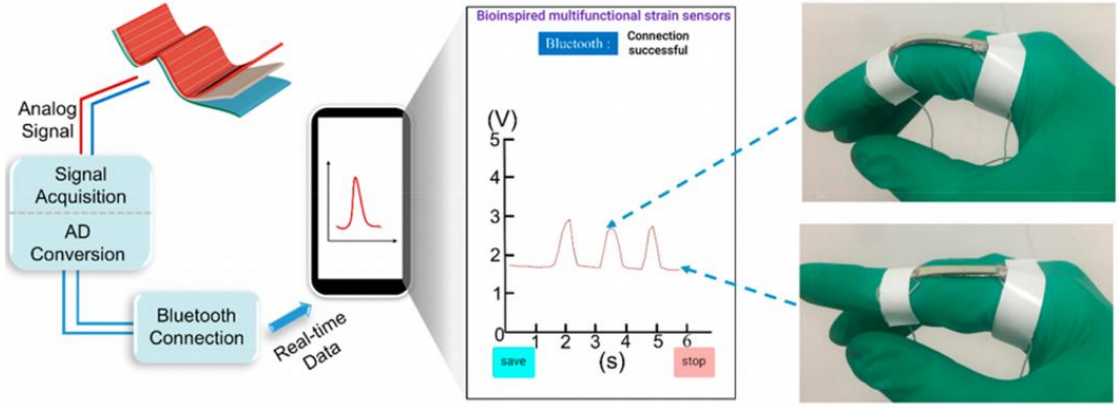
INTERNATIONAL SOCIETY OF
BIONIC ENGINEERING

Bionic Research on Functional Structure of Micro-vibrational Sensilla of Scorpion

From Mechanoreceptor to Mechanosensor

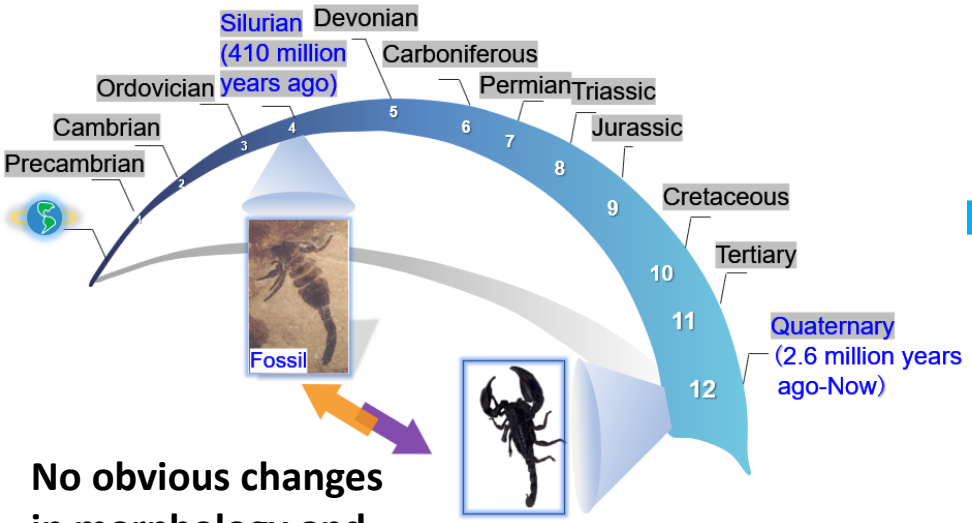


The case was provided by the Individual Member of ISBE

(*Shichao Niu, Jilin University*)

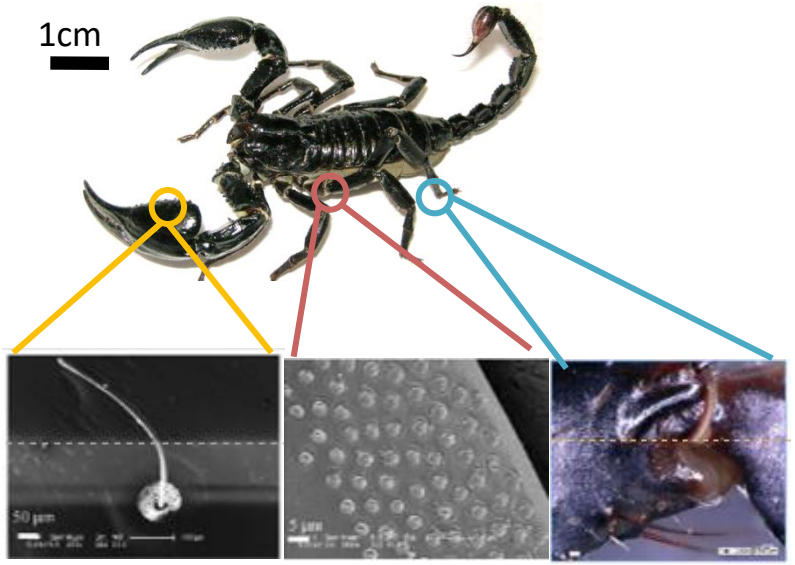
1. Biological Prototype

Billions of years of evolution



No obvious changes in morphology and structure

Sophisticated sensory organs

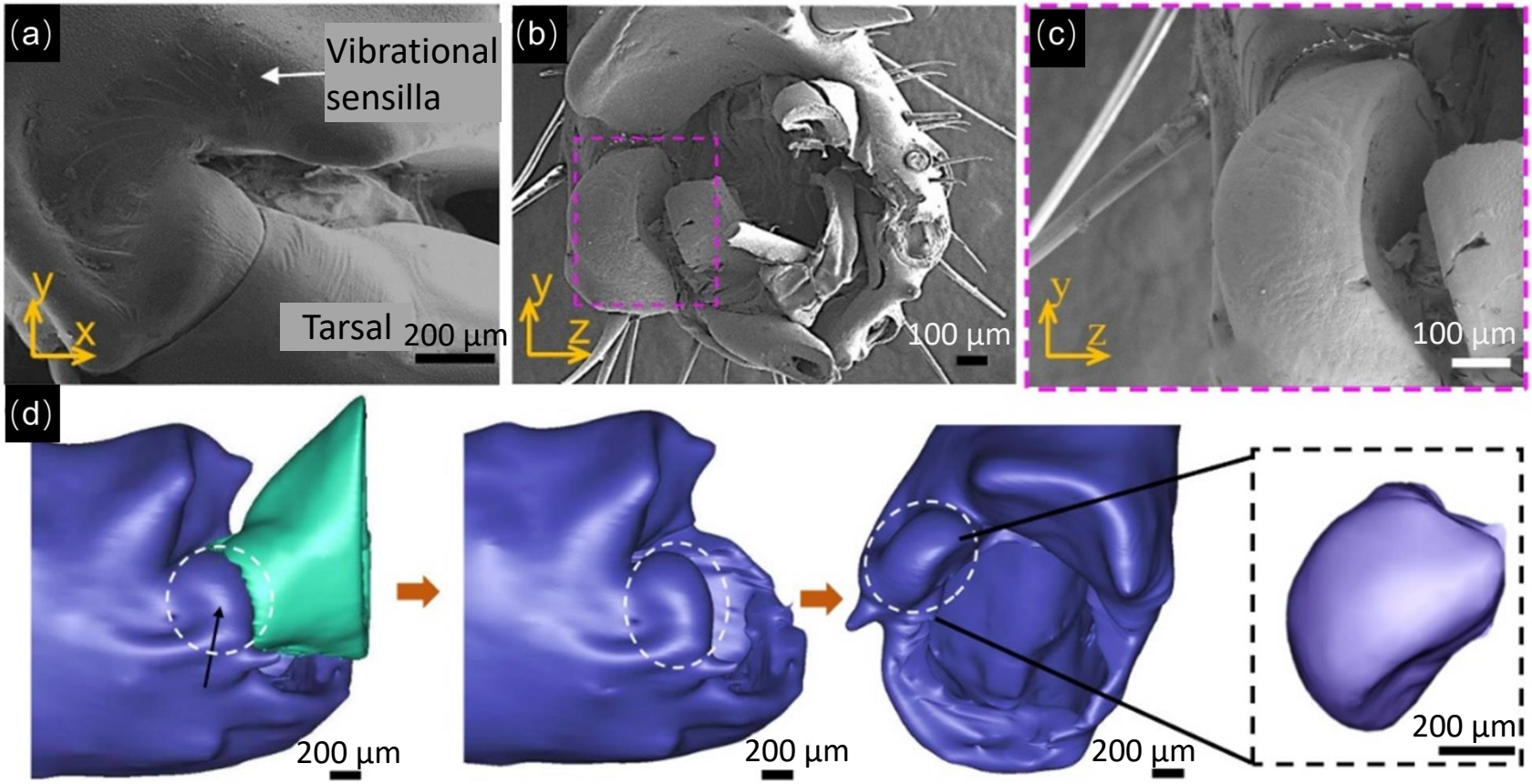


Air/water flow receptors | Chemoreceptor | Vibrational sensilla

- **Scorpion: Ancient and vibration-sensitive species**
- **Scorpion evolution is relatively conservative, its appearance has not changed significantly**
- **The scorpion *H. Petersii* is the most advantageous to carry out experiment (Maximum size, Least toxicity)**

2. Bionic Study

2.1 The structural and material characteristics——Morphology



Characterization of the morphology around the vibrational sensilla by SEM and Micro-CT

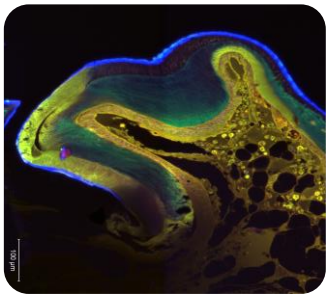
The Micro-CT present there is a horseshoe-like structure(HLS) in the front of the vibrational sensilla

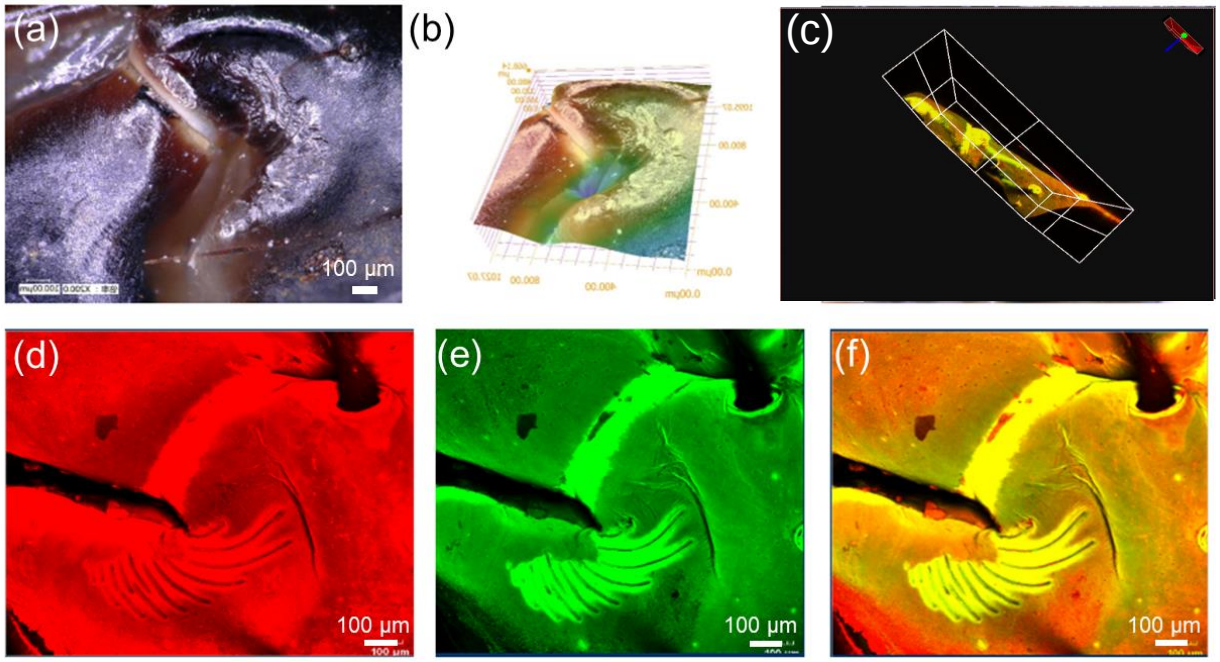
2. Bionic Study

2.1 The structural and material characteristics——Material properties

confocal laser scanning microscopy (CLSM)

Visualize the exoskeleton using autofluorescences and to estimate material properties of structures



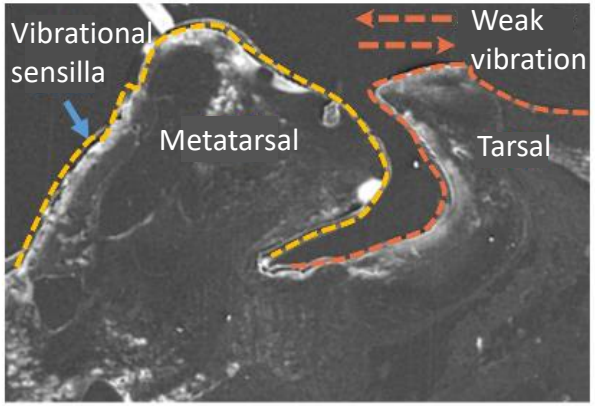


The CLSM present the HLS in the front of the vibrational sensilla has the flexible cuticle

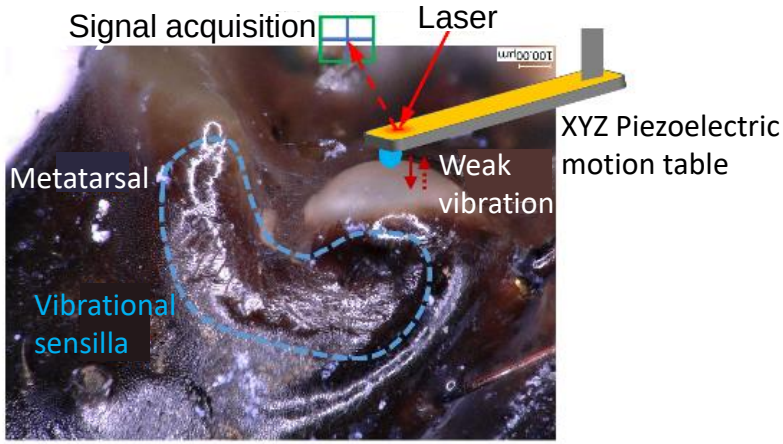
2. Bionic Study

2.2 Mechanical property characterization——Living tissue

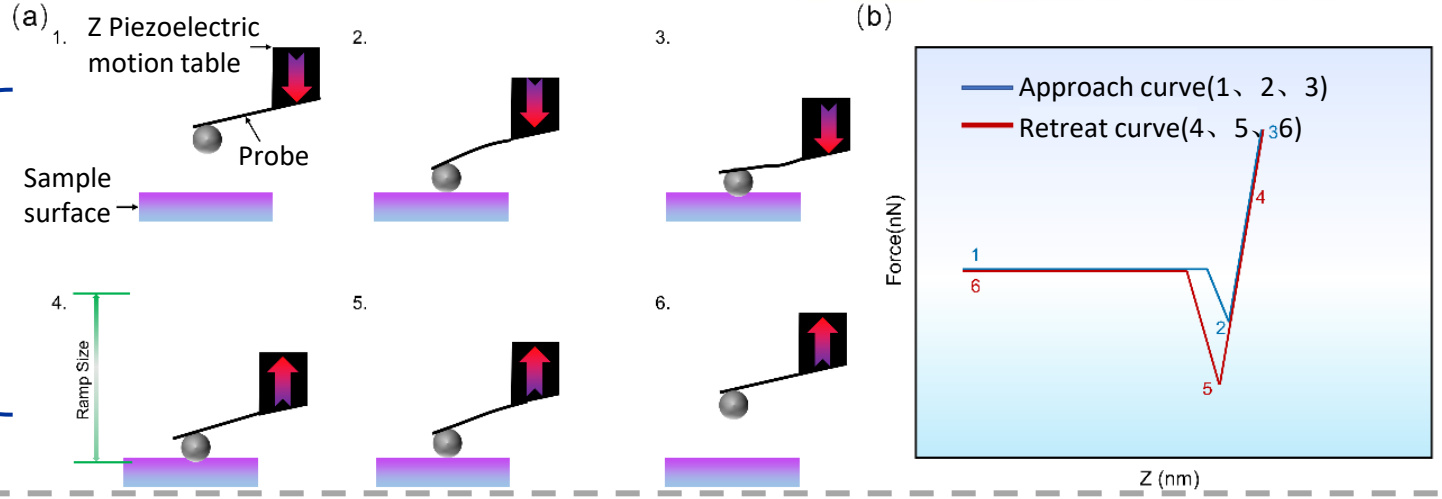
Approximate substitution



substitution

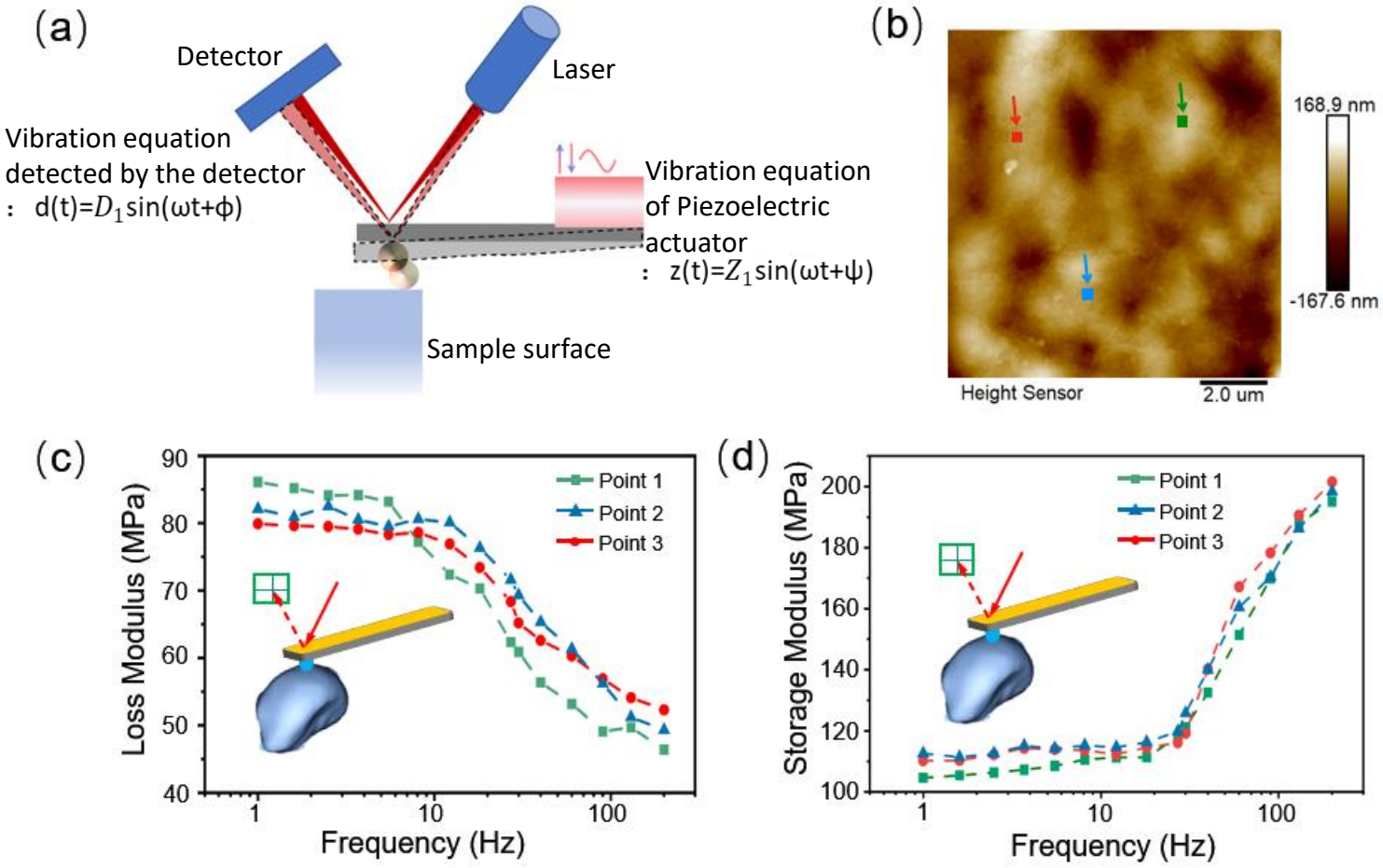


Experimental Principle



The process of tarsal squeezing metatarsal was approximately substitute by AFM, so as to explore the role of HLS in the process of vibration signal transmission

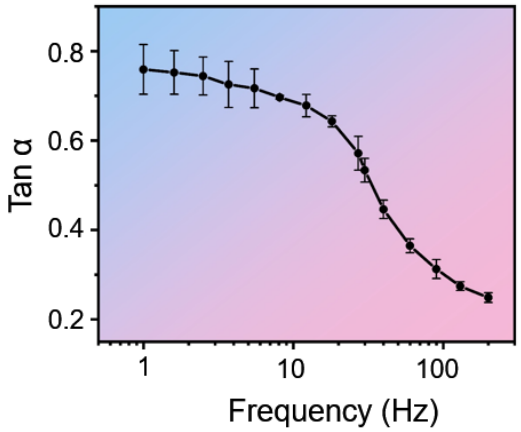
2. Bionic Study



- AFM-nanoDMA module was used to test the dynamic mechanical properties of the HLS
- The results show that the loss modulus decreases with the increase of frequency, and the storage modulus increases with the increase of frequency

2. Bionic Study

2.3 Low frequency signal filtering mechanism

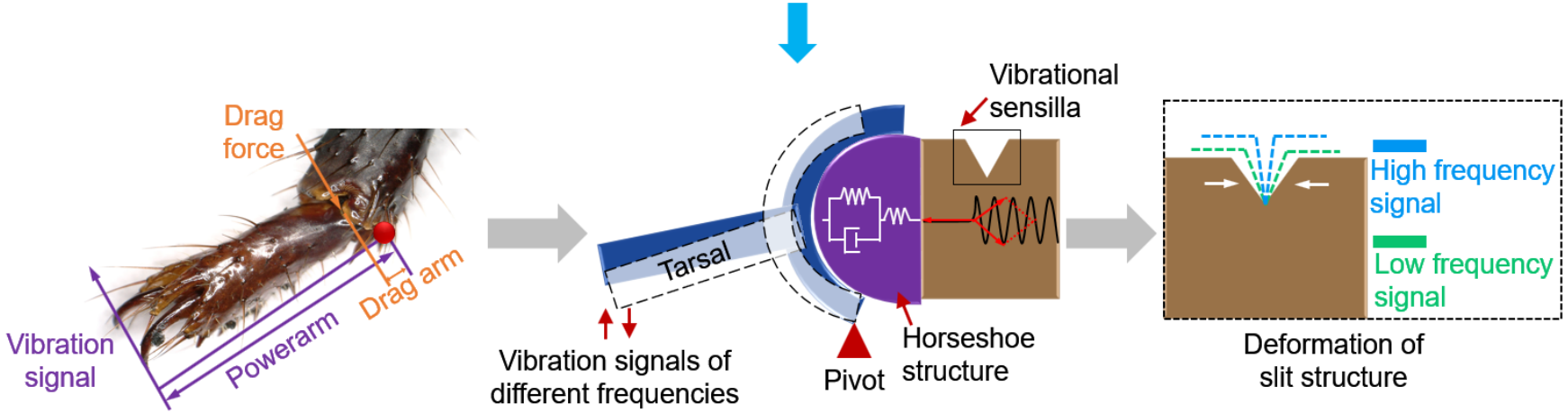


$Tan\ \alpha = E'' / E'$

Tan α:Ratio of dissipation modulus to storage modulus in each cycle

E'': Loss modulus

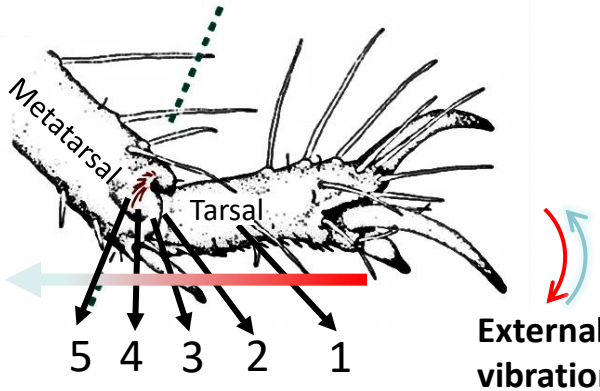
E': Storage modulus



Scorpions filter low-frequency signals through non-neural viscoelastic materials, which is conducive to slit receptors receiving high-frequency vibration signals.

3. Design and Processing

3.1 Bionic design principles



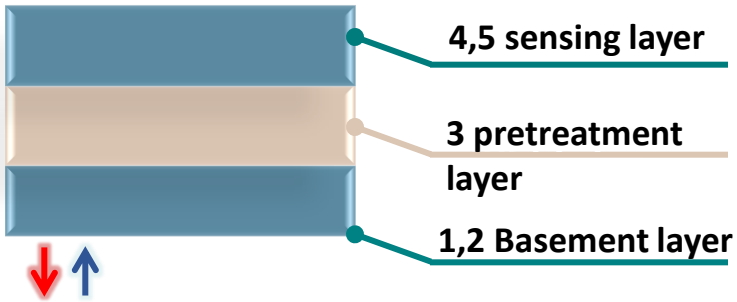
External vibration signal

Transmission direction of vibration signal

Transmission path of micro vibration signal in organism:

- External signal is transmitted to tarsal 1 → 2
- Pretreatment with viscoelastic material 2 → 3
- Transfer to the outer cuticle 3 → 4
- Transfer to vibrational sensilla 4 → 5

Inspire



Viscoelastic sandwich model

Transmission path of micro vibration signal on sensing element:

- External signal is transmitted to basement layer 1 → 2
- Pretreatment with viscoelastic material 2 → 3
- Transfer to sensing layer 3 → 4,5

Compared with the traditional single-layer strain sensing element, the viscoelastic intermediate layer is introduced to realize the pre-processing of external signals

3. Design and Processing

3.2 Selection of artificial materials

boric acid （**BA**）

✚

Hydroxyl terminated polydimethylsiloxane （**H-PDMS**）

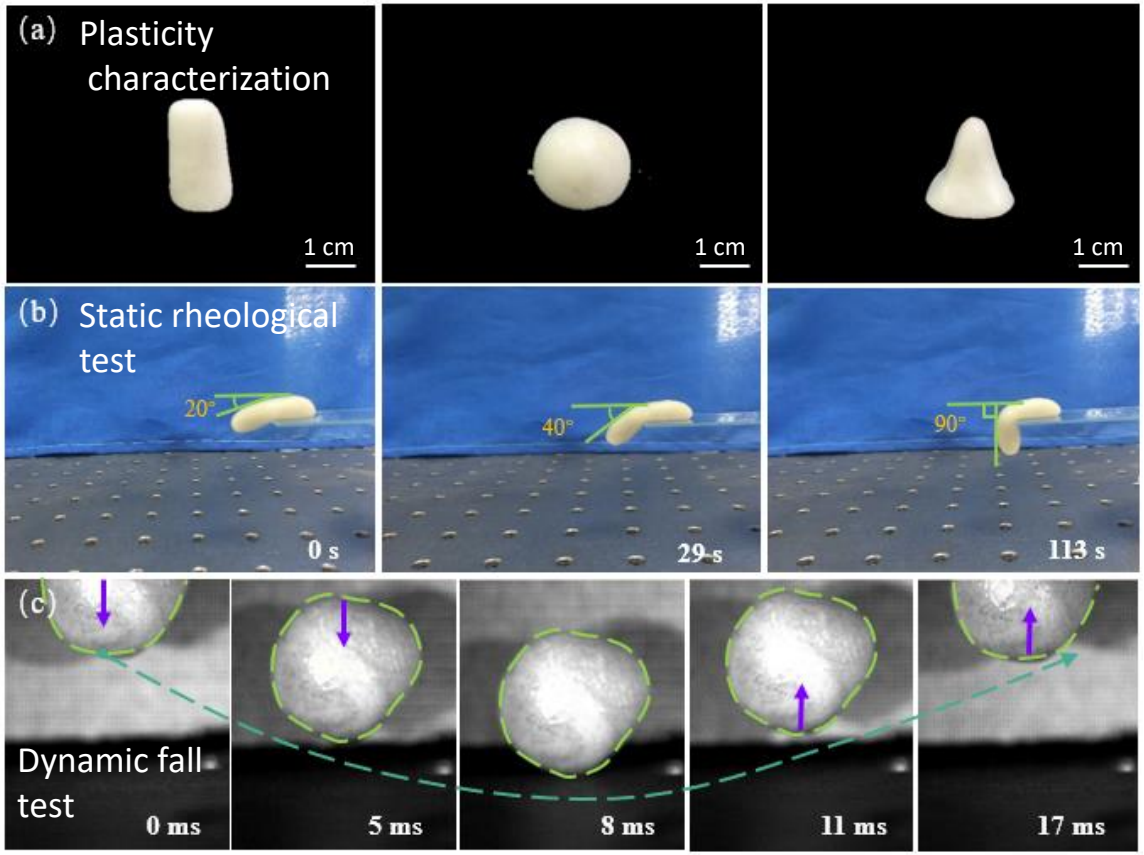
1. BA：H-PDMS (mass ratios): 4:1,5:1,6:1

2. Heat the mixed solution at 190 ℃ for one hour

3. Select 200nm filter membrane for filtration

4. Air drying

Polyborosiloxane （**PBS**）

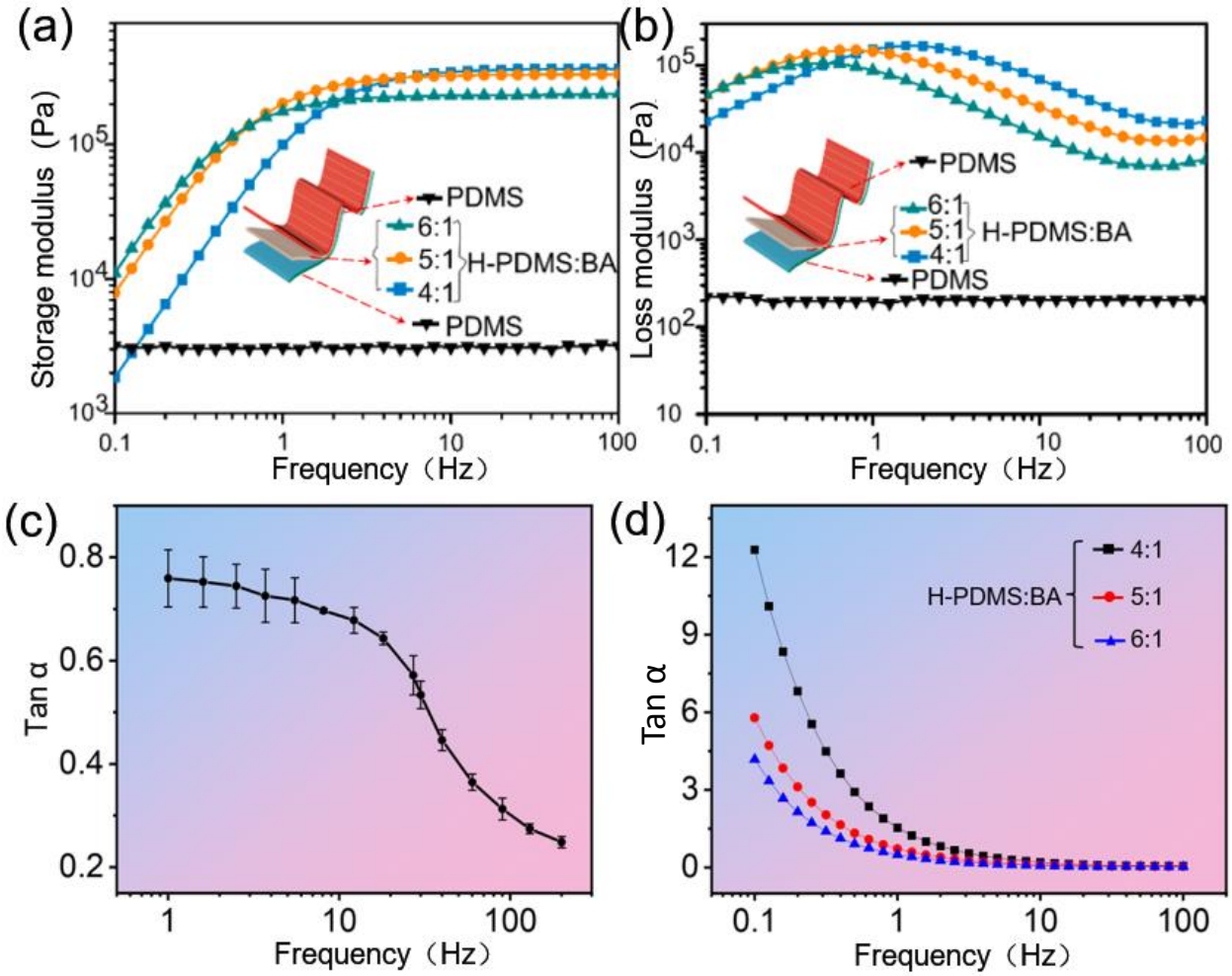


Qualitative test of viscoelastic properties of PBS

- **PBS was selected as the substitute material of the HLS**
- **Static and transient tests demonstrate that the prepared PBS has obvious viscoelastic properties**

3. Design and Processing

3.2 Selection of artificial materials

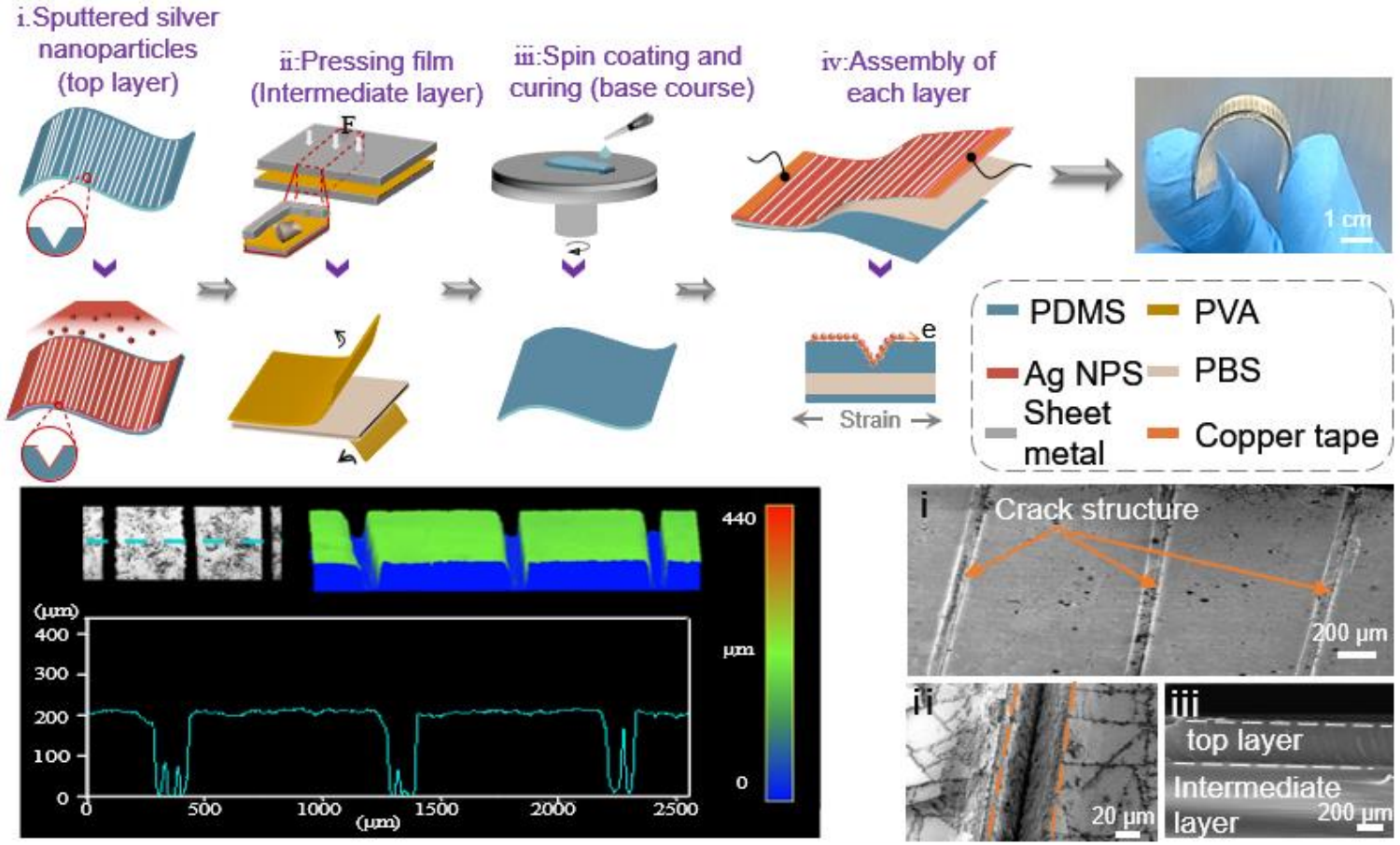


Quantitative rheological property measurement of PBS by rheometer

The change trend of loss factor of PBS is close to that of the HLS

3. Design and Processing

3.3 Fabrication process

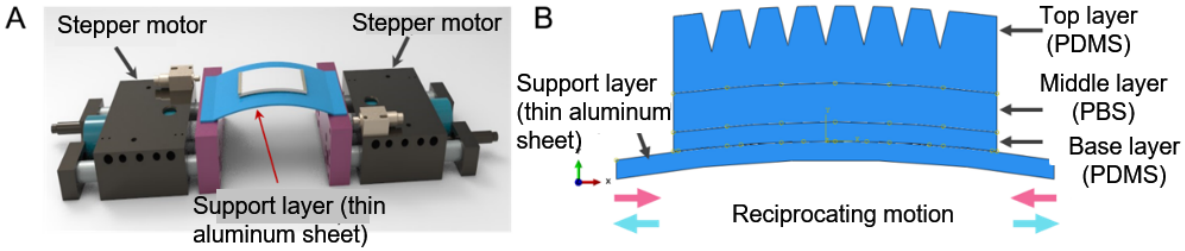


- Fabrication of flexible sensor with sandwich structure by using the strong adhesion between PBS and PDMS
- The thickness of the three layers (from top to bottom) is about 400 μm， 200 μm and 100 μm

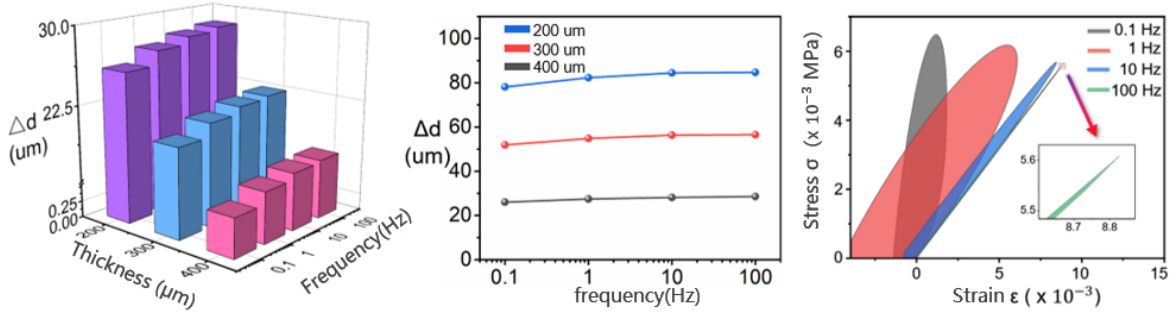
3. Design and Processing

3.4 Finite element simulation analysis

Finite element simulation



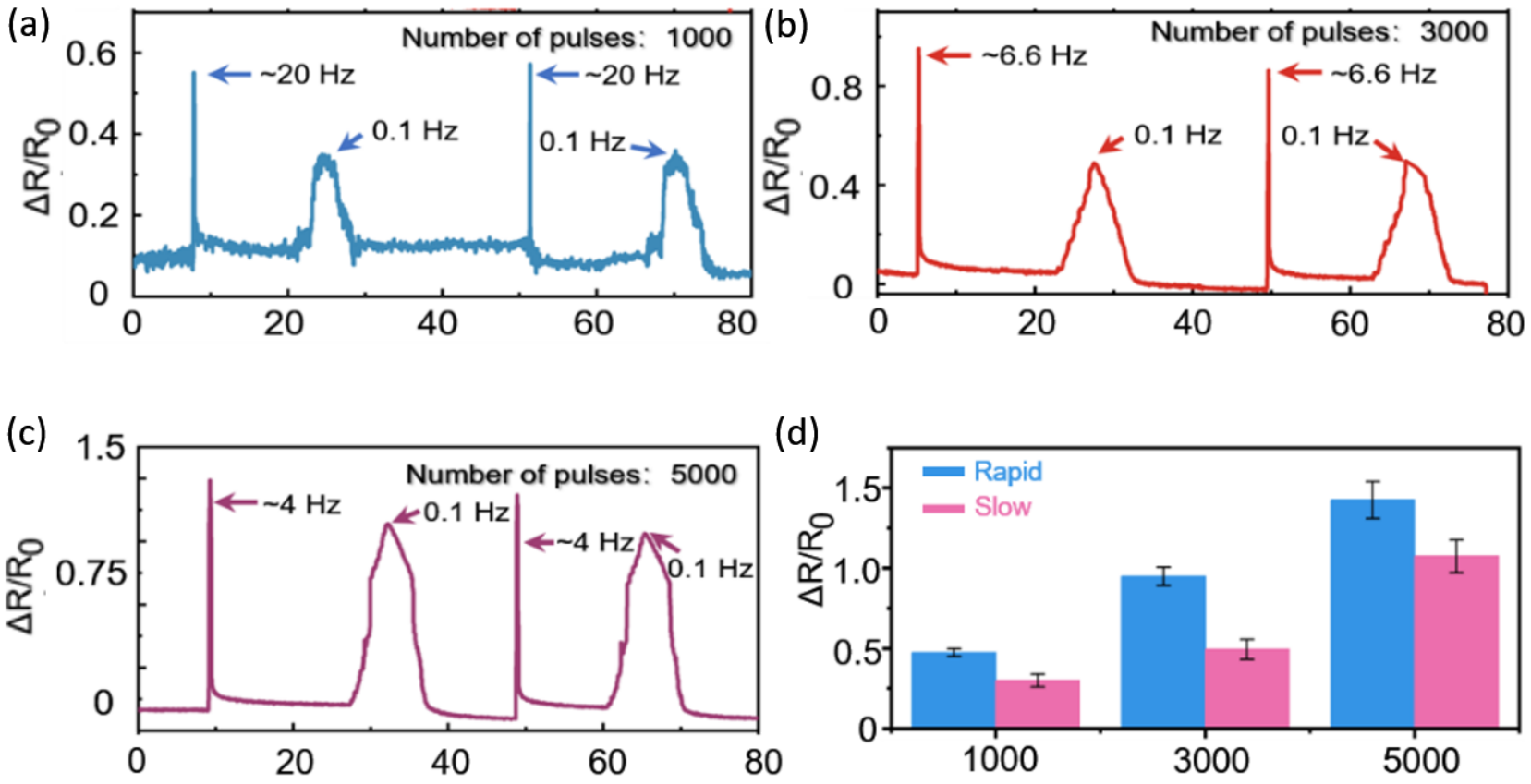
Result analysis



- When the external force velocity is small, the mechanical signal loss of the middle material is large
- When the speed of external force is large, the loss of vibration signal by the middle material is small

4. Achievements and Application

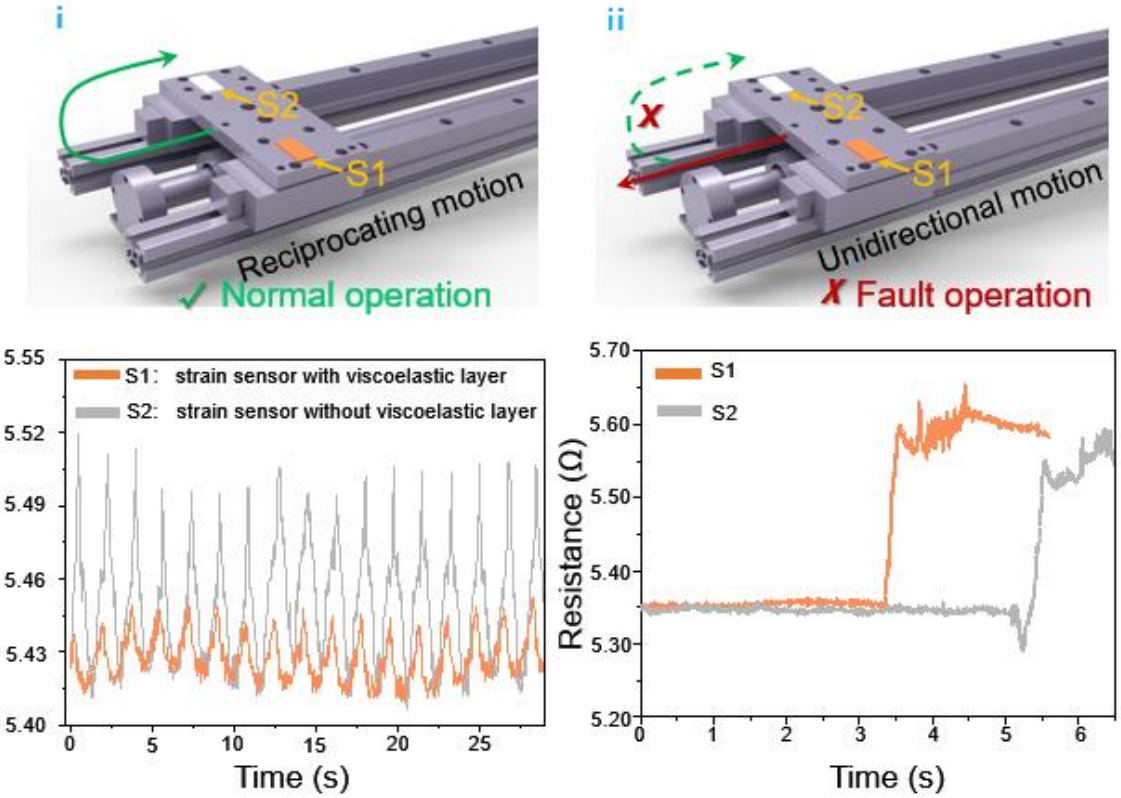
4.1 Performance characteristics——Resistance variation at different speeds



- At the same pulse number, the greater the speed of applying external force, the higher the change of resistance
- Its relative change in resistance can be achieved ~110% at 0.1 and 20 Hz

4. Achievements and Application

4.2 Performance characteristics——Non-contact low frequency vibration



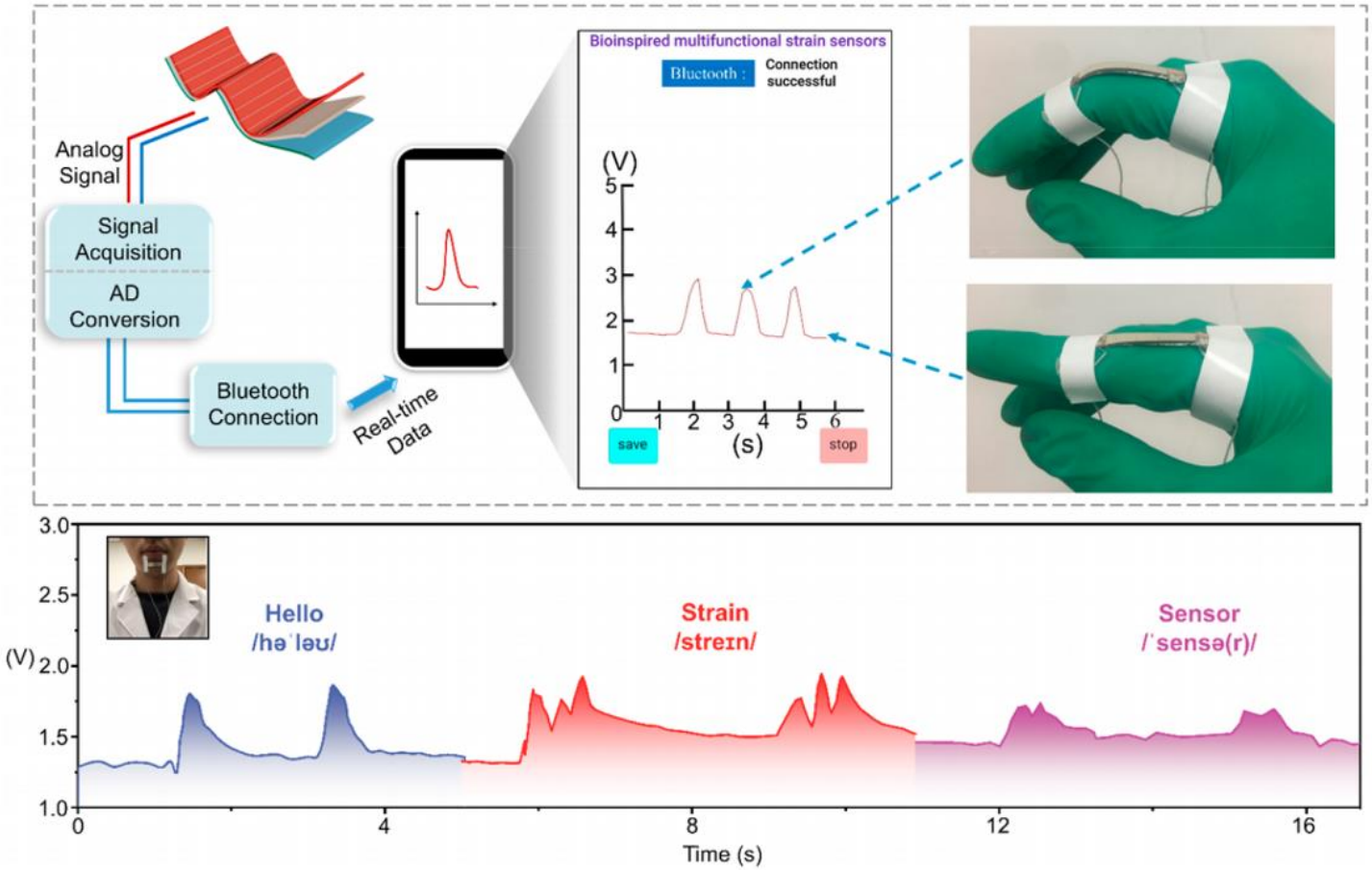
Normal operation: In this state, the horizontal displacement table operation is very smooth, and only a tiny low-frequency vibration will be produced.

Fault operation: In this state, an instantaneous impact vibration will be generated, which is equivalent to a high-frequency signal.

- when the displacement table is in normal operation, the signal of S1 is significantly lower than that of S2, indicating that the low-frequency signal can be effectively suppressed.
- when impact vibration occurs, viscoelastic materials will not attenuate this high-frequency signal

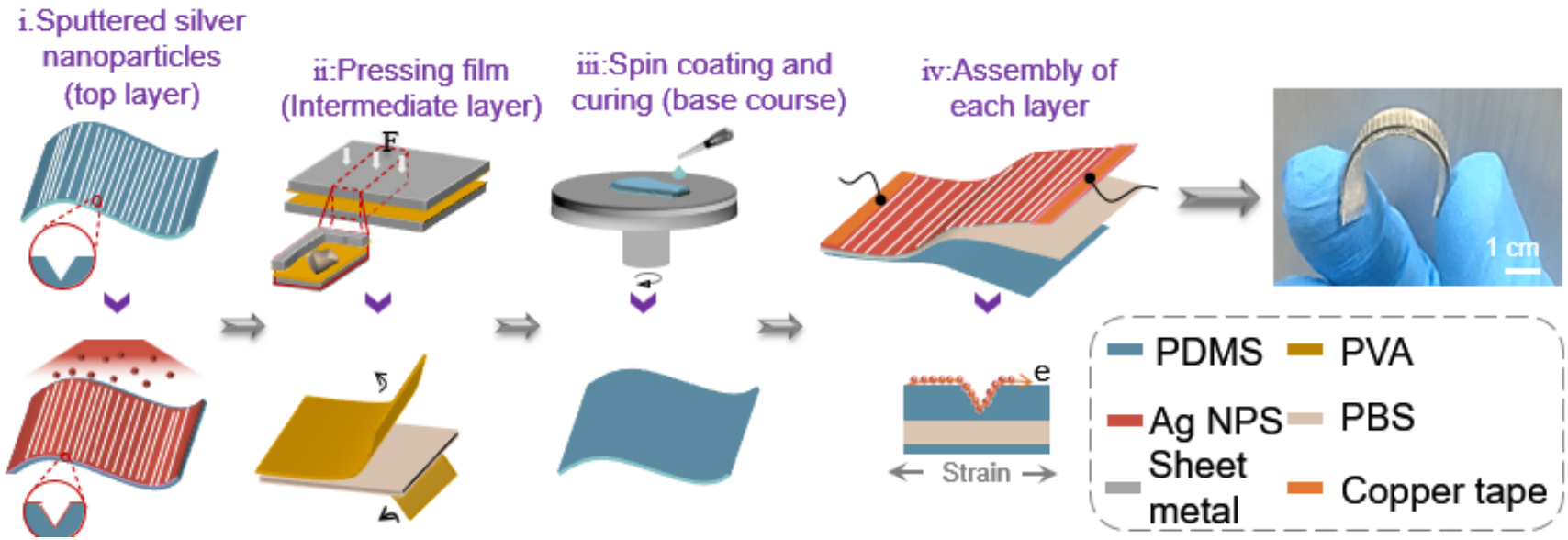
4. Achievements and Application

4.3 Performance characteristics——Wireless monitoring of human signal



Through the design of corresponding mobile phone apps, the wireless monitoring functions such as undistorted movement of human finger joints and recognizable voice signals are realized.

Zhiwu Han et al. *ACS Nano.* 2021, 15(12), 19629-19639.



The current bioinspired signal filtering technique has been applied in design of mechanosensors.