Effects of Microstructures on the Sensitivity of Flexible Pressure Sensor

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Introduction

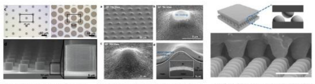
a. Application of flexible pressure sensor

Applications: AI, personalized health-monitoring, human-machine interfaces, flexible displays, soft robotics.

Requirements: High sensitivity; Broad pressure range; Fast response speed; Skin-mountable; …

b. Proposed strain sensor designs

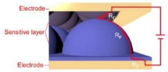
Common Microstructures: micro pillar, micro pyramid, micro sphere, micro dome, micro groove, micro domain, etc.



Q. Shao. Small, 2014, 10(8): 1466. C.L. Chung. Adv. Mater. 2014, 26 (21): 3451. Park. ACS Nano, 2014, 8 (5): 4689

What's the relationship between MICROSTRUCTURE and SENSITIVITY ?

c. Structure and mechanism of sensor



The microstructures deform with pressure, leading to the change of contact area and the increase of current.

Sensitivity $(S) = \frac{\Delta I/I_0}{P} \propto (\frac{R_0}{R_t} - 1) \Rightarrow S \propto \frac{A_t}{A_0} - 1 = \frac{1}{SF} - 1$

I_0 (R_0) : original current or resistance without loading

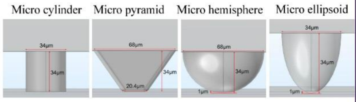
I_t (R_t) : current or resistance at a certain load

Surface Factor $(SF) = \frac{A_0}{A_t} = \frac{\text{the contact area}}{\text{total area could be contacted}}$

SF ↓ Sensitivity ↑

Hence, SF could quantify the capacity of contact area and further the resistance change of piezoresistive sensors.

d. SF of four typical microstructures



Regular microstructure based sensors

a. Influence of microstructures' shape

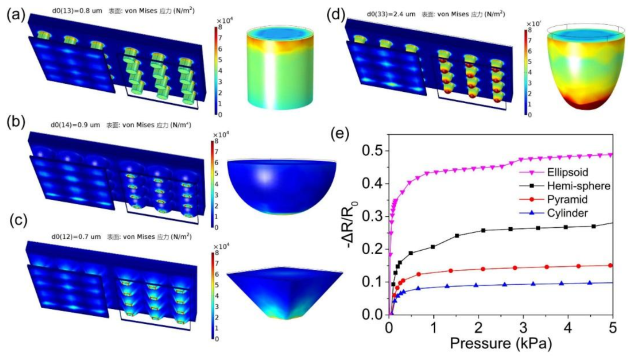


Fig. 1 Surface Von Mises stress of pressure sensors with (a) micro cylinders, (b) micro hemispheres, (c) micro pyramids and, (d) micro ellipsoids, respectively. (e) COMSOL simulation of $-\Delta R/R_0$ versus pressure plot.

	Ellipsoid	Hemisphere	Pyramid	Cylinder
S_L/kPa^{-1}	12.23	1.90	0.96	0.64
S_H/kPa^{-1}	0.0069	0.0039	0.0037	0.003
SF	0.01	0.029	0.057	0.25

S_L: Sensitivity in low pressure range
S_H: Sensitivity in high pressure range

Tab. 1 Sensitivities of the pressure sensors based on different microstructures by linear fitting of COMSOL calculation results and the corresponding SF.

Micro ellipsoids based pressure sensor exhibits highest sensitivities in both low and high pressure range.

b. Influence of microstructures' density

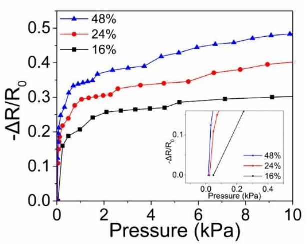


Fig. 2 The simulation result of $-(R_t-R_0)/R_0$ versus pressure of the micro ellipsoids structured sensor with different densities.

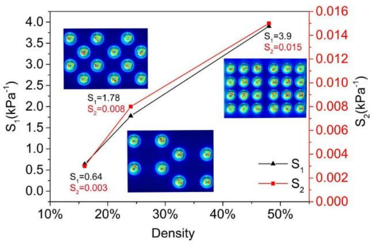


Fig. 3 The simulation results of S_L and S_H versus the density of microstructures..

Number of micro units ↑ ➡ Change of contact area ↑ ➡ Current increment ↑

Sensitivity increases with the number of micro units linearly.

Irregular microstructure based sensors

a. Mechanism of pressure sensor based on irregular micro-humps

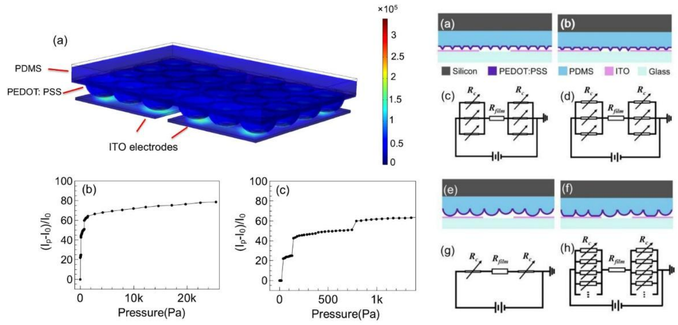


Fig. 4 (a) Surface Von Mises stress of 24 micro-humps in four different height, (b) $(I_p-I_0)/I_0$ versus pressure (0-26kPa), (c) Zoomed in figure of $(I_p-I_0)/I_0$ versus pressure (0-1.4kPa).

Mechanism of irregular pattern: The 24 micro-humps are of four groups with different height. It is found out that during for the loading process, when the shorter micro-humps touch the counter electrode, the current will dramatically increases. It confirms the hypothesis that shorter micro-humps contact counter electrodes will act as a new parallel resistor and will result in dramatic resistance decrease, and current increase.

Change of contact area
Shorter micro-humps contact counter electrodes } ➡ Dramatic current increment

b. Comparison of irregular micro-humps and regular pyramids

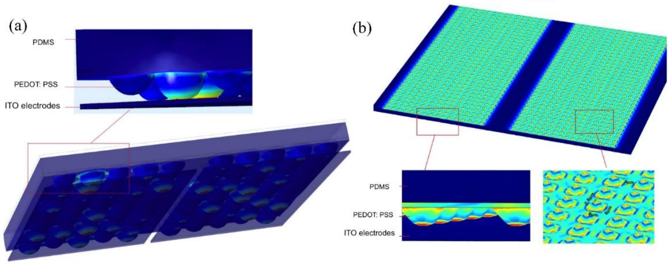
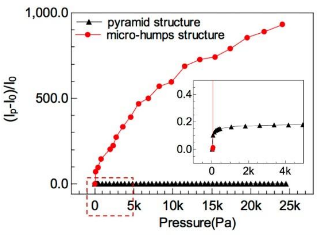


Fig. 5 (a)Surface Von Mises stress of 10×10 micro-humps structure,(b)Surface Von Mises stress of 32×32 pyramid structure.



Micro-humps based pressure sensor exhibits highest sensitivities in both low and high pressure range.

Fig. 6 $(I_p-I_0)/I_0$ versus pressure curve for pressure sensor based on 10×10 micro-humps and 32×32 pyramid.

Conclusion

A parameter SF was proposed to evaluate the performance of piezoresistive pressure sensor and COMSOL Multiphysics was used to simulate the sensing process of the sensor with different microstructures. The simulation results revealed that the sensor with micro ellipsoids exhibited highest sensitivity and broad pressure range and the next were hemispheres, pyramids and cylinders, respectively. The influence of the microstructures density was also calculated and the sensitivity as well as sensing pressure range increased with the density.

Pressure sensors based on irregular microstructures exhibit much higher sensitivities than the regular ones. Two sensing mechanisms are combined in the irregular sensors.

Reference

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[2] Choong C L, Shim M B, Lee B S, Jeon S, Ko D, Kang T, Bae J, Lee S, Byun K, Im J, Jeong Y, Park C, Park J and U-In Chung. Advanced Materials, 2014, 26(21):3451.
[3] Park J, Lee Y, Hong J, Ha M, Jung YD, Lim H, Kim SY, Ko H. ACS Nano, 2014,8 (5):4689