A Novel Accordion-Like Disk Resonator Gyroscope

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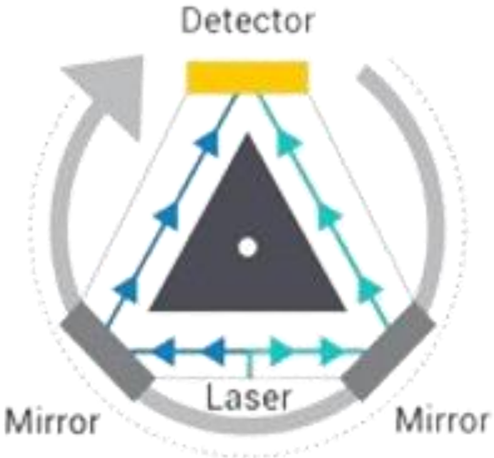
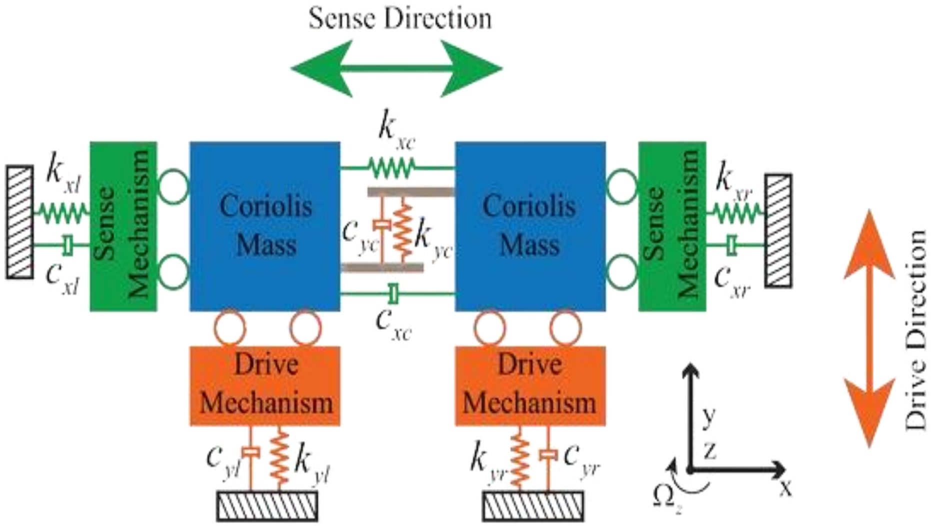
Types of Gyroscopes



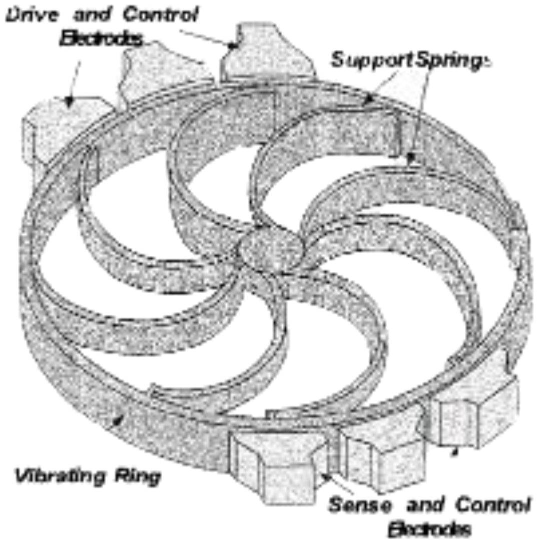
Ring Laser Gyroscope

Image Source: https://www.ceva-ip.com/



Dual Mass Gyroscope

Image Source: https://www.mdpi.com/1424-8220/18/4/1037

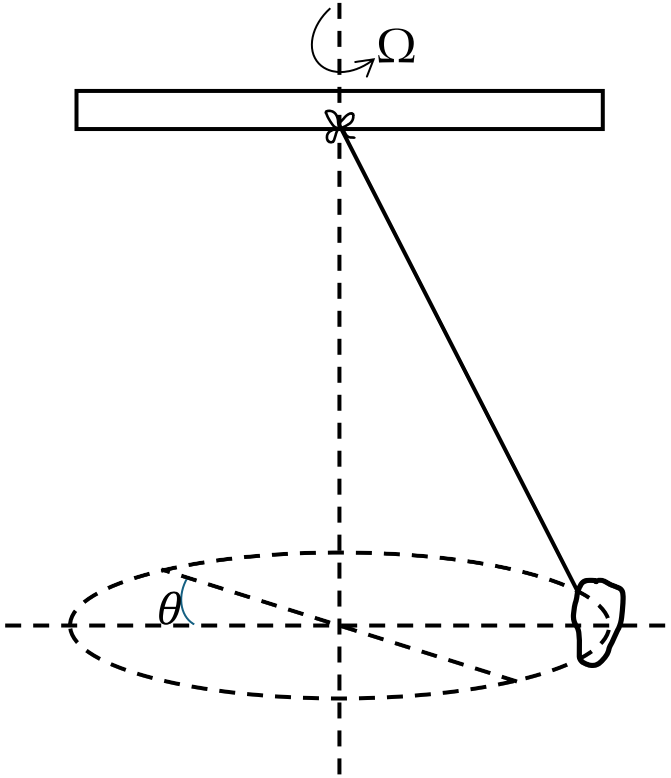


Vibrating Ring Gyroscope

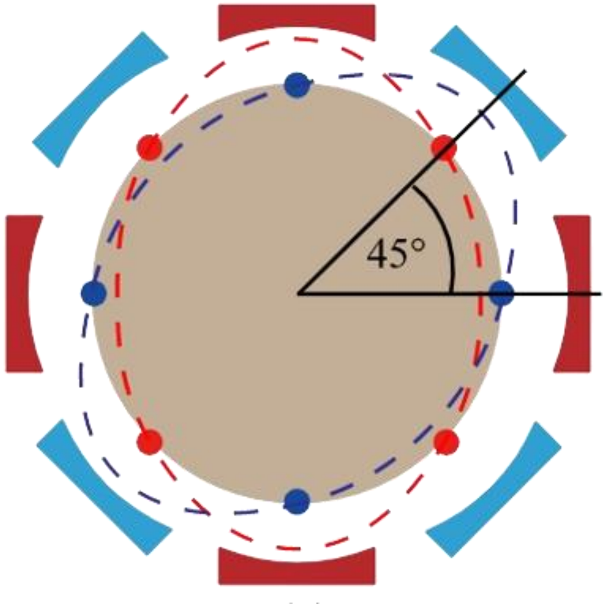
Image Source: https://doi.org/10.1109/MEMSYS.1998.659829

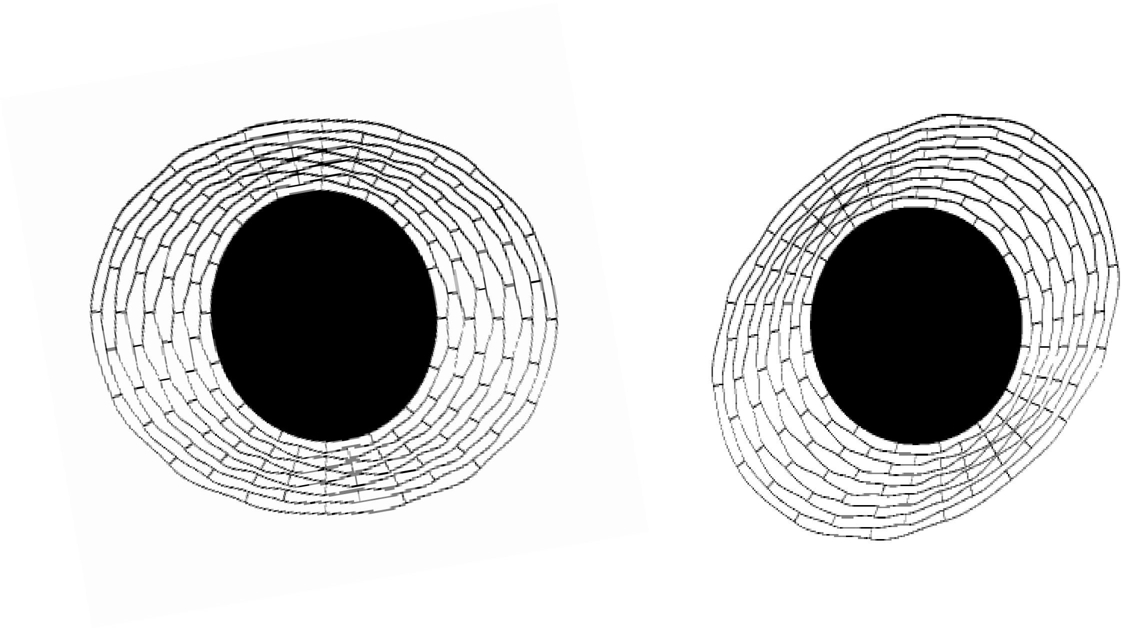
MEMS Gyroscope

Working of Resonating Gyroscope



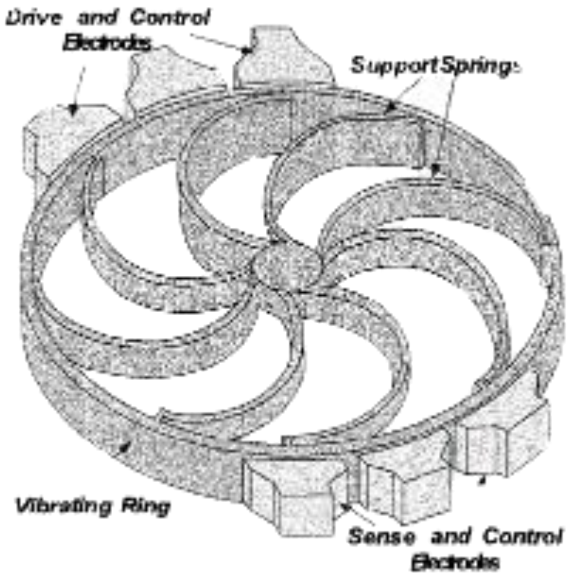
Foucault Pendulum





Coriolis force(F_c) = 2mΩ × Velocity

Vibrating Ring Gyroscopes

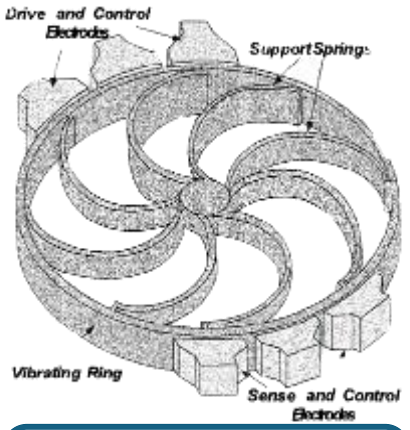


- Design and fabrication of the first polysilicon vibrating ring gyroscope.
- Achieved a sensitivity of 0.04 deg/sec
- Material : Polysilicon

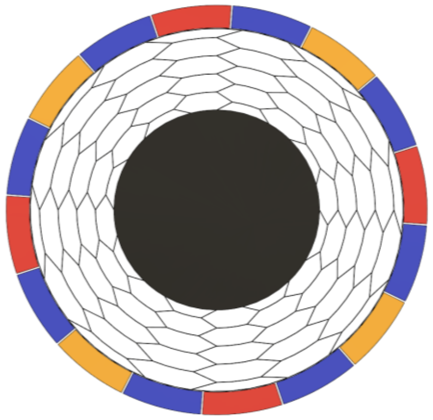
Limitations:
- The number of Sense and Drive Electrodes.
- The spoke design prevents the use of internal electrodes.

Polysilicon Vibrating Ring Gyroscope (1998)

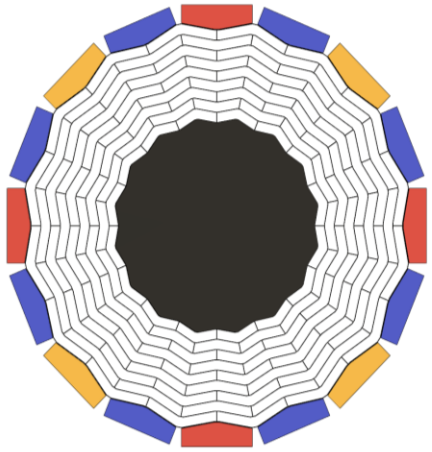
History of MEMS Gyroscope



Polysilicon Vibrating Ring
Gyroscope (1998)
0.04 deg/sec

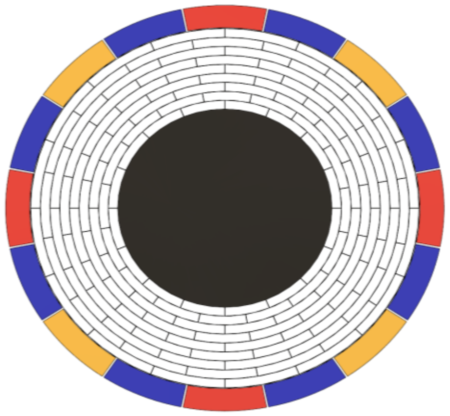


Honeycomb Disc Resonator
Gyroscope (2017)
0.015 deg/sec

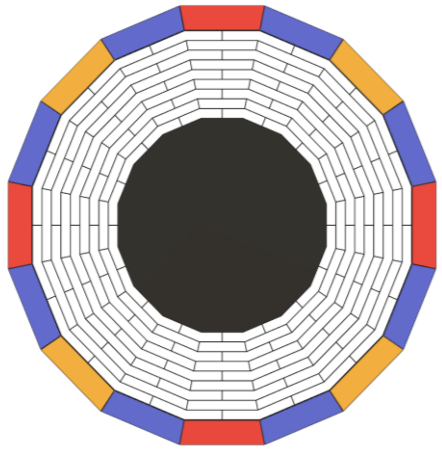


Gear Disc Resonator
Gyroscope (2021)

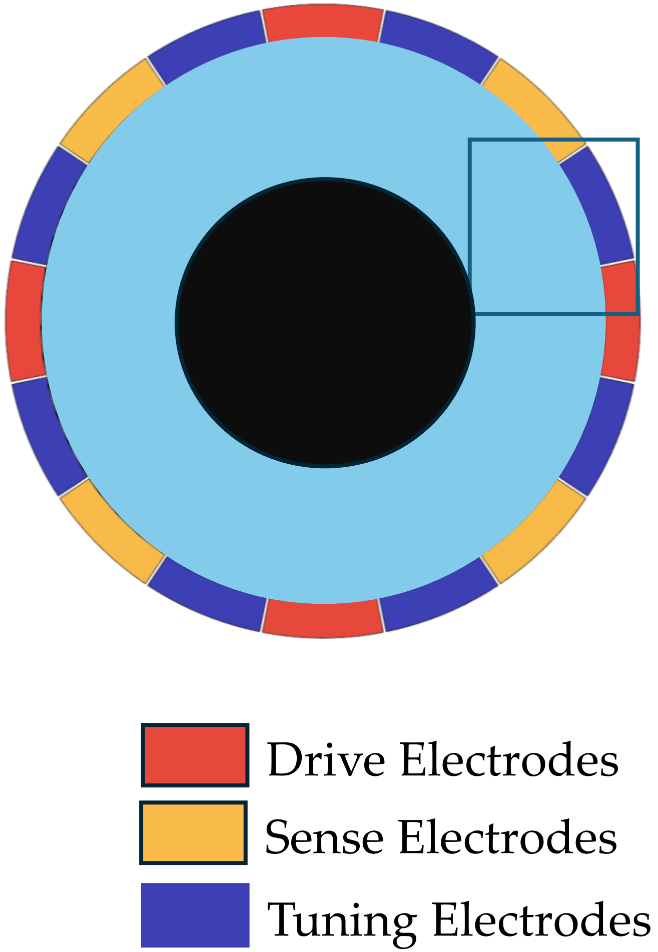
Boeing Disc Resonator
Gyroscope (2014)
0.016 deg/sec

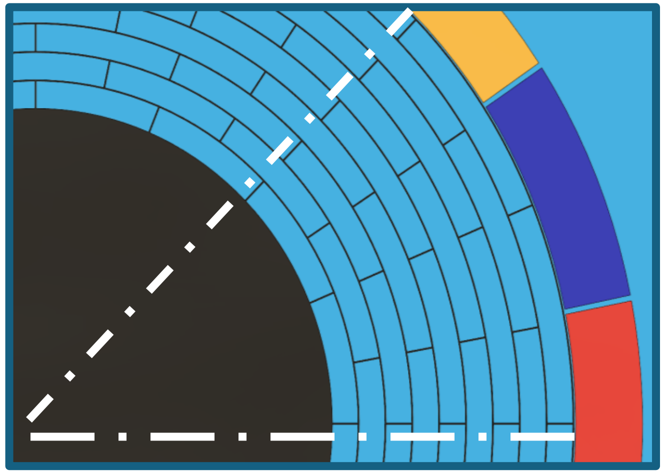


Cobweb Disc Resonator
Gyroscope (2019)

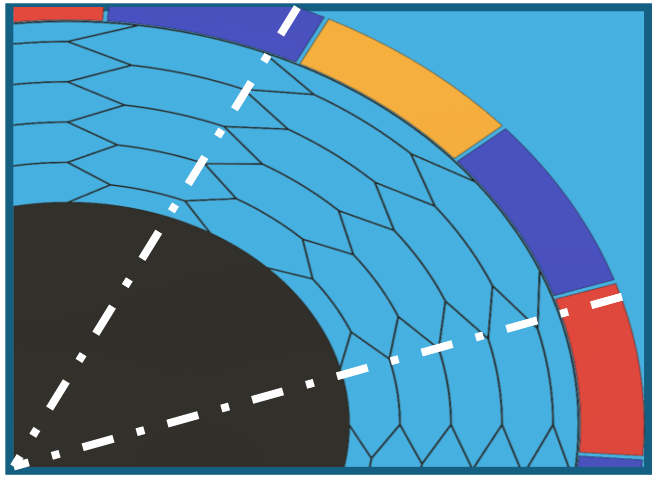


Types of Disk Resonating Gyroscopes

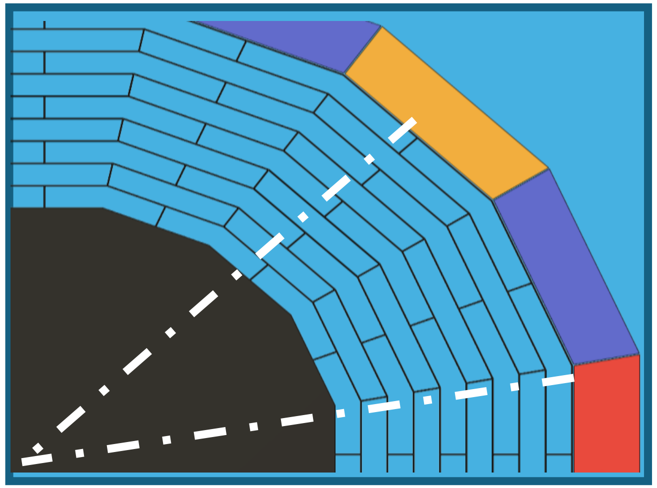




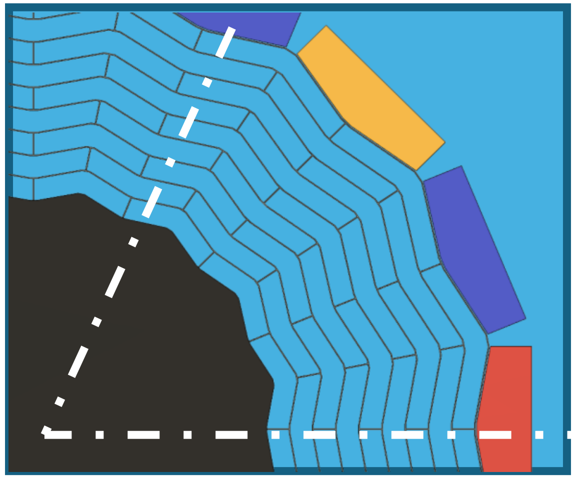
Boeing Disk Resonating Gyroscope- 2014
0.016 deg/sec



Honeycomb Disk Resonating Gyroscope- 2017
0.015 deg/sec

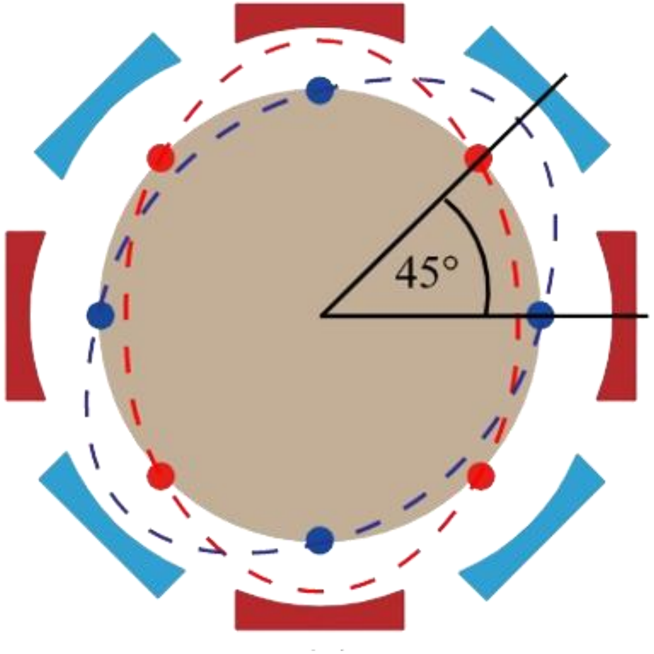


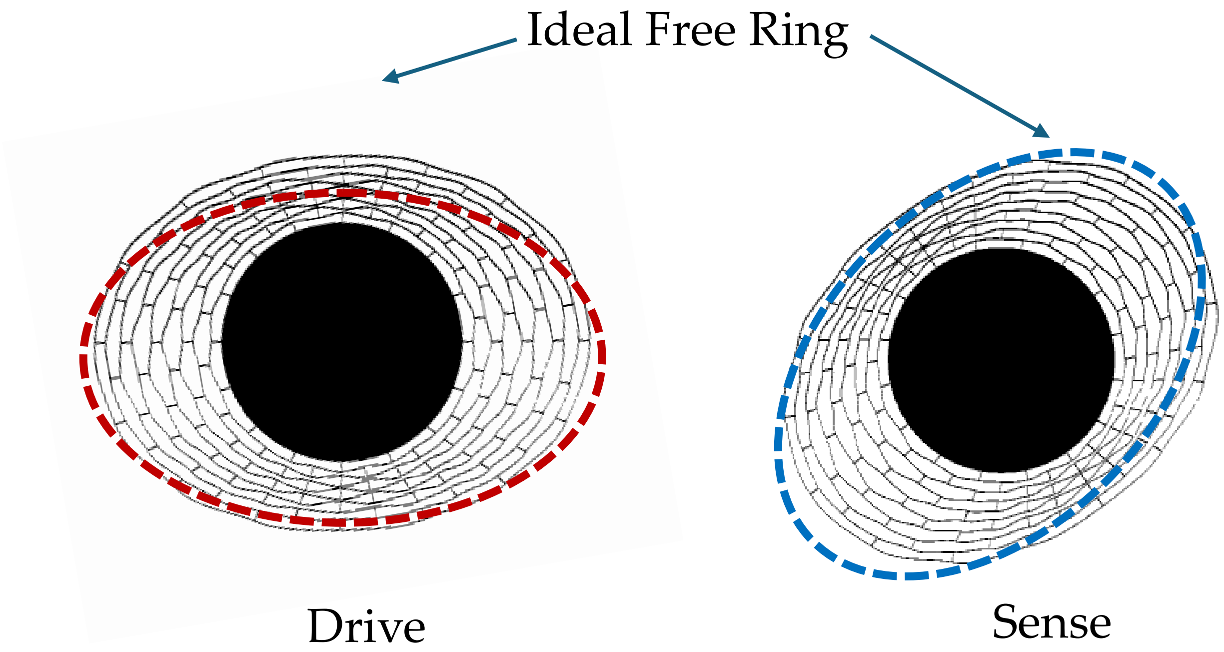
Cobweb Disk Resonating Gyroscope- 2019



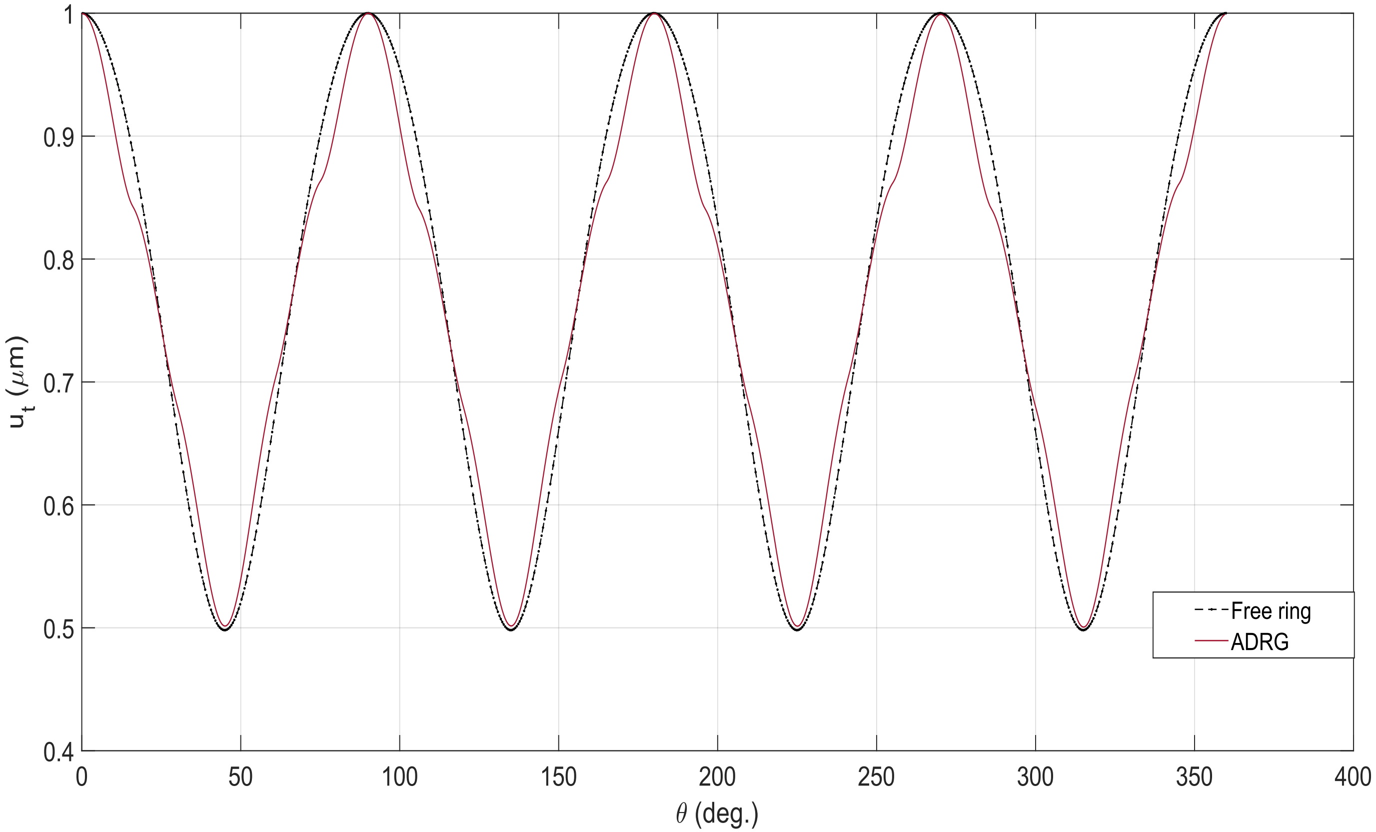
Gear Disk Resonating Gyroscope- 2021

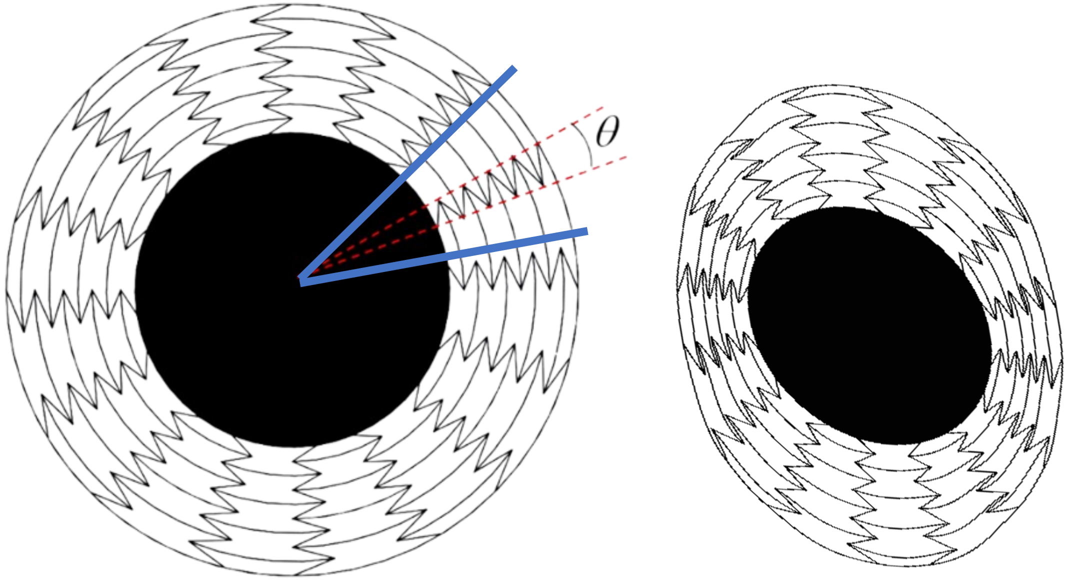
Approach





Design Methodology

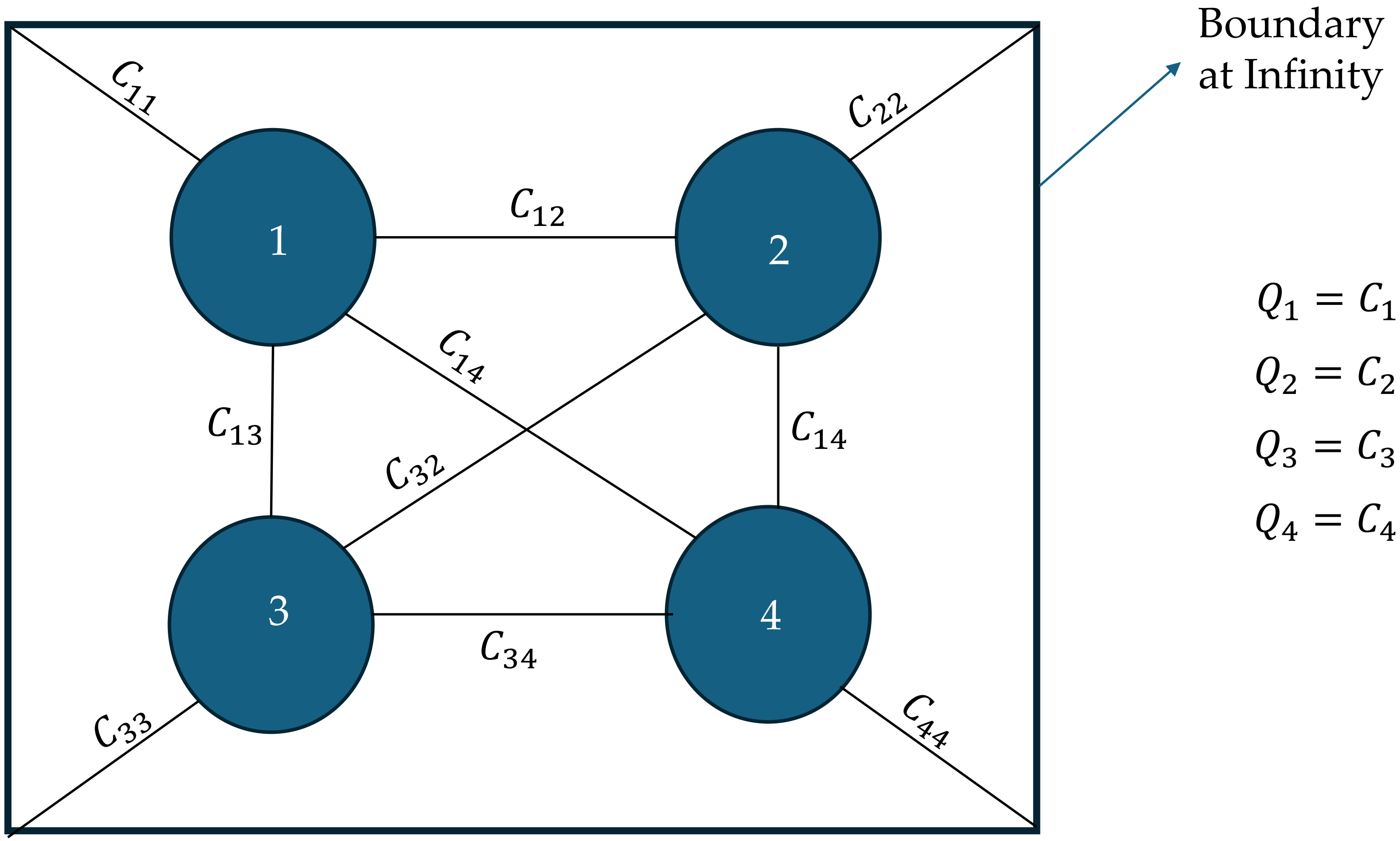




ADRG

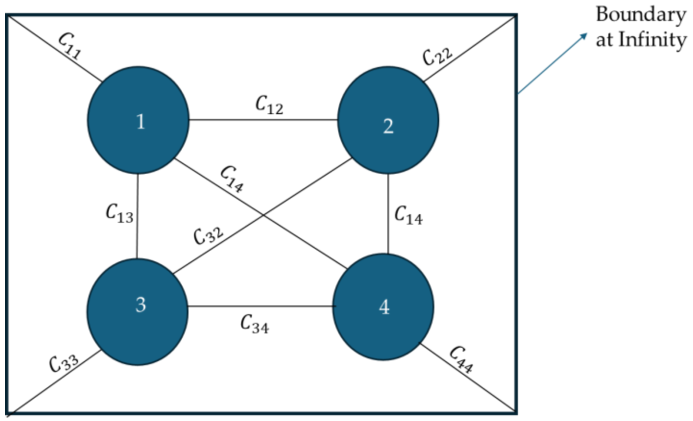
A for accordion

Capacitance of Multiple Bodies



$$Q_1 = C_{11}V_1 + C_{12}V_2 + C_{13}V_3 + C_{14}V_4$$
$$Q_2 = C_{21}V_1 + C_{22}V_2 + C_{23}V_3 + C_{24}V_4$$
$$Q_3 = C_{31}V_1 + C_{32}V_2 + C_{33}V_3 + C_{34}V_4$$
$$Q_4 = C_{41}V_1 + C_{42}V_2 + C_{43}V_3 + C_{44}V_4$$

Capacitance of Multiple Bodies Continued



$$where\ V_{ij} = V_i - V_j$$

$$Substituting\ it\ in\ the\ above\ equations\ we\ get:$$

$$Q_1 = C_{11}V_1 + C_{12}(V_1 - V_2) + C_{13}(V_1 - V_3) + C_{14}(V_1 - V_4)$$

$$\vdots$$

$$Q_4 = C_{41}(V_4 - V_1) + C_{42}(V_4 - V_2) + C_{43}(V_4 - V_3) + C_{44}(V_1)$$

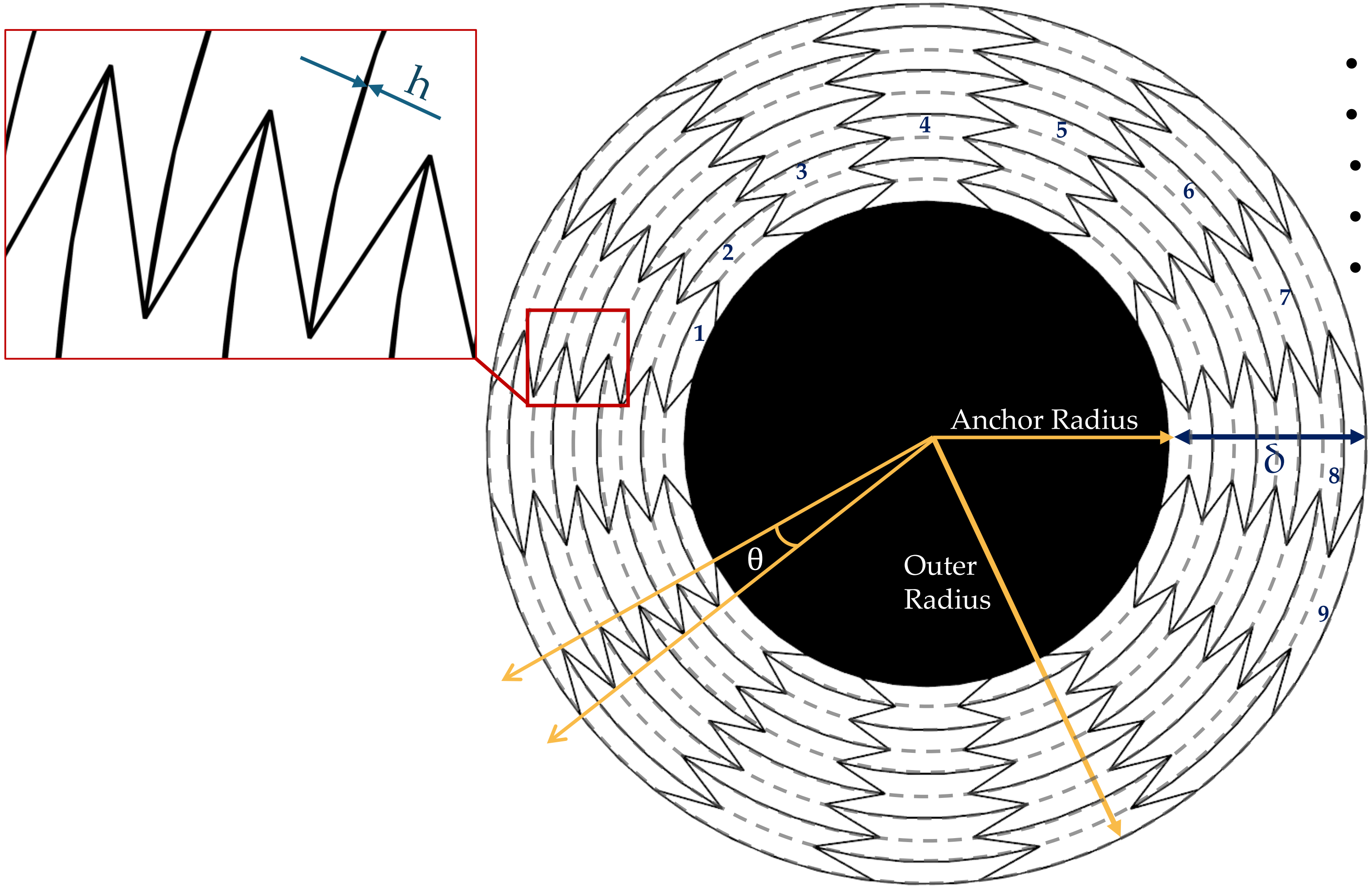
$$Rearranging\ the\ above\ equations\ into\ the\ matrix\ of\ the\ form:$$

$$\begin{pmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{pmatrix} = \begin{bmatrix} C_{11} + C_{12} + C_{13} + C_{14} & -C_{12} & -C_{13} & -C_{14} \\ -C_{12} & C_{21} + C_{22} + C_{23} + C_{24} & -C_{23} & -C_{24} \\ -C_{31} & -C_{32} & C_{31} + C_{32} + C_{33} + C_{34} & -C_{34} \\ -C_{41} & -C_{42} & -C_{43} & C_{41} + C_{42} + C_{43} + C_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

Capacitance Comparison of DRG’s

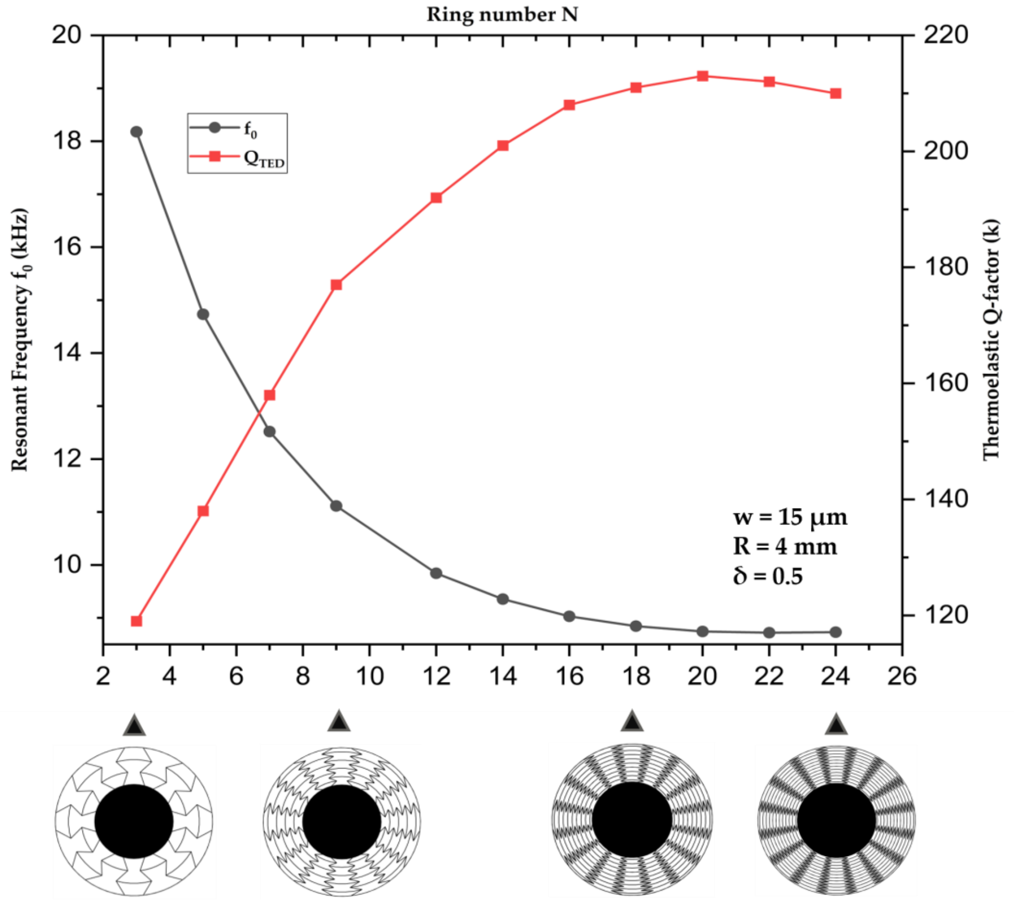
DRG Type	Base capacitance (C_0) in pF	Sense capacitance (ΔC_0) in pF	Relative sense capacitance ($\Delta C_0/C_0$)
DRG	3.32	0.216	14.37037
HDRG	3.6	0.207	16.3913
CDRG	3.42	0.125	26.36
GDRG	3.8	0.125	29.4
ADRG	5.93	0.125	46.44

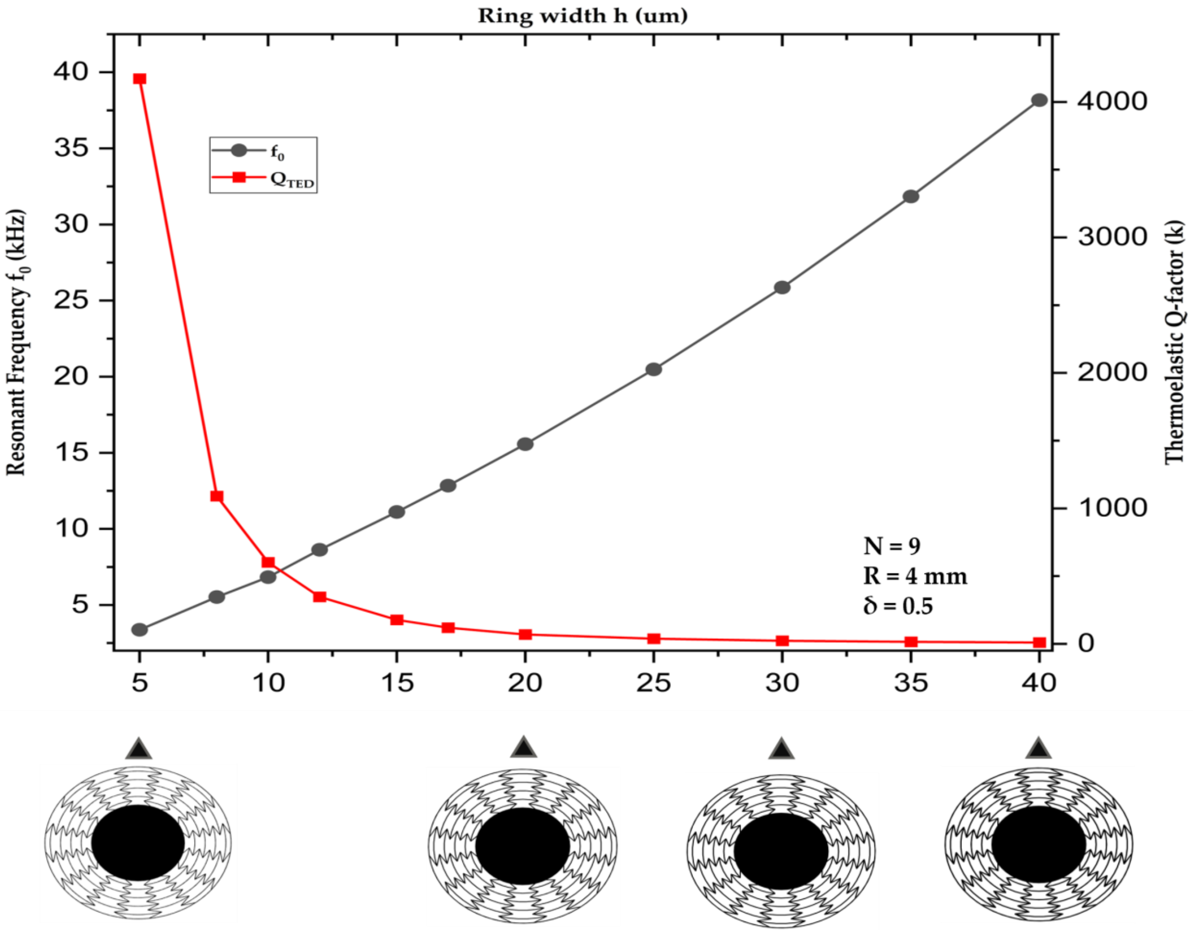
Improving Mechanical Parameters



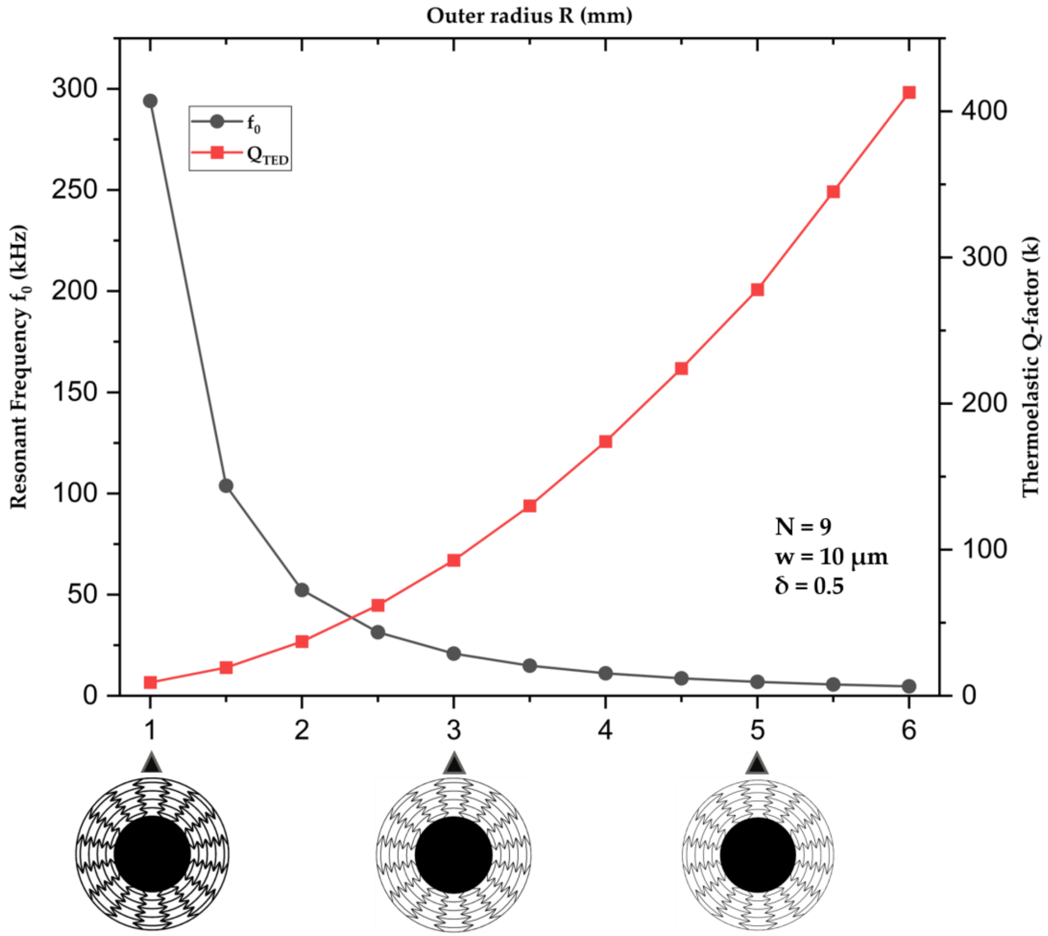
- Ring Number (N): 1-9
- Ring Width (h)
- Outer Radius (R)
- Anchor Radius to Outer Radius (AOR) (δ)
- Spoke Angle (θ)

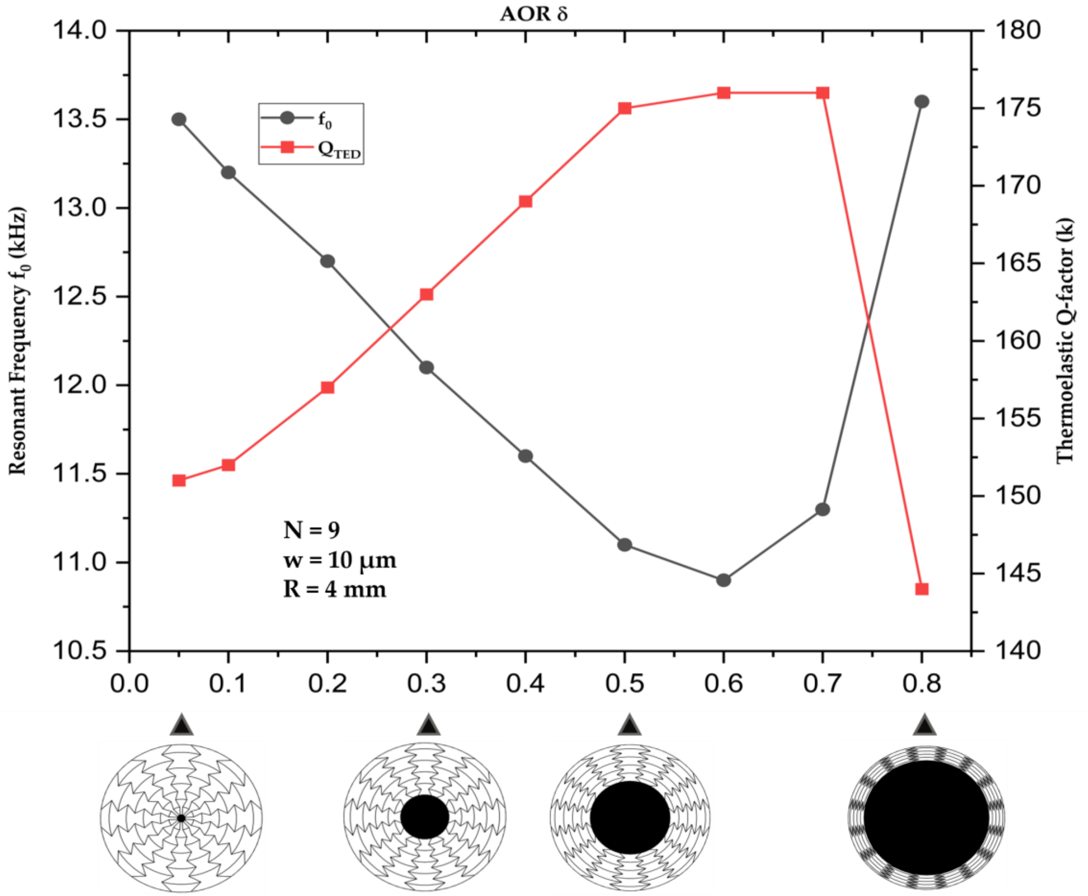
Selection of Parameters





Selection of Parameters

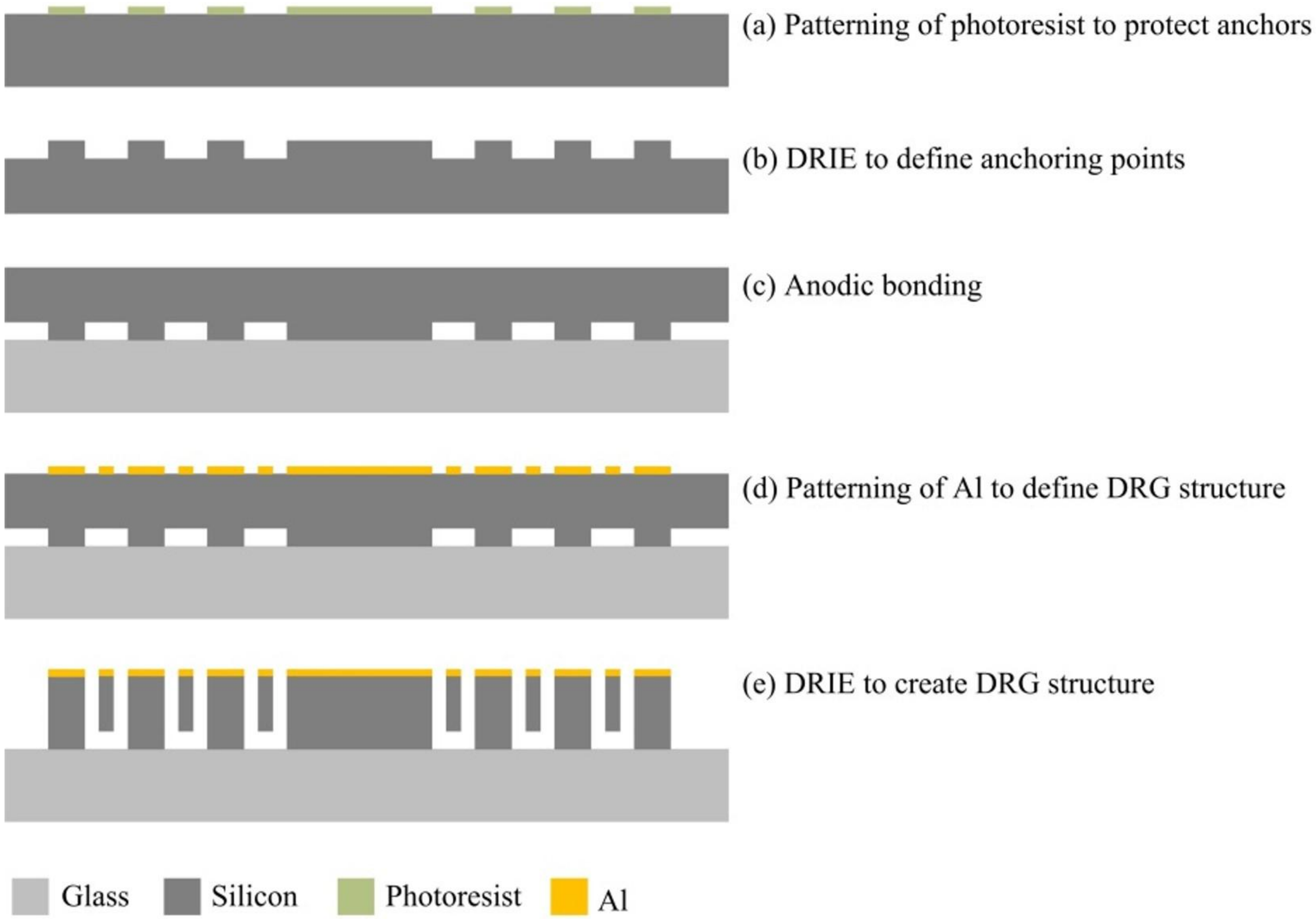




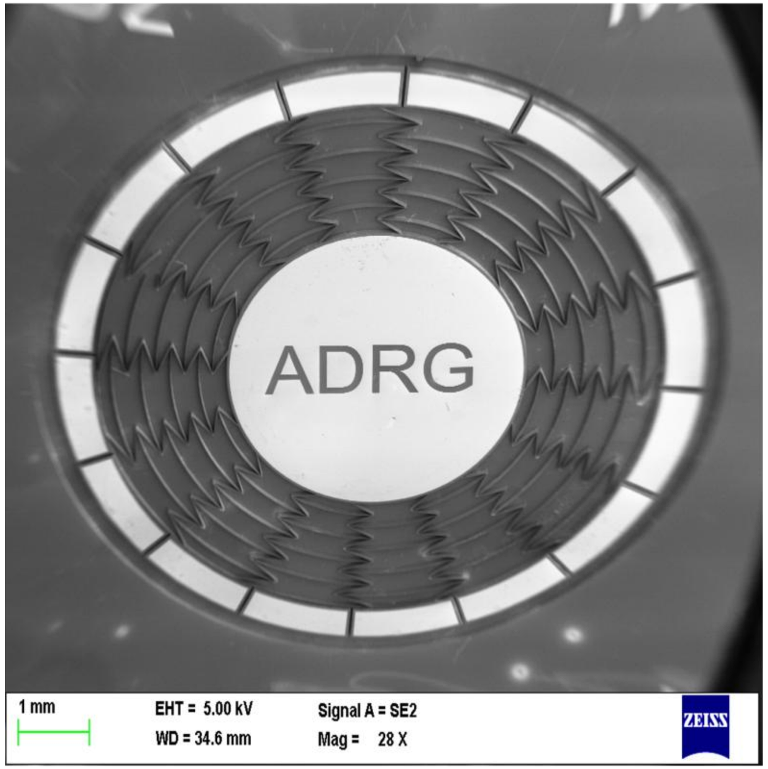
Comparing the various DRG's

DRG Type	Eigenfrequency in Hz	Thermo-elastic quality factor in k	Mechanical sensitivity (S_{mech}) in µm/(rad/sec)	Average Brownian Noise (Ω_{mech}) in rad/sec/√Hz
DRG	12720	103.62	3.83e-6	1.01e-6
HDRG	11306	105.42	4.27e-6	1.29e-6
CDRG	12611	99.99	3.61e-6	1.12e-6
GDRG	14761	91.58	2.76e-6	1.17e-6
ADRG	6771	181.55	12.1e-6	1.07e-6

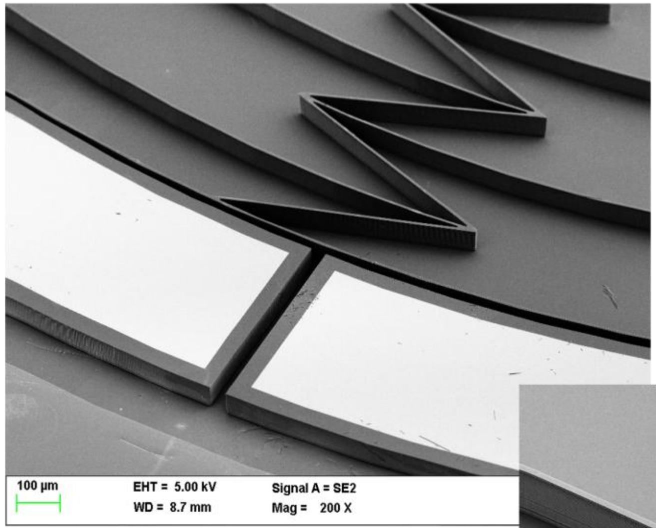
Microfabrication Process



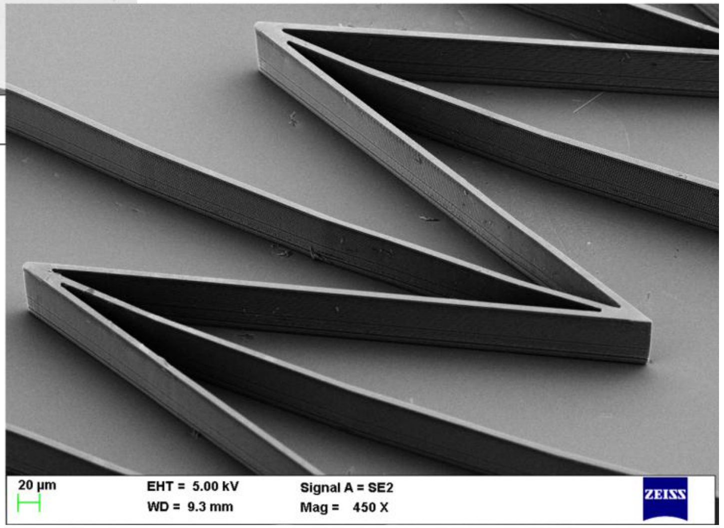
Scanning Electron Microscope (SEM) Images



Accordion-like DRG (ADRG)

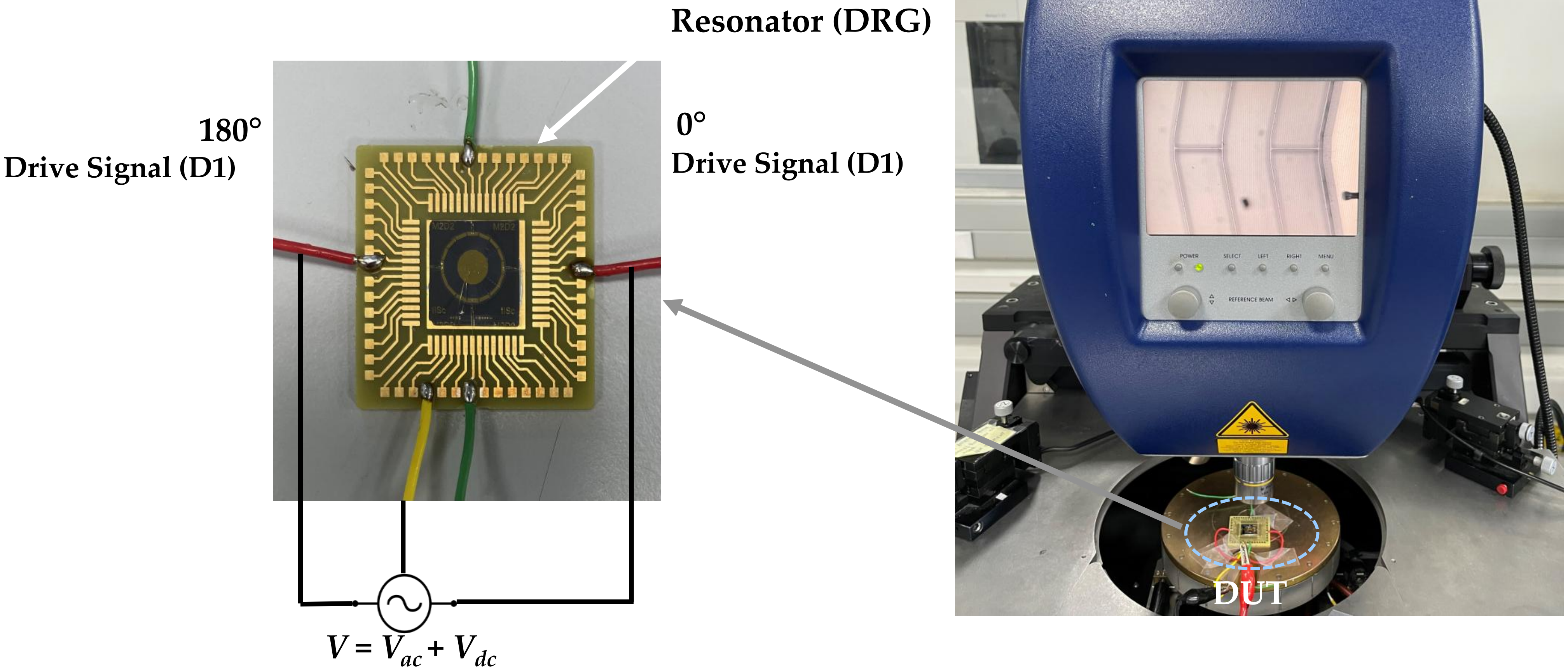


- Device thickness – 60 µm
- Ring width – 10 µm

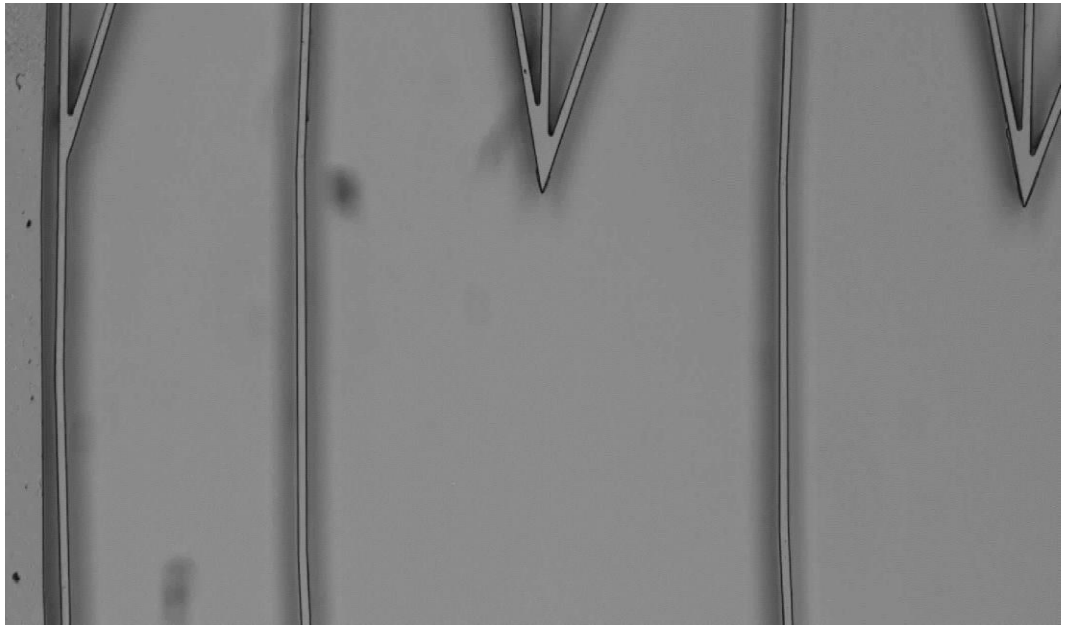


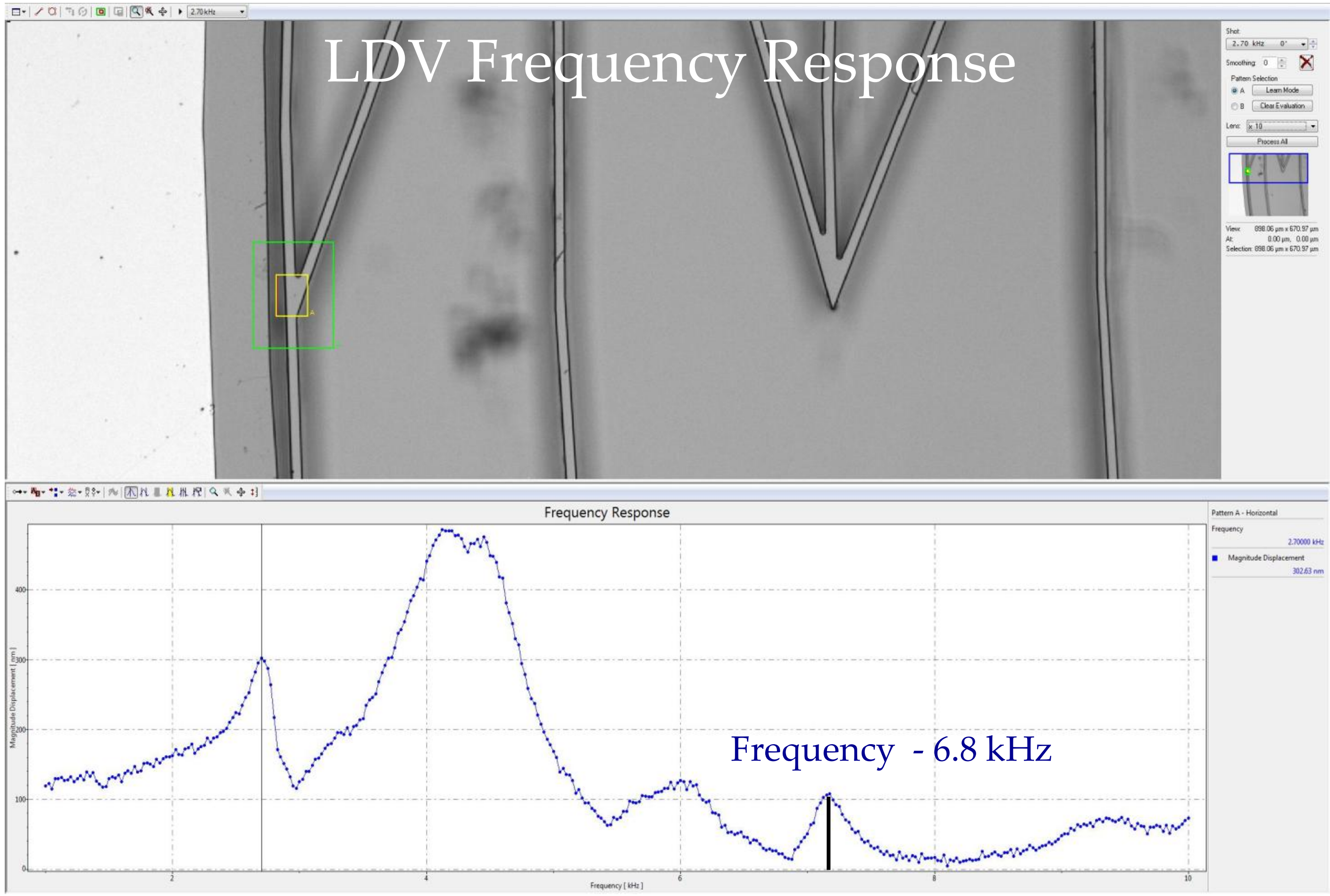
Testing

Measurement setup



Testing




LDV Frequency Response
Frequency Response
Frequency - 6.8 kHz

Summary

- The proposed DRG design(ADRG) was tested under controlled atmospheric conditions (1 atm, 25° C).
- Fabricated ADRG response was found to be in close agreement with FEM results.
- Tested device's eigenfrequency has an error range of 1.2-1.4 %.

Acknowledgement

Guidance: Prof. Ananthasuresh and Karthik(ISRO)

Design and Simulation: Sai Kumar, Suman Acharya

Fabrication: Sudhanshu Shekhar

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