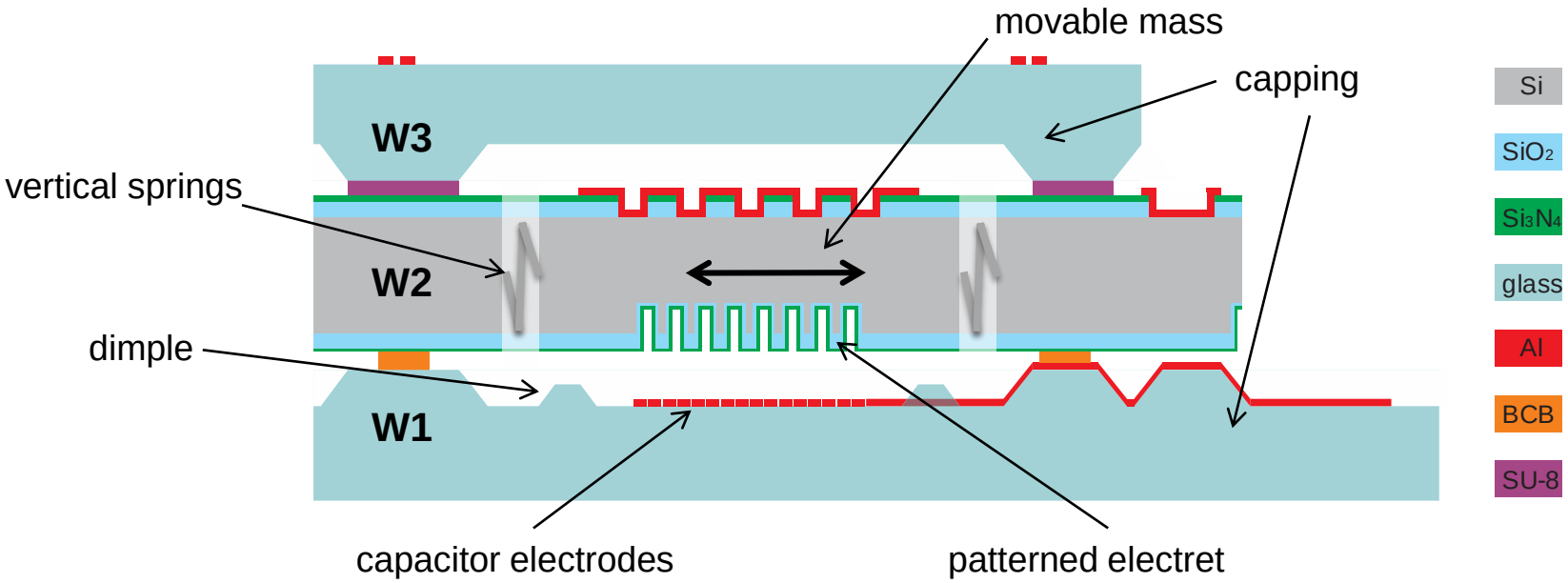
Electrostatic energy harvester

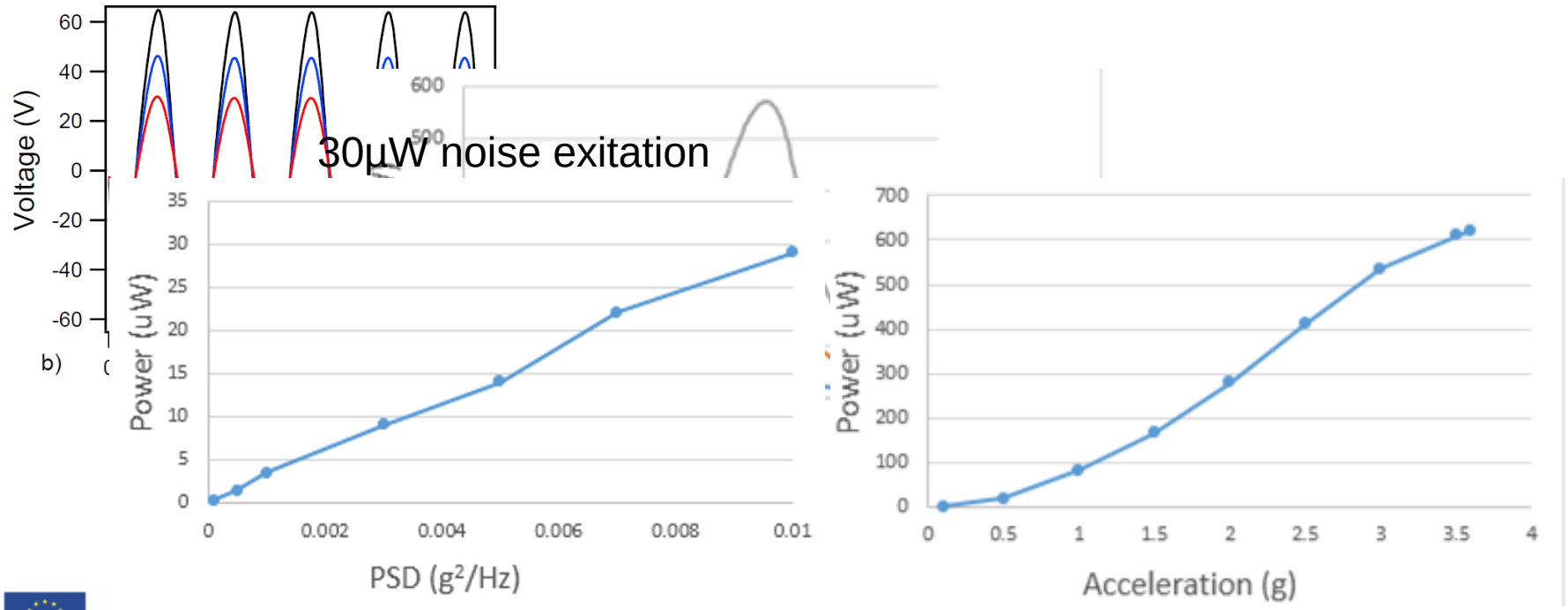


- 1st gen device design, materials, fabrication process
  - Si mass on DRIE etched vertical springs
  - Corrugated DRIE etched Si with SiO_2/Si_3N_4 electret
  - Glass capping with cavity, dimples and electrodes
  - BCB or SU-8 polymer waferbond
  - Stepped dicing for access to electrodes

Device characterization

- Device characterisation 1st generation harvesters
  - Shaker with sinusoidal input

→ 600µW output power

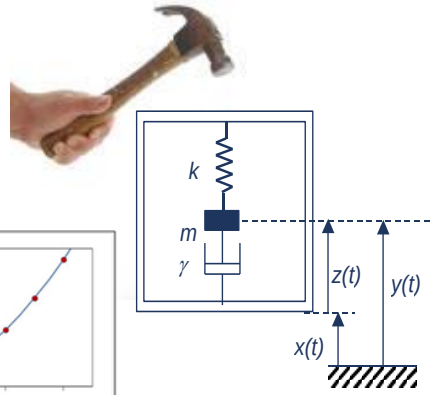


Shock excitation

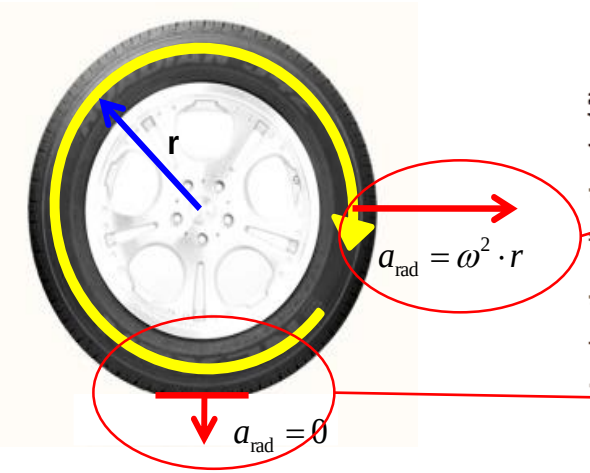
inside tire

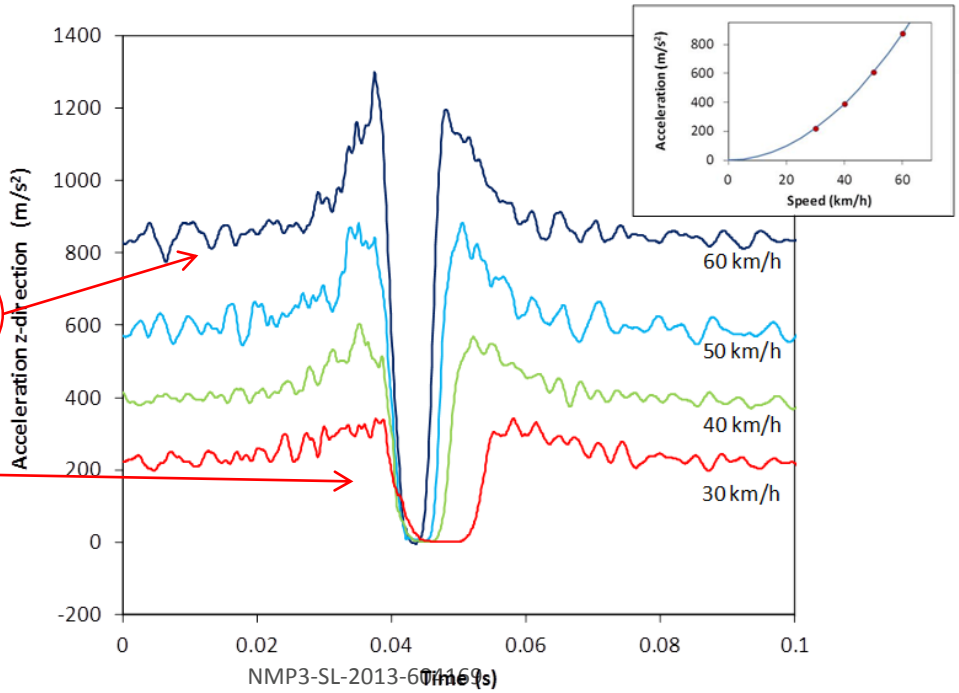
- Power generation by shock excitation
- Large shocks available inside tire
- Reliability is the main challenge!

Velocity damped resonator

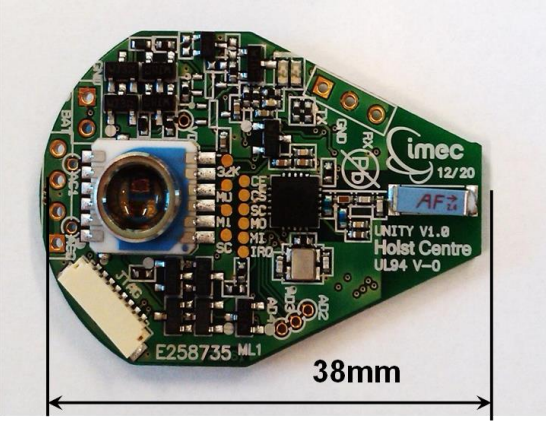


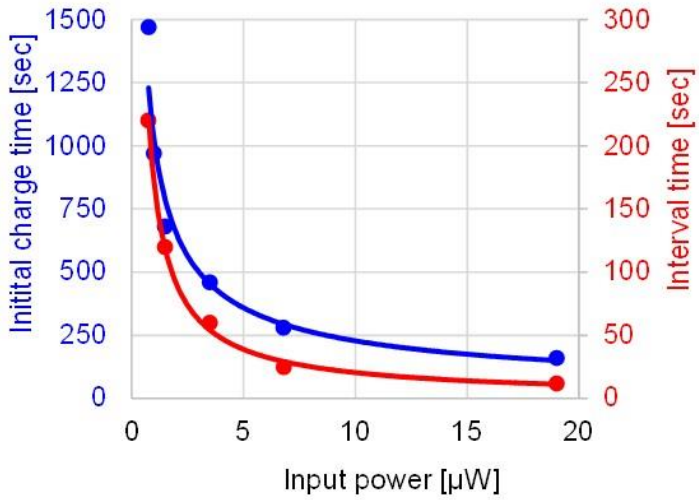
Energy generation inside tire





TPMS application





TPMS SENSOR BOARD

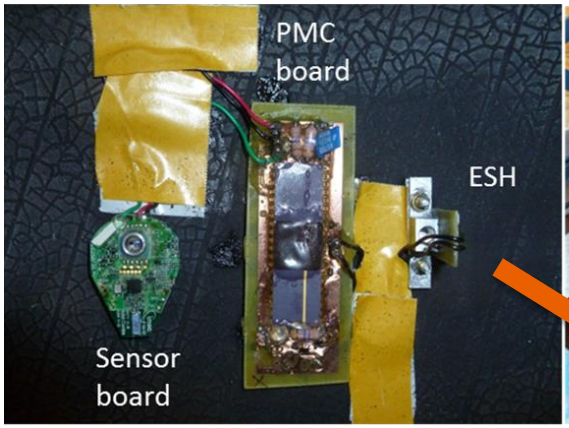
- Off-the-shelf components
- Pressure and Temperature
- 2.4 GHz
- µC : timing and data
- Charging from 0 Volts
- At 33 km/h, after 12 minutes → transmissions
- 60 seconds interval → 3.5 µW

Fully autonomous

Extreme low power

Small form factor

TPMS application



Sample	ESH	PMM	Sensor Board
	✓	✓	X
		✓	✓
			✓
			✓

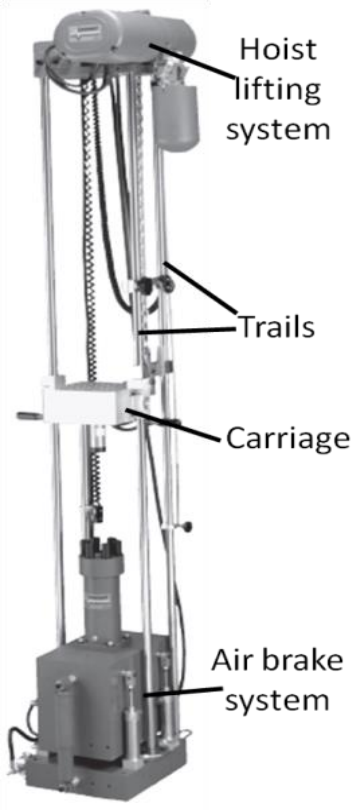
TPMS breakdo

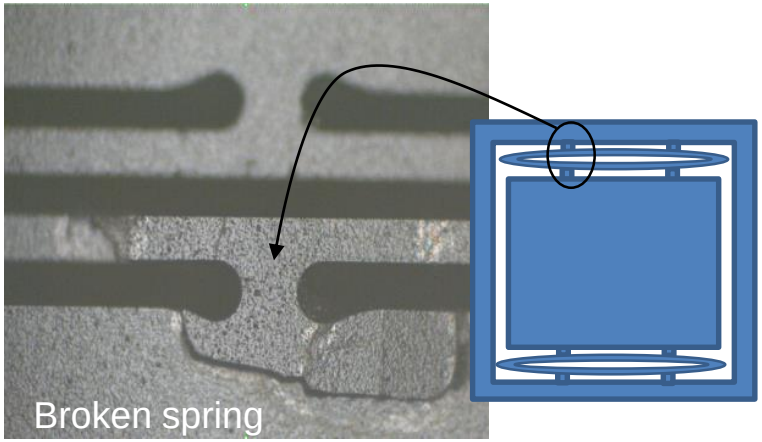
- Harvesters: spri
  - 2nd generatio

  Optimized device a
  - Output power i
    - Higher electret volta
  - Reliability improve
    - Confine the mass movement (stoppers)
- Soldering connections → Better system integration needed

Reliability of electrostatic energy harvester

– Automotive standards requires components to survive high amplitude shocks*





- Tests were carried out on a drop tester
  - Half sine profiles ~0.5ms up to 2500g
  - 100% survived > 2500g for best designs
- Several elements to improve the reliability of the harvester have been investigated:
  - Spring design improvements
  - Impact reduction by stoppers and soft coatings

*JEDEC Standard Mechanical Shock JESD22-B104-B

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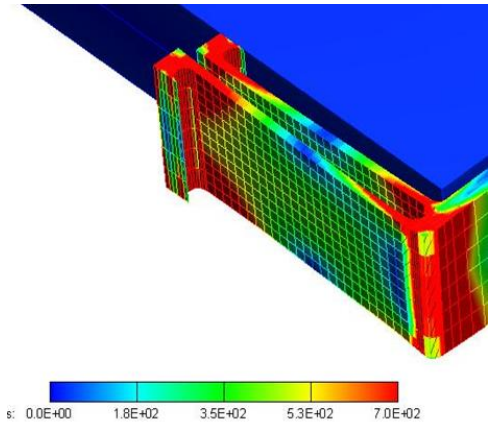
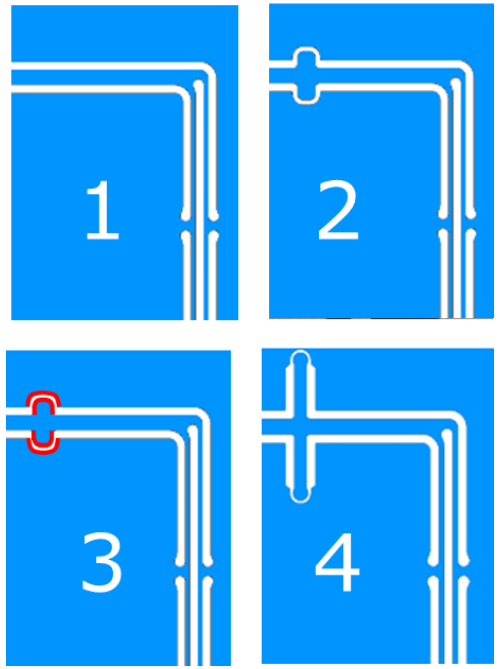
Reliability improvements

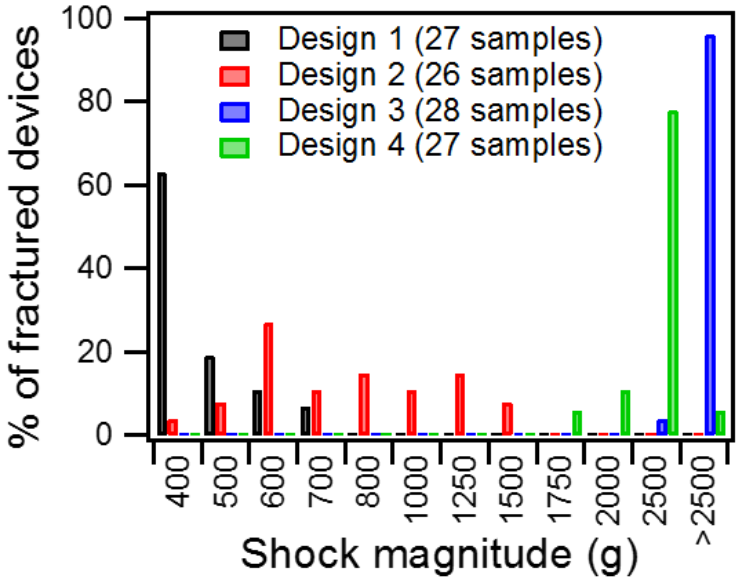
- Failure mode
  - Impact of anchor points
- Approach
  - Prevent / soften impact
- 4 designs
  - No stoppers
  - Rigid stoppers
  - Rigid stoppers with flexible coating
  - *Flexible stoppers*
- Drop tests
  - Shock acceleration up to 2500g

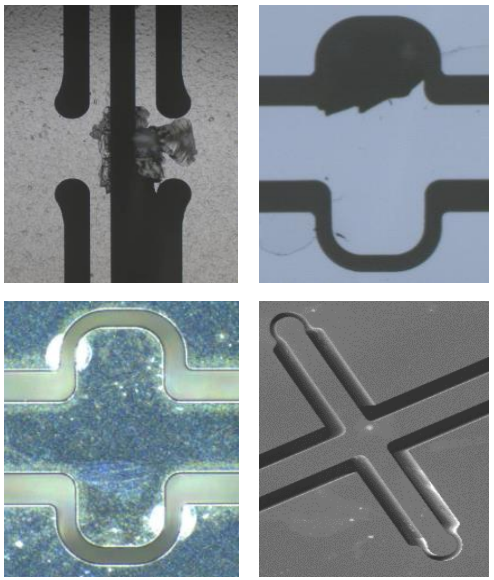




Mechanical reliability improvements

- Main failure mode: spring breakage → design improvements
  - No stoppers: < 700g, break at anchors
  - Rigid stoppers: <1500g, with large spread, breaks at stoppers
  - Rigid stoppers with flexible coating: **>2500g** (drop tester limit)
  - Flexible stoppers: > 2000g





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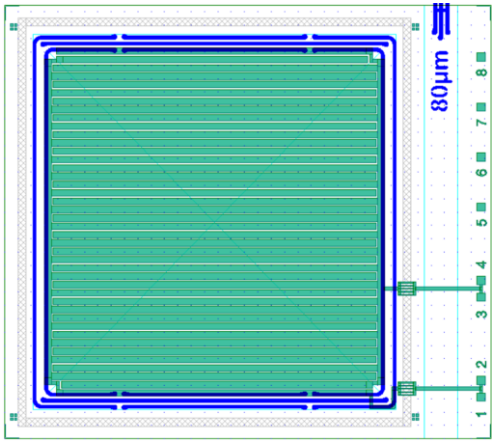
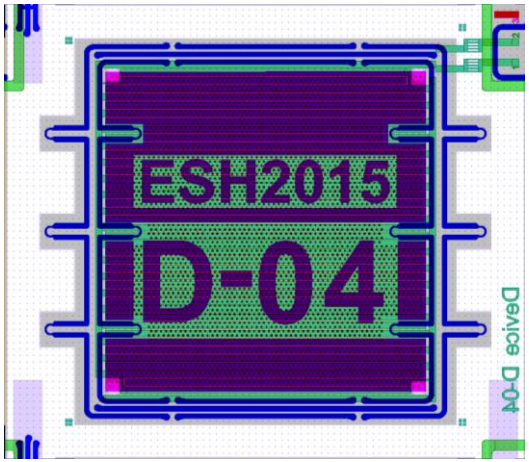
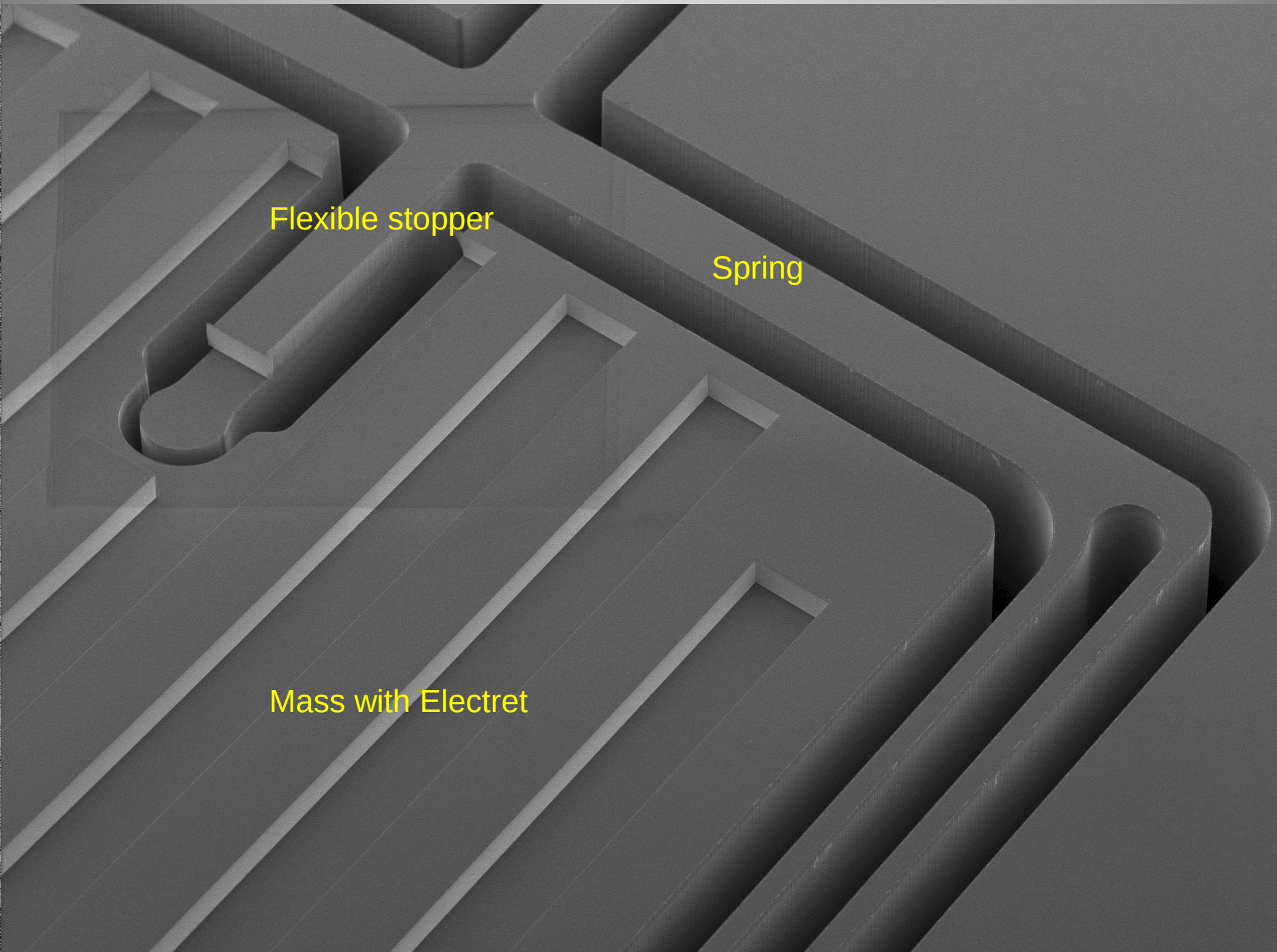
- Device architecture
  - Flexible stoppers / shock absorbers
  - Deep W3 cavities with dimples
  - Improve waferbond
  - Elimination of stepped dicing

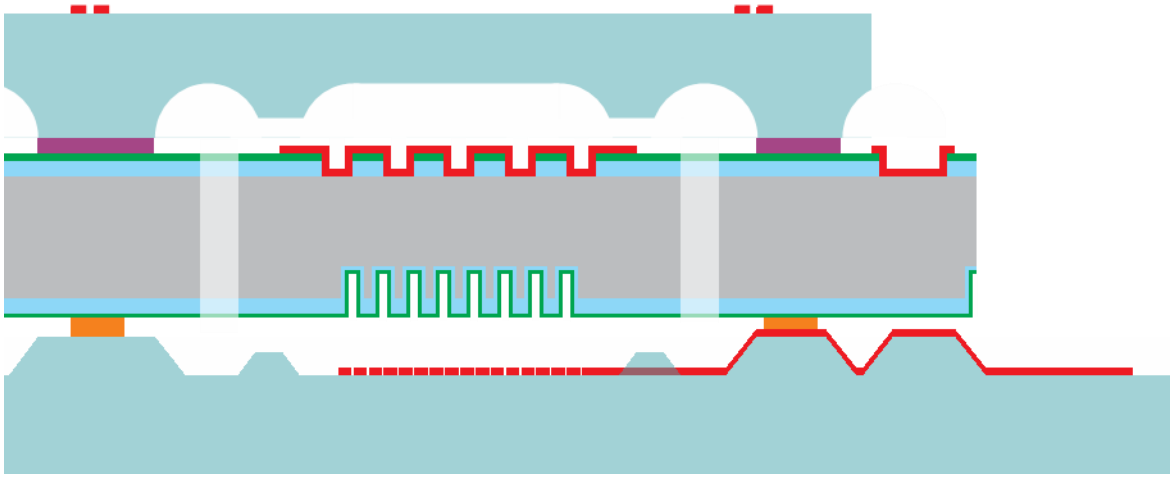


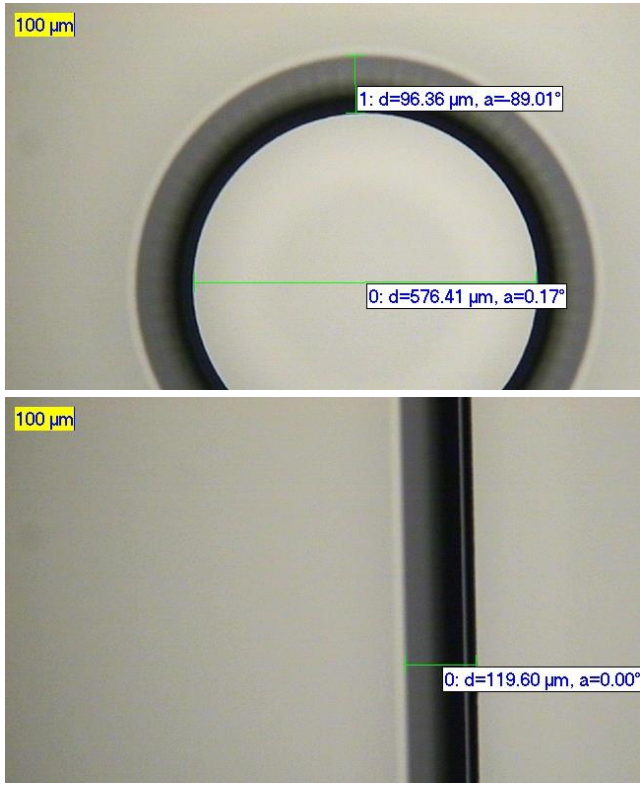
- Active part of harvester unchangec
  - Electret, electrodes, mass, springs



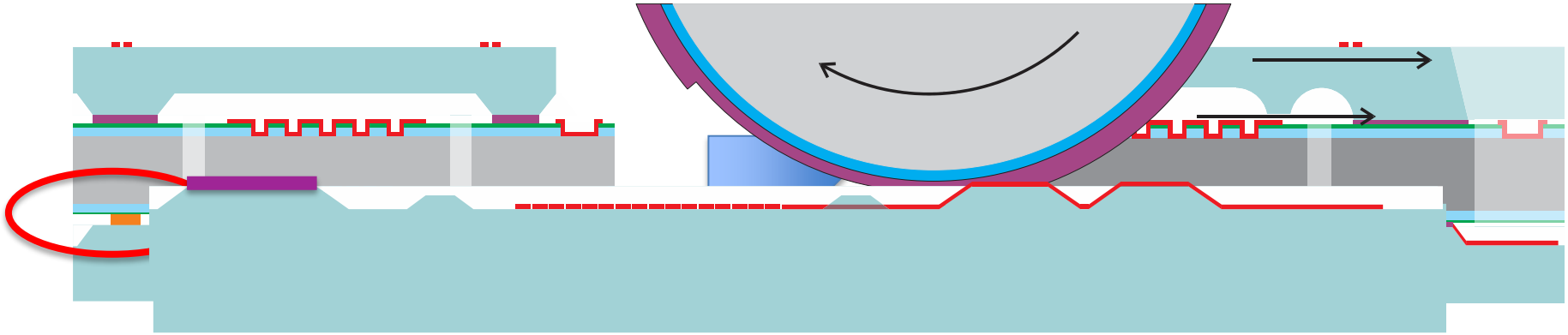

Flexible stopper
Spring
Mass with Electret

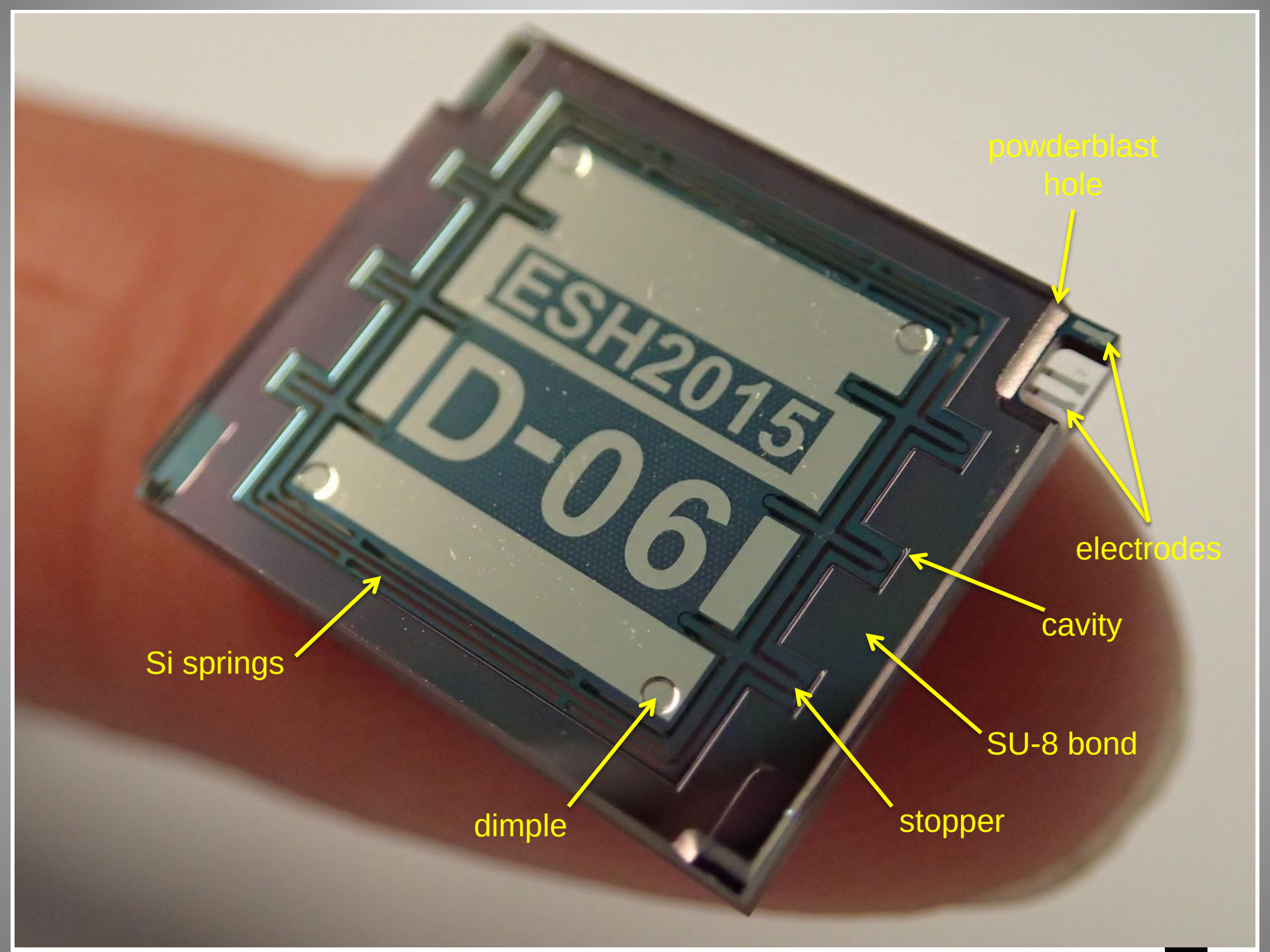
- Deep W3 cavities with dimples
  - Restricted out-of-plane movement
  - No extra air damping
  - 2-step HF etching process





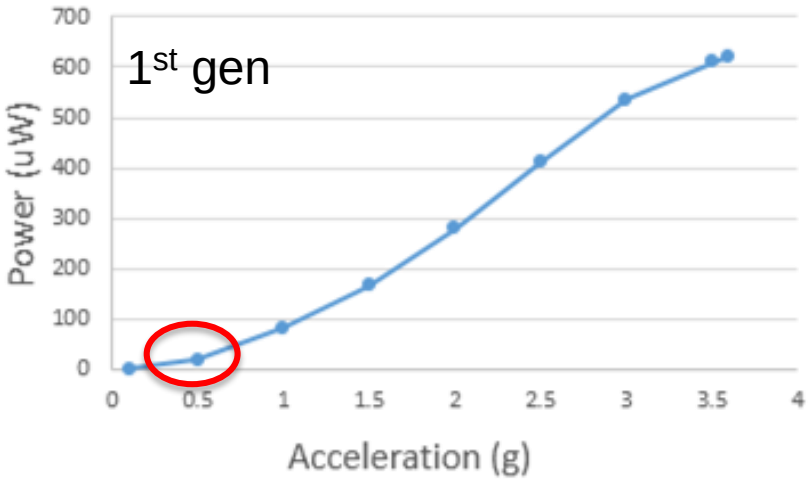
- Improved W1-W2 waferbond
- Increase waferbond area
- Replace BCB by SU-8
  - Larger BCB bond area would need higher bond pressure
  - SU-8 bond is thinner → more hermetic

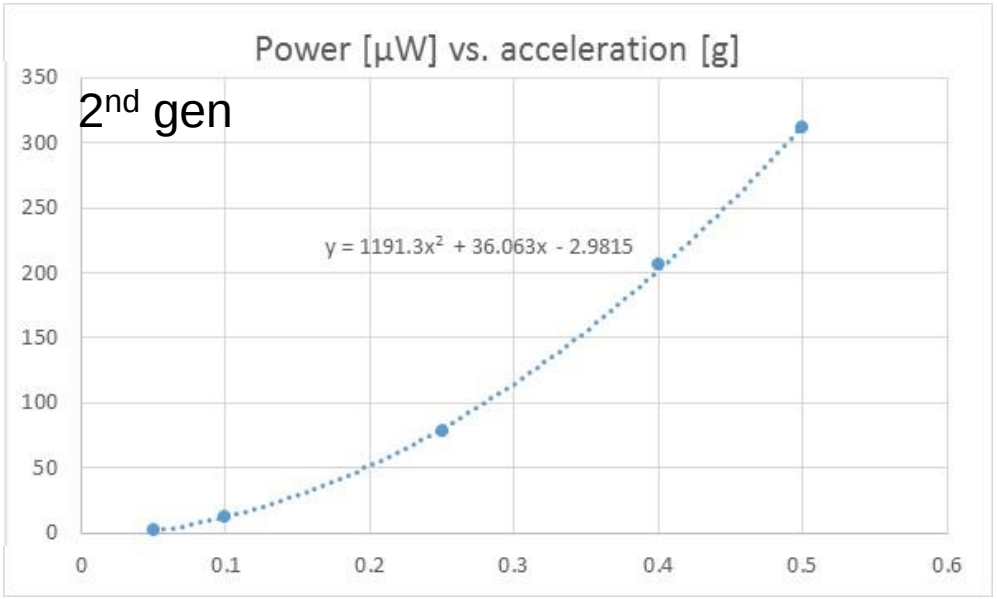



ESH2015
D-06
powderblast hole
electrodes
cavity
Si springs
SU-8 bond
dimple
stopper

Device characterization

- Device from wafer edge → electret voltage 140V
  - Quadratic relation power vs. acceleration → OK
  - Very sensitive 1200 µW/g^2 → higher than 1st gen (50 µW/g^2)
  - Very high Quality factor ~500 → higher than 1st gen (~150)
  - Max power ~300 µW at 0.5g → lower than 1st gen (600 µW)





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Conclusions

- Electrostatic energy harvesters with electret show high power output → up to 600µW
- Shock excitation in tire delivers sufficient power for TPMS
- Robustness improved with flexible stoppers
- Improved wafer level bonding with SU-8
  - Better bond and hermiticity (lower damping losses)
- Next step: *integration in a robust TPMS module*

Devices are very promising for integration in TPMS

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