

Modelling of flexible capacitive ultrasonic transducers for medical applications

ICN2^R

R. Pieres¹, E. Masvidal¹, J. A. Garrido^{1,2*}

¹Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, Spain.

²ICREA, Barcelona, Spain.

Motivation

A finite element model was developed to validate the physical feasibility of flexible polyimide-based CMUTs and enable application-specific design by tuning their natural oscillation frequencies.

Current Ultrasound probes

Flexible Ultrasound (FLEXUS)

COMSOL Model Setup

CMUT Cross-Section

Meshing Strategy

Geometrical Parameters

2D Axisymmetric Revolution (315° view)

Parameter	Value	Description
R	$25\text{ }\mu\text{m}$	Radius of the device
t_b	$2.5\text{ }\mu\text{m}$	Bottom dielectric layer
$t_{e,\text{bot}}$	100 nm	Bottom electrode thickness
$t_{p,\text{bot}}$	200 nm	Passivation between cavity and bottom electrode
t_c	200 nm	Cavity thickness
$t_{p,\text{top}}$	200 nm	Passivation between top electrode and cavity
$t_{e,\text{top}}$	100 nm	Top electrode thickness
t_{mem}	$2.5\text{ }\mu\text{m}$	Top plate thickness
$r_{\text{elec,end}}$	$R\left(1-\frac{1}{5}\right)$	End position of the ground electrode
$r_{\text{cav,end}}$	$R\left(1-\frac{1}{6}\right)$	End position of the cavity

Results and Discussion

Stationary Analysis: Pull-In, Pull-Out Voltage Extraction and Membrane Displacement Theoretical Pull-In Validation

Physical Validation: Von Mises Stress and Dielectric Breakdown

Eigenfrequency Analysis: The Spring Softening Effect

Prestressed Voltage Frequency Perturbation Analysis: The Impedance Resonance and Antiresonance Peaks

Parameter Extraction

Parameter	Initial Value	Optimized Value
k_{eff} [N/m]	16088.45	15110.24
m_{eff} [kg]	2.335×10^{-11}	2.191×10^{-11}
d_m [N·s/m]	1.294×10^{-5}	1.758×10^{-5}

$V_{DC} = 5\text{ V}$
 $V_{AC} = 1\text{ V}$

$V_{DC} = 5\text{ V}$
 $V_{AC} = 1\text{ V}$

$V_{DC} = 5\text{ V}$
 $V_{AC} = 1\text{ V}$

$\Phi = 0.788\text{ }\mu\text{C/m}$

Parameter	Mason's Model Calculation	Optimized BVD Value	Relative Error
L_m [H]	35.26	35.93	$\approx 1.8\%$
C_m [F]	4.111×10^{-17}	4.035×10^{-17}	$\approx 1.8\%$
R_m [Ω]	2.829×10^7	2.842×10^7	$\approx 0.4\%$

Parameter	Initial Value	Optimized Value
L_m [H]	78.612	35.931
C_m [F]	1.844×10^{-17}	4.035×10^{-17}
R_m [Ω]	2.841×10^7	2.842×10^7
C_0 [F]	3.854×10^{-14}	3.852×10^{-14}

Conclusions

- Pull-In Voltage Validation: Simulated pull-in voltage using an inverse displacement-controlled solver, validating it against the theoretical $d_{\text{eff}}/3$ value.
- Dynamic Analysis: Successfully conducted eigenfrequency analysis and modeled the spring-softening effect.
- Physical Safety: Confirmed the structural validity of the device through the Von Mises Stress and dielectric breakdown analysis.
- High-Precision Modeling: Achieved a negligible relative error (less than 2%) when mapping mechanical variables into the electrical domain via Mason's ideal transformer compared to the BVD model.
- Future Impact: Proves the viability of flexible CMUTs, providing a foundation for fluid-coupled vibroacoustic optimization and the fabrication of arrays for continuous, deep-tissue medical imaging.

Acknowledgments & References

Action funded by Grant CEX2021-001214-S, MICIU/AEI/10.13039/501100011033

Contact person

Roger Pieres Termes, roger.pieres@icn2.cat, PhD Student
Advanced Electronic Materials and Devices group, ICN2