NANOPOROUS SILICON STRUCTURES FOR TOXIN DETECTION

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OUTLINE

- Introduction
- Use Of COMSOL Multiphysics
- Sensor Fabrication
- Results And Discussions
- Conclusion
- References
- Acknowledgements

Introduction

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AFLATOXIN - THE CHALLENGE

Aflatoxins:

- Mycotoxins produced by fungi
- Most abundant naturally occurring aflatoxin – Aflatoxin B1 (AFB1) (carcinogenic)

Detection is difficult because…

- Small molecular size
- Low molecular weight

Drawbacks of existing electrochemical detection techniques:

Unable to achieve high sensitivity because:-

- Use of secondary antibody is not possible.
- Distance between electrodes have to be comparable to the toxin molecule size.

WHY NANOPOROUS SILICON

In nanoporous silicon,

High sensitivity can be achieved by-

- Confinement of toxin molecules in dimensionally comparable spaces.
- Use of simple widely spaced lateral electrode configuration to effectively confine electric field lines

Novelty of Our Proposal:

- First report on the use of nanoporous silicon substrates as impedance sensors for high sensitive toxin detection

Use Of COMSOL Multiphysics

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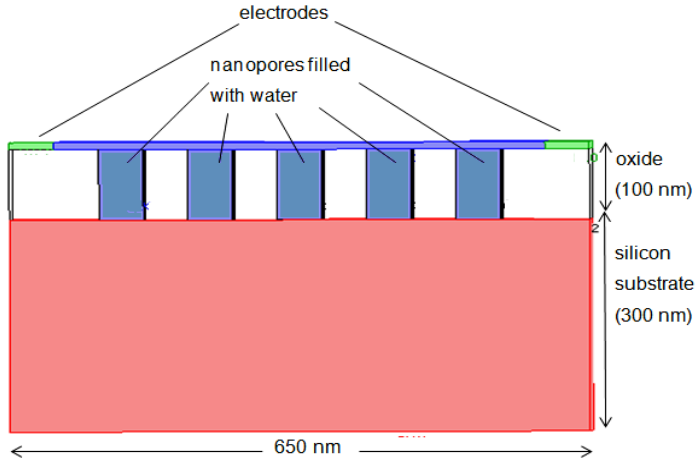
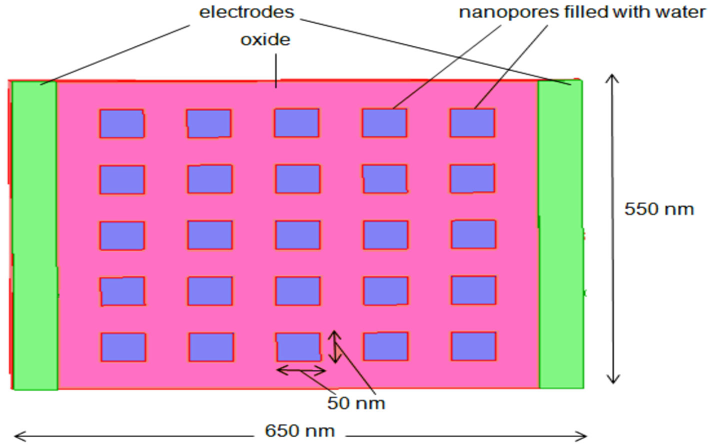
STRUCTURE 1

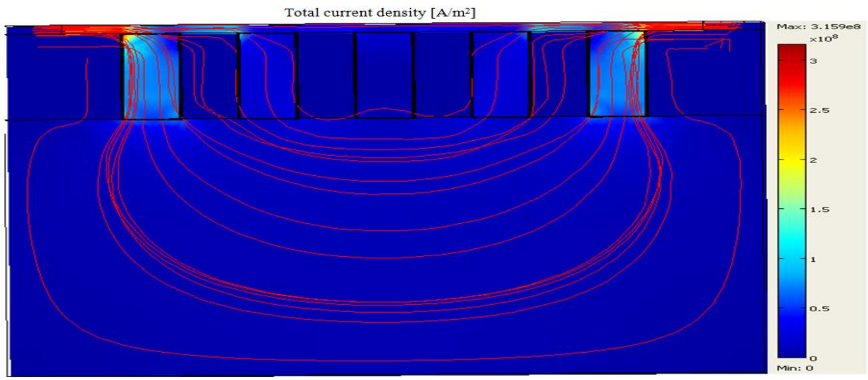
- Nanopore dimensions – 50 nm * 50 nm * 100 nm
- Ratio (R) of nanopore height to distance between electrodes – 1:5



Cross-sectional view



Top view



Current flow distribution

- Current lines from electrodes enter pores and then pass through silicon substrate
- Almost 75% of the current lines are confined within a distance of 150 nm from the electrode edge

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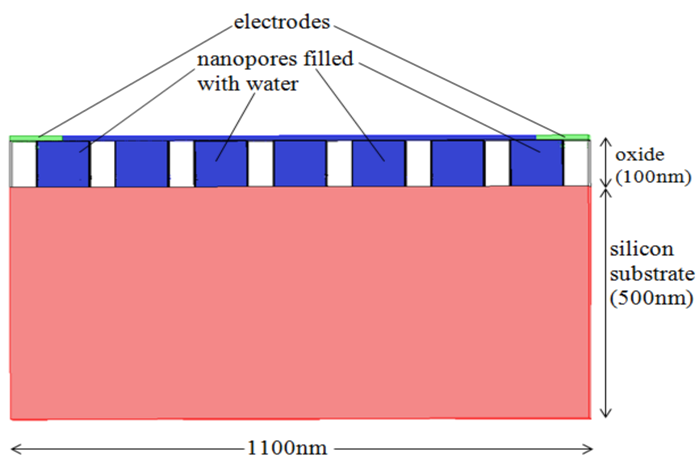
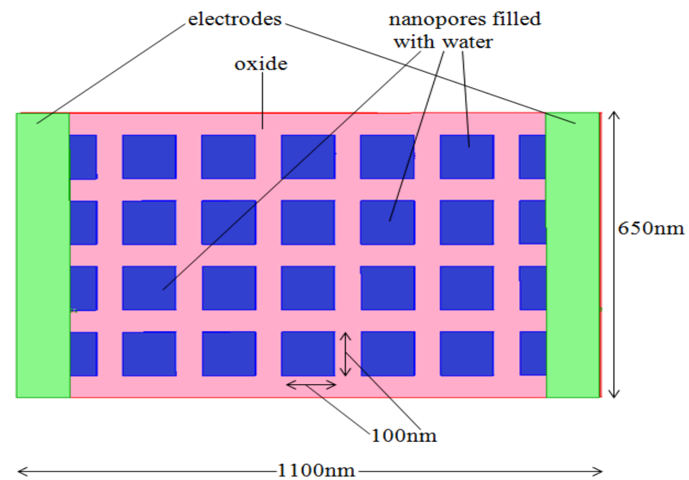
STRUCTURE 2

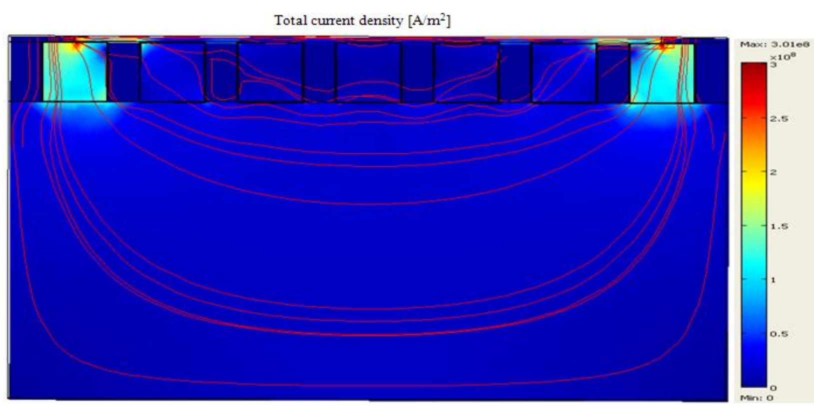
- Nanopore dimensions – 100 nm * 100 nm * 100 nm
- Ratio (R) of nanopore height to distance between electrodes – 1:10



Cross-sectional view



Top view

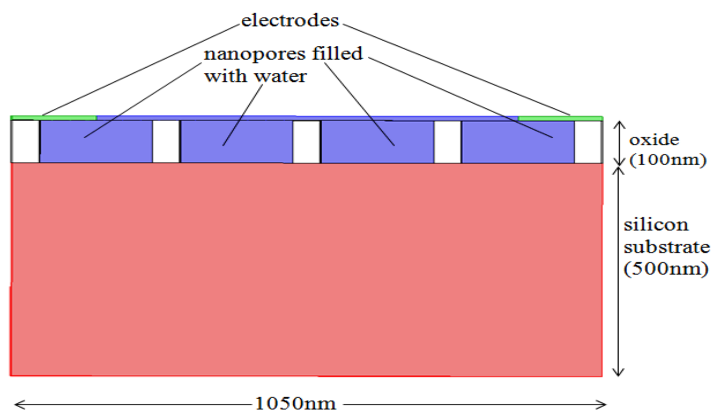


Current flow distribution

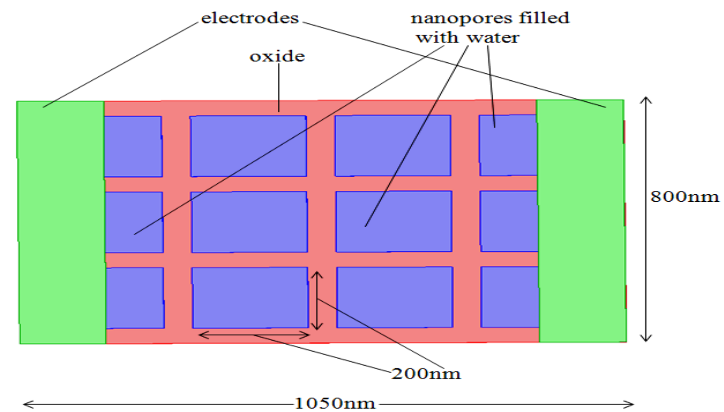
- Almost 85% of the current lines are confined within a distance of 150 nm from the electrode edge
- **In actual fabricated samples, R is very very small, enabling more effective confinement of current lines**

STRUCTURE 3

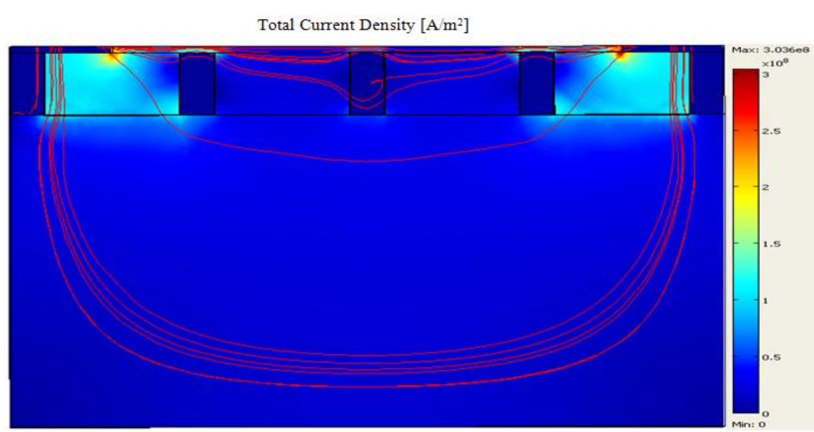
- Nanopore dimensions – 200 nm * 200 nm * 100 nm
- Ratio (R) of nanopore height to distance between electrodes – 1:10



Cross-sectional view



Top view



Current flow distribution

- Different pore dimensions are considered to study the effect of different oxide thickness on nanoporous silicon.
- Confinement of current lines near electrode edge is poor compared to previous structure.

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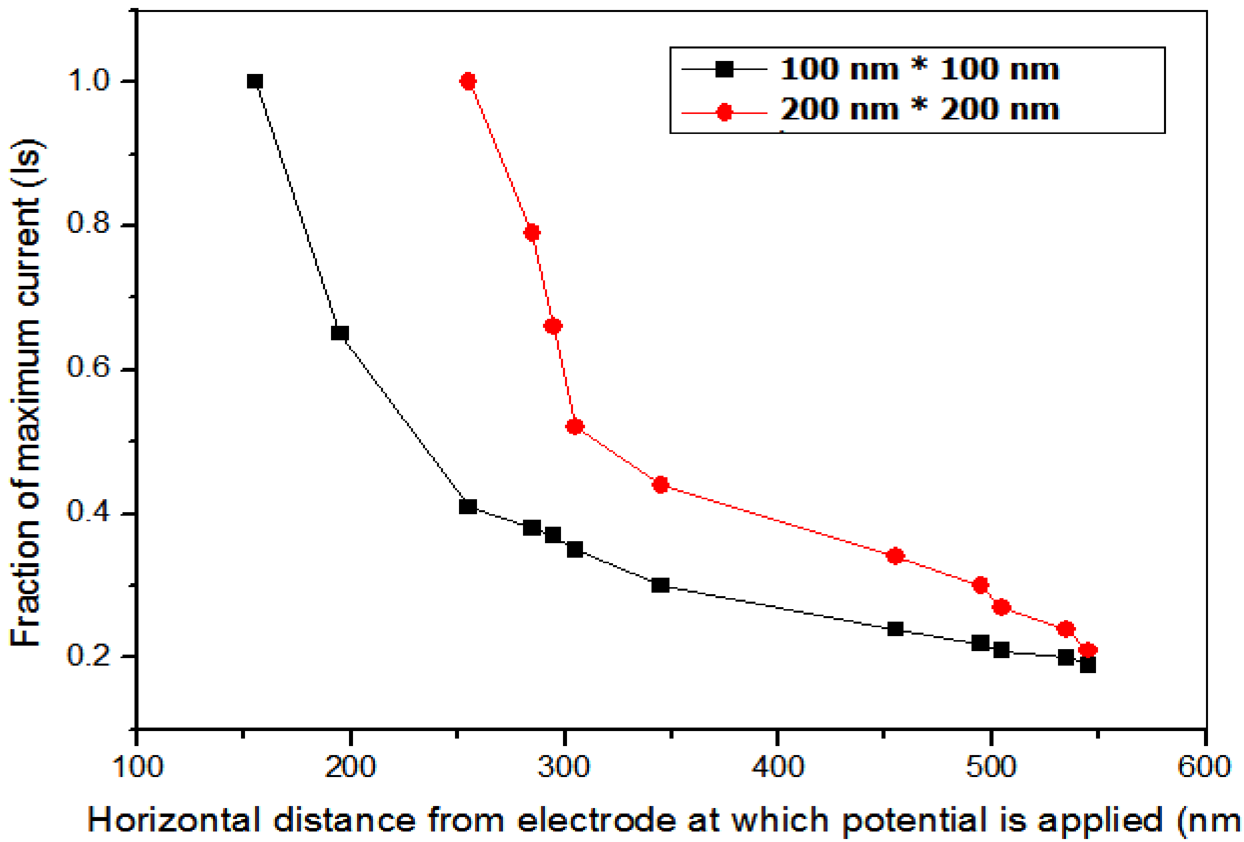
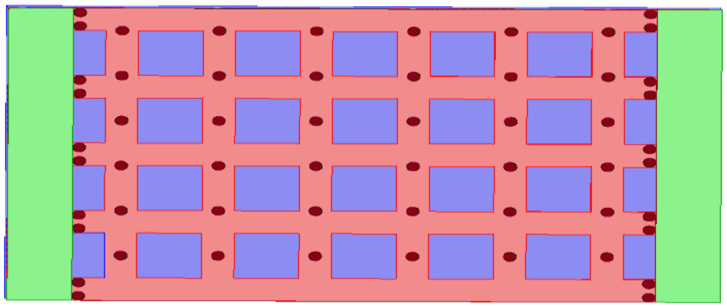
CURRENT VARIATION GRAPH

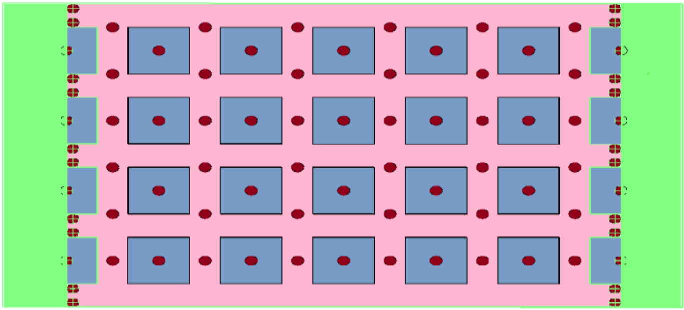


Graph showing variation of current along sample surface for both Structure 2 (pore diameter 100 nm) and Structure 3 (pore diameter 200 nm)

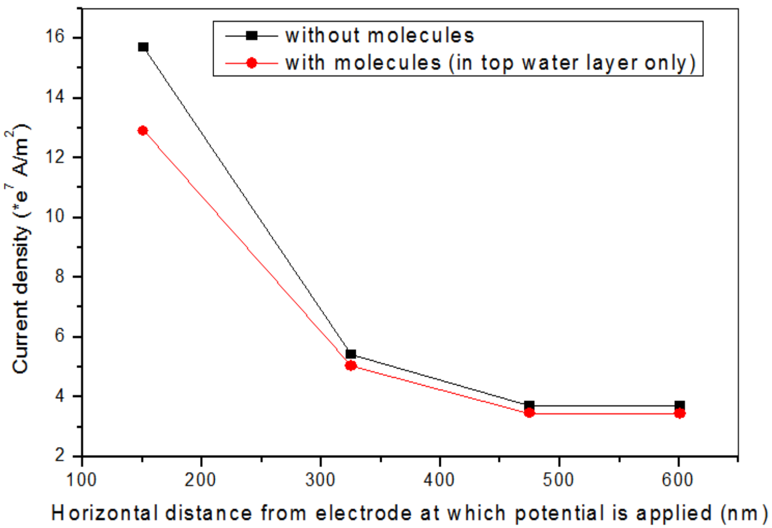
STRUCTURE 4 AND STRUCTURE 5



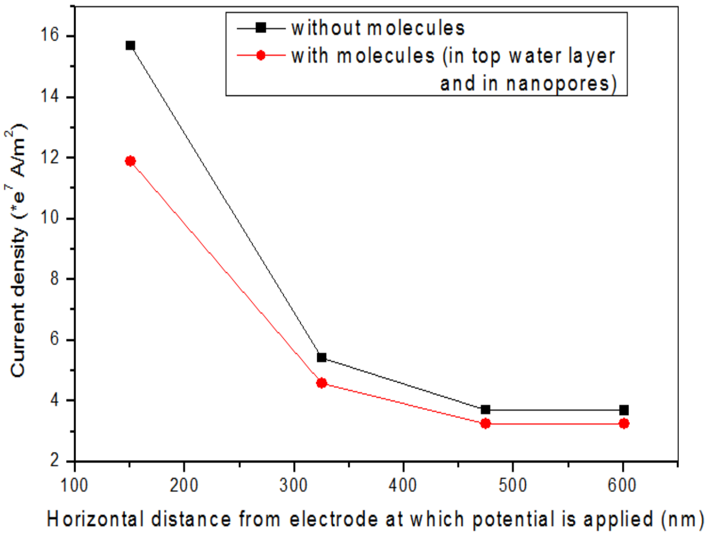
Top view of Structure 4



Top view of Structure 5



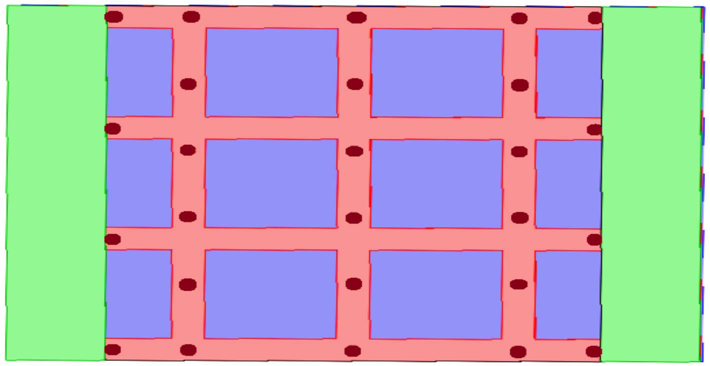
Current density comparison of Structure 2 with Structure 4

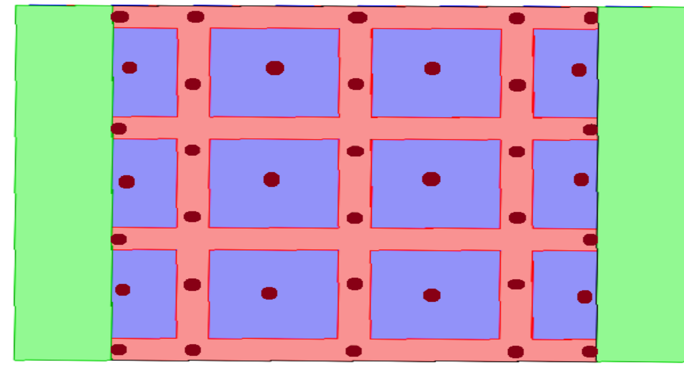


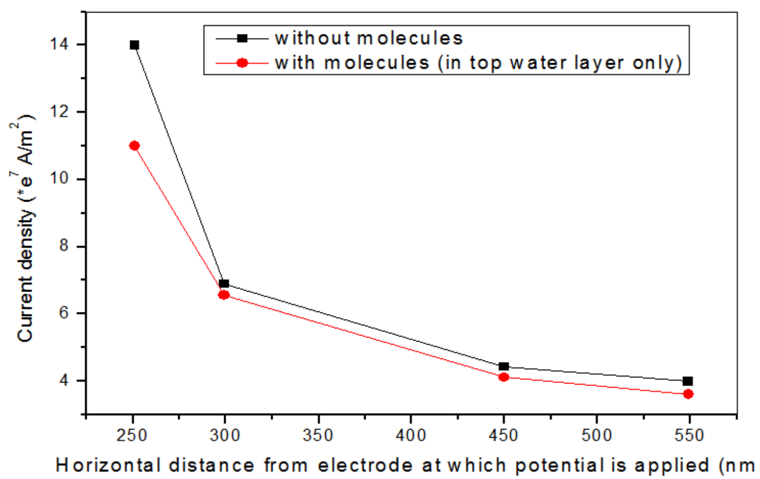
Current density comparison of Structure 2 with Structure 5

Current density decreases due to the presence of the spherical cells

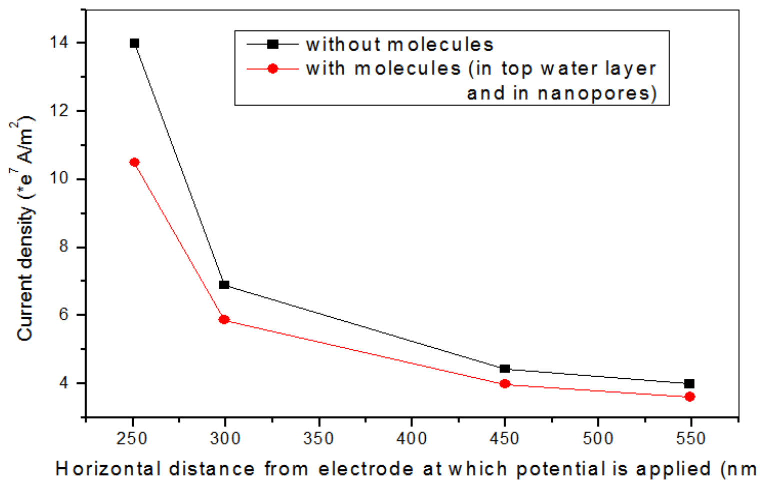
STRUCTURE 6 AND STRUCTURE 7


Top view of Structure 6


Top view of Structure 7



Current density comparison of Structure 3 with Structure 6



Current density comparison of Structure 3 with Structure 7

Current density decreases due to the presence of the spherical cells

Sensor Fabrication

FABRICATION STEPS

- Cleaning of p-type <100> silicon wafers (resistivity 10-20 Ωcm)

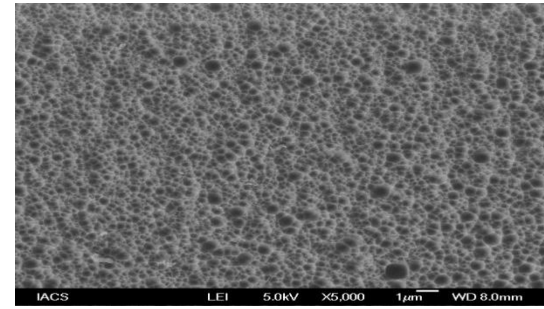
- Etching with electrolytic mixture of HF and DMSO in the ratio 1:9 by volume to obtain nanoporous silicon with:

  pore thickness – about 100 nm
  pore diameter – about 250 nm
  Parameters:
  Etching area – 1.6 cm^2
  Etching time – 30 minutes
  Constant current source of 2.35 mA

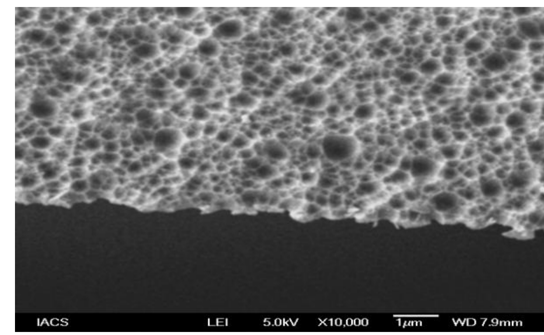
- Thermal oxidation to obtain two oxide thicknesses of 0.15 µm and 0.05 µm

- Fabrication of screen-printed silver electrodes followed by gold deposition by evaporation

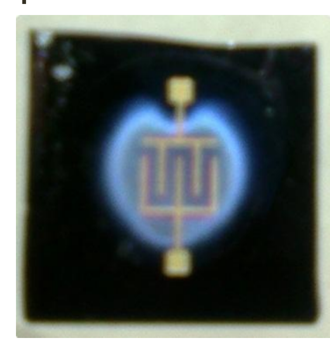
- Sample surface functionalization and immobilization of anti-AFB1 antibody



SEM image of top surface of nanoporous silicon formed



SEM image of cross-section of nanoporous silicon formed



Final view of sensor

Results And Discussions

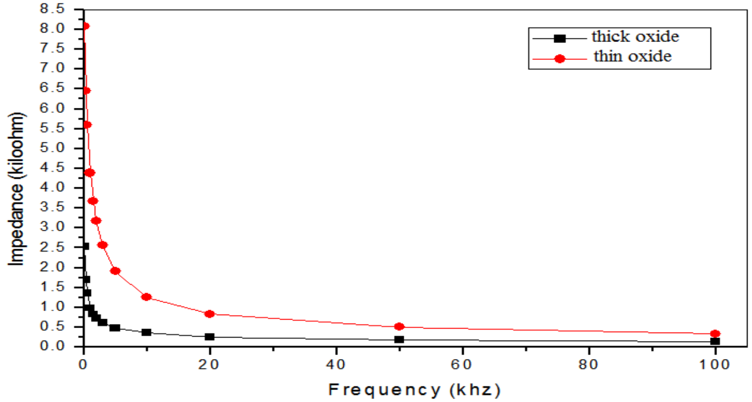
EDX ANALYSIS

- Done to determine presence of nitrogen

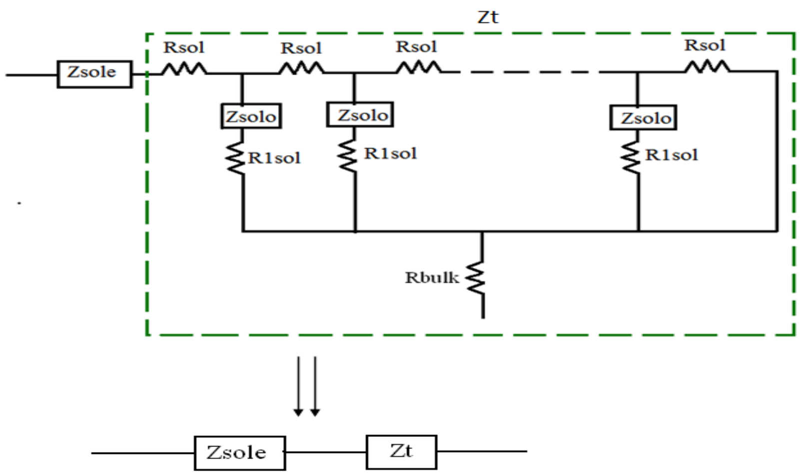
- After antibody immobilization, nitrogen is present, which has probably been contributed by the antibody

Element	Weight%	Atomic%
Carbon	12.92	16.36
Nitrogen	6.50	7.05
Oxygen	80.59	76.59
Total	100.00	100.00

IMPEDANCE MEASUREMENT (BEFORE ANTIBODY IMMOBILIZATION)



Variation in impedance with frequency

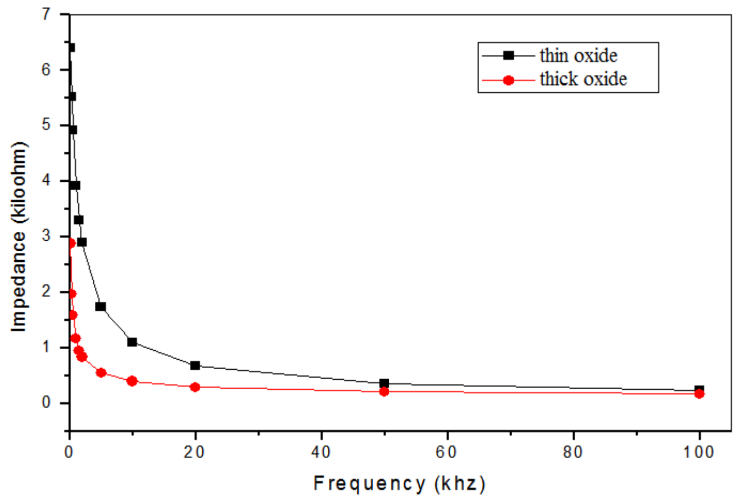


Electrical model of nanoporous silicon in presence of liquid

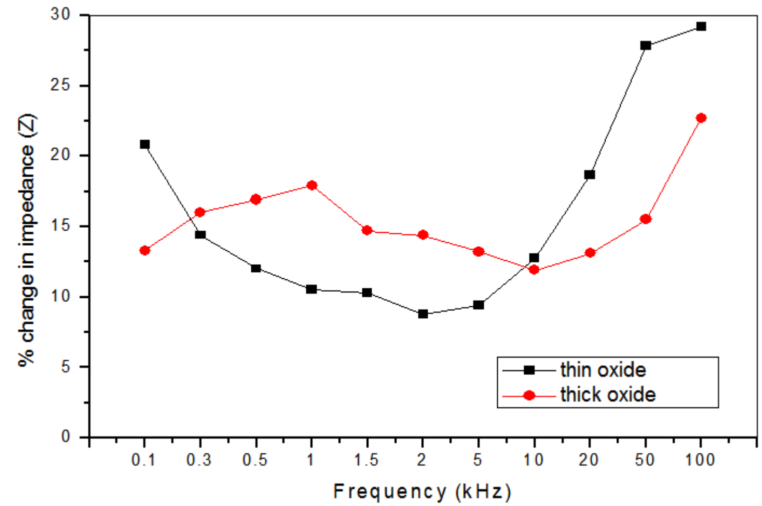
- Impedance decreases with frequency for both samples
- Sample with thin oxide offers greater impedance than sample with thick oxide

With increase in oxide thickness, the effective transmission line impedance *Zt* decreases and so, thinner oxide offers more impedance than thicker oxide

IMPEDANCE MEASUREMENT (AFTER ANTIBODY IMMOBILIZATION)



Variation in impedance with frequency



Percentage change in impedance with frequency

- After antibody immobilization, *Zt* decreases and *Zsole* increases for both samples

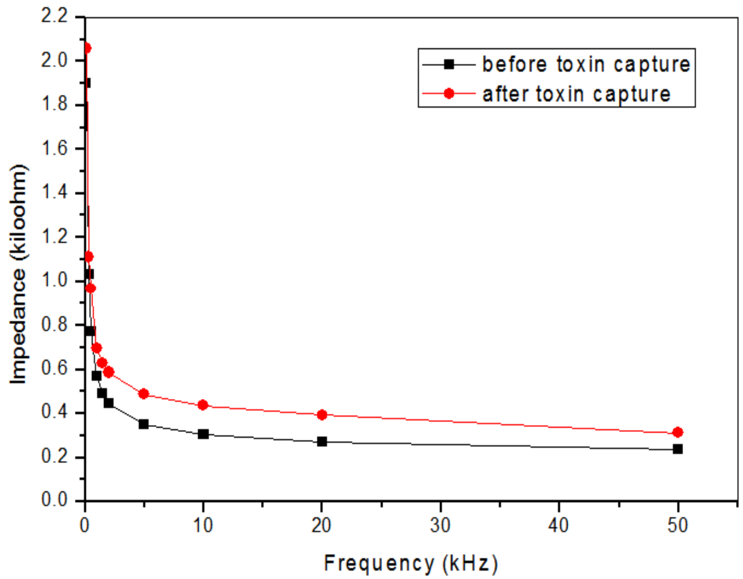
For thin oxide, *Zt* dominates over *Zsole* and so, impedance decreases

For thick oxide, *Zsole* dominates over *Zt* and so, impedance increases

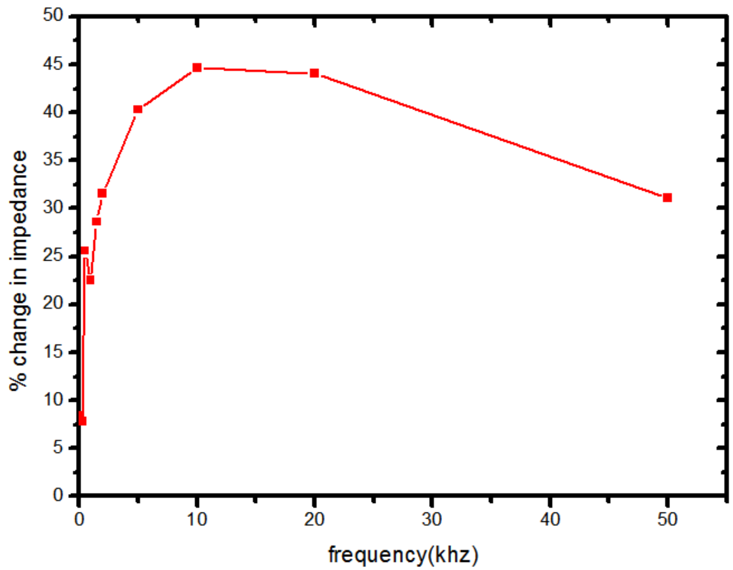
- Sensitivity increases with frequency

At lower frequency, *Zsole* dominates and in thick oxide, effect of Zsole is more than that in thin oxide and so, sensitivity is more for thick oxide

IMPEDANCE MEASUREMENT (AFTER ADDITION OF 100 FG/ML AFB1 SOLUTION)



Variation in impedance with frequency before and after capture of toxin molecules



Percentage change in impedance with frequency after toxin detection

- Impedance change caused by specific antigen-antibody binding

- Sensitivity increases with increasing frequency and is maximum (about 40% to 44%) in the range of 5 kHz to 20 kHz

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Conclusion

CONCLUSION AND FUTURE WORK

The developed sensor has been observed to be highly sensitive, detecting AFB1 at a concentration as low as 100 fg/ml with a significant sensitivity of around 40%.

Hence it has the potential to detect toxin molecule down to 10 fg/ml which is lower than all existing reports of electrical sensors for detection of toxin molecules.

Further work has to be done in order to test the cross-sensitivity of the sensor and also to test its sensitivity at lower detection limits.

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THANK YOU