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◀ SESSION C [562호] ▶

Optimization of ITO resistor pattern to improve linearity

in contact-type pressure sensor

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Abstract

This paper introduces a novel contact-type pressure sensor with linearization property using indium-tin-oxide (ITO) resister. The pressure sensor consists of a silicon diaphragm with a conducting layer and Pyrex glass with the ITO resistor. The middle of the ITO resistor is contacted to the conductive diaphragm at a desired pressure. The contact area of ITO resistor to the diaphragm is increased with the increase of applied pressure. Meanwhile, the ITO resistance is linearly decreased with the increase of the contact area. The pattern of ITO resister is optimized by FEM simulation, which makes the sensor output value to be linear. The change of the electrical resistance between both ends of the ITO resistor is measured by using a simple electrical circuit. The fabricated pressure sensor has a sensitivity of 15.6Ω/kΩ•bar and a dynamic range of 1bar~10bar. Contact-type pressure sensor has advantages that no need to use additional circuit technology for amplifying signal or removing noise.

Keywords: pressure sensor, diaphragm, indium-tin-oxide(ITO)

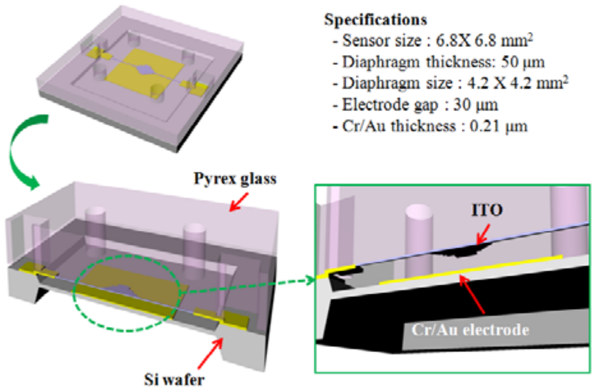

Figure 1. Schematics of contact-type pressure sensor

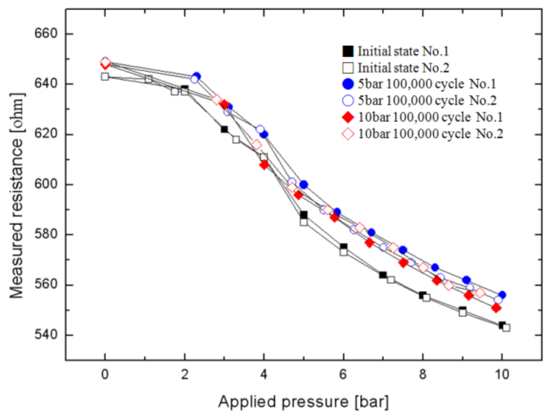

Figure 2. The change of out resistance versus applied pressure

References

[1] C.S. Park, Y.S. Choi and D.W. Lee, "A new type of a MEMS pressure sensor with mechanical micro-switch array", *33rd International Conference on Micro and Nano-Engineering*, pp. 377-378, Copenhagen, Denmark, 2007.

[2] H. Seidel, L. Csepregi, A. Heuberger, and H. Baumgartel, "Anisotropic etching of crystalline silicon in alkaline solutions, I. Orientation dependence and behavior of passivation layers", *J. Electrochem. Soc.*, vol. 137, pp. 3612–-3632, 1990.

접촉형 압력센서의 선형성 개선을 위한 ITO 저항체 패턴의 최적화

Optimization of ITO resistor pattern to improve linearity in contact-type pressure sensor

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2013. 11. 22

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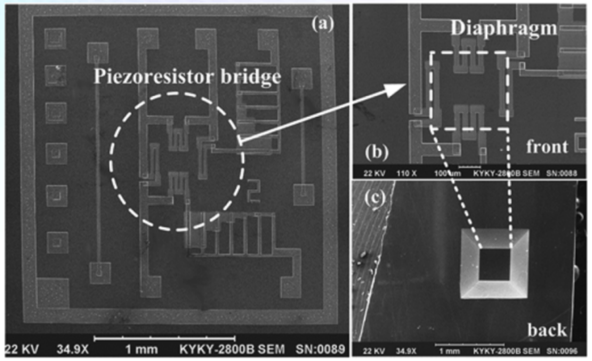
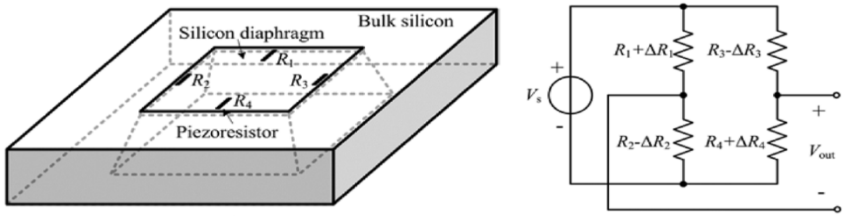
연구 배경 – 압저항형 압력센서

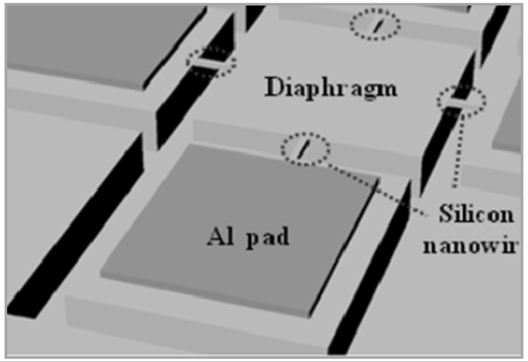
"A Novel Pressure Microsensor With 30-μm-Thick Diaphragm and Meander-Shaped Piezoresistors Partially Distributed on High-Stress Bulk Silicon Region" Yan-Hong Zhang et al., IEEE SENSOR 2007

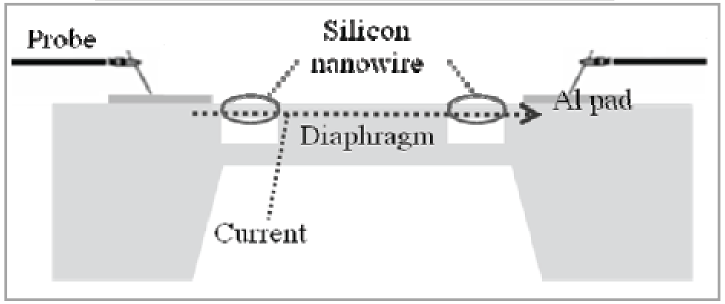




Sensitivity : 32.2 mV/V·MPa
Pressure range : 0~1MPa

"Fabrication of a piezoresistive pressure sensor for enhancing sensitivity using silicon nanowire" J.H. Kim et al., Transducers 2009





Sensitivity : 337.5 mV/V·MPa
Pressure range : 150 kPa~300 kPa

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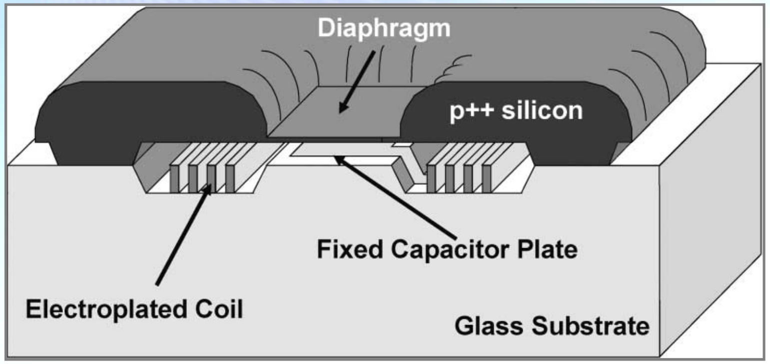
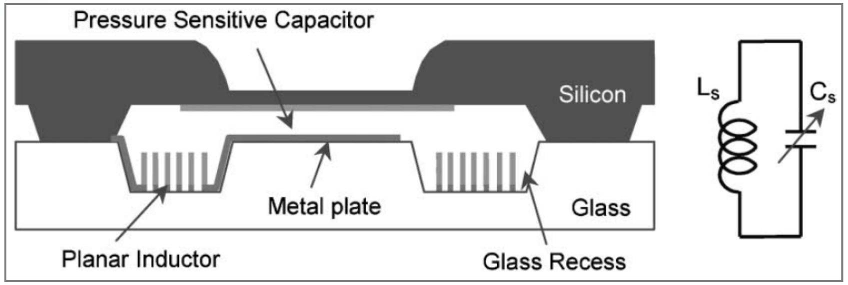
연구 배경 – 정전용량형 압력센서

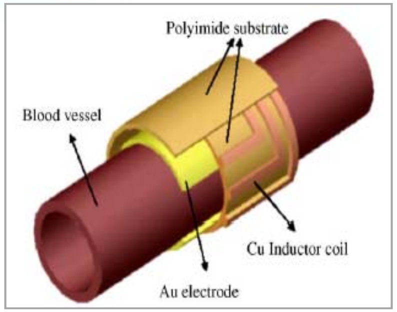
"A wireless batch sealed absolute capacitive pressure sensor",Orhan Akar et al., Sensors and Actuators A, 2001

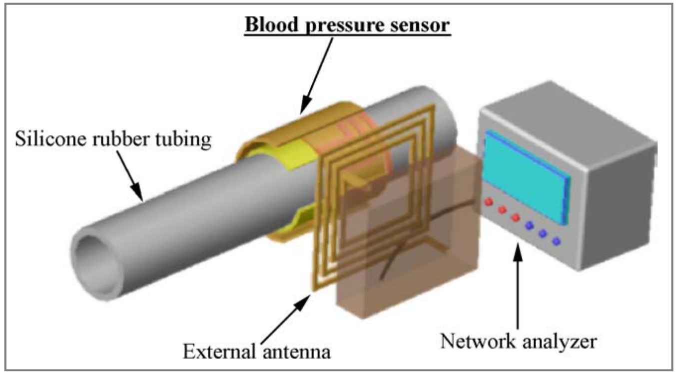




Sensitivity : 160 kHz/mmHg
Pressure range : 0~50mmHg

" Flexible wireless pressure sensor module", Kyu-Ho Shn et al, Sensors and Actuators, 2005





Sensitivity : 11.25 kHz/kPa
Pressure range : 0~213.3 kPa

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연구 배경 – 실리콘기반 압력센서

❖ 기존 압력센서의 비교

	압저항형 압력센서
원리	Diaphragm 표면에 스트레인 게이지를 형성하고 저항치의 변화를 검출하는 방법
장점	일반적인 압력 측정에 널리 이용 될 수 있음 단가가 낮고 보편화 되어 있음
단점	압력강도가 낮고, 온도 드리프트의 영향을 크게 받음 고감도 및 온도의존성이 낮고 소비전력이 작은 시스템에 적용이 불가함

	정전용량형 압력센서
원리	Diaphragm과 다른 전극 사이의 용량변화를 검출하는 방법
장점	온도 특성이 우수하고 소형임 고감도인 관계로 생체 등 미압의 영역에서 사용에 적합함
단점	압저항에 비해 고감도이나 전극의 형성, 외부 회로와의 연결이 복잡함 응답성이 좋지 않음

기존 실리콘 기반 압력센서의 문제점을 보안하기 위하여
새로운 형태의 압력센서 개발이 필요함

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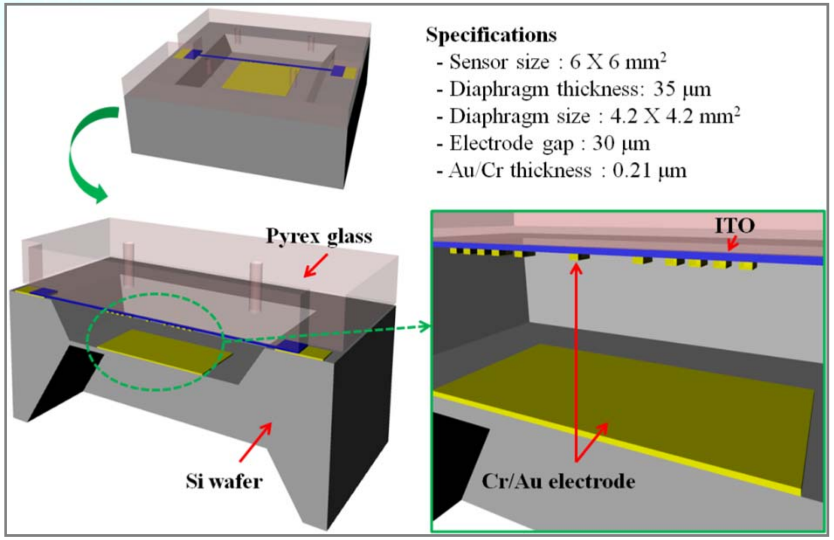
연구 배경 – 접촉형 압력센서 : 기존 실험실 연구내용

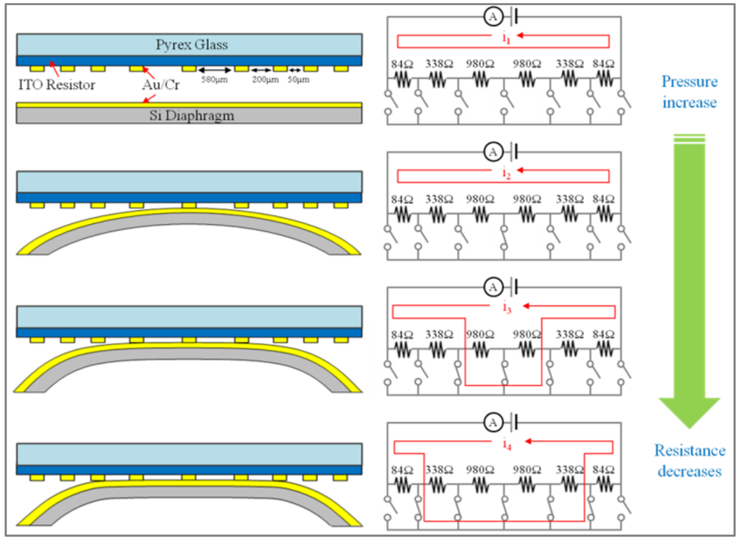
❖ Micro array를 이용한 접촉형 압력센서의 장점

- 압력 감도가 향상됨 (1680.5 mV/V•MPa)
- 높은 초기 저항과 인가 압력에 따른 높은 저항 변화
  - 신호증폭 및 노이즈 제거회로 불필요
- 단계별 저항 변화를 보이므로 레벨 센서로 활용 가능함

"Pressure-Controlled Variable Resistor for Limit Switch Applications", JCK MEMS/NEMS 2013, Tohoku University, 2013



압력센서의 개략도



압력센서의 동작원리

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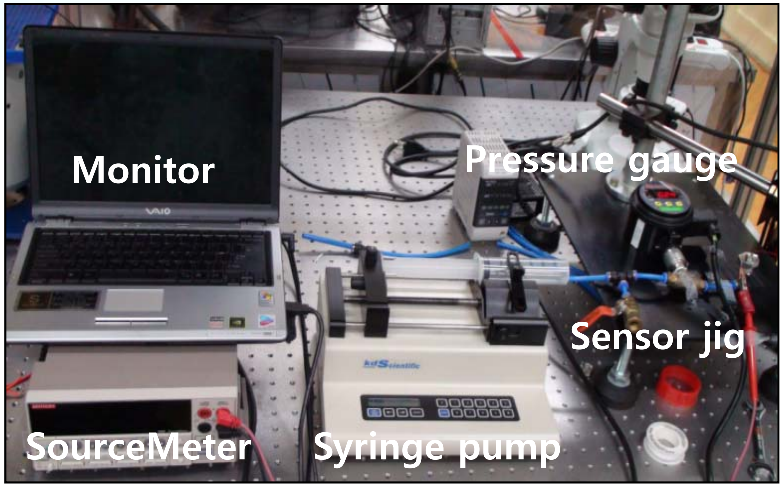
연구 배경 – 접촉형 압력센서

❖ 인가 압력에 따른 저항 변화 결과

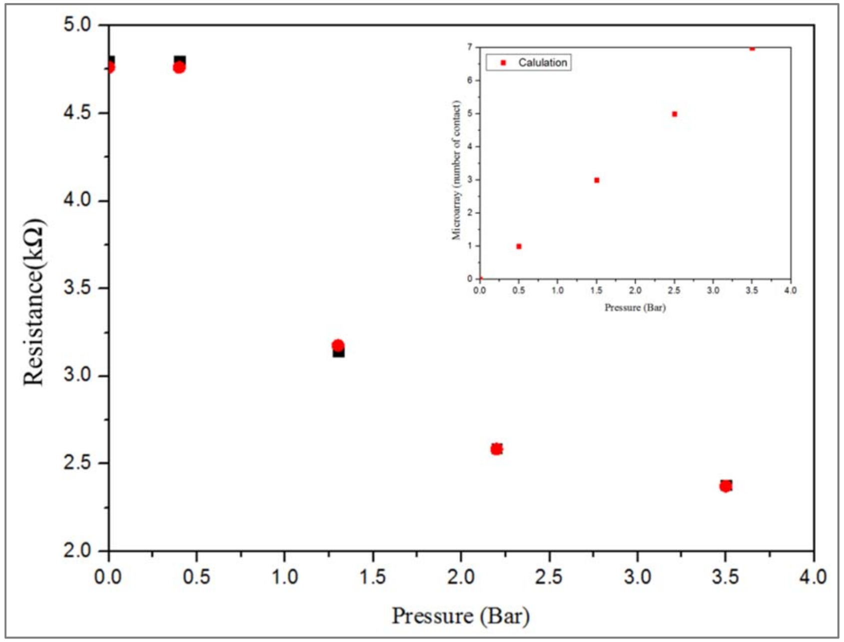
- 압력 인가 전 센서 저항 : 4800Ω
- 최소 Diaphragm 접촉 압력 : 0.5bar
- 압력(3.5Bar) 인가 후 저항 변화 : 2419Ω
- 압력감도 : 1680.5mV/V·MPa

❖ Micro array를 이용한 접촉형 압력센서의 단점

- 특정 압력에서의 저항변화 측정
- 출력 특성의 선형화 필요



계측 시스템



압력인가에 따른 저항 변화 측정

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연구 목표 및 내용

❖ 연구 목표

ITO resistor의 구조개선 통한 접촉형 압력센서의 선형성 향상

❖ 연구 내용

- 다이어프램의 접촉 면적 변화를 이용한 압력센서의 설계 및 제작
  - 다이어프램의 응력 및 변위 해석
  - 다이어프램의 접촉 면적 해석
  - ITO resistor의 선형화 설계
- 측정 시스템 구축 및 특성 평가
  - 온도에 따른 ITO 비저항 측정
  - 센서의 압력에 따른 저항 변화 측정
  - 센서의 내구성 테스트

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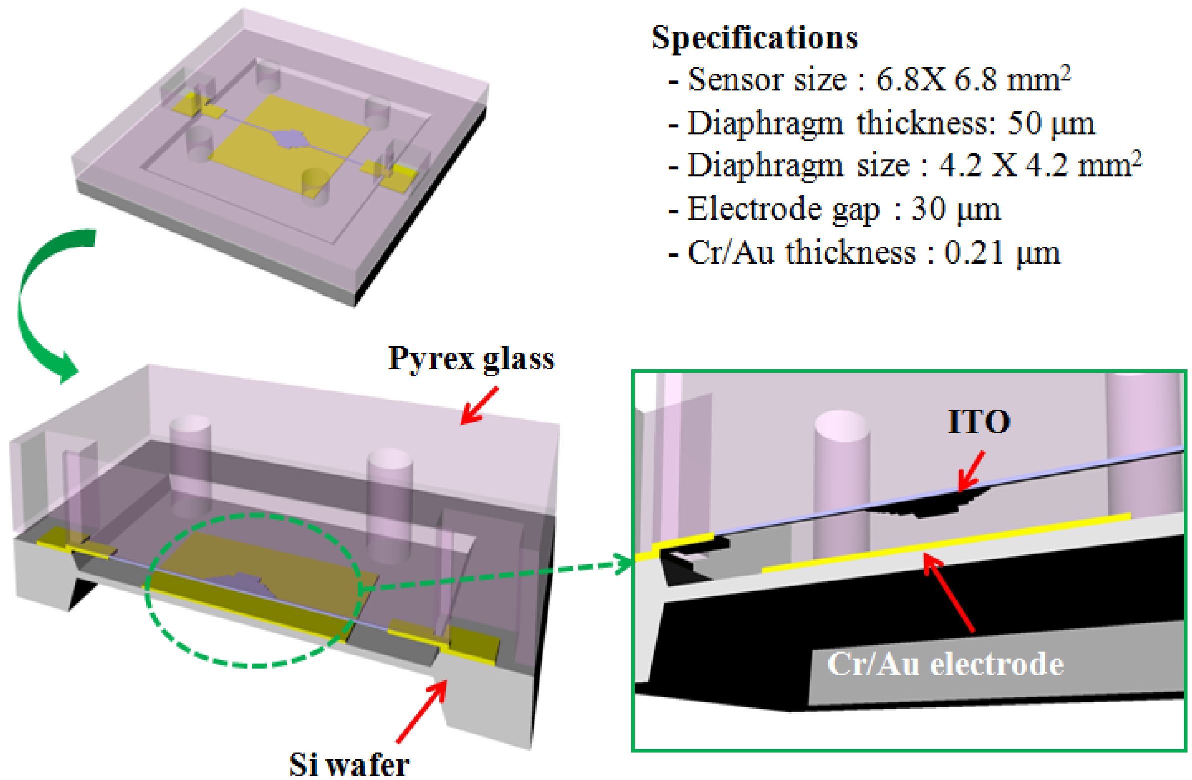
압력센서 – ITO resistor 구조개선

Specifications

- Sensor size : 6.8X 6.8 mm^2
- Diaphragm thickness: 50 µm
- Diaphragm size : 4.2 X 4.2 mm^2
- Electrode gap : 30 µm
- Cr/Au thickness : 0.21 µm



압력센서 개략도

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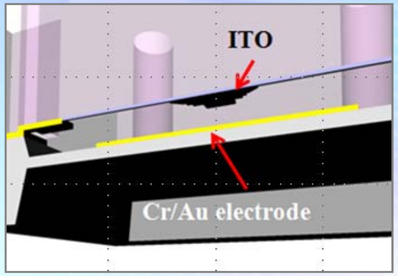
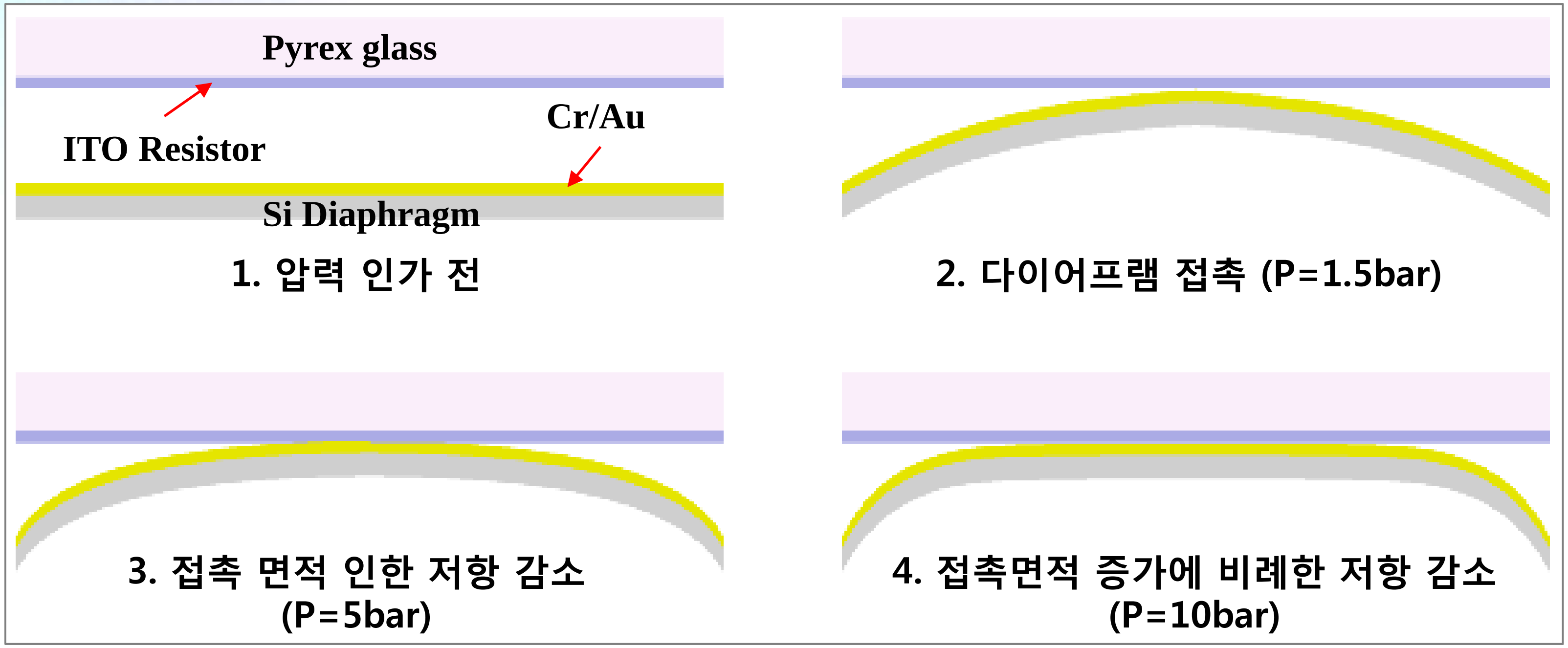
압력센서 – 동작원리



압력 인가 후 Diaphragm 변형 ➡ Diaphragm의 접촉 면적 증가

➡ 전기 저항 값의 변화를 검출함으로써 인가된 압력 측정



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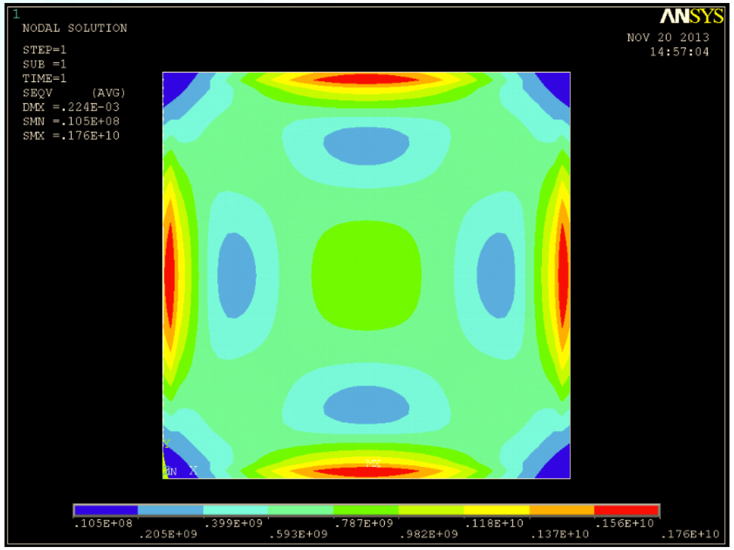
설계 – Diaphragm 응력 해석 (동작 범위 : 1.5~10bar)

- Diaphragm size : 4.2 X 4.2mm^2
- Diaphragm thickness : 50μm
- Pressure : 10Bar

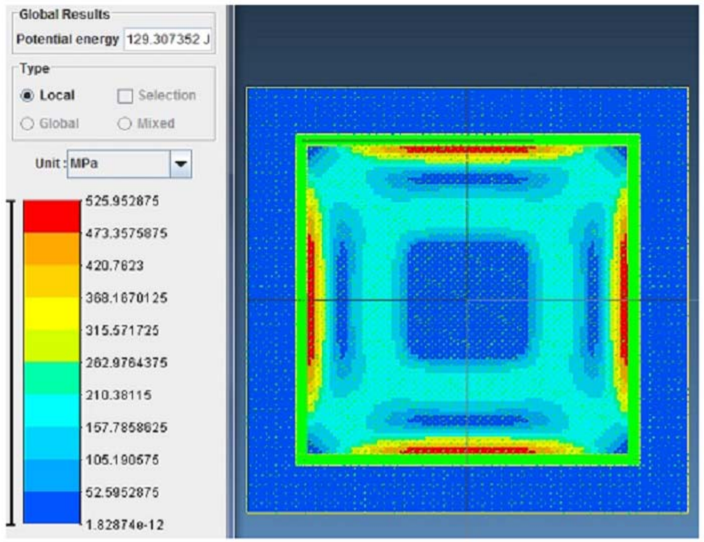
- Diaphragm size : 4.2 X 4.2mm^2
- Diaphragm thickness : 50μm
- Electrode gap : 30μm
- Pressure : 10Bar

Diaphragm 해석



Stress : 1.7GPa

Glass bonding Diaphragm 해석



Stress : 525.9MPa

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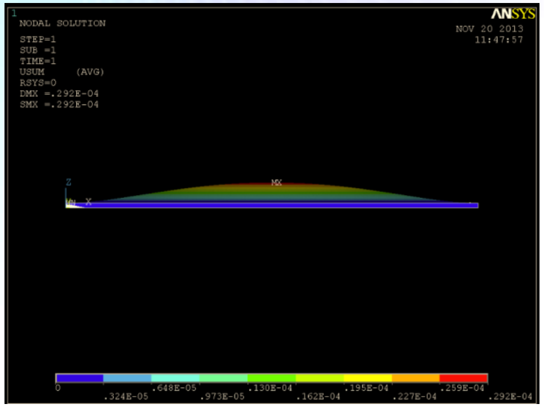
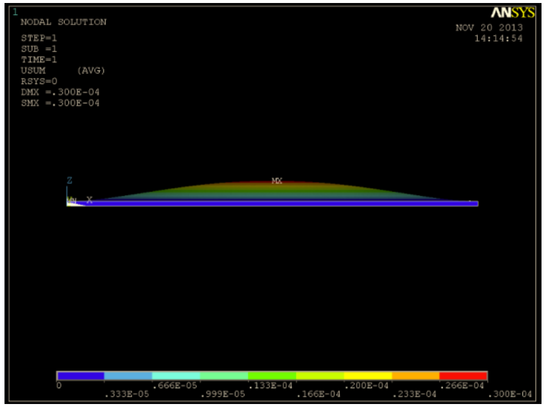
설계 – Diaphragm 접촉 압력 해석 (동작 범위 : 1.5~10bar)

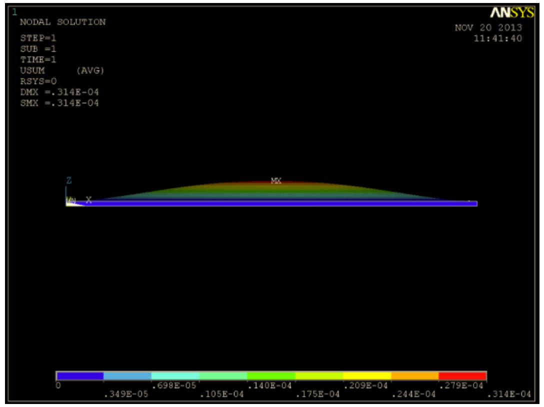
- Diaphragm size : 4.2 X 4.2mm^2
- Diaphragm thickness : 50μm
- Electrode gap : 30μm



Pressure : 1.3bar
Displacement : 29.2μm



Pressure : 1.34bar
Displacement : 30μm



Pressure : 1.4bar
Displacement : 31.4μm

ANSYS 해석 결과 35μm의 두께를 갖는 Diaphragm의 경우 1.34 bar에서 Diaphragm과 ITO가 접촉할것으로 예상됨 → **압력 범위 0~1.34 bar 에서 불감대 형성**

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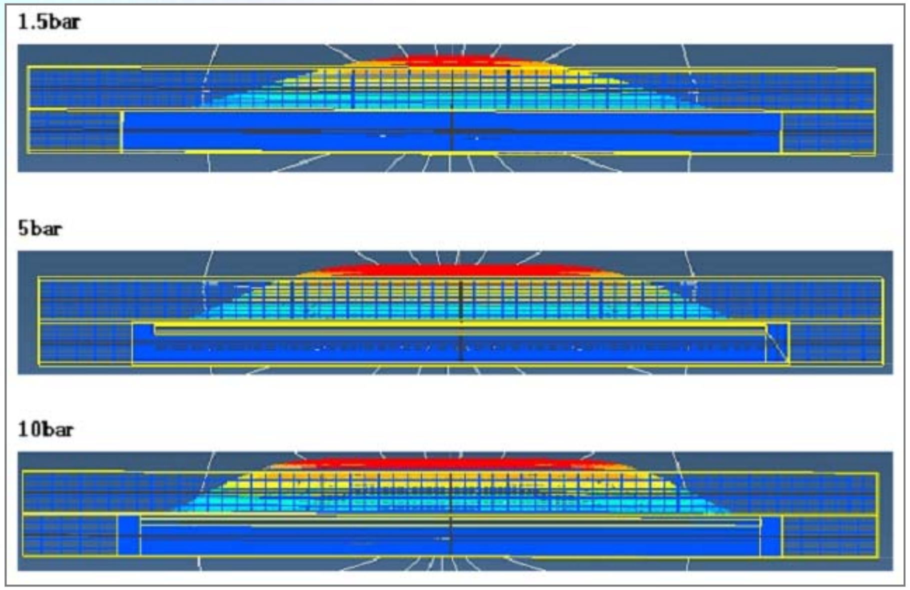
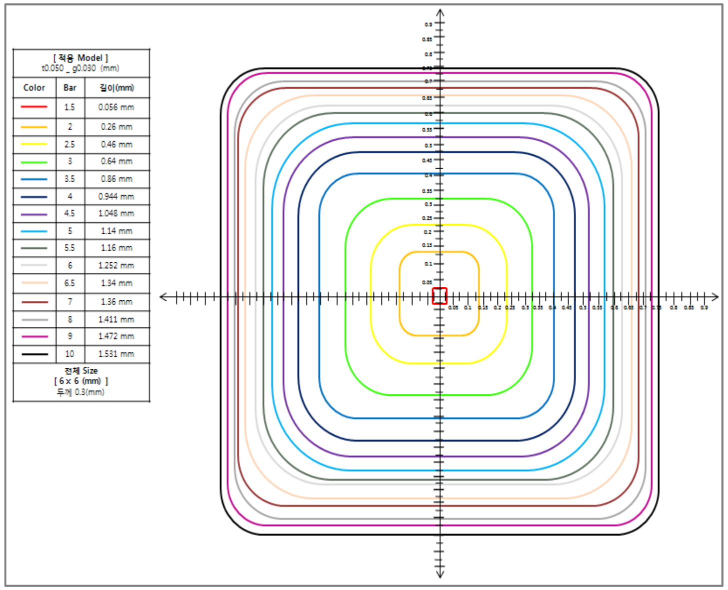
설계 – Diaphragm 접촉 면적 해석

- Diaphragm size : 4.2 X $4.2mm^2$
- Diaphragm thickness : 50µm
- Electrode gap : 30µm

❖ 인가 압력에 따른 diaphragm의 접촉 길이

- 인가 압력 : 1.5bar → 접촉 길이 : 56µm
- 인가 압력 : 5bar → 접촉 길이 : 1.14mm
- 인가 압력 : 10bar → 접촉 길이 : 1.53mm





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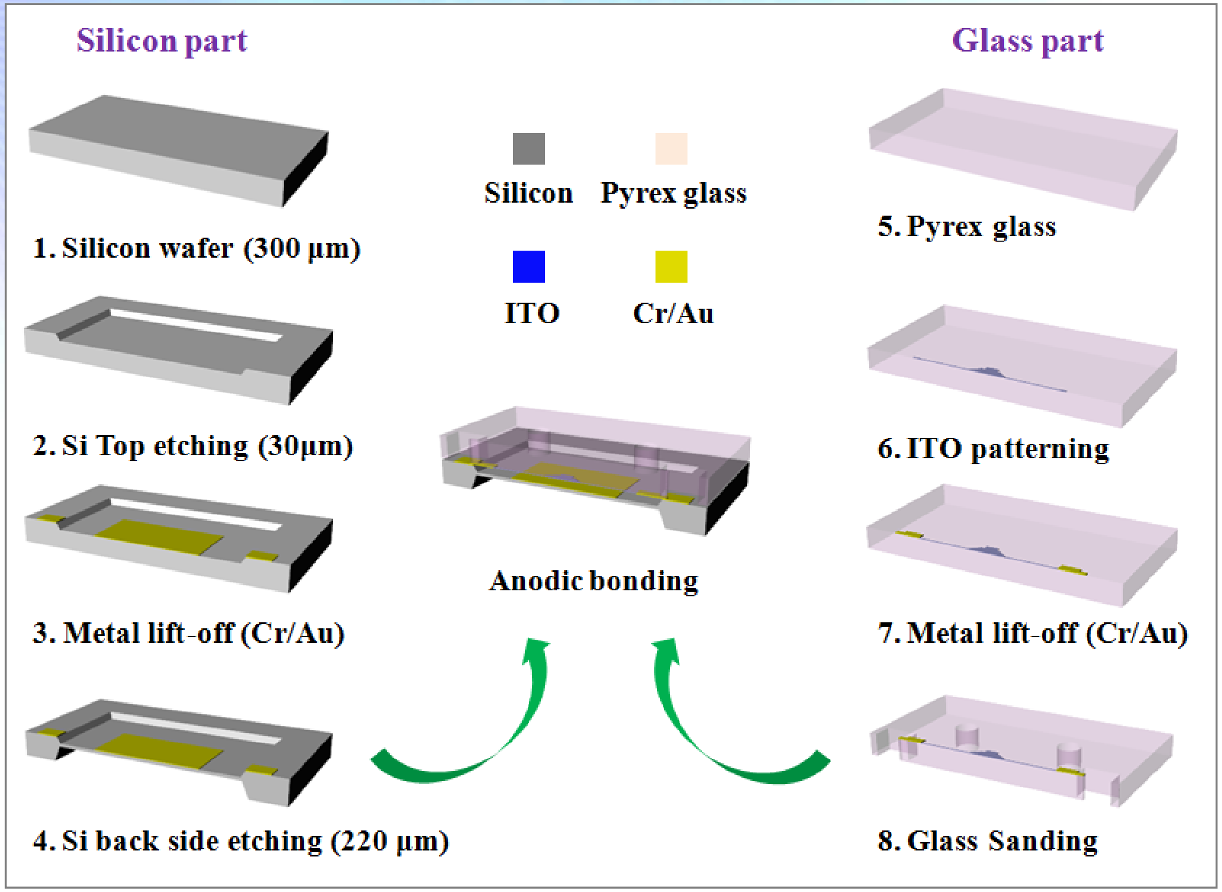
압력센서 – 제작



압력센서 공정 순서도

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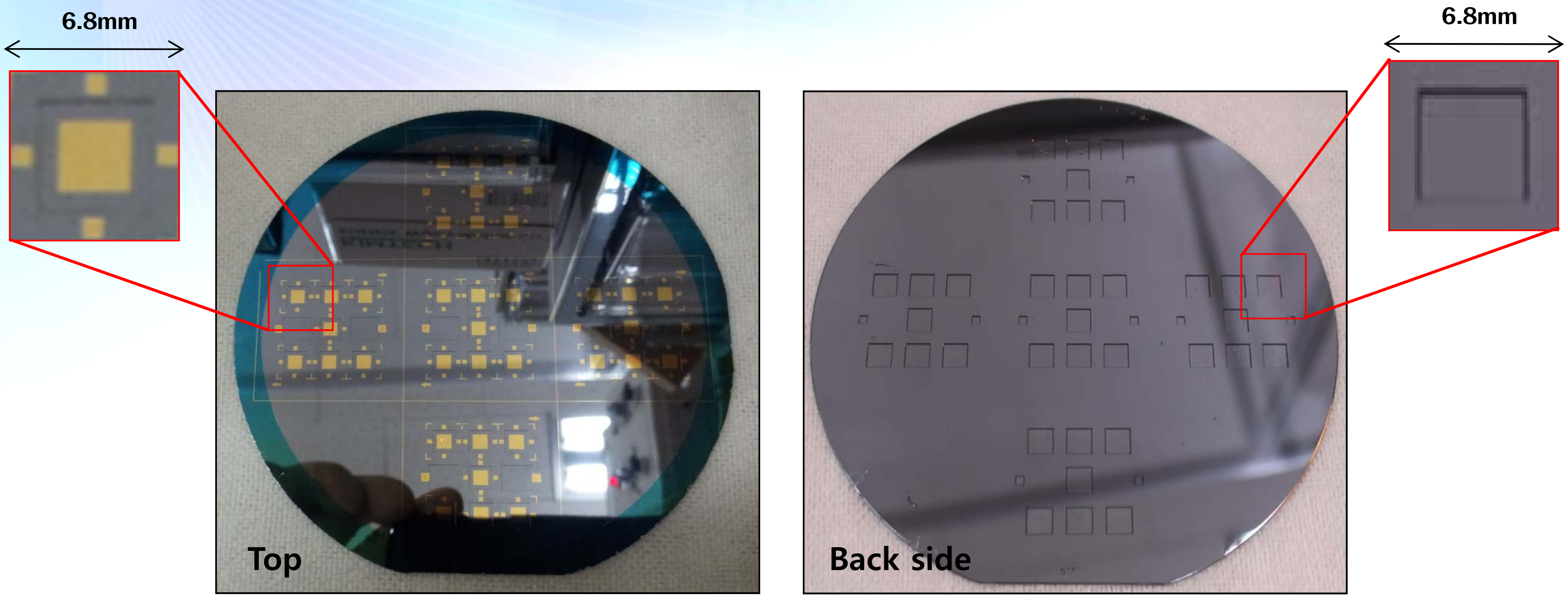
제작 – Silicon Part

❖ Silicon wafer



- Si Top etching
- Metal Lift-off

- Si Back side etching

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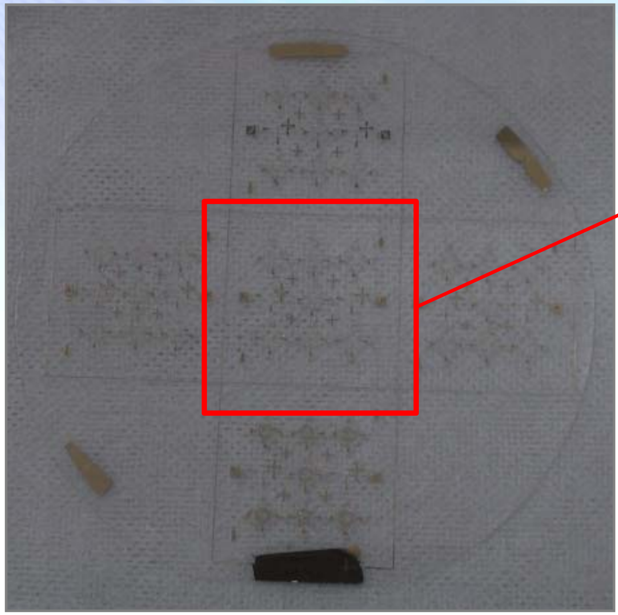
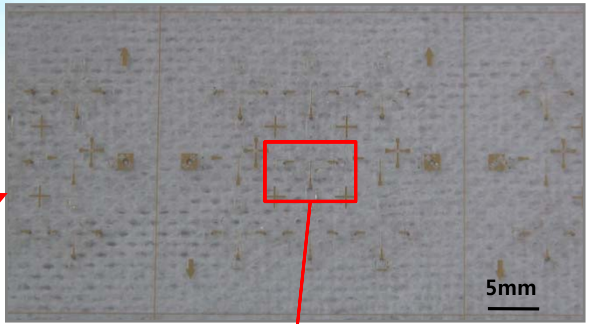
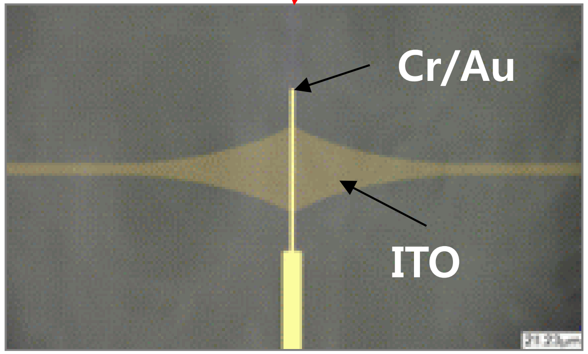
제작 – Glass Part

❖ Glass wafer



제작된 Glass wafer





- Photo lithography 공정을 이용한 ITO pattern 형성
- Cr/Au를 증착하여 mater layer 형성
- Sand blast 실시

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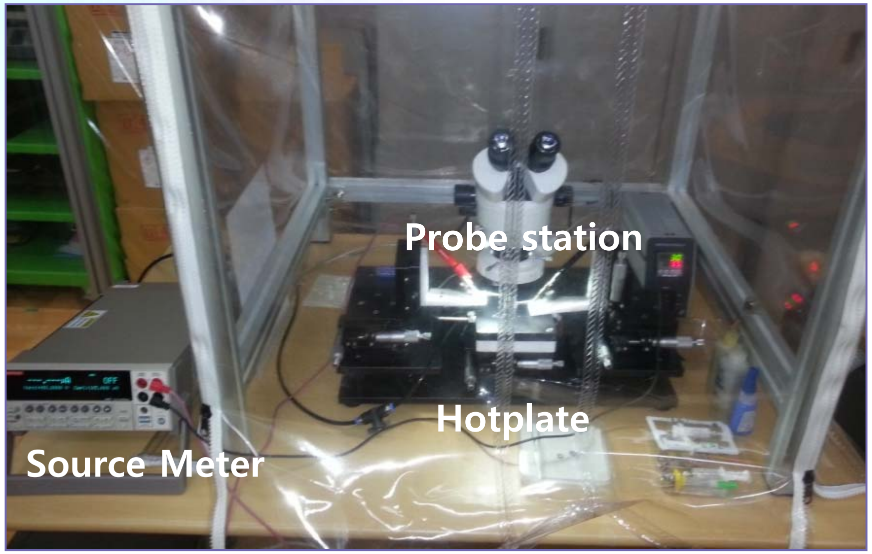
특성 평가 – ITO의 비저항 측정

❖ 온도에 따른 ITO의 비저항 측정 결과

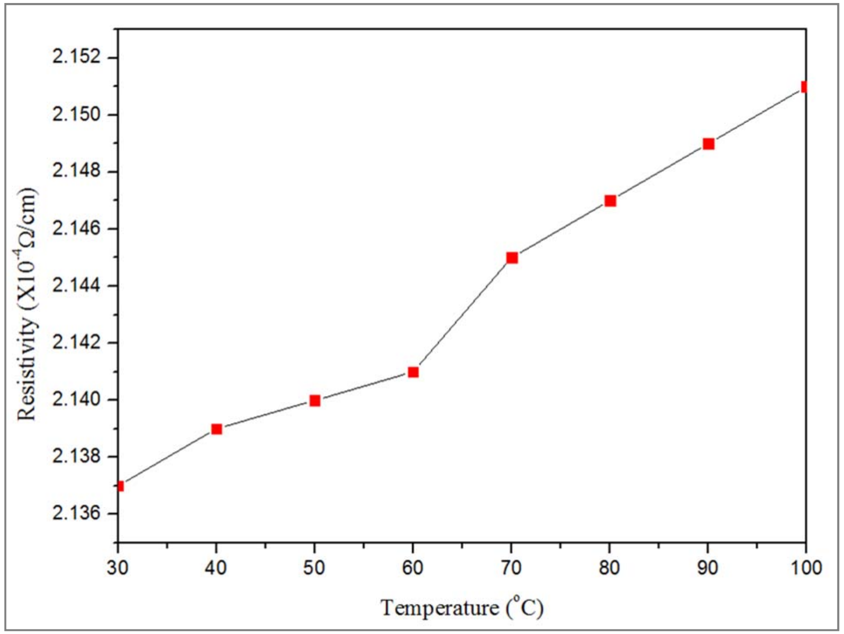
- 30℃에서 ITO의 비저항 : 2.137X10-4 Ω/cm
- 100℃에서 ITO의 비저항 : 2.151X10-4 Ω/cm

ITO 비저항 약 0.6% 증가

(30℃ → 100℃)



측정 시스템



온도에 따른 ITO 비저항 측정

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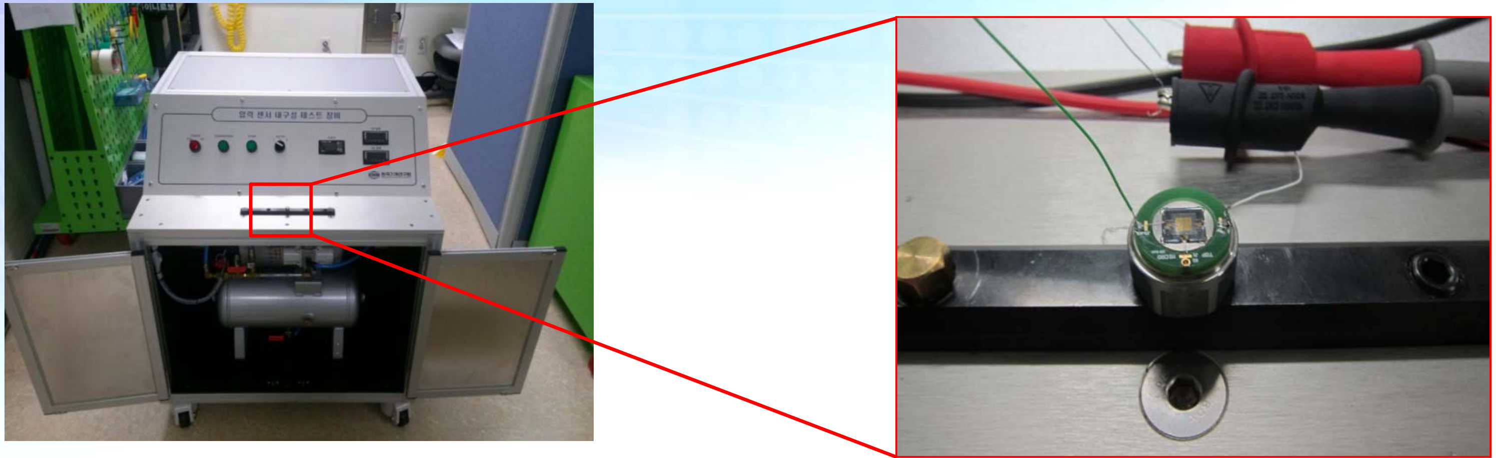
계측 시스템 구축



압력에 따른 ITO 저항 측정 장비

Compressor

Pressure booster

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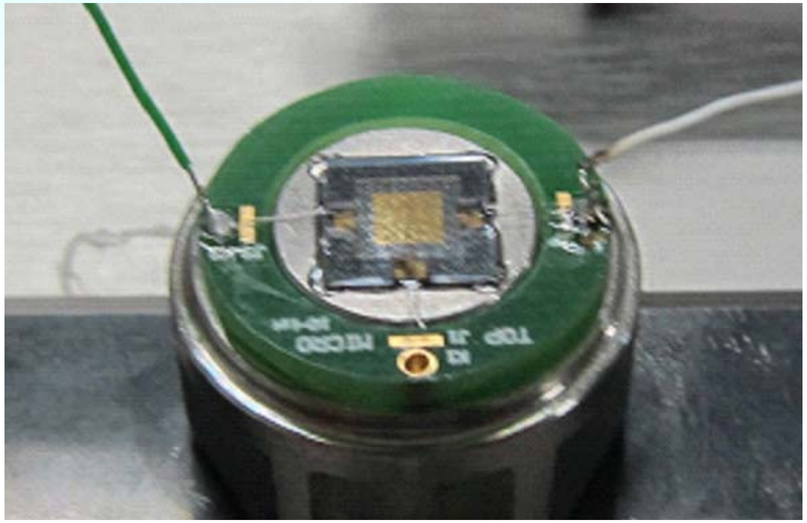
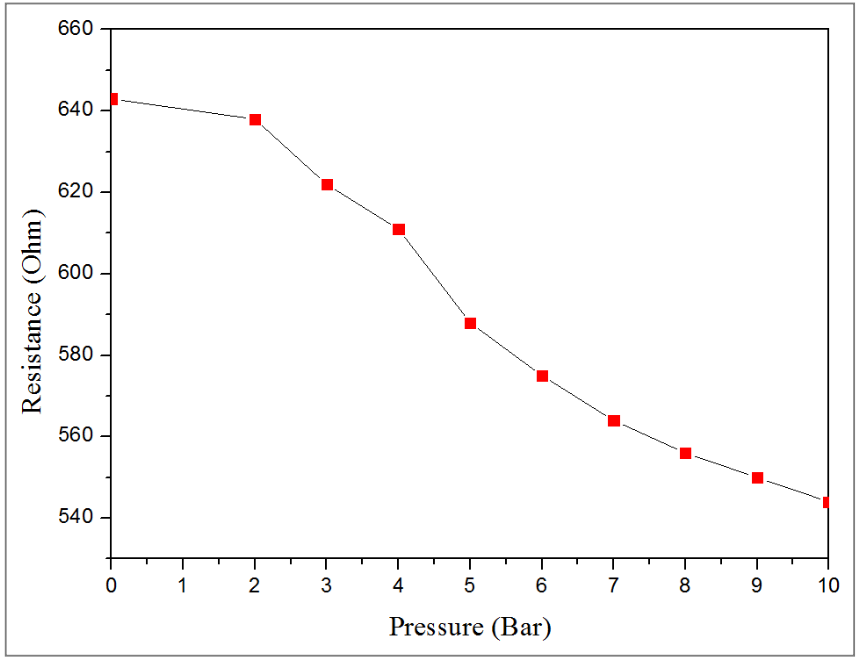
계측 – 인가압력에 따른 저항 변화

❖ 2.4Bar 압력 인가시 저항 변화 결과
- 압력 인가 전 센서 초기 저항 : 643Ω
- 최소 Diaphragm 접촉 압력 : 1.4bar
- 압력(10 Bar) 인가 후 저항 변화 : 99Ω



Jig를 이용한 센서 고정



압력인가에 따른 저항 변화 측정

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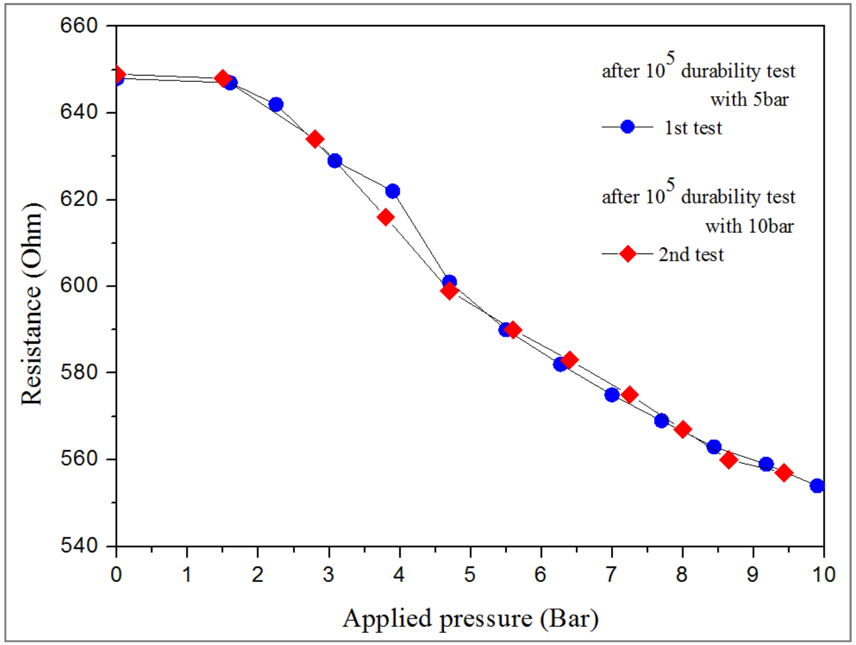
계측 – 내구성 테스트

- 인가압력 5bar에서 10,000회 동작 후 특성 평가
- 인가압력 10bar에서 10,000회 동작 후 특성 평가

센서의 내구성 테스트



내구성 테스트 이후 센서 특성평가

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계측 – 무선 통신 기능

+

Bluetooth 송수신 모듈

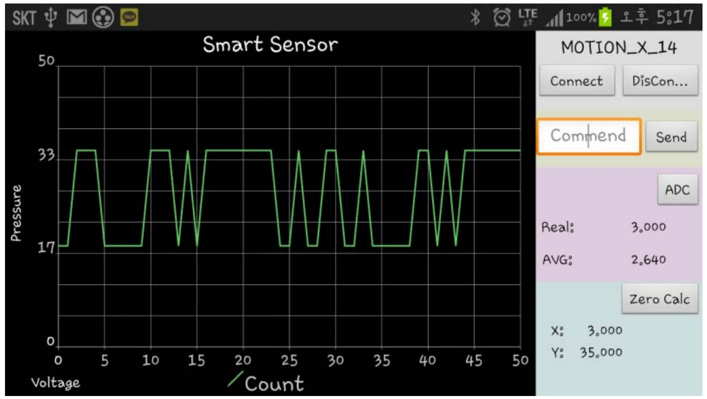
조립된 압력센서

Data Send

Wireless Communication

Smart Phone

❖ 현대에 필수품인 Smart Phone에서도 쉽게 주변에 있는 센서를 검색할 수 있도록 설계 되었으며, 무선 통신을 이용하여 센서의 데이터 확인 할 수 있도록 설계함



Android Smart Phone 용 스마트 센서 데이터 운용 프로그램

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결론

❖ 압력센서의 설계 및 제작

- 압력센서 초기 저항 : 463 Ω
- 측정 압력 범위 : 0.1~1MPa
- 압력 감도 : 156Ω/kΩ•MPa

❖ ITO resistor의 구조 개선을 통한 접촉형 압력센서의 장점

- 높은 압력 감도
- 인가 압력에 따른 높은 저항 변화 → 신호증폭 및 노이즈 제거 회로 불필요
- 출력 특성의 선형성 향상

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Thank you for your attention!!!

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