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Design and analysis of Bioinspired hair like sensor

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Objective

HERE I PRESENTS

- The morphology and Mechanical interface of the hair base and the dendrite tip of the insect Nabis Rugosus.

- Design of Bioinspired hair-like sensor.

- Analysis of Bioinspired hair-like sensor due to tactile loading over it.

Nabis rugosus insect

- Nabidae play a significant role in maintaining the biological balance of the environment.
- They are good at sensing all environmental changes with the help of their receptors which are spread on their overall body.
- In Comparing with other insects, the dendrite tip with its thick material known as dendrite sheath is directly coupled to the hair base which we observed by our experiments

Fig 1. Nabis insect observed under light microscope

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Experimental Procedure for

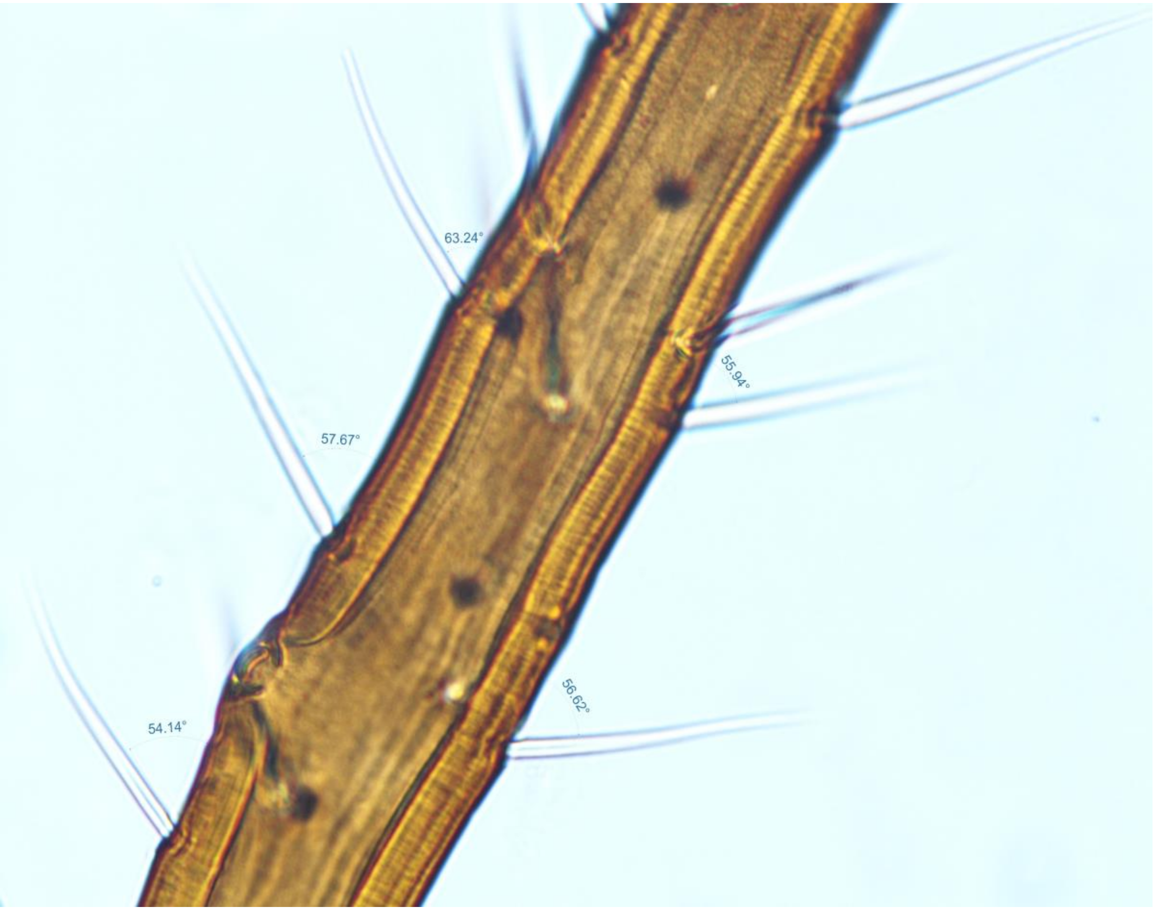
Structure of hair base and Dendrite Connection

- Nabis Rugosus insects are collected and reared at the University of Silesia, Entomology lab at a temperature 22deg Celsius.

Processes for light microscopes were

- Prefixation in 2.5% glutardialdehyde in 0.08 mol CaCo buffer solution with 0.1 mol sucrose at pH 7.5 for 8 h
- washing in buffer solution; fixation in 1% OsO4 (in 0.08 mol l) CaCo buffer with 0.1 mol PsO4 for 8–10 h; washing with buffer solution;
- Dehydration with ethanol;
- Embedding in Spur epoxy resin and polymerization at 70C for 14 h. Ultrathin sections were cut.
- Sections were kept in acetate and lead citrate and then examined under a high-resolution light microscope of 1000µm.

Hair shaft with multiple Trichoid sensilla over it of the Nabis Pedicel



- This hair shaft after undergoing all chemical treatments, it was fixed on the glass slide and was glued with Acrytol.
- To avoid the collision of the covering glass onto the hair shaft, the two glasses were distanced by the glass ionomer cement and were observed under the light microscopy

Fig 2. Hair embedded into the socket with an angle of **57±6 deg** from the cuticle

Morphology of the Nabis trichoid sensilla

- The trichoid sensillum is elevated out of the socket, bent to the lateral position at an angle, and connected through a joint membrane.
- The hair base and socket were connected with suspension fibres used to control the extensive movement of the hair base.
- The tip of the dendrite was attached to it and supported by the socket septum.

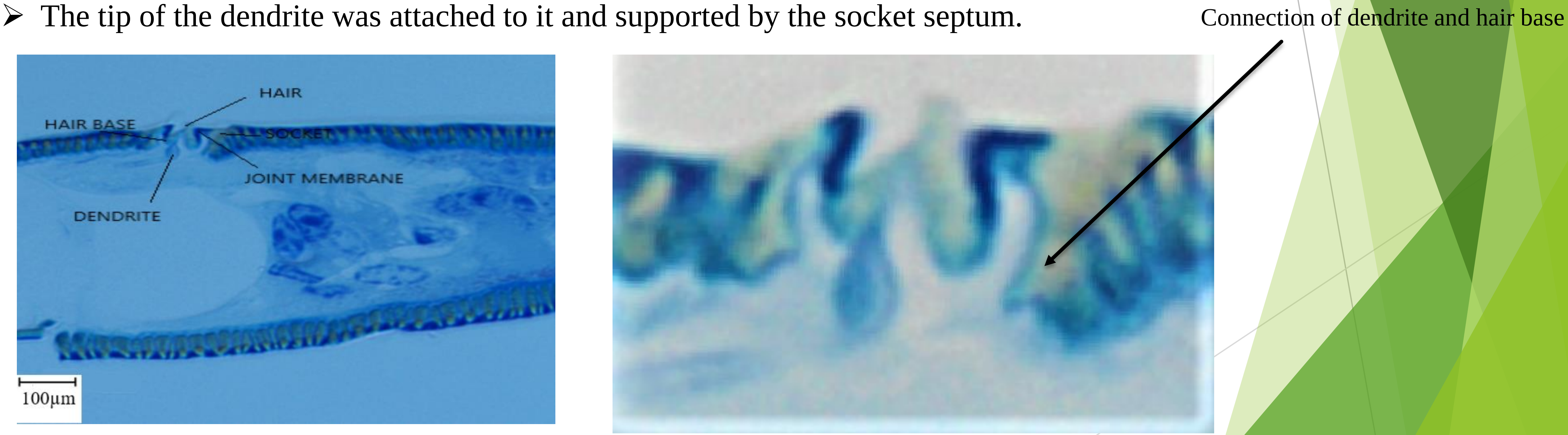


Fig.3. Internal structure of insect N.R trichoid sensilla

Reconstructed a two-dimensional (2D) model of Nabis Rugosus Trichoid sensilla

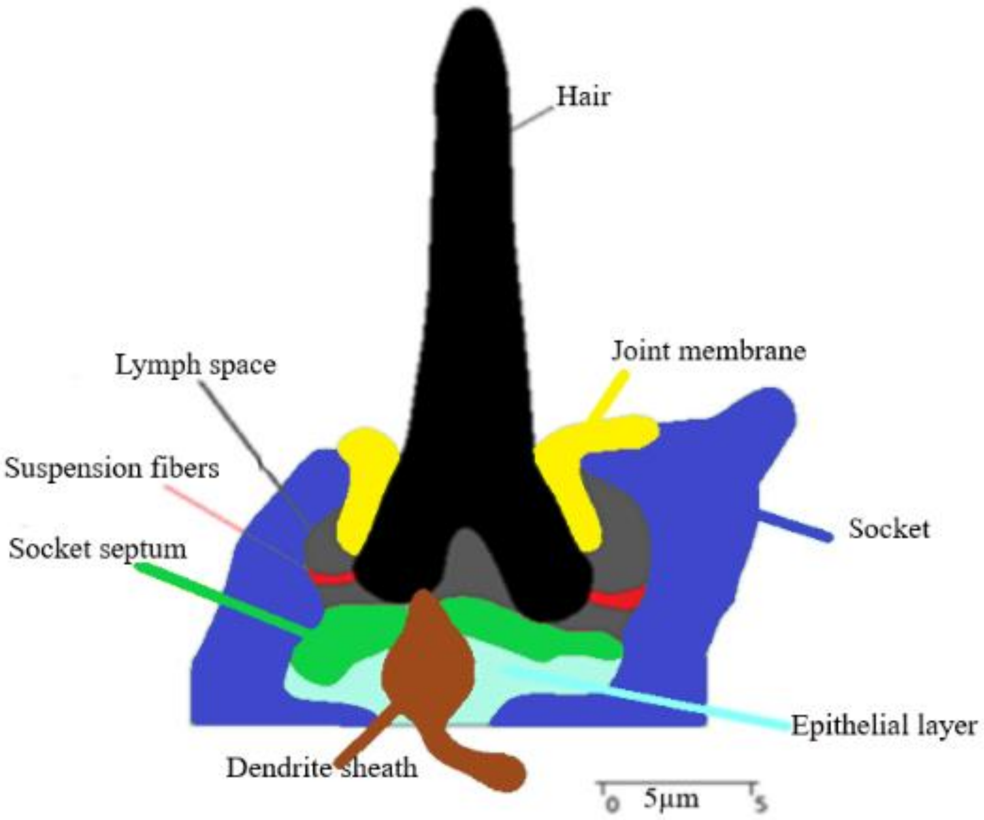


Fig 4. This model was developed from AMIRA software based on the TEM data

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OPTIMIZATION TASK FOR DESIGN PARAMETERS OF BIHS

- **objective function :**

$max \int_0^L F_{int} dx$ (on the base of the dendrite sheath edge) (Eqn 1)

Subjected to

$$\frac{E}{2(1+v)}\left(\frac{1}{1-2v}\nabla(\nabla.U)+\nabla^2 U\right)+f=0$$

$x^l < x < x^u$, $y^l < y < y^u$, $E^l < E < E^u$. (Design variables)

$\{U\} = (u, v)$ Displacements of the sheath in x & y components

Constraints of the system are the Navier's equation and design variables which are the coordinates and material properties

BIHS DESIGN AND COMPUTATIONAL SCHEME

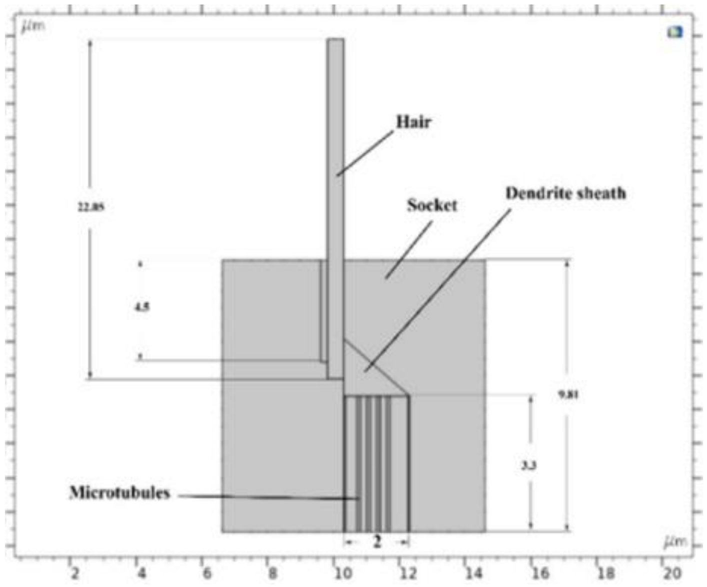

Fig.5. Design of BIHS.

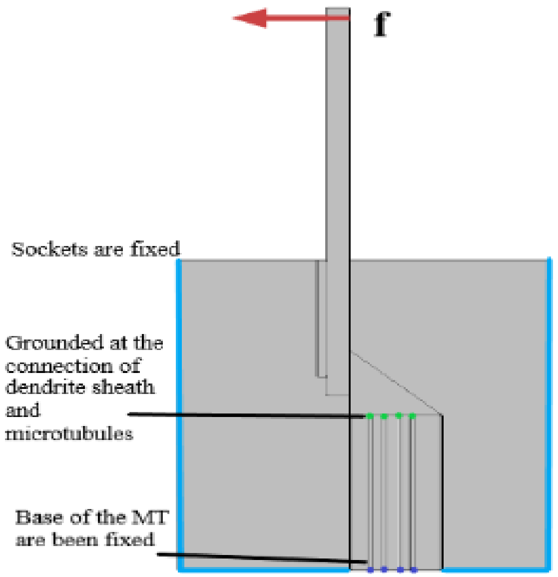

Fig.6.BIHS boundary conditions and the applied load **f** at tip of hair shaft.

Components	Material	Young's modulus	Poisson's ratio	Density
Socket	Liquid silicon	2Gpa	0.49	7600kg/m3
Hair	PDMS	1Gpa	0.49	970kg/m3
Joint membrane	Polyurethane rubber	150 kpa	0.2	6020kg/m3
Dendrite sheath	Ag+Gylosol solution film	300 kpa	0.36	3300kg/m3
Membrane (electrodes)	Cr and Au mixture	100kpa	0.46	1100kg/m3
EDM	Epoxy EPO TEK 301-2	300 kpa	0.4	5200 kg/m3

Table.1. Mechanical properties of BIHS parts.

STATIONARY ANALYSIS AND MODAL ANALYSIS OF BIHS

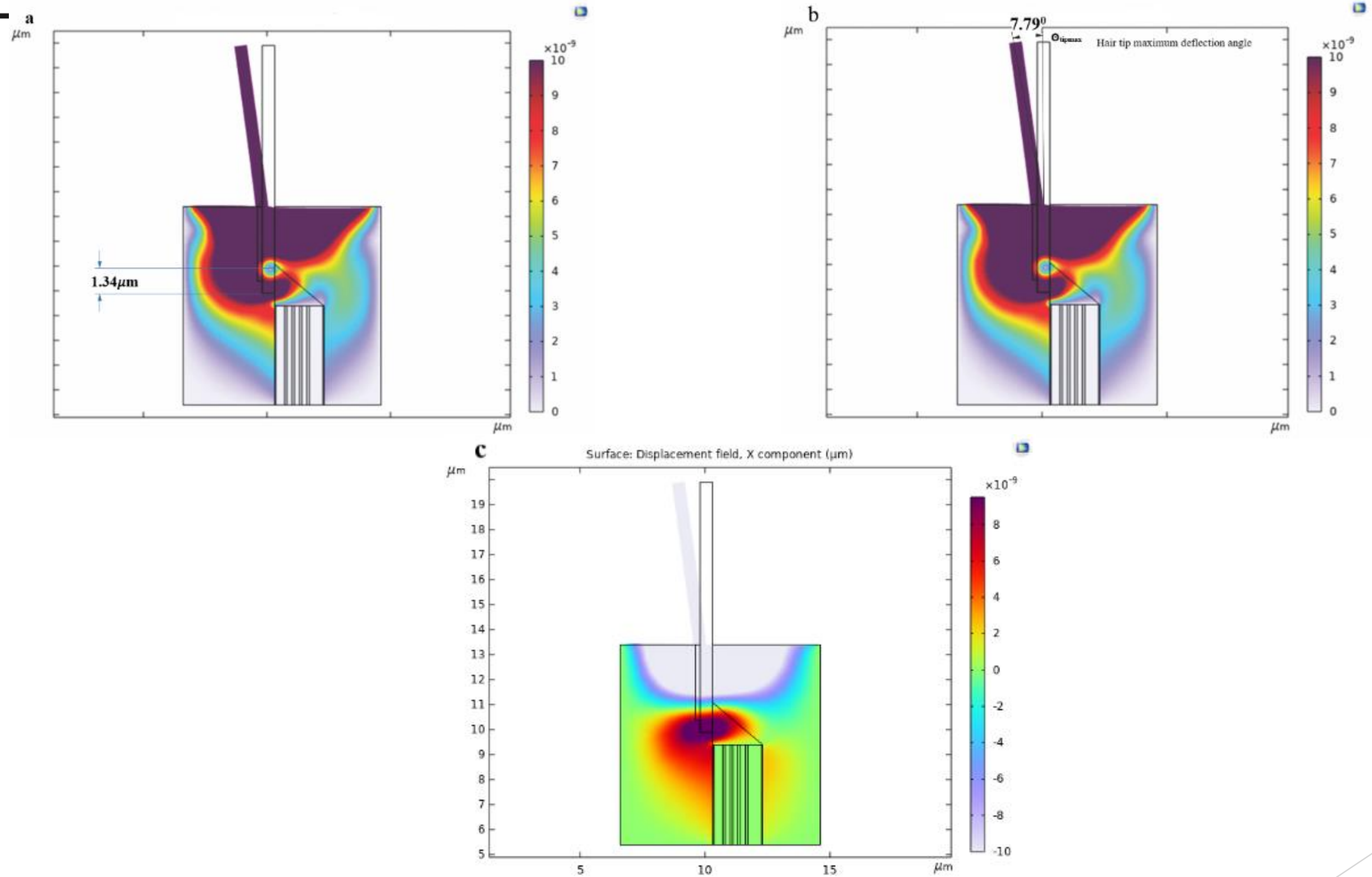

Fig.7. Bioinspired hair-like sensors parameters like hair shaft deflection, and point of rotation are identified due to applied load of 1 μN. a). Pivot point at the hair shaft base. b). Hair shaft tip deflection angle. c). Horizontal displacement of dendrite sheath.

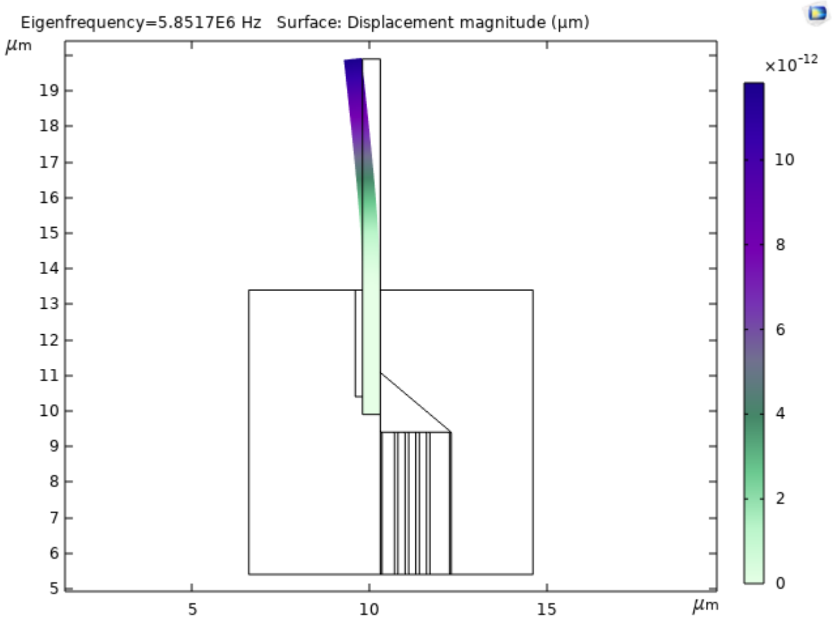

Fig.8. Eigenfrequency (1st Mode) of the BIHS (5.851KHz)

ELECTRO-MECHANICAL ANALYSIS OF BIHS.

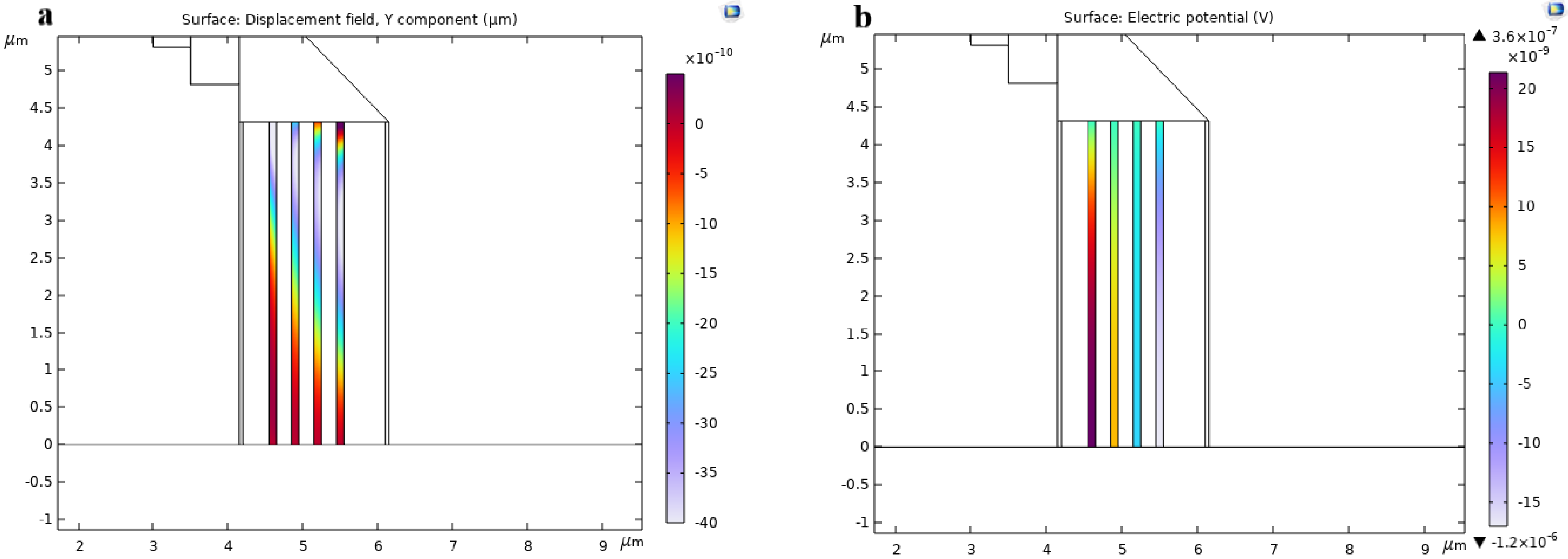

Fig.9. Electrostatic responses of the microtubules. a). Vertical displacement field of the microtubules (μm). b). Microtubules' electrical potential developed in their core Volts (V).

TRANSIENT ANALYSIS OF BIHS.

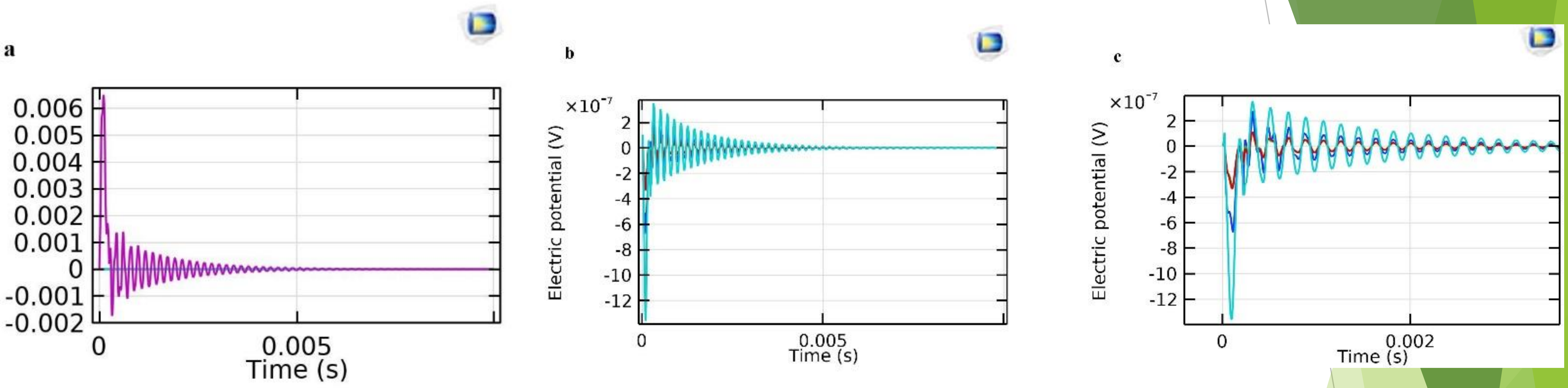

Fig.10. Bioinspired hair-like sensors response with time interval (0 to 1sec). a). Hair tip horizontal displacement due to the applied force. b). Microtubule's electric potential responses at 0.005sec. c). Microtubule's electric potential responses at 0.002sec.

Results and Discussion

- Fig.7a the static analysis was performed to analyze the parameters like a pivot point, observed at 1.34µm from the base of the hair shaft.
- Fig.7b shows the displaces about the 7.79deg when the external load of 1µN on the hair shaft.
- Fig.7c shows the dendrite sheath connected to the hair shaft base of a BIHS displaces about 8nm.
- Fig.8 shows the natural frequency of BIHS is 5.851KHz, the greater natural frequency helps to respond faster to external stimuli.
- Dendrite sheath transverse loading transforms perpendicularly onto the microtubules which results in compression longitudinally shown in Fig.9a.
- The electric potential developed in the core of each microtubule is shown in Fig.9b. even in this BIHS observed that the microtubules that are near the connection site of the hair shaft base and dendritic sheath have the maximum positive potential.
- In contrast, microtubules far from the connection site have a negative potential similar to the potential developed in the microtubules of the insect *Nabis rugosus* trichoid sensilla. The bioinspired hair-like sensor generates a maximum electric potential of 1.2µV (negative) and 0.36µV (positive).

Results and Discussion

- Fig.10a show the horizontal displacement of the hair tip of bioinspired hair-like sensor response with time ranging from 0 to 0.1 sec. It is observed that a sudden spike in the response of displacement of 0.006µm (6nm) in the positive direction due to the application of external loading at its tip, then after the hair undergoes oscillations, the amplitude of the displacement oscillations reduces gradually due to some internal damping mechanism (joint membrane) and comes to the equilibrium position wrt to time. The result shows that the oscillations gradually lose energy over time until they eventually come to a stop.
- Fig.10b shows the microtubule's response to their electric potential with time ranging between 0 to 0.1 sec, and it is observed that all the microtubules are spiked due to the application of load but in a negative direction. However, these microtubules undergo oscillations, and gradually there is a loss of energy, and the amplitudes are very low from 0.005sec come to rest.
- Fig.10c shows the clear oscillations(underdamped) of all four microtubules at 0.002sec.it is observed that the microtubules which are near the connection site have a lower amplitude compared with the microtubules which are far from the connection site.

Conclusion

- The study of the morphology of trichoid sensilla in *Nabis rugosus* shows that the hair base and the dendrite sheath are coupled together compared to other insects' trichoid sensilla in which these are not directly coupled together.
- The Trichoid sensilla are quite large in numbers in *Nabis rugosus* insects and are very effective in responding to environmental changes like flow, tactile, etc so this study helps in the understanding of mechano-tranduction intern helps in developing sensitive biosensors.
- The BIHS model was developed based on the insect *Nabis rugosus* trichoid sensilla TSa structure. The design was optimized using the direct iterative optimization procedure that maximization of the integral of internal forces subjected to the system of constraints and design variables. The static analysis was performed to analyze the parameters like a pivot point, observed at 1.34µm from the base of the hair shaft. The dendrite sheath connected to the hair shaft base of a BIHS displaces about 8nm. The natural frequency of BIHS is 5.851KHz, the greater natural frequency helps to respond faster for external stimuli. The maximum potential generated in BIHS is **0.36 µV** and observed that the positive electric potential generated in microtubules near the connection site and the negative potential developed in microtubules that are far from the connection site. The hair shaft of BIHS undergoes oscillations due to the application of point load, an instant increase of displacement amplitude to 6nm was shown and gradually decreased with time and comes to equilibrium. The sensing elements undergo oscillations due to the transversal loading applied on their apex portion through the dendrite sheath. The potential developed in the microtubule core spiked within less time to 1.2 µV (negative) and undergoes damping and comes to rest within the interval of time.


Thank you