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DESIGN OF MEMS BASED HIGH SENSITIVITY AND FAST RESPONSE CAPACITIVE HUMIDITY SENSOR

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Objectives of the research:

1. To model a parallel plate **capacitive humidity Sensor** structure.
2. To state the **theoretical background** required to tackle transient response modelling.
3. To Simulate the sensor model using **Comsol Multiphysics**®
4. Use **Finite Element Method** to find the optimal geometrical dimensions for fast response time and high sensitivity.

Requirements of humidity sensor

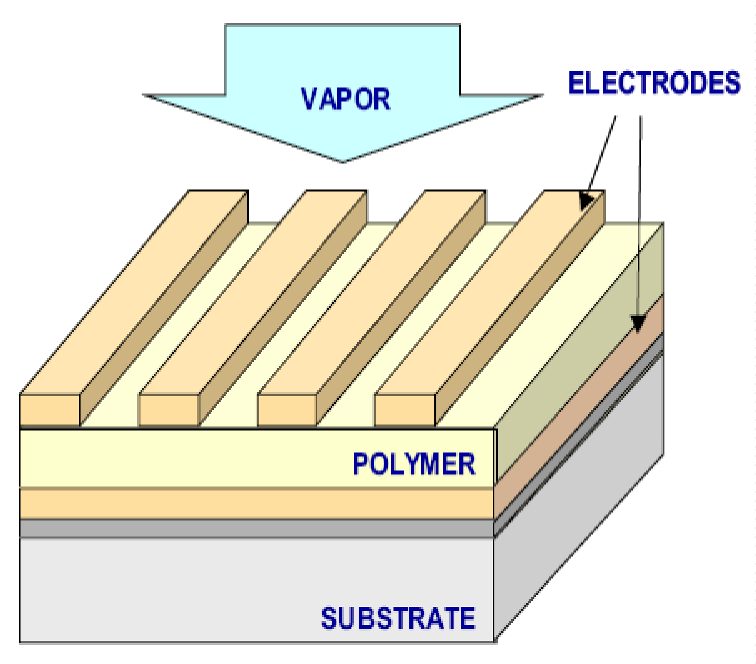
- Fast **response time** and high sensitivity.
- The mean duration of a forced exhalation is about 3 sec, the typical response time of commercially available humidity sensors is about 100 ms.
- This humidity sensor is expected to exhibit a short response time, ideally **much less than 30 ms** and sensitivity in the range of nF/%RH.

Types of humidity sensor

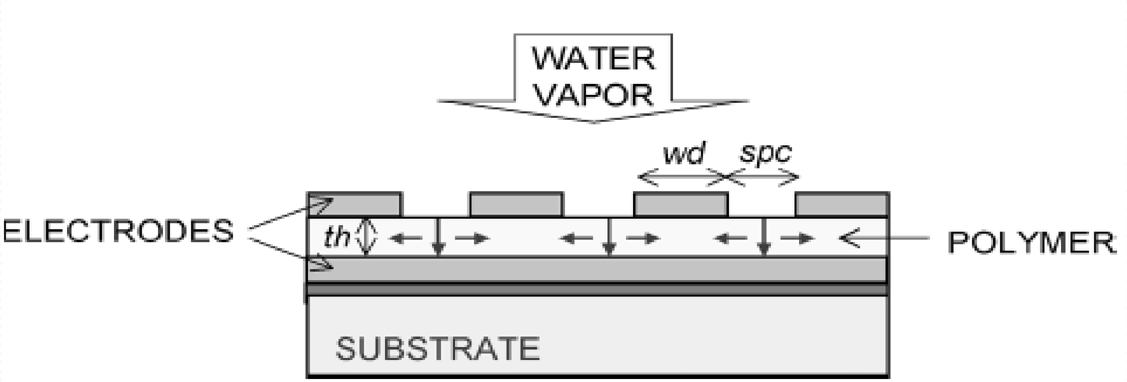
Types / properties	Capacitive	Resistive	Displacement
RH range	0-100% possible	Only at higher RH range	Fair below 25%
Sensitivity	High even at low RH	moderate at low RH	Low at low RH
Temperature range	Up to 200ºc	-40ºc to 100ºc	10ºc to 100ºc
Response time	Fast	Moderate	Moderate
Resistive to other contamination	High due to film coating	Low	Low
Accuracy	±2%	±2%	±4%
Hysteresis	Minimum	Comparatively More	More

Structure of the proposed sensor

- The sensor is a parallel plate capacitor with the sensitive layer.
- Sensitive layer is sandwiched in between the electrodes.
- The lower electrode is a full plate, the upper electrode is a grid which allows the vapour to penetrate into the sensitive layer.



Working principle:



- When water vapour blows over the surface, it is adsorbed on the surface.
- Then the adsorbed molecules diffuse in the polymer inducing a variation of its permittivity.
- The variation in permittivity causes variation in capacitance

$$C= \varepsilon_0\varepsilon_r A/T$$

Theoretical modeling

Relative Humidity:

$RH\ \% = P_a / P_s$

P_a - absolute vapour pressure P_s - saturation vapour pressure

By determining $\mathbf{P_s}$ at particular temperature, we can derive P_a for various humidity.

P_a can be converted to concentration by using the formula

$kg/m^3 = 0.02166 * P_a / (t+273.16)$ derived from $PV=nRT$

To get in $mols/m^3$ divide the equation by 18.02 which is the molecular weight of water vapour

Diffusion modeling:

$$\partial c/\partial t = D\partial^2 c/\partial x^2$$

Permittivity of sensing film:

$$\Delta\varepsilon_r = \varepsilon_{r(RH)} - \varepsilon_{r(0)}$$

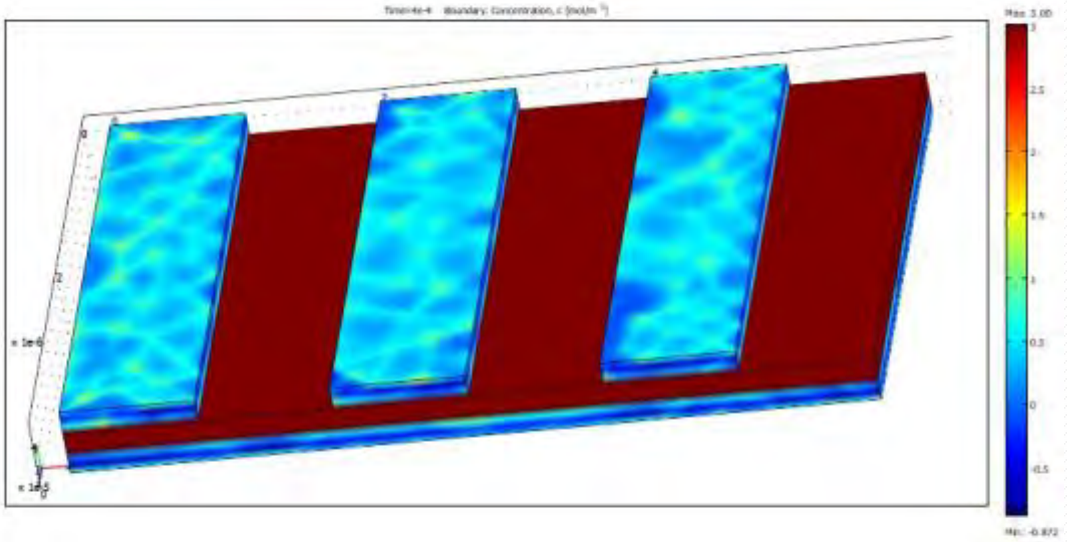
Capacitance modeling:

$$\Delta\Gamma = \Delta\varepsilon_r\varepsilon_0 A / th$$

Geometrical modeling

Parallel plate consist of upper electrode and a lower electrode, lower electrode in the inform of grid with a sensitive layer is in between them which act as dielectric.

- Electrode plates width – 20µm
- Spacing between plates - 20µm
- Thickness of plates - 1µm
- Thin film thickness - 1.5µm(DVS- BCB)

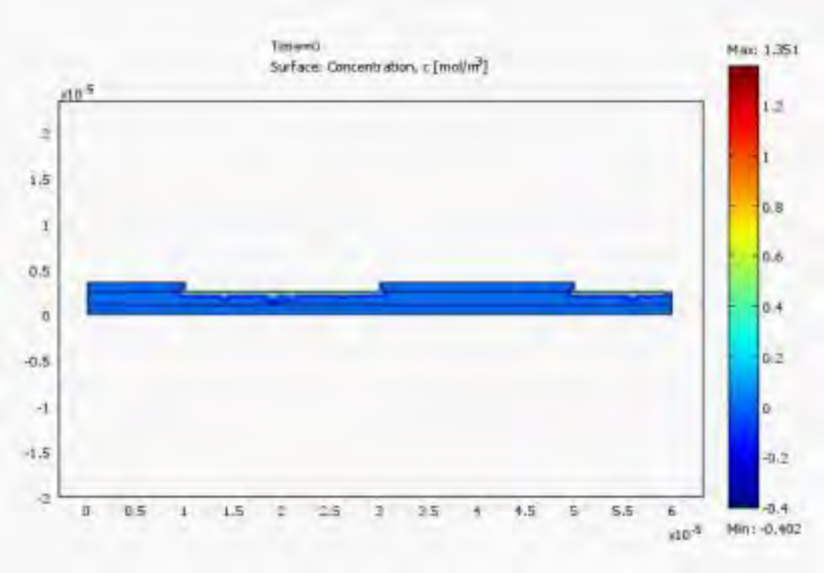


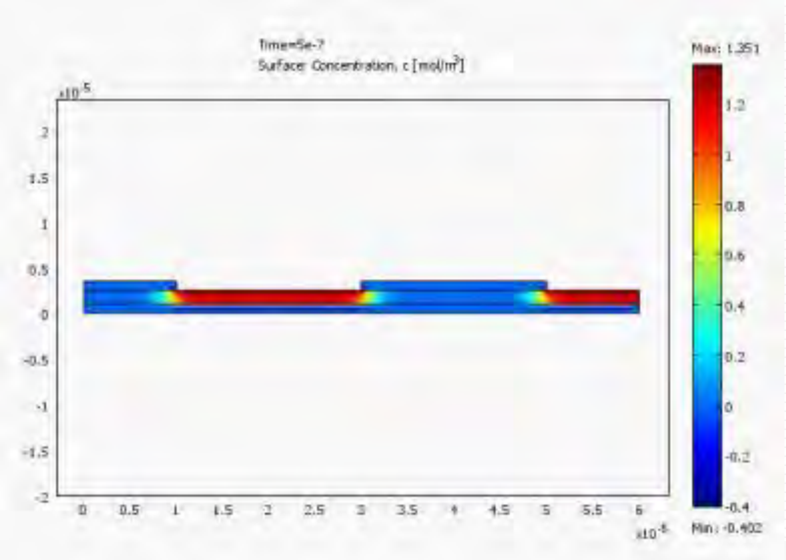
Test Structure

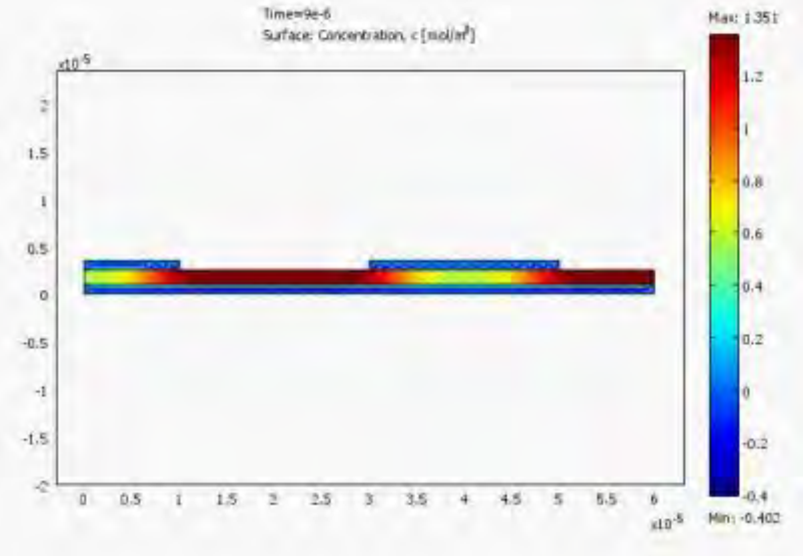
The resulting test structure consists of

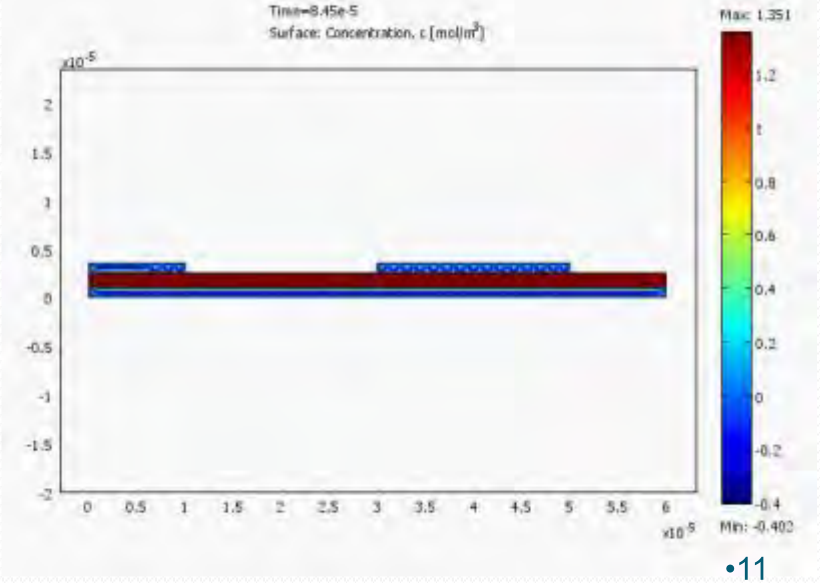
1. Thin film thickness – 1.5 µm
2. Thin film – DVS – BCB
3. Electrode plate thickness – 1 µm
4. Response time – 18 ms
5. Desorption time - 2.4 ms
6. Sensitivity – 0.8pf

Diffusion in 2-dimension



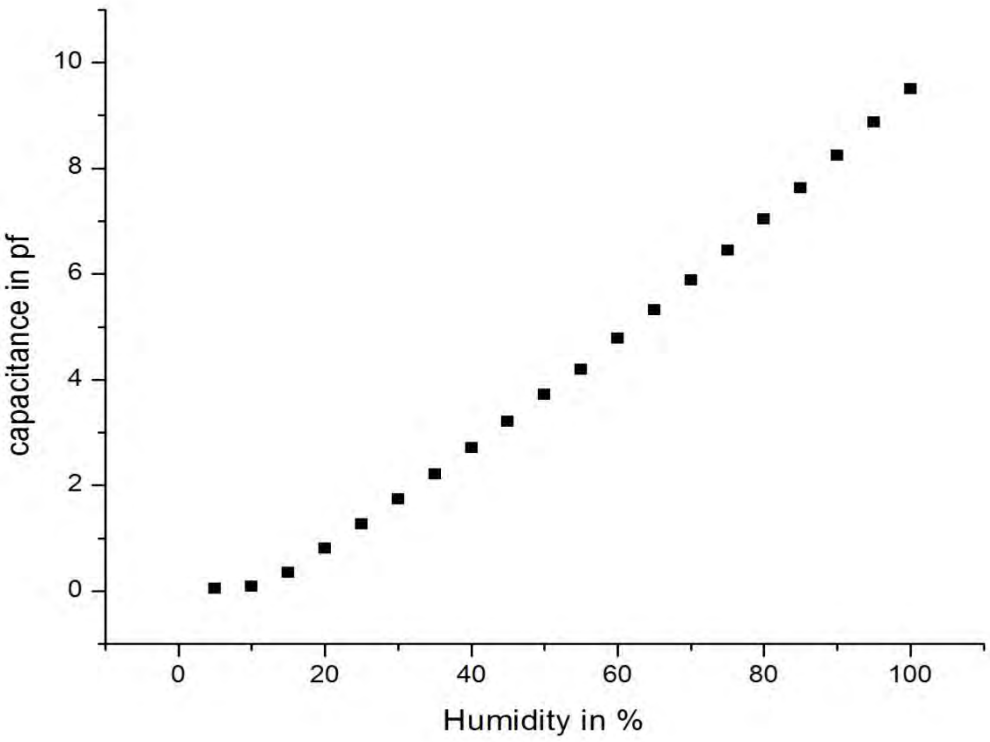






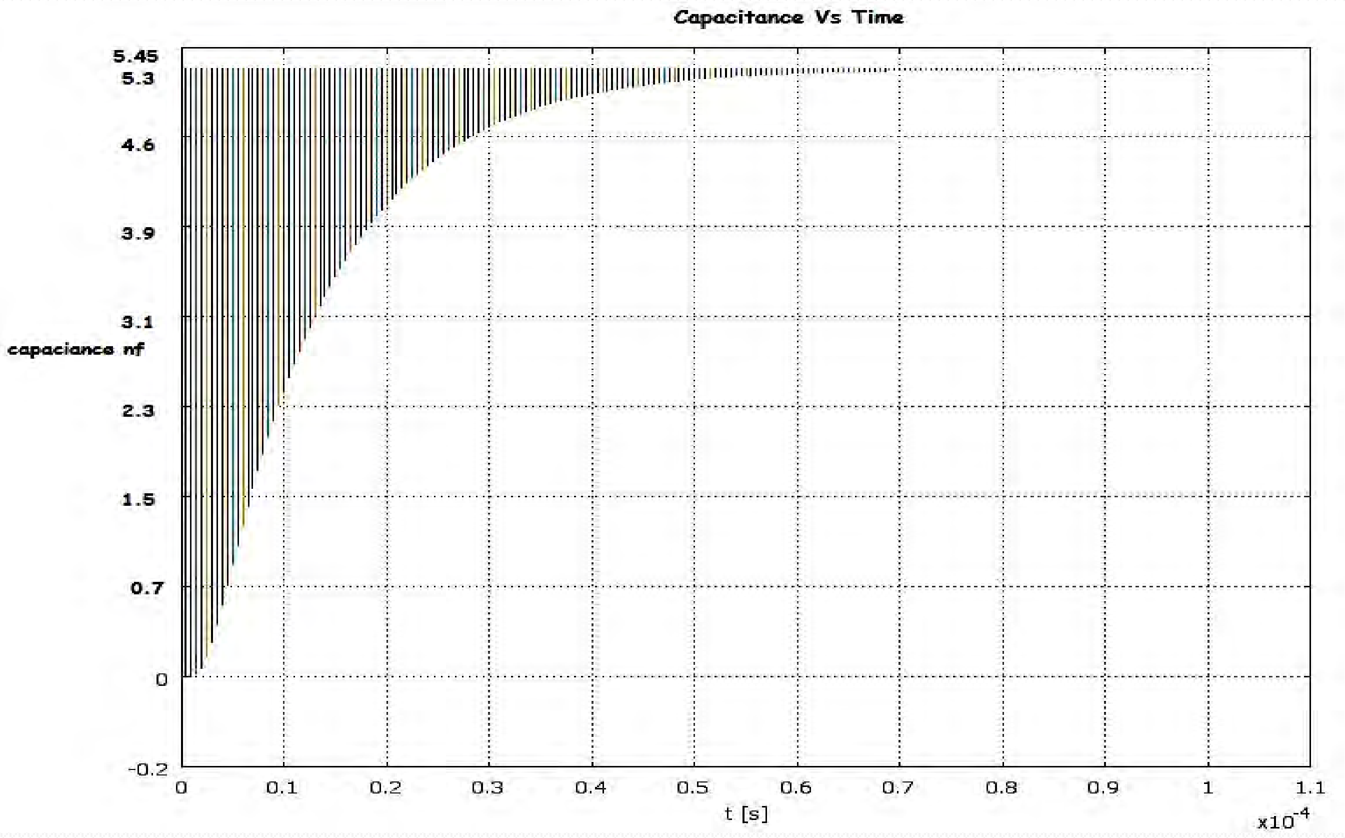
Capacitance Vs Humidity

At 26ºc with ∆RH 100%



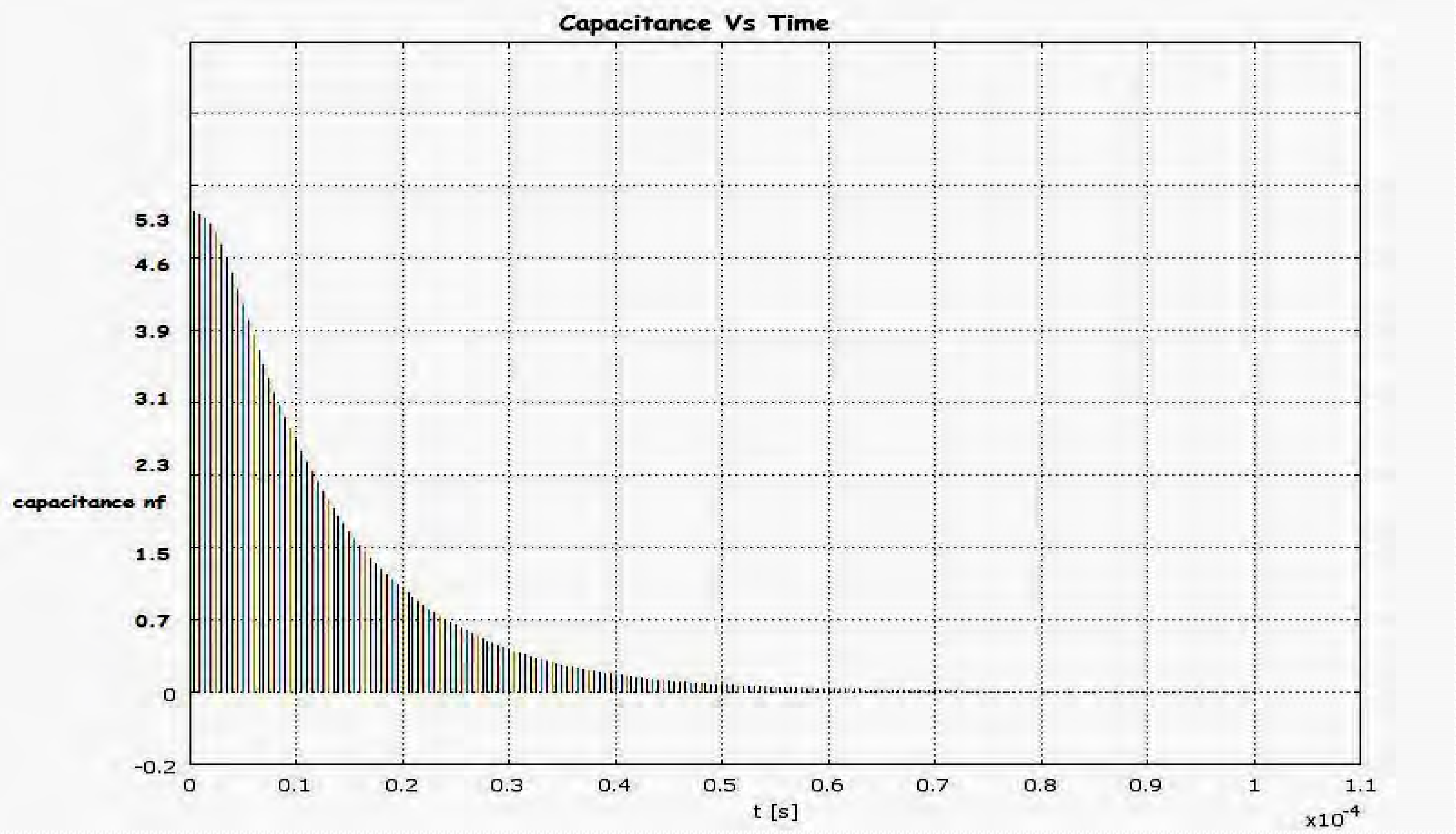
Capacitance Vs Time in absorption

At 26^{o}c with ΔRH 100%



Capacitance Vs Time in desorption

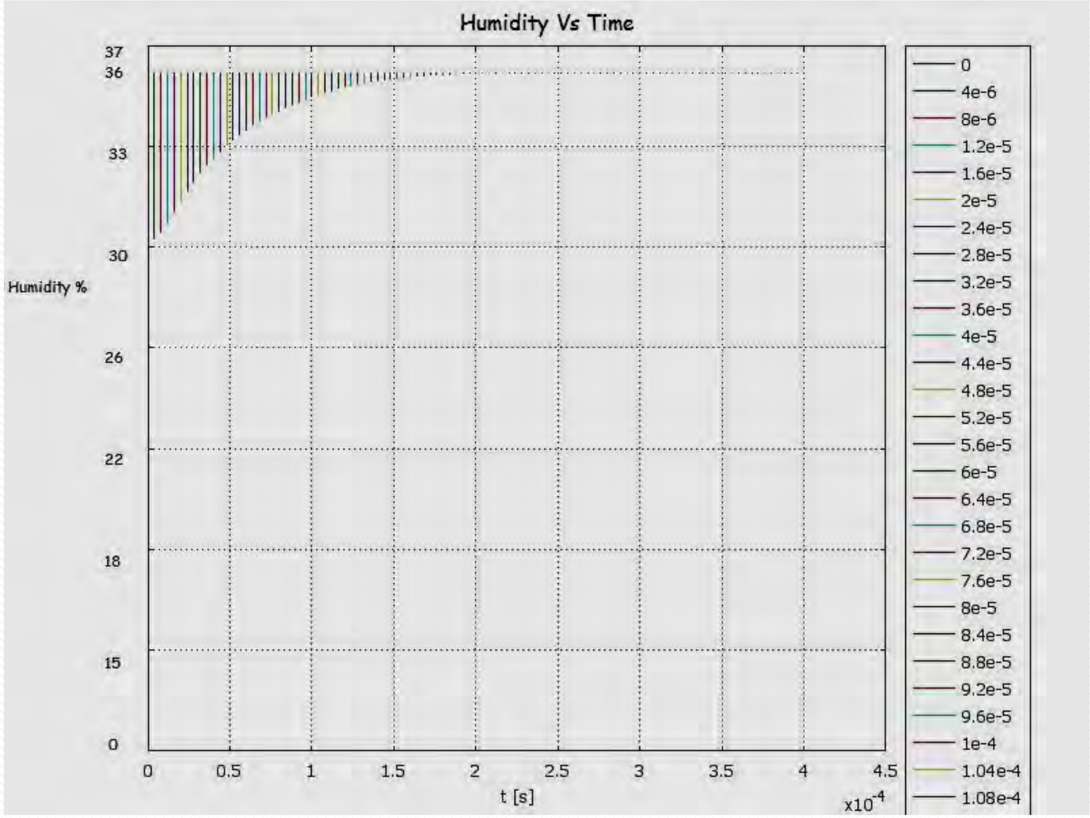
At 26ºc with ΔRH 100%



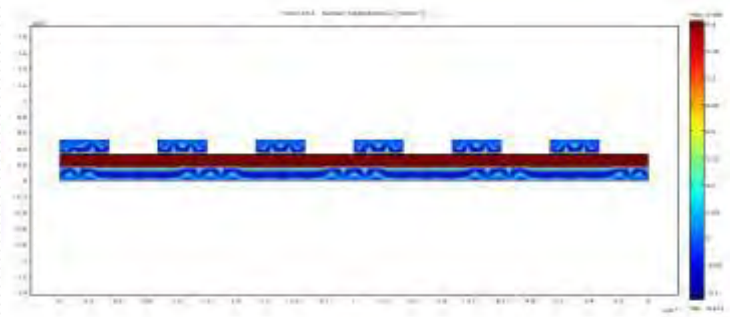
Choosing the best polymer

polymers	Diffusivity μm^2 / s	Concentration mols	Time sec
DVS-BCB	**4.5 e-6**	**2.4374e-15**	**0.003**
PDMAA	8.7 e-10	1.7 340e-15	0.03
PDMAEMA	10 e-10	1.7783 e-15	0.03
PAA	3.5e-10	1.5023 e-15	0.03
PHEMA	32 e-10	1.4841 e-15	0.03
POLYVINLY ACETATE	11 e-10	1.8103 e- 15	0.03
POLYIMIDE	2.81 e-13	2.0850 e-16	0.03

Measuring small variation in humidity Δ6% at 26 ^{0} c



Optimizing for fast response time



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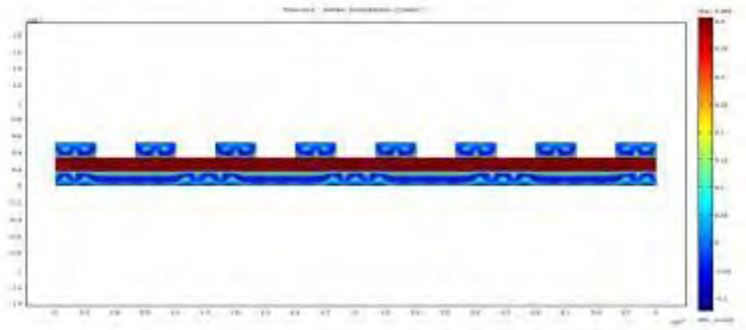

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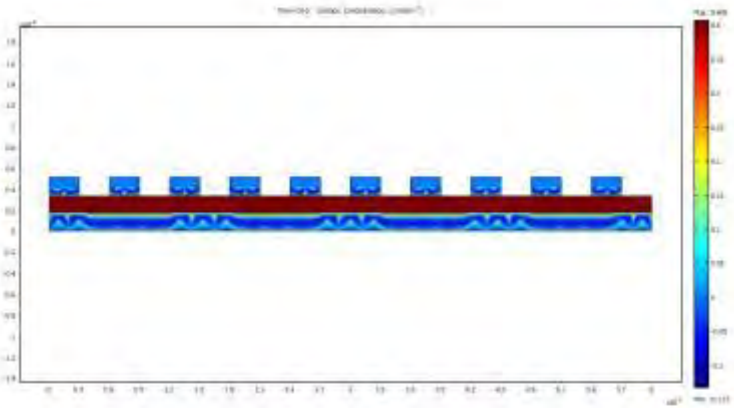

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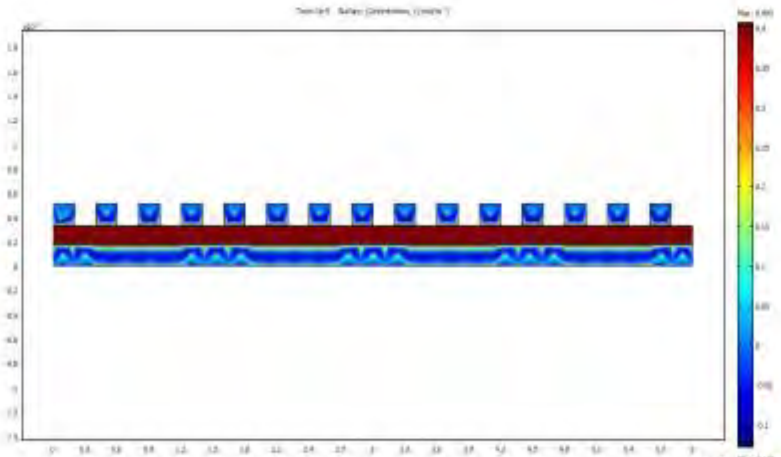

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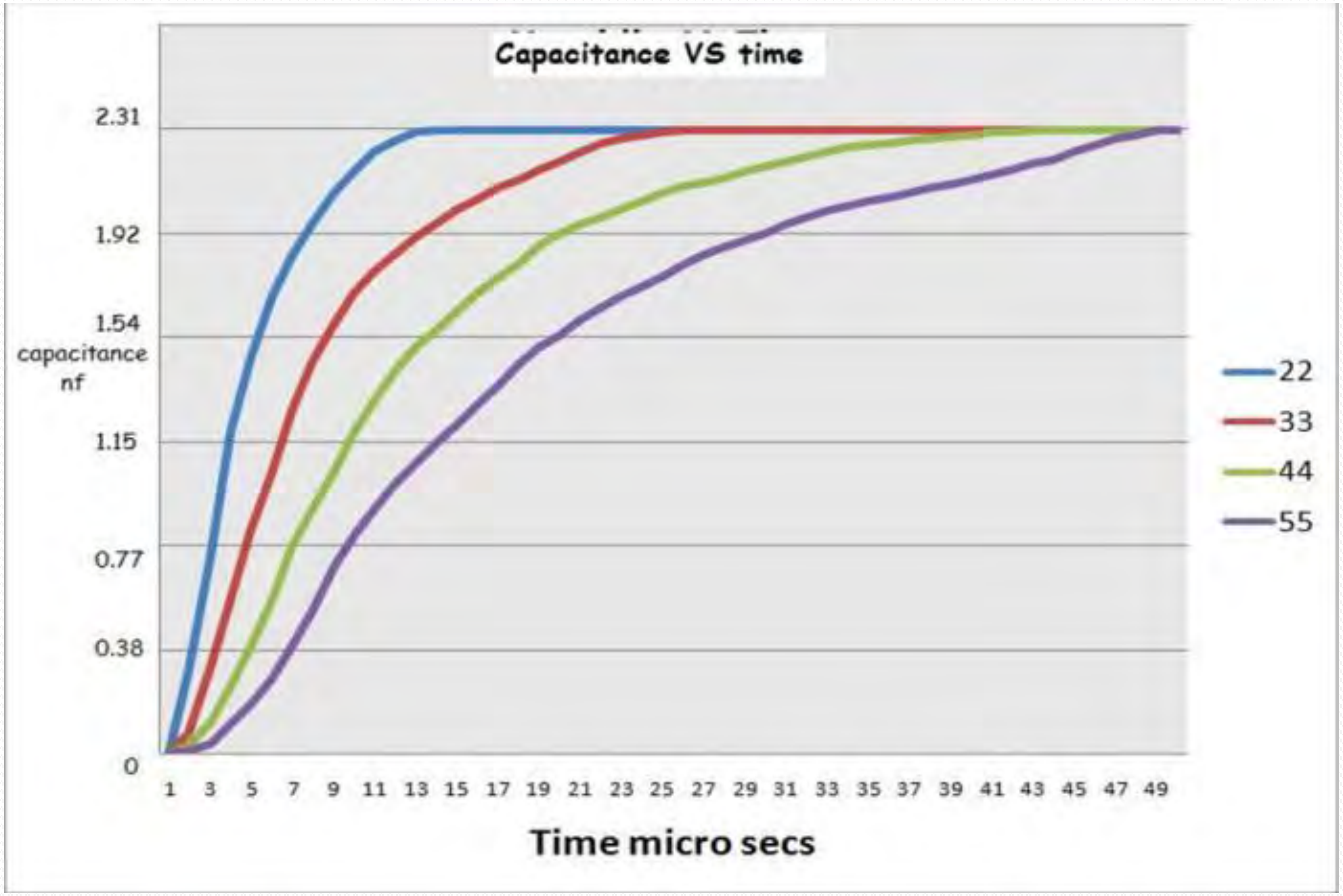
Comparison response time



Optimizing for response time
At 26^0c ΔRH 3%

structure	Response Time µ secs	Desorption time in µ secs	Sensitivity nf/%RH
2/2	2.5	4	0.77
3/3	7	8	1.15
4/4	8.8	14	1.54
5/5	12	18	1.92

Optimizing for sensitivity
At 26^{0}c ΔRH 3%

Structure	Response Time μ secs	Desorption time in μ secs	Sensitivity nf/%RH
10/20	180	220	8.36
40/20	250	320	29.96
30/30	200	280	22.47

Optimizing for sensitivity and response time At 26^{0}c ΔRH 3%

structure	Response Time μ secs	Desorption time in μ secs	Sensitivity nf/%RH
20/10	50	70	14.89
15/30	120	140	22.47
40/40	200	240	29.96

Conclusion

A Capacitive based MEMS humidity sensor is designed and tested using **Comsol Multiphysics**®

The consolidated results obtained from the design and simulation of the sensor are

1. 2/2 structure is suitable for fast response time
2. 10/20 structure for high sensitivity and
3. 20/10 structure for fast response time and high sensitivity.

References

- “Modelling and Optimization of a Fast Response Capacitive Humidity Sensor,” IEEE - 2006
- “Accurate model of the dynamic response of a capacitive humidity sensor,” IEEE - 2003
- “Computer-aided response time optimization of capacitive humidity sensors,” IEEE - 2004
- “Dynamic behaviour of a chemical sensor for real-time measurement of humidity variations in human breath,” IEEE - 2004
- “Fast response humidity sensors for a medical Microsystems,” IEEE - 2003

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