The Fourier Transform and FTIR System as a Technique in Semiconductor Research

Sandar Maung, Pho Kaung & Sein Htoon

Abstract

In this paper a simple treatment of Fourier transform in FTIR with an introductory picture of its use in Semiconductor Research is described. A brief account of research focusing on optical characterization of silicon (Si) wafers is outlined. The measurement of residual oxygen (O₂) concentration is an important indicator in determining the overall quality of the finished Si wafers. The O₂ concentration is determined directly from an infrared absorption band occurring at 1106 cm⁻¹ in the Si lattice.

Key words: FTIR, Optical Characterization, Semiconductor

Introduction

The technique of Fourier transform spectroscopy (FTS) was originally confined to the far infrared region of the spectrum. However, as microcomputers have become cheaper, faster and more powerful, it has gradually superseded more conventional methods at shorter wavelengths. Infrared Spectroscopy is widely used as a non-destructive method for measuring the concentration of the residual oxygen in a Silicon (Si) wafer. Since the oxygen-related absorption peak in silicon is observed at 1106 cm⁻¹ in infrared spectrum, the concentration of interstitial oxygen (O₂) in a Si wafer is determined with the help of Shimadzu 8400 Fourier Transform Infrared Spectrometer.

Department of Physics, University of Yangon
Theory of Fourier transform spectroscopy

Fourier transform spectroscopy has a great spectrometric advantage over dispersive methods in the infrared region. In the visible, this advantage is usually less important. The infrared region is the range of electromagnetic spectrum between 0.78\(\mu\)m and 1000 \(\mu\)m. In infrared spectroscopy, wavelength is measured in wave number, which have the unit \(\text{cm}^{-1}\). There are three sections of infrared region: near, mid and far infrared. They can be seen in Table 1.

Table 1. The Three Sections of Infrared Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Wavelength range ((\mu)m)</th>
<th>Wave number range ((\text{cm}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near</td>
<td>0.78 --- 2.5</td>
<td>12800 --- 4000</td>
</tr>
<tr>
<td>Middle</td>
<td>2.5 --- 50</td>
<td>4000 --- 200</td>
</tr>
<tr>
<td>Far</td>
<td>5 --- 1000</td>
<td>200 --- 10</td>
</tr>
</tbody>
</table>

The FTIR 8400 relies on a Michelson interferometer with the Ceramic light source, which is electrically heated\(^\text{(3)}\). After passing through the aperture, light is turned into a parallel by the collimator mirror and enters the beam splitter. It splits the single beam into two, reflecting one to the fixed mirror and transmitting the other to the movable mirror. Both mirrors reflect their beams back to the beam splitter. The transmitted light from the movable mirror and the reflected light from the fixed mirror recombine and interfere with each other as they travel towards the converging mirror as shown in Fig 1.
Fig 1. Schematic Diagram of the FTIR System

From the converging mirror, the parallel beam creates an image of light source in the center of the sample compartment. Collecting mirror gathers the beam that passed through the sample and reflects it to a detector as the interferogram. It is amplified by the preamplifier and the gain amplifier, passes through high-pass and low-pass filters, and is digitized by A/D converter. After the signal is digitized, it travels through the PC where Hyper-IR Software transforms the interferogram into the spectrum.

The FT process is most easily visualized in terms of the emission of radiation. The technique can also be applied to absorption. A 'white' source would show a single decay signal with no beats, an approximation to this is shown in Fig 2. (a), where a very broad emission line and its Fourier Transform are shown. Although the time domain signal decays
very rapidly, it does show some beats. We can nor imagine an absorbing sample making some 'holes' in this radiation, as shown on the left hand side of Fig 2 (b), with its resulting FT signal on the right.

Although it is difficult to imagine Fourier-transform the absence of radiation at some frequencies, in practice a detector will collect a perfectly sensible signal which can be stored by a computer, transformed and displayed as the normal absorption spectrum.

![Figure 2 (a) An Approximation to a 'White' Source and its Fourier Transform](image)

![Figure 2 (b) Some Absorptions from a 'White' Source and their Fourier Transform](image)
Experimental

In this experiment, there are two kinds of measurements, Reflection and Transmission method. All of these measurements were recorded by using Shimadzu 8400 Spectrometer. The schematic diagram of reflection attachment is shown in Fig 3. There are eight aluminium (Al) mirrors in it. In the condition with no sample, the background spectrum, reflection due to eight Al mirrors and air is firstly obtained. After removing the No 5 mirror, the sample is placed at that position. The reflection spectrum of seven Al mirrors, sample and air is observed. Taking the ratio of two single beam spectra, the reflection spectrum of sample (compared with Al) is obtained as follow.

\[
\% R = \frac{R (\text{Sample} \cdot \text{seven Al mirrors} \cdot \text{air})}{R (\text{Eight Al mirrors} \cdot \text{air})}
\]

\[
\% R = \frac{R (\text{Sample})}{R (\text{Al})} \quad \text{........................................... (1)}
\]

![Reflection attachment diagram](image)

Fig 3. Reflection attachment
For transmission process, the schematic diagram is shown in Fig. 4.

![Sample compartment diagram]

Fig 4. Transmission attachment

If the sample is placed at the sample holder, the spectrum becomes single beam spectrum as $T_{\text{sample and air}}$. Then sample is removed and it becomes single beam background spectrum, $T_{\text{air}}$. To eliminate the background effects,

$$% T = \frac{T_{\text{Sample . air}}}{T_{\text{air}}}$$

(2)

Results and Discussion

There are two measurements for non-layered Si substrate. The first reflection spectrum of Si in comparison with an Al mirror and the second transmission compared with air are shown in Fig. 5.
From the reflections spectrum, the reflectivity of Si can be obtained according to Eqn (1),

\[
% R = \frac{R \text{ (Si)}}{R \text{ (Al)}}
\]

The reflectivity of Al as a standard value is 0.91 in literature and that of spectrum is 30% from the figure. Therefore \( R \text{ (Si)} \) is 0.273. The refractive index of Si can be derived as follow

\[
R \text{ (Si)} = \frac{(n_0 - n)^2}{(n_0 + n)^2}
\]

where \( n_0 \) is the refractive index of air and \( n \) is for Si. This equation is derived from the Maxwell's boundary conditions and Fresnel amplitude coefficients for reflectance. Thus the refractive index of Si is 3.2 and it is 3.4 in literature.

The interference patterns are caused by interference of all transmission spectra as shown in Fig 6.
Fig. 6 Transmitivity Spectrum of Silicon Substrate

The thickness of sample can be measured by using the interference features.

\[ d = \frac{1}{\left(2\sqrt{n^2 - \sin^2 \theta}\right) \nabla V} \]  \hspace{1cm} (4)

In this equation \(n\) is refractive index of Si and \(\theta\) is the angle of incidence. Fig 6. shows an example of an interference fringe pattern at the incident angle 0°. \(\nabla V\) is the spacing between two successive features. Thus, the thickness of Si is found to be 0.0578 cm in this work.

The \(O_2\) concentration is determined directly from an infrared absorption band occurring at 1106 cm\(^{-1}\) in Si lattice. Two transmitivity equations (Eqn 5 and Eqn 6) are used to determine the absorption coefficient of \(O_2\)\(^{(4)}\).
If we choose the known O\textsubscript{2} concentration 7.9 \times 10^{17} cm\textsuperscript{-3} from Fig 7, the absorption coefficient \( \alpha_0 \) will be 2.55 cm\textsuperscript{-1} as shown in Fig 8.
Fig. 8  Relation between Oxygen Concentration and Infrared Absorption Coefficient

Since \( R^2 \exp \{ -2 (\alpha_1 + \alpha_f + \alpha_o) d \} \gg 1 \) and \( R^2 \exp \{ -2 (\alpha_1 + \alpha_f) d \} \gg 1 \), the ratio of peak and base line transmissivities becomes

\[
\frac{T_P}{T_B} = \exp \{ -\alpha_0 d \} \hspace{1cm} (7)
\]

If read \( T_P = 0.278 \) and \( T_B = 0.33 \) from Fig. 5 and taking \( d = 0.0578 \) from previous section, when \( \alpha_0 \) is determined from Eqn 7, the relation between O\(_2\) concentration and \( \alpha_0 \) can be expressed as shown in Fig 8. Since the absorption coefficient \( \alpha_0 \) is 2.98, the O\(_2\) concentration is Si wafer can be determined as the value of \( 8.94 \times 10^{17} \) cm\(^{-3}\) proving the good quality of Si wafer.
Conclusion

Fourier Transform Infrared Spectroscopy has been used to measure some parameters namely the refractive index and the layer thickness of a silicon wafer. The refractive index of Si wafer is found to be 3.2 which is the acceptable result when compared with the literature value of 3.4. The thickness of the wafer is 0.0578 cm which is agreed well with the manufacturer's inscription. Since the absorption coefficient of interstitial oxygen in Si lattice ($\alpha_0$) is 2.98 cm$^{-1}$, the $O_2$ concentration of this wafer ($C_0$) is determined to be $8.94 \times 10^{17}$ cm$^{-3}$ proving the good quality of the Si wafer.

References

de Haseth, J A (Editor) 1997) "Fourier Transform Spectroscopy (Seventh International Conference)" (New York : American Institute of Physics).


2002 "FTIR Application for Semiconductor and Electronics Industry" (Singapore: Shimadzu).