

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 surface acoustic wave (SAW) chemical sensors. It combines the technique of electronic frequency shifting measurement (phase lock lop) with the IR microscopic spectral analyzer and performs an in-situ measurement. Using this method, we could conduct ultrahigh sensitive measurement in mass change (from a few ppb to a few ppm range) of the SAW chemical sensors by cross-comparison with the electronic signals of the SAW device and the Fourier-Transform Infrared (FT-IR) spectro-microscopic data of the molecular imprinted polymer (MIP) recognition thin film which is deposited on the surface of the SAW device. With the use of the MIP thin films, the target recognition is functioned by identifying the geometry shape of the targets. We are able to provide a more accurate molecular selectivity and sensitivity than those current SAW chemical sensors which were based on regular chemical absorbed films. Spectrum results of MIP films will be presented herein.

Key Words: Surface Acoustic Wave (SAW), Molecular Imprinted Polymer (MIP), Fourier-transform Infrared (FT-IR)

1. Introduction

In 1965, White and Voltmer in UC Berkeley fabricated interdigital transducer (IDT) on the surface of a piezoelectric substrate and successfully generated surface acoustic wave. Since then, SAW devices have been widely used in various applications. SAW device has several merits: (1) extremely high sensitivity; (2) high SNR value; (3) small in size; (4) wide operational frequency range (10 MHz to 1 GHz); (5) easiness of being integrated with planar 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. SAW is a kind of elastic wave 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. Inversely, the external loading causes the shift in the natural resonance frequency of the SAW device. Based on this principle, a lot of techniques have been developed for extremely sensitive detection for chemical and biological specimens [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.

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

In this paper, we combine the electronic measurement technique of frequency-shift 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 (NSRRC), Hsinchu.

We 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 the electronic and spectral measurements simultaneously. The spectral and microscopic information acquired by this FT-IR spectro-microscope can be used to characterize the electronic signals due to the absorption of different chemical and biological specimens.

2. Working Principle of SAW

A Y-Z 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

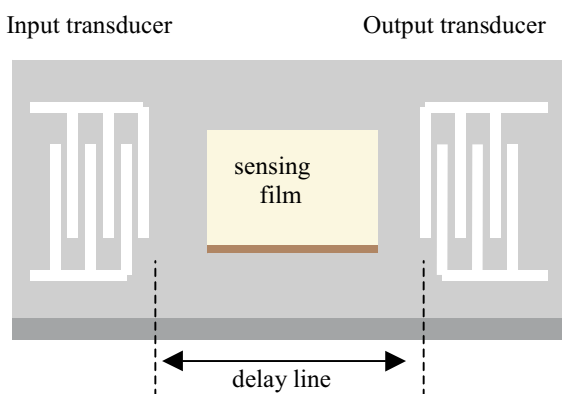


Figure 1. The schematic of a SAW chemical sensor.

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 (MIP) as the thin film to selectively absorb the target gas molecules. By different MIPs 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 obtain the chemical information regarding the absorption mechanism, we perform FT-IR spectrum measurement in the mid-infrared regime ($2.5\text{--}25\ \mu\text{m}$) to

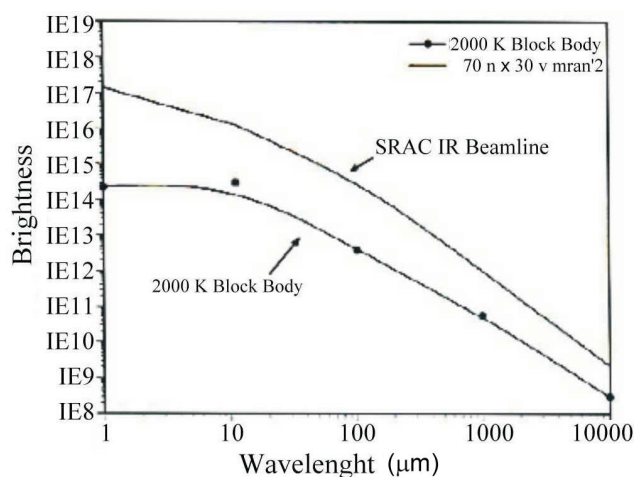


Figure 2. Comparison of the brightness of the NSRRC IR beamline with the 2000 K black body source.



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

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 $10\ \mu\text{m}$ [7]. The FT-IR microscope at the NSRRC can provide an IR light source with the spectral brightness of 1000 times larger than one provided by the conventional FT-IR equipment (shown in Figure 2). This enables us to perform microscopic as well as spectral survey on our specimen down to about $10\ \mu\text{m}$ area.

3. Design of the Measurement Device

Our goal is to construct a measurement device 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

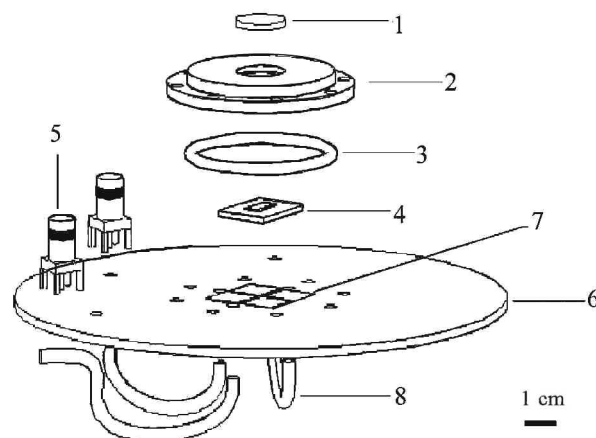


Figure 4. The components of the device: 1. IR window, 2. chamber, 3. O-ring, 4. sample, 5. SMA connector, 6. PCB, 7. bonding pad, 8. pipe.

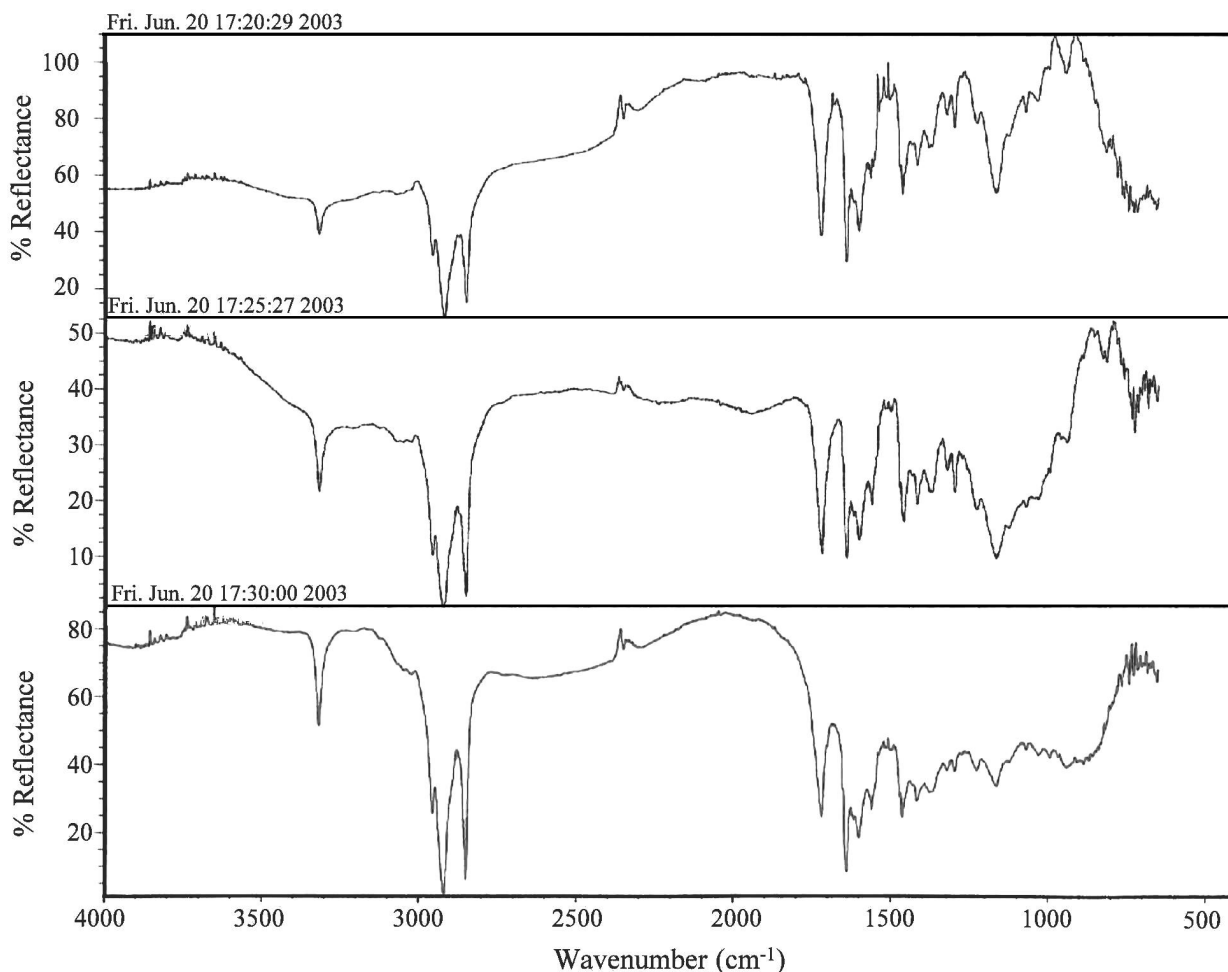


Figure 5. Result of the absorption spectrum of the caffeine-MIP thin film taken at different locations on the film.

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.

4. Results and Discussion

The experimental results shown in Figure 5 are measured from the caffeine macromolecule thin film, which is made using the 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 4 cm^{-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 spectro-microscopic 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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