Ion-assisted E-beam Evaporated Thin Film Gas Sensor

A. Wisitsoraat, A. Tuantranont, V. Patthanasettakul, T. Lomas, and P. Chindaudom

Nanoelectronics and MEMS Laboratory

National Electronics and Computer Technology

Outline

- Introduction
- Materials and methods
- Experimental results and discussion
- Conclusions

Introduction

- Why Gas sensor?
  - Environmental monitoring: Increasing atmospheric pollution problems → Higher need of effective and low cost monitoring and controlling systems for detection and quantification of pollution sources
  - Electronic nose: Ordor detections
    - Alcohol detection: Driver testing
    - Classify different ripeness degrees of fruits
    - Tracking of the aroma evolution of ice stored meat
    - Discrimination and test of perfume
    - Discrimination between single volatile compounds
    - Classification of wines

Introduction

- Semiconductor gas sensor
  - Low cost
  - High sensitivity
  - Fast response
  - Simple electronic interface
  - Low selectivity
  - High power consumption
- Thin film type gas sensor
  - Microelectronic compatibility
  - Ease of control process parameters
  - Reproducibility
  - Fast response
  - Relatively low power consumption and low cost

Introduction

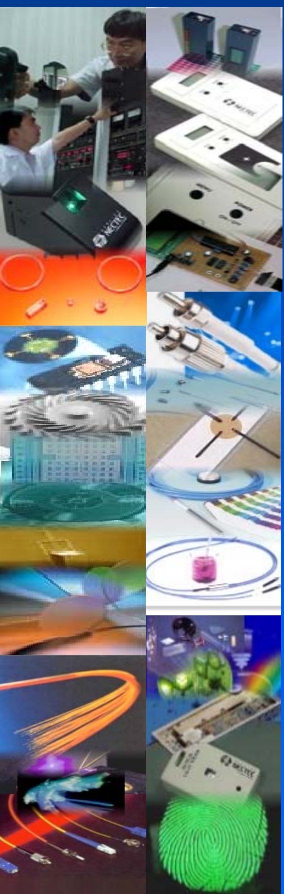
- Thin film deposition techniques
  - Sputtering
  - Electron beam evaporation
  - Chemical vapor deposition (CVD)
  - Spray pyrolysis
  - Sol-gel
- Electron beam evaporation
  - Ease of batch fabrication
  - Ability to form high-quality multilayer thin film structures
  - Poor gas-sensing sensitivity

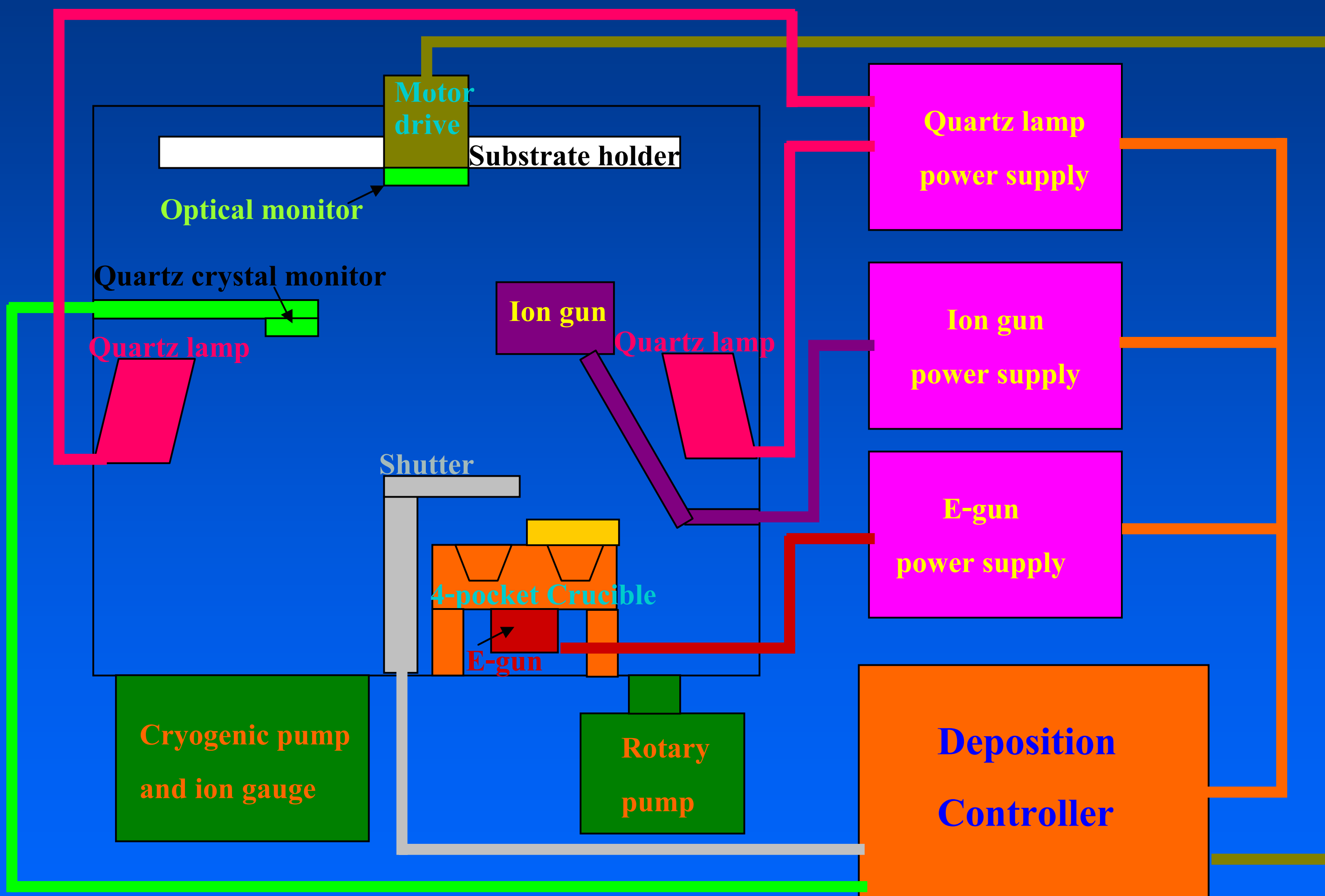
Introduction

- Electron beam evaporation with ion-assisted deposition (IAD)
  - Improved evaporation technique for high quality thin film deposition
  - Reactive deposition for chemical composition control: vary oxygen component in metal oxide film during deposition by adjusting gas flow and ion power
  - Substrate pre-cleaning for excellent adhesion
  - Gas sensor thin film by this method may not need post-deposition annealing

Material and methods

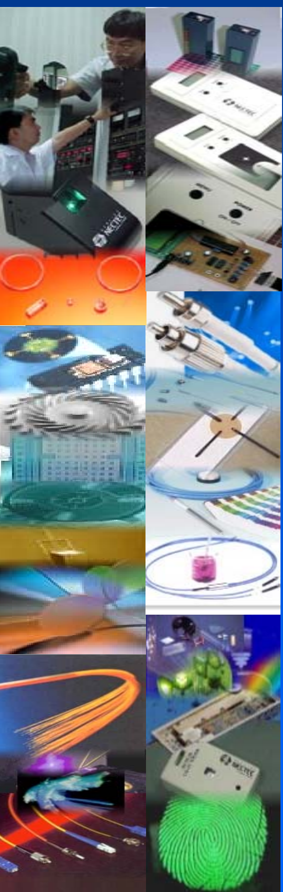
- **Ion-assisted e-beam evaporation system**

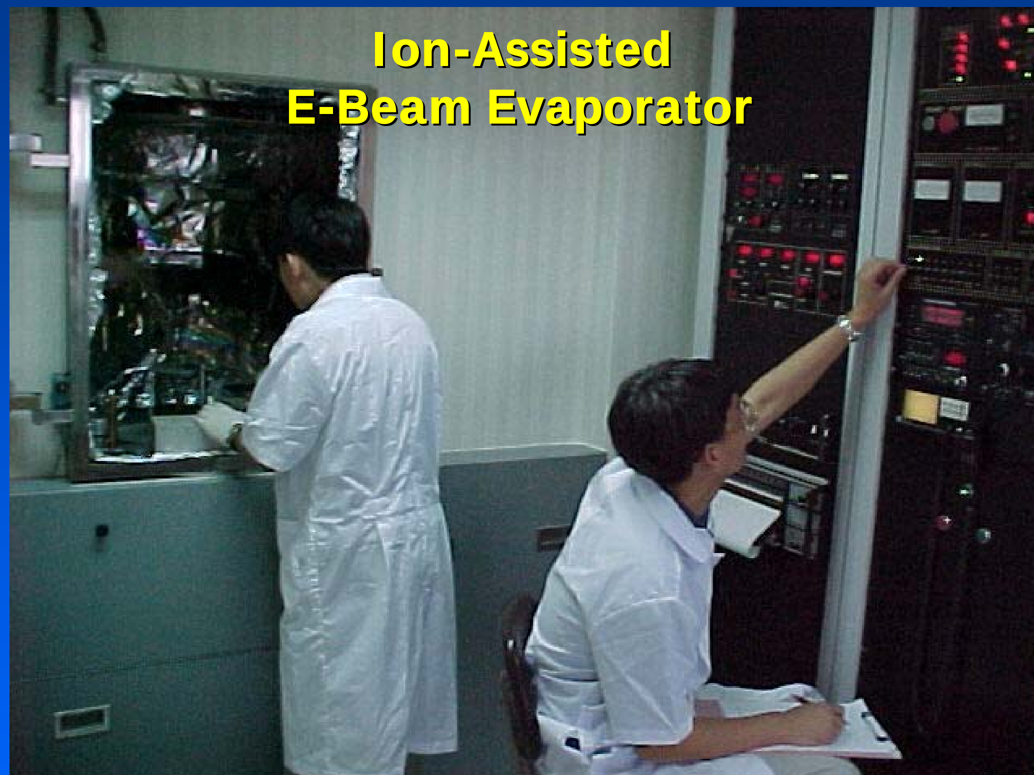




Material and methods

- **Ion-assisted e-beam evaporation system**



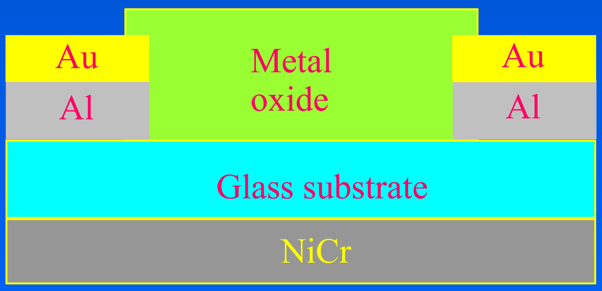


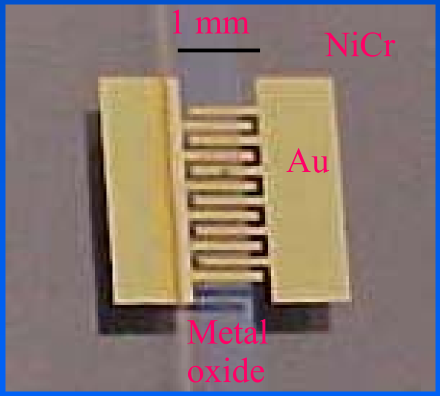
Material and methods

- SnO_2 / WO_3 Deposition with IAD
  - SnO_2 material: compressed 99.5 % SnO_2 powder
  - WO_3 material: compressed 99.99 % WO_3 powder
  - Substrate: BK7 glass slide
  - Pre-deposition cleaning with oxygen-ion beam
  - SnO_2 / WO_3 evaporated under oxygen-ion beam
  - Ion source parameters
    - Driving voltage and current: ~400 V and ~0.13 A
  - Varing IAD parameters
    - Oxygen flow rate: 0 to 30 sccm
  - Substrate temperature: 130 ^{o}C
  - Film thickness: 2000 Å

Material and methods

- **Metal oxide gas sensor fabrication**
  - **Al/Au interdigitated electrode coating by e-beam evaporation through an electroplated shadow mask: Interdigit spacing ~ 100 μm**
  - **Metal oxide deposition with IAD through another electroplated shadow mask**
  - **NiCr heater blanket evaporation on the back side**

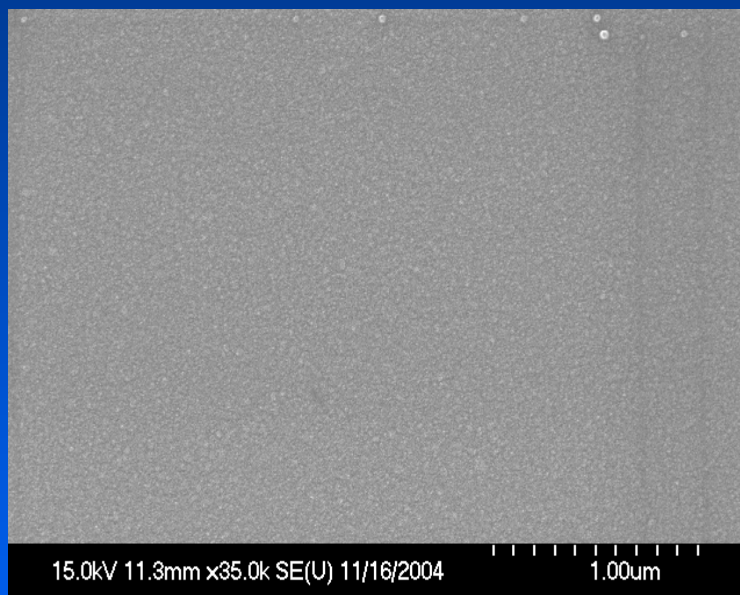


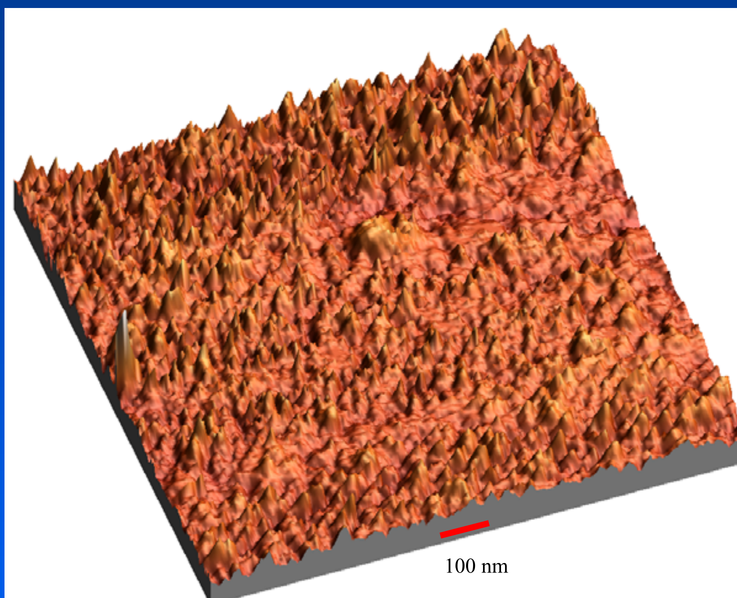


Structure and photograph of a metal oxide thin film gas sensor with built in NiCr heater

Material and methods

- **Metal oxide gas sensor**



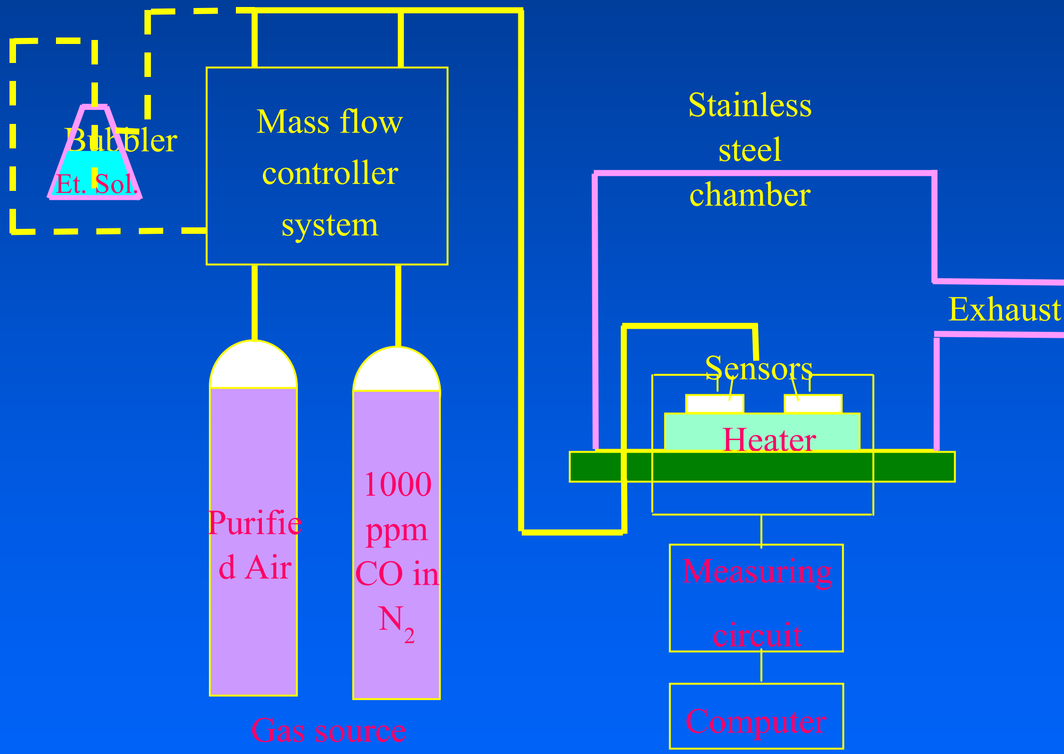


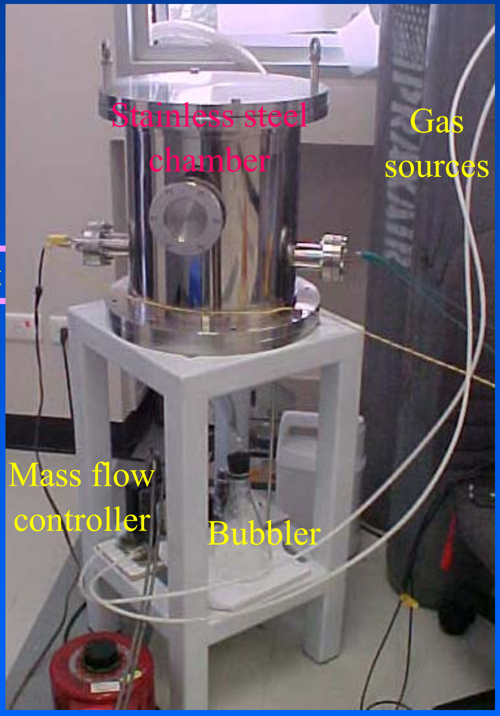
Typical SEM and STM micrograph of surface morphology of e-beam evaporated metal oxide thin film

Material and methods

Gas-sensor Characterization

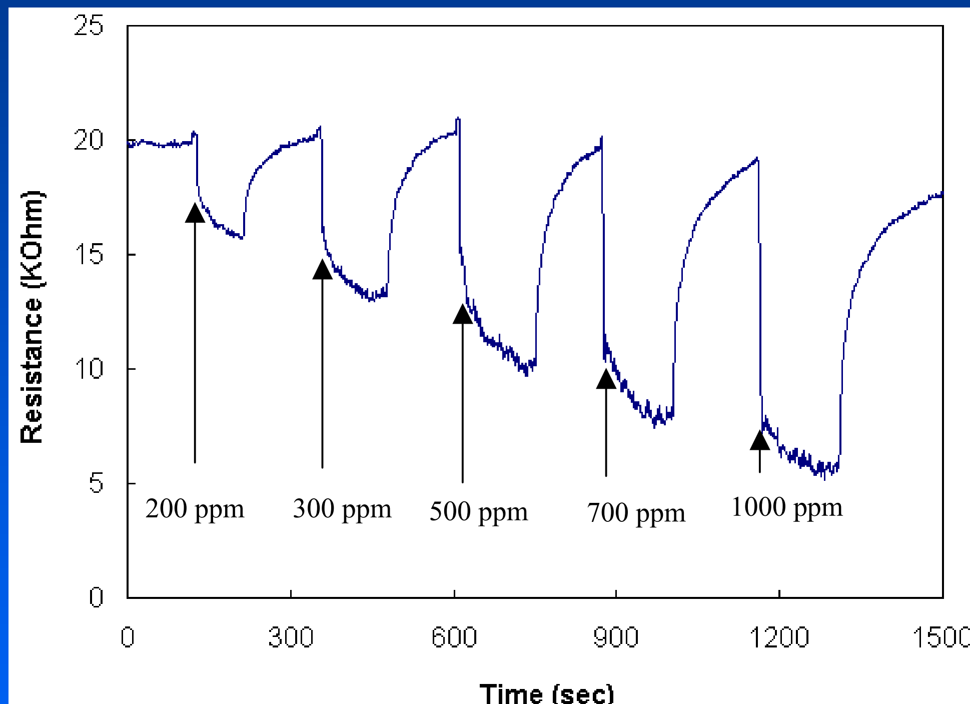
Gas sensing measurement





Experimental results and Discussion

- **Gas sensing characteristics of SnO_2 thin film**
  - **Time response characteristics**

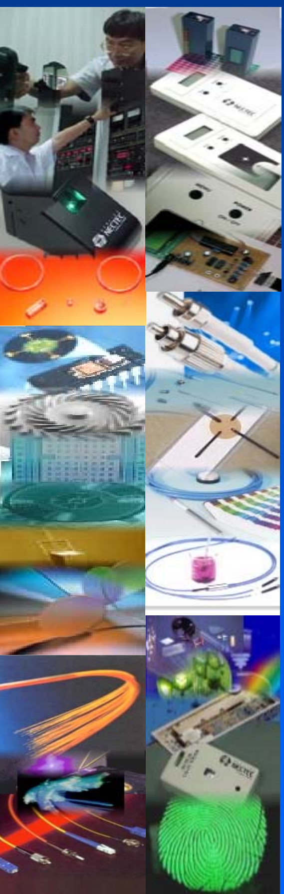


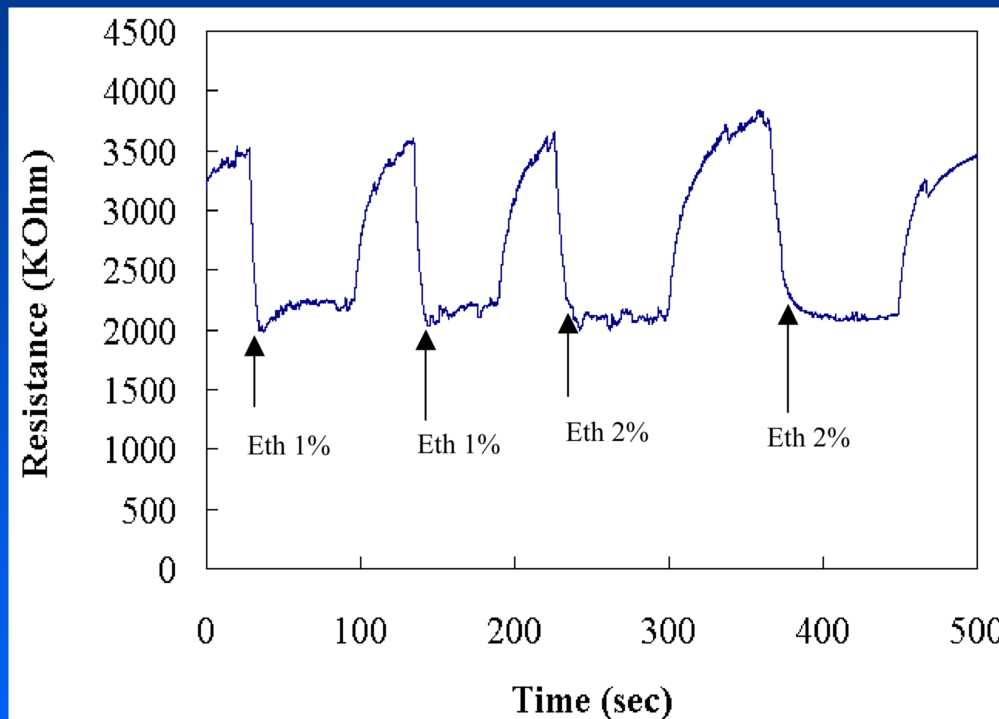
Response time ~ 3 s
Recovery time ~ 50 s

Time responses to CO at 300 °C of tin oxide thin film with oxygen flow rate of 30 sccm

Experimental results and Discussion

- **Gas sensing characteristics of WO_3 thin film**
  - **Time response characteristics**





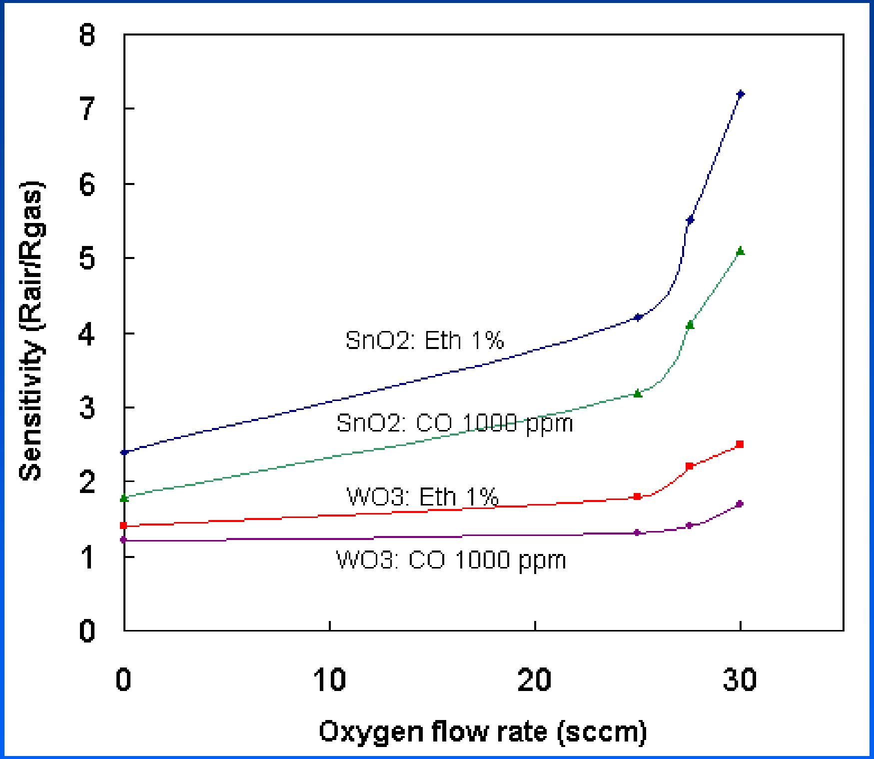
Response time ~ 5 s

Recovery time ~ 60 s

Time responses to ethanol at 300 °C of tungsten oxide thin film with oxygen flow rate of 30 sccm

Experimental results and Discussion

- **Gas sensing characteristics of SnO_2 thin film**
  - **The effect of oxygen flow rate on sensitivity**



Sensitivity tends to increase as oxygen flow rate increases for both metal oxide and both reducing gases

Typical sensitivity to ethanol and CO vs. oxygen flow rate of tin and tungsten oxide thin film

Experimental results and Discussion

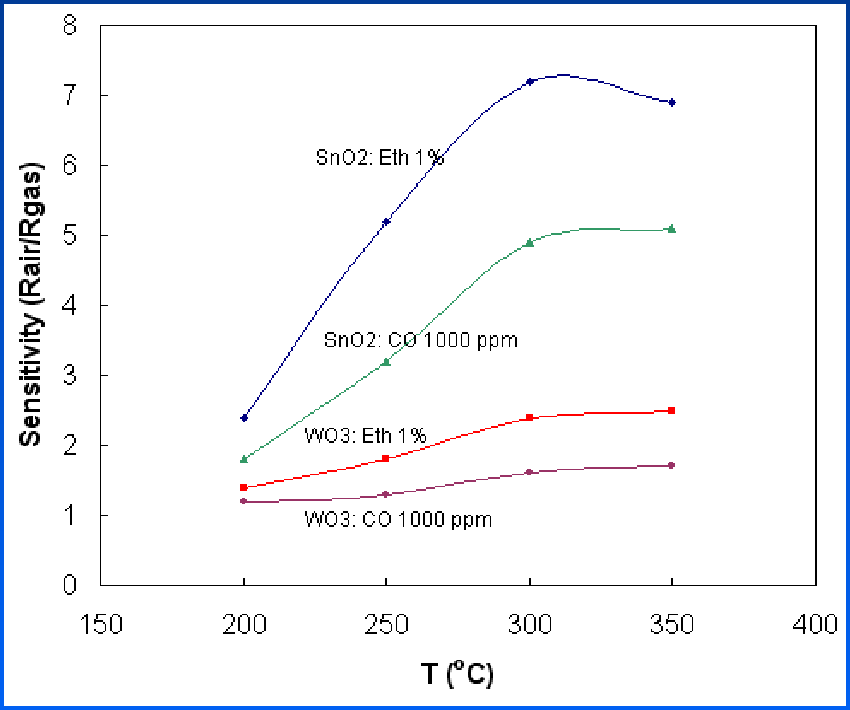
- **The effect of oxygen flow rate on sensitivity**
  - **As oxygen flow rate increases above 25 sccm, Sensitivity to ethanol and CO tends to increase**

    Possible explanation:

    - **Addition of oxygen-ion and the increase of oxygen flow rate enhance the reducing reaction at the surface of thin film because the number of oxygen vacancies in and on the surface of thin film is reduced: The advantages of reoxidizing the thin film by oxygen-ion over conventional annealing are the much lower process temperature and higher thin film quality**
    - **Oxygen ion bombardment during deposition increase film porosity and surface roughness: Increase gas adsorption site**

Experimental results and Discussion

- Gas sensing characteristics of Metal oxide thin film
  - The sensitivity as a function of temperature



Sensitivity to alcohol and ammonia are Good in T ~300-350 °C

Typical sensitivity to ethanol and CO vs. oxygen flow rate of tin and tungsten oxide thin film

Conclusion

- **Gas sensor were fabricated based on ion-assisted electron beam evaporated metal oxide thin film and gas-sensing characteristics of the gas sensor were studied with no post-deposition annealing**
- **Sensitivity to CO and alcohol of metal oxide thin film**
  - Improved with oxygen-ion addition during e-beam evaporation and tends to increase as the oxygen flow rate increases
  - Possible explanation: the increase of oxygen flow rate enhance oxygen content and reduce oxygen vacancies in and on the surface of thin film
  - Good sensitivity at moderate temperature of 300-350 °C
- **Ion-assisted e-beam evaporation is a potential process for thin film gas sensor fabrication that can produce gas sensors having good response at moderate temperature with no post-deposition annealing**