

A Novel Measurement Device for SAW Chemical Sensors with FT-IR Spectro-microscopic Analytical Capability

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Abstract

In this paper, we propose a novel characterization technique of the SAW chemical sensors. It combines the technique of electronic frequency shifting measurement (phase lock lop) with the IR microscopic spectral analyzer and performs a *in-situ* measurement. Using this method, we could conduct ultrahigh sensitive measurement in mass change (a few ppb–a few ppm range) of the SAW chemical sensors by cross-compared with the electronic signals of the SAW device and the FT-IR spectro-microscopic data of the molecular imprinted polymer (MIP) recognition thin film which deposit on the surface of the SAW device. With the use of the MIP thin films, we are able to provide a more accurate molecular selectivity than those current SAW chemical sensors which were based on regular chemical absorb films. Spectrum results of MIP films will be presented below.

Key Words: SAW, MIP, FT-IR

1. Introduction

In 1965, two professors White and Voltmer in UC Berkeley, California, fabricated interdigital transducer (IDT) on the surface of piezoelectric materials and successfully generated surface acoustic wave on the substrate. Since then, SAW devices have been widely used in various applications. SAW device has several merits, i.e., (1) extremely high sensitivity, (2) high SNR value, (3) small in size, (4) wide operational frequency range (10 MHz to 1 GHz), (5) easy to be integrated with semiconductor processing technology. Base on these advantages, SAW devices have been

extensively used in wireless applications, such as television, wireless communications and radar systems [1,2].

Not only being widely used in wireless electronic applications, SAW device also finds extensive applications in chemical and bio sensing. Surface acoustic wave is some kind of elastic waves traveling on the surface of piezoelectric material with certain characteristic natural resonance frequency. The resonance condition is extremely sensitive to external loading (such as pressure, temperature and mass change, etc.), which, in turn, causes the shift in its natural resonance frequency. Based on this principle, a lot of techniques have been developed for extremely sensitive detection for chemical and bio specimen

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[3,4]. Typically, a chemically active thin film with chemical selectivity is coated on the delay line area of the SAW device for specimen recognition.

Most of the signal measurement techniques are based on network analyzer, vector analyzer or an external RF circuit to measure the shift in natural resonance frequency due to the mass change in the thin film. However, there is no way of acquiring chemical information relevant to the absorption of the specimen.

In this paper, we combine the electronic frequency shifting measurement technique with the microscopic spectral analyzing technique in the infrared region. In order to match the extremely sensitive detection in mass change, we need a powerful spectral analyzing tool with high spectral sensitivity and microscopic feature in the infrared region. In Taiwan, the only tool that fulfills this requirement is located at the FT-IR microscopy beamline at the National Synchrotron Radiation Research Center (NSRR), Hsinchu.

We have designed a compact reaction chamber to be inserted into the tiny space inside this powerful FT-IR microscope. The reaction chamber allows the gas to flow into the chemically active thin film on the SAW surface, while enabling simultaneous electronic and spectral measurements. The spectral and microscopic information acquired by this FT-IR spectromicroscope can be used to characterize the electronic signals due to the absorption of different chemical and biological specimen.

2. Working Principle of SAW

A YZ cut LiNbO_3 piezoelectric material is used as the substrate for SAW chemical sensor as shown in Figure 1 [5]. One pair of IDT fabricated by thin film process is placed on each side of the substrate. Based on piezoelectric effect, one IDT serves as a transducer; the other is used as a receiver. The space in between the pair of IDT is called the delay line region, where the chemically active thin film is coated for the purpose of sensing.

The principle of SAW chemical sensor is based on detecting the mass change due to the absorption of certain chemical specimen in this thin film. In our case, we will use molecular recognition polymer as the thin film to selectively absorb the target gas molecules. By engineering different recognition polymers for different target gas molecules, one can detect different target gas molecules with high sensitivity and high selectivity. In order to qualitatively as well as quantitatively

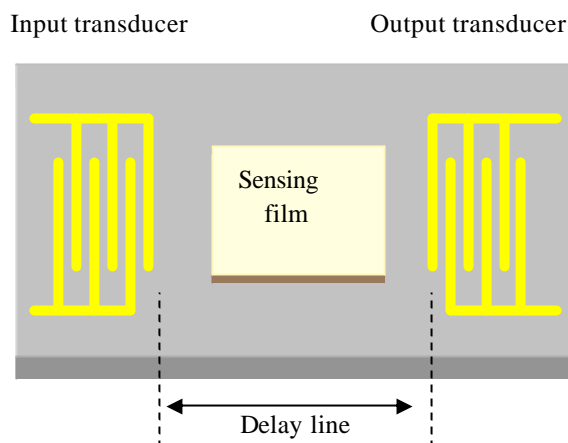


Figure 1. The schematic of a SAW chemical sensor.

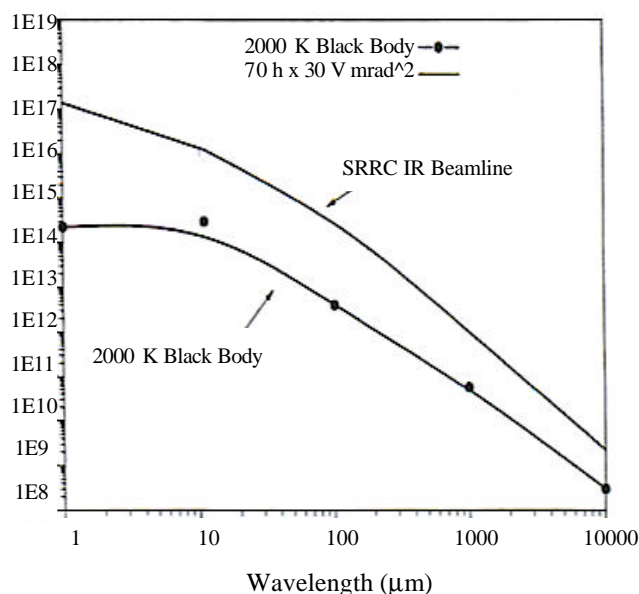


Figure 2. Comparison of the brightness of the NSRRC IR beamline with the 2000K black body source.

obtain the chemical information regarding the absorption mechanism, we perform FT-IR spectrum measurement in the mid-infrared regime (2.5–25 μm) to acquire vibrational spectrum for most of organic molecules [6]. By analyzing the spectrum, we can obtain and analyze the chemical bonding information.

The intensity of conventional IR light sources is too weak to perform microscopic survey on the thin film with detection area smaller than 10 μm [7]. The FT-IR microscope at the NSRRC can provide an IR light source with 1000 times spectral brightness as compared to the conventional FT-IR equipment (shown in Figure 2). This enables us to

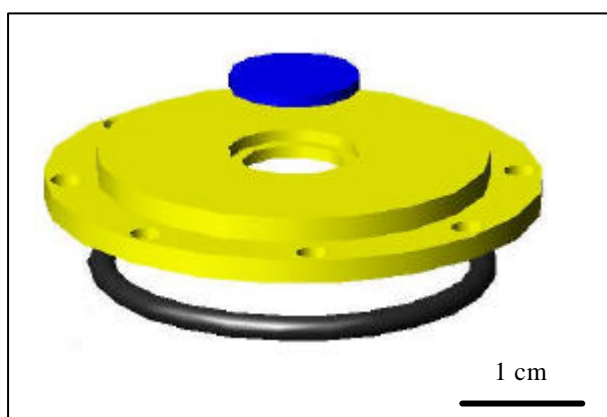


Figure 3. Drawing of the chamber of the measurement device.

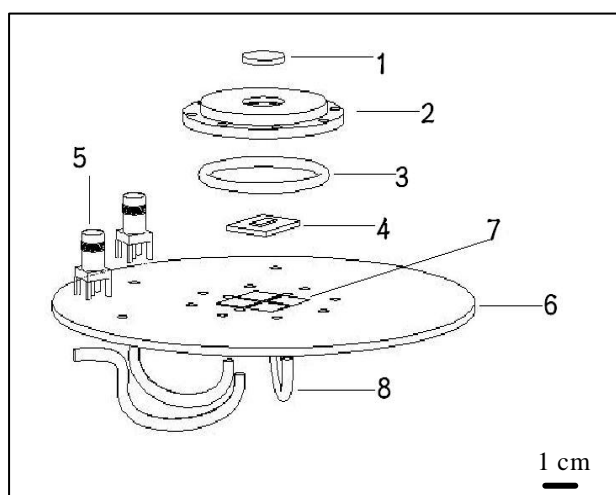


Figure 4. The components of the device. 1. IR window, 2. chamber, 3. O-ring, 4. Sample, 5. SMA connector, 6. PCB, 7. bonding pad, 8. pipe.

3. Design of the Measurement Device

Our goal is to construct a measurement device perform microscopic as well as spectral survey on our specimen down to about $10\ \mu\text{m}$ area, which can measure spectral as well as electric signal in the same environment. This requires a design for an air tight reaction chamber with gas manifold for the thin film to react with the target gas molecules. In this chamber, we should also allow the measurement of IR and the measurement of the electronic signals. The design is shown in Figure 3. The window on top of this chamber is made of CaF_2 for the transmission of the IR light source. At the bottom of the chamber, which connects the PCB board, we use an O-ring to ensure an air tight system. Figure 4 shows the components of the system.

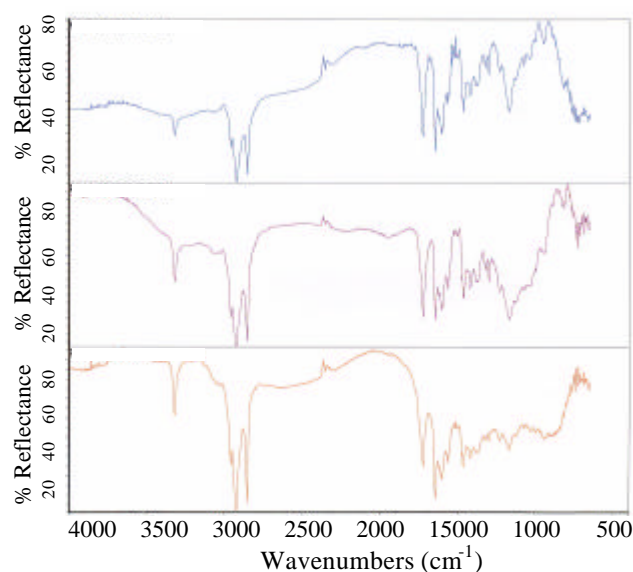


Figure 5. Result of the absorption spectrum of the caffeine-MIP thin film taken at different locations on the film.

4. Results and Discussion

The experimental results shown in Figure 5 are measured from the caffeine macromolecule thin film, which is made using the Molecular Imprinting Polymer (MIP) technique developed by the Union Chemical Laboratories of the Industry Technology Research Institute, Taiwan. The MIP thin film is deposited on top of a gold thin layer to enhance the IR signal for the measurement.

The FT-IR microscope is set up to scan back and forth 64 times at a 4cm^{-1} spectrum resolvance. The spatial resolution is set to $70\ \mu\text{m}$. The result is shown in Figure 5. The three spectra represent three different locations on the MIP thin film. It can be easily found in Figure 5 that several specific frequencies have obvious and meaningful chemical spectral features.

By acquiring the spectra obtained at different locations and under different conditions, the chemical binding mechanism can be revealed in great details.

5. Conclusion

We have successfully designed a device to perform the spectromicroscopic and electronic measurements under the same environment and condition for the SAW sensors while it is interacting with the target gas molecules. In the near future, we will further develop this technique to become a standard characterization tool for SAW sensor device.

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