Micro Variable Infrared Filter

Member Hitoshi Hara (Yokogawa Electric Corporation)
Member Hideaki Yamagishi (Yokogawa Electric Corporation)

Summary

A micro infrared filter capable of transforming a transmitted wavelength is the most important component of a micro infrared spectroscope. This report describes the spectrum characteristics resulting from a Micro Variable Infrared Filter being experimentally produced. The design theory of the filter is based on the phenomenon that as the spacer layers thickness varies along the length of the filter, so does the transmitted wavelength. The correlation between coating thickness and spatial position is very repeatable. We adopted a structure that transforms the center wavelength by changing the thickness of the only type spacer layer in the five layers SHW filter. The thickness of the spacer ranges of 400nm to 550nm. By using a sputtering system that includes a slit shutter with a film thickness error within 1% of the 1 inch diameter, we can make the Micro Variable Infrared Filter with a continuous wavelength of 1.8 to 2.1 μm. The results of the experiment are in good agreement with the thin film optical simulation for the spectrum transmission characteristics, with the linearity of the transmitted band being within 1% for different wavelengths.

Keywords: infrared spectroscope, infrared filter, Micro Variable Infrared Filter, continuous spectrums,

1. INTRODUCTION

Infrared spectrum measurement is able to measure an object in a noncontact, nondestructive manner. This characteristic is used for atmospheric and other analysis. Infrared spectrum measurement used to be carried out with a dispersion type spectroscope that consisted of a prism or diffraction grating.

In the 1970’s, Fourier transform infrared spectroscopy (FTIR) became a popular measurement method for the spectrochemical analysis of the infrared range. Both apparatuses have become applied to the measurement in online and in line. There is a demand for an analysis apparatus that can measure in a short period of a minute range. While FTIR responds to these demands, it has drawbacks such as a complicated optical system, long data processing time and its high price.

Therefore, we propose a micro filter type spectroscope as shown in figure 1. We are currently developing a Micro Variable Infrared Filter (MVIF), the most important component for the development of a micro infrared spectroscope.

For example, the selectaband Linear Variable Filters (LVF) currently on the market, produce the spectrum characteristics shown in figure 2. These filters produce a continuous spectrum within the near infrared wavelength region. Such filters are formed by multiple layer membrane with the film ramped thickness of dielectric materials.
The process of making the filter is complicated and increasing in cost. By evaluating both the membrane structure and the process of making filters, we are now able to propose a filter that allows spectrum characteristic to be freely specified with low cost. This report outlines the spectrum characteristics resulting of the MVIF experimentally produced.

2. DESIGN AND FABRICATION

2.1 PRINCIPLES

The filter of a dielectric multiple layer membrane is composed of three parts as shown in figure 3, two sets of \( \lambda/4 \) type multiple layers and a type spacer layer. The value \( \lambda \) is a center wavelength of a filter, the \( \lambda/4 \) shows optical thickness \( nd \), where \( n \) is the refractive index, and \( d \) is the film thickness. Such filters are called single halfwave (SHW) type filters. The five Layers SHW filter is defined as follows. These filters consist of dielectric coating materials deposited onto substrates in a vacuum.

\[
\begin{align*}
\text{Air} & |HL|HHH[HH|LH|Substrate} \\
\text{Spacer} & | \text{Layer}
\end{align*}
\]

\( H = \lambda/4=nd \) : the high refractive index layer

\( L = \lambda/4=nd \) : the low refractive index layer

Generally, the selectaband infrared linear variable filters consist of ramp film thickness layers. However, we adopted a structure that transforms the center wavelength by changing the thickness of the only spacer layer in the five layers SHW filter.

The first MVIF experimentally produced, is a continuous wavelength of between 1.8 and 2.1 \( \mu m \). This filter is hypothesizing that uses it for a moisture meter \(^1\). This wavelength range includes infrared absorption by water, water vapor and cellulose. In a paper making process, paper must be manufactured under strict quality control in both machine-direction and the cross-direction. The qualities controlled are the basis weight (paper weight per unit area), the percent of moisture, the thickness, etc. The basis weight and the percent of moisture are the most important qualities in paper, so accuracy and high reliability are required of these sensors. The moisture meter uses infrared-ray of a wave length range from 1.8 to 2.1 \( \mu m \). The peculiar absorption wavelength of water is 1.94 \( \mu m \). The peculiar absorption wavelength of cellulose is 2.1 \( \mu m \).

Figure 4 shows the relationship between the thickness of the spacer layer and the transmission characteristics in a thin film optical simulation to solve Maxwell’s equations. It is OPTAS-FILM by Cybernetsystem Co.. The filter used in this experiment is made of two types of materials: silicon for the high refractive index and silicon dioxide for the low refractive index on top of a BK7 glass substrate.

Figure 4 shows the relationship between the thickness of the spacer layer and the transmission characteristics in a thin film optical simulation to solve Maxwell’s equations. It is OPTAS-FILM by Cybernetsystem Co.. The filter used in this experiment is made of two types of materials: silicon for the high refractive index and silicon dioxide for the low refractive index on top of a BK7 glass substrate.
2.2 PROCESS SEQUENCE

To meet the specification demands, we used a sputtering system, called the magnetron sputtering system enhanced with an inductively coupled rf plasma. The cathode in this system has a rf coil attached to the planer magnetron sputtering target, as shown in figure 5. This system produced a thin film that is high quality and good thickness distribution. The film thickness error in the experiment was within 1% of the 1 inch diameter.

The slit shutter was established to make a ramp film into the sputtering system, as shown in figure 5. It is driven by a pulse motor and a onaxis insertion system, and can also be controlled using a programmable controller. The distance of the slit shutter and the substrate are held to 2mm.

The reciprocated horizontal of the shutter is started by the signal that reached to the specified film thickness. The shutter moves at the speed of 3.5mm/sec toward X axis, and it moves in opposite directions with equal velocities when it becomes 35 mm position. The speed 3.5 mm/sec is the value optimized by an experiment to reduce the film thickness error. The shutter is moved while monitoring the film thickness and it stops in a shunting position from the substrate by the signal of the maximum film thickness of the spacer layer. In the MVIF production process of a later description, the slit shutter reciprocates horizontal to 45 times.

3. RESULTS

To check the performance of this system, we made a ramp thin film with a film thickness of 400 to 550nm. The thickness range is equivalent to the spacer layer of the MVIF. The relationship between the film thickness and the measurement position are shown in figure 6. This reveals that the performance of a ramp thin film deposited by the system is the same as the design.

The MVIF experimentally produced using this system, has a membrane structure as shown in table 1. It is a continuous wavelength of between 1.8 and 2.1 μm. This filter is hypothesizing that uses it for a moisture meter. We adopted a structure that transforms the center wavelength by changing the thickness of the only type spacer layer in the five layers SHW filter. The thickness of the spacer ranges of 400 to 550nm. The size of the MVIF is 1 cm². The spectrum transmission of the MVIF measured by a spectrometer is shown in figure 7 and table 2. Points A, B and C in the figure show the measured position in the filter. The experiment results agree with the simulation results for the spectrum transmission characteristics. The linearity of the transmitted bands for different wavelengths at different measurement position is within 1%. The causes of error 1% is the
film thickness dispersion. It satisfies the condition mentioned previously (<2%).

The reason that transmittance differs with calculation and measurement is absorption and scattering by a wafer and many layer film material. By Infrared spectrum measurement, the absorption is 5% and the scattering was 2%.

4. CONCLUSIONS
The results of the experiment are in good agreement with the thin film optical simulation for the spectrum transmission characteristics, with the linearity of the transmitted band being within 1% for different wavelengths.

Therefore using the new slit shutter sputtering system, we can make the Micro Variable Infrared Filter for the future micro infrared spectrocope, for example the moisture meter. A specific wavelength may be selected by simply adjusting the MVIF to the appropriate position. If the MVIF may be directly mounted to a detector array, it is possible no moving part in the micro infrared spectrocope.

5. ACKNOWLEGMENTS
This work was performed under the management of Yokogawa Electric Corporation as a part of the R&D "Micromachine Technology" supported by NEDO (New Energy and Industrial Technology Development Organization).

(Manuscript received May 7, 1998, revised Aug. 10, 1998)

References
1) Optical Coating Laboratory, Inc. (OCLI) : Stock Products catalog Vol. 5.

Hitoshi Hara
Now with Yokogawa Electric Corporation.
Primary Research Area: Infrared Filters, Micro Infrared Sensors and Micro Infrared Spectroscopes.
Member: The Institute of Electrical Engineers of Japan, The Japan Society of Applied Physics and The Optical Society of Japan.

Hideaki Yamagishi
Now with Yokogawa Electric Corporation.
Primary Research Area: Chemical Analyzers, Optical Devices, Micromachined Infrared Sensors and Their Applications.
Member: The Institute of Electrical Engineers of Japan, The Japan Society of Applied Physics, The Japan Society for Precision Engineering and The Institute of Electrical and Electronics Engineers.