APPLICATION OF A NOVEL FORMALDEHYDE SENSOR WITH MEMS (MICRO ELECTRO MECHANICAL SYSTEMS) IN INDOOR AIR QUALITY TEST AND IMPROVEMENT IN MEDICAL SPACES

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Abstract. In the indoor air environment in Taiwan, formaldehyde concentration stays at a high level, which is an important issue affecting indoor air quality, and the formaldehyde issue in medical building spaces is more severe. The novel formaldehyde sensor based on microelectromechanical systems (MEMS), which uses quartz glass as basic material, platinum as micro heater resistance, as well as a heat sensing layer and NiO film as a sensing layer. NiO film was used to form a sensing layer in the method of sputter deposition. Platinum was used as electrode to measure and sense resistance change. When there was formaldehyde gas in the environment, the electrical conductivity on the NiO film increased, thus causing the resistance on the sensing layer to decrease. The sensor displayed the value of formaldehyde concentration. The novel formaldehyde sensor with MEMS was applied and tested in a large medical center (medical space) in southern Taiwan. The formaldehyde concentration in 120 points in one medical building was tested. The results showed that the indoor formaldehyde concentration was between 0.01-2.31 ppm, exceeding the indoor air quality standard - 0.08 ppm, and the failure rate of the whole building was over 50%.
Keywords: *healthy environment, exposure assessment, cancer risk, building materials, plasma*

Introduction

Taiwan is located in a humid subtropical region. Intensive development and environmental pollution can affect indoor environmental quality (Chiang et al., 1996), and indoor air pollution in particular can harm health and re-duce comfort and safety. The problems with indoor environment pollution are especially severe in developed countries located in temperate regions. Existing buildings currently take up 97% of total buildings. The functions of Existing buildings de-cline as they approach the end of their cycles; dis-eases such as sick building syndrome (SBS), sick house syndrome (SHS), building related illness (BRI) (Molhave and Thorsen, 1991; Molhave, 2003; Wolkoff and Nielsen, 2001; Wieslander et al., 1997). Sick buildings and sick houses often develop during the "completion of new construction" or "renovation of building construction" stages (WHO, 1989; EURO, 2006; Jarnstrom et al., 2006). Studies on sick houses and buildings in taiwan show exceeding levels of methanol hazardous to health;

the risk of cancer development by methanol is 100~1000 times greater than that of cancers caused by other mean (Wu et al., 2003, 2005).

Taiwan is located in the subtropical climate region. It is hot and humid on summer, in addition to the cold and humidity winter have significant effects in medical buildings. The medical space in southern Taiwan are renovate with large amount of building materials in indoor, which causes formaldehyde and VOCs emissions from these indoor building materials to accumulate inside. (Wolkoff et al., 1998, 2003) Although Green Building Materials Labels provide a category for Low-Emission Materials in Taiwan, but the la-bels are only for encouragement purposes and are rarely being used. In a hot and humid environment with low ventilation, Sick House Syndrome (SHS) or Multi-Chemicals sensitivity (MCS) (WHO., 2000, 2001) to chemical sub-stances often affect medical patient (*Figures 1 and 2*).

Figure 1. *The interior equipment of medical space in southern taiwan*

Figure 2. *The indoor environment of medical space in southern taiwan*

Literature Review

The Indoor Air Quality Management Act in Taiwan

The indoor air quality management act which would test and manage the indoor air quality, With the legislative passing of the Indoor Air Quality Management Act, Taiwan joined South Korea and become the second nation in the world to enact a law regulating indoor air quality. The air quality management act targets public areas, such as schools, cram schools, medical and government organizations, financial institutions, opera houses, hotels, post offices as well as public transportation platforms. Particular air quality requirements are given to different premises depending on their size, area, and exposure. The Environmental Protection Administration (EPA) and other environmental agencies can conduct unscheduled inspections, testing for excessive levels of CO_2, VOCs, formaldehyde, TVOC, bacteria, fungi and other airborne pollutants.

A Novel Formaldehyde Sensor with MEMS (Micro Electro Mechanical Systems) for indoor air quality test

A novel micro-fabricated formaldehyde gas sensor with an integrated micro-hotplate (Lee et al., 2006). A new fabrication process has been developed for the formaldehyde gas sensor with a self-heating NiO thin film. The NiO thin film is deposited on the microstructure, and Pt metal resistors are deposited as micro-heaters. Au IDEs are formed to measure the conductivity change caused by formaldehyde oxidation at the

oxide surface. Not only can the high stability, the low hysteresis value and a quick response time be attained for the proposed MEMS-based sensor, but decreasing the grain size of the oxide sensor material in the sputtering process also significantly increases the sensitivity of the gas sensor (0.14 Ωppm^{-1}) and improves its detection limit capability (1.2 ppm). The integrated micro hotplate simplifies the experimental set-up and can be realized using a simple fabrication process. The present micro-fabricated formaldehyde gas sensor with a self-heating NiO thin film is suitable not only for industrial process monitoring, but also for the detection of formaldehyde concentrations in buildings in order to safeguard human health.

Methodology

Research methods

This study developed a novel formaldehyde sensor based on microelectromechanical systems (MEMS), which uses quartz glass as basic material, platinum as micro heater resistance, as well as a heat sensing layer and NiO film as a sensing layer. NiO film was used to form a sensing layer in the method of sputter deposition. Platinum was used as electrode to measure and sense resistance change. When there was formaldehyde gas in the environment, the electrical conductivity on the NiO film increased, thus causing the resistance on the sensing layer to decrease. The sensor displayed the value of formaldehyde concentration (*Table 1*).

The methods of detection for formaldehyde gas may bedivided into three main categories: Gas chromatography–mass spectrometry (GC/MS), optical detection devices, and Micro Electro Mechanical Systems (MEMS) based gas sensors. Gas chromatography mass spectrometry (GC/MS) is a method that combines the features of gas–liquid chromatography and mass spectrometry to identify different substances within a test sample. Although it provides high sensitivity and selectivity, the drawbacks of high preventive costs and ponderous uses cannot be ignored. Numerous researchers have studied optical sensor with formaldehyde quantification applications. Even though the optical sensors are capable of simultaneous samplings and have instantaneous analyzing time, the associated optical arrangements tend to be rather bulky and elaborate. In the last decade, emerging MEMS and micro-machining techniques have led to the development of miniaturized sensing instrumentation that is capable of accessing information at a micro scale level. Most important, the functionality and reliability of these micro sensors can be increased through their integration with mature, logic IC technology or with other sensors.

Table 1. The MEMS sensor test for formaldehyde gas
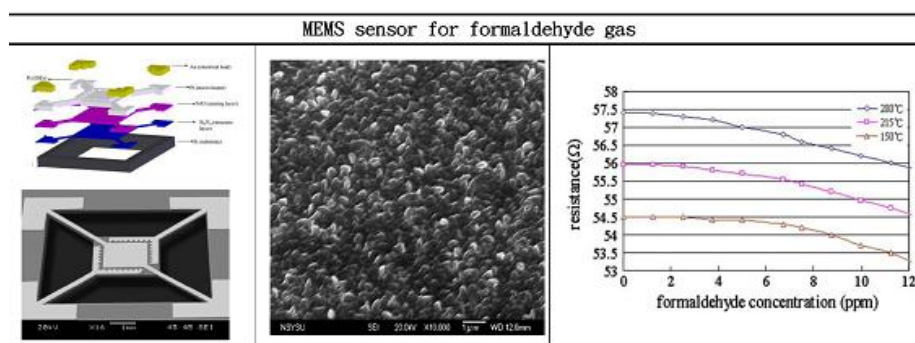
The IAQ sampling plan in medical space

The medical space was a large building (the total floor is 12F). The formaldehyde concentration in 120 points in one medical building was tested.

According to the indoor air quality management act (*Table 2*). The amount of indoor air sampling point have be provide. Each floor had to be calculate by floor area (*Table 3*).

Table 2. The sampling point per area

Floor Area (A) m^2	Sampling point
A≦5000	S≧1
15000≧A>5000	S≧2
30000≧A>15000	S≧3
A>30000	S≧4

Table 3. The sampling point plan in medical spaces

floor	Sampling points	Sampling time
1st FLOOR	10	24hr
2nd FLOOR	20	1hr-8 hr
3rd FLOOR	5	1hr-8 hr
4th FLOOR	10	1hr-8 hr
5th FLOOR	10	1hr-8 hr
6th FLOOR	10	1hr-8 hr
7th FLOOR	10	1hr-8 hr
8th FLOOR	10	1hr-8 hr
9th FLOOR	10	1hr-8 hr
10th FLOOR	10	1hr-8 hr
11th FLOOR	10	1hr-8 hr
12th FLOOR	5	1hr-8 hr

IAQ screen test and methods

The IAQ experiment test method based on the ISO 16000-1,2. Screening test methods (*Table 4*) are of the type which can quickly provide an indication of the air pollution present without using expensive analy-sis techniques. The result can inform a decision on the extent of further required measurements. When using screening tests, the basic demands of the measuring strategy have to be considered in this case.

The diffusive sampling method for formaldehyde is suitable for measurements in atmospheres of up to relative humidity and for monitoring at air velocities as low as . Potential interferences, including those due to the presence of other carbonyl compounds, should be eliminated by the chromatographic step in the method. The sampling method gives a time-weighted average result. This test method is applicable to the measurement of formaldehyde) in indoor air over the range from 0.001 mg/m^3 to 1 mg/m^3 for a sampling period of between 24hr and 72hr .

Table 4. *The IAQ screen test and methods*

MEMS Sensor	diffusive sampling	24hr Sampling

Research Results
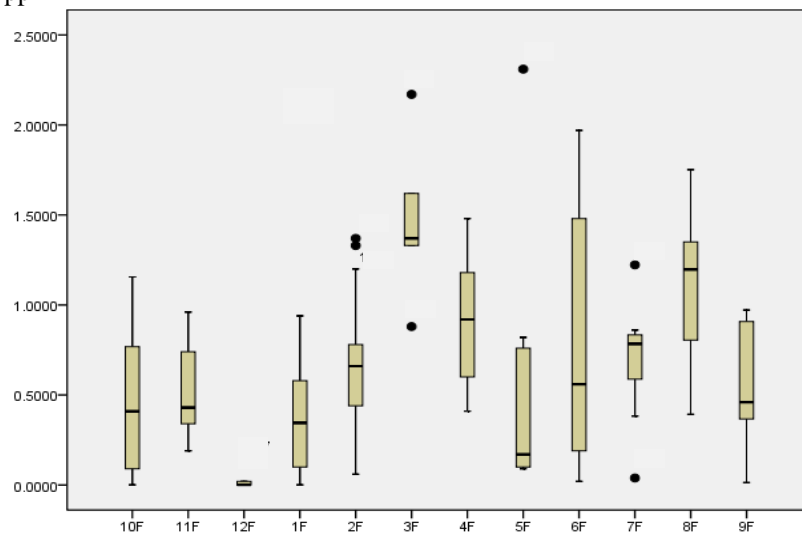
Formaldehyde concentration in medical space

The novel formaldehyde sensor with MEMS was applied and tested in a large medical center (medical space) in southern Taiwan. The formaldehyde concentration in 120 points in one medical building was tested. The results showed that the indoor formaldehyde concentration was between 0.01-2.31 ppm (*Table 5*), exceeding the indoor air quality standard - 0.08 ppm, and the failure rate of the whole building was over 50%. Moreover, indoor air quality was improved in the areas with a relatively high formaldehyde concentration (dental rooms) by adopting the plasma formaldehyde removing technology in the indoor air conditioning system. Under the 10-day formaldehyde control with the plasma formaldehyde removing technology, the indoor formaldehyde concentration reduced from 1.32ppm to 0.95ppm (*Figure 3*).

Seen from the results sampled from 6 monitoring spaces which are under continuous monitoring for 24h by novel formaldehyde sensor with MEMS, diachronic changes of formaldehyde in 24h all exceed 0.08ppm reference value, with an average concentration of 0.22ppm (*Figure 4*). Concentration of formaldehyde reduces only at 7:00am since the air conditioners are shut down, that at the other time periods are all higher than the healthy reference value. This indicates that the indoor environment is polluted seriously by formaldehyde and concentration of in-door formaldehyde is affected directly by air-conditioning system.
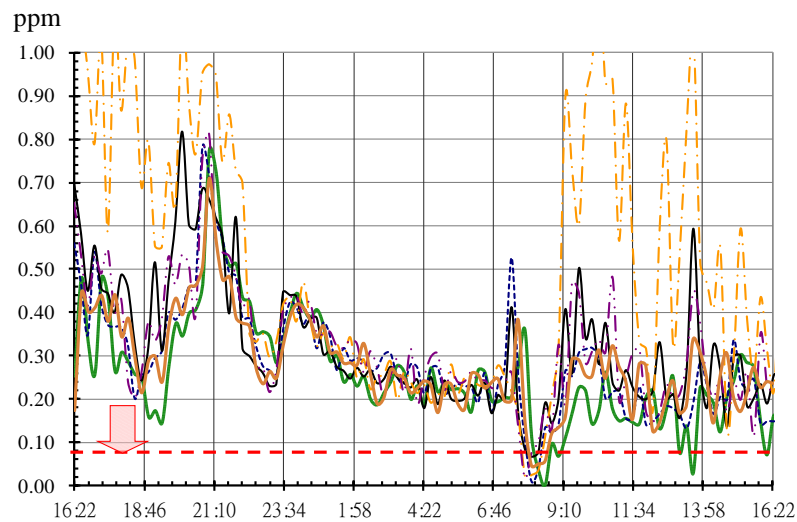
Table 5. *The formaldehyde concentration in medical space*

floor	Ave. ppm	Max. ppm	Min. ppm
1st FLOOR	0.513	2.09	0.001
2nd FLOOR	0.648	1.37	0.06
3rd FLOOR	1.474	2.17	0.88
4th FLOOR	0.898	1.48	0.41
5th FLOOR	0.541	2.31	0.09
6th FLOOR	0.83	1.97	0.02
7th FLOOR	0.702	1.22	0.03
8th FLOOR	1.09	1.75	0.3
9th FLOOR	0.547	0.97	0.01
10th FLOOR	0.432	1.1	0.001
11th FLOOR	0.535	0.96	0.19

floor	Ave. ppm	Max. ppm	Min. ppm
12th FLOOR	0.031	0.13	0.001

Figure 3. *The formaldehyde concentration in different floor*

Figure 4. *The 24hr sampling on formaldehyde concentration in medical space*

Dynamic changes of indoor CO_2 are compared, as seen, concentration of formaldehyde increases in the area with higher CO_2 concentration. It is the problem of formaldehyde accumulation due to poor ventilation of air conditioner. Improvement by means of ventilation and dilution: pollutants are removed in the way of increasing fresh external air amount and raising the fresh external air ratio to improve the indoor air quality.

The dissusive formaldehyde flux from materials

Passive formaldehyde sensing patch is used in indoor decoration materials through pollution source identification technology. Seen from the results, formaldehyde

emission rate for indoor build-ing materials is 2 times higher than green building materials (*Table 6*). This indicated that indoor building mate-rials emit formaldehyde in the long term and absorb formaldehyde in the air to become the pollution source.

Table 6. *The dissusive formaldehyde flux from materials*

Sample NO.	dissusive formaldehyde flux
1	0.146 mg/m^2*hr
2	0.157 mg/m^2*hr
3	0.136 mg/m^2*hr

The plasma formaldehyde removing technology

Plasma formaldehyde-removal technology is used in indoor air-conditioning system to remove the pollutants and improve indoor air quality. Indicated by the results, indoor formaldehyde pollutants can be discomposed and removed effectively. the plasma formaldehyde removing technology in the indoor air conditioning system. Under the 10 day formaldehyde control with the plasma formaldehyde removing technology, the indoor formaldehyde concentration reduced from 1.32ppm to 0.95ppm (*Figure 5*).
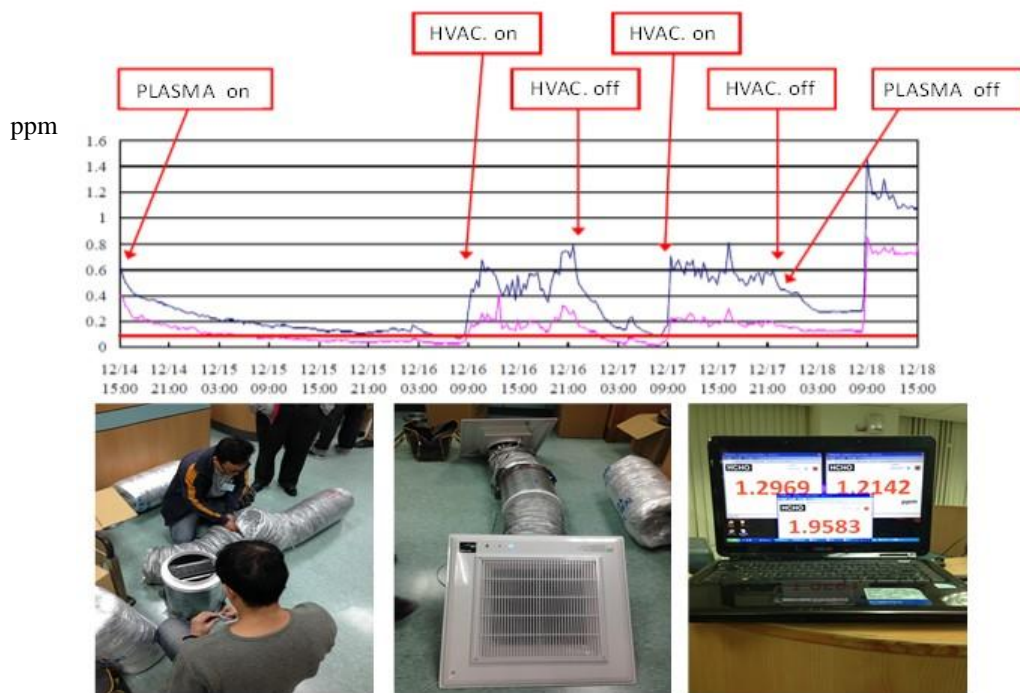
Figure 5. *The plasma formaldehyde removing technology*

Conclusion

This study developed a novel formaldehyde sensor based on microelectromechanical systems (MEMS), which uses quartz glass as basic material, platinum as micro heater resistance, as well as a heat sensing layer and NiO film as a sensing layer. NiO film was used to form a sensing layer in the method of sputter deposition. Platinum was used as electrode to measure and sense resistance change. When there was formaldehyde gas in the environ-ment, the electrical conductivity on the NiO film increased, thus causing the resistance on the sensing layer to decrease. The sensor displayed the value of formaldehyde concentration.

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Although it was not reduced to the indoor air quality standard value, the results showed that the method can effectively dissolve indoor formalde-hyde. The novel formaldehyde sensor with MEMS can be widely used to test and improve indoor air quality, and can be combined with intelligent moni-toring systems and intelligent air conditioning and ventilating equipment in future, to maintain indoor air quality and effectively ventilate the space. The research achievement can be popularized to indus-try for immediate application.

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