Study of Microwave Optics

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Microwaves are a form of electromagnetic radiation with wavelengths ranging from roughly one meter to one millimeter. Despite that there are some different definitions for the wavelengths of microwaves, the frequencies of them are generally between 300 MHz and 300 GHz. The target for this experiment is to observe and study the phenomena of microwave optics.

1. Introduction

In modern world, microwaves technology is quite important for human. It's no exaggeration to say that microwaves technology is a great invention from the mid-20th to 21th century. There are some reasons to support this claim.

First is that the "higher energy". Compared to the radio waves, microwaves have shorter wavelengths and higher frequencies, which means the energy of microwaves is higher than that of radio waves due to the higher frequencies (that is, the energy of electromagnetic waves is proportional to their frequencies).

Second is that the way of the propagation. Microwaves travel rather by line-of-sight than by diffracting around blocks(it's just the way of propagation for radio waves), they just follow the earth's surface as surface waves, or reflect from the ionosphere.

Microwaves are widely used such as in point-to-point communication links, wireless networks, radar, satellite and spacecraft communication as well as cancer treatment, astronomy, particle accelerators, keyless entry systems, and for cooking food in microwave ovens.

To observe the phenomena of microwaves optics, we need to know some basic optical instruments and their principles. They are Gunn Diode Transmitter (GDT), Lloyd's Mirror, Fabry－Pérot Interferometer and Michelson Interferometer, respectively.

GDT can provide the single-frequency, high-coherence and linearly-polarized microwave. In spite of the same properties of the laser, the differences between them are the directionality and the intensity. We can observe fundamental optical phenomena such as reflection, refraction, diffraction and interference by using GDT.

Lloyd's Mirror, an optics experiment that was first described in 1834 by Irish physicist, Humphrey Lloyd , is the system that light from a monochromatic slit source reflects from a glass surface at a small angle and appears to come from a virtual source as a result. The reflected light interferes with the direct light from the source, forming interference fringes. Generally, the two waves would interfere with each other when the optical path difference (OPD) of the two waves is proper to interfere.

Fabry－Pérot Interferometer (FPI), named after the French physicists Charles Fabry and Alfred Pérot, who developed the instrument in 1899, is made of a transparent plate with two parallel highly reflecting mirrors.

Michelson Interferometer, invented by American physicist Albert Abraham Michelson, is using a beam splitter, a light source split into two arms. Each of those light beams is reflected back toward the beam splitter which then combines their amplitudes following the superposition principle.

Michelson Interferometer is employed in many scientific experiments and became well known for its use by Albert Michelson and Edward Morley in the famous Michelson-Morley experiment in 1887 , which have detected the earth's motion through the supposed luminiferous aether that most physicists at the time believed was the medium in which light waves propagated. The result of that experiment essentially disproved the existence of such an aether, which leading eventually to the special theory of relativity and the revolution in physics at the beginning of the 20th century.

2. Method

In the experiment, we used the following equipment: Gunn Diode Transmitter and Receiver, the protractor, angle square, the goniometer and some optical apparatus such as metallic reflecting mirrors, the prism model, semi-reflecting mirrors, the cubic lattice which are composed of 100 metal balls and polarizers. This experiment consisted of eight independent sections, for the first part was to observe the properties of microwaves.

We placed GDT and the receiver on the angle square and set the apparatus as the distance between the microwave source and the receiver is R. Then measure and record the data M on the receiver with changing the value of R and repeating this procedure. Finally, we could determine the types of this wave from getting the relation between M, R and R^2 as well as know the relation between the intensity of this wave and the angle by rotating the arm of Goniometer.

The second part was to observe the refraction of microwaves. We first set up the apparatus as shown in Fig.1

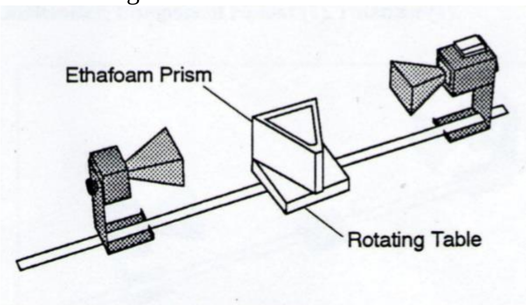

Fig.1: The set up for the refraction of microwaves

Then we expected that the incident direction of microwaves would be shown as in Fig.2

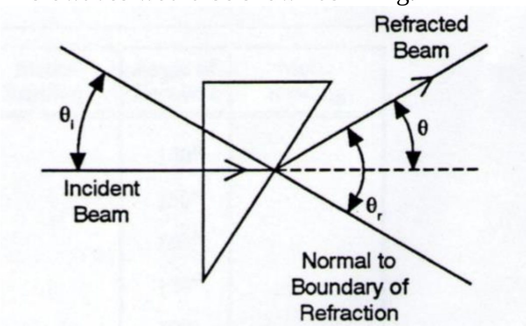

Fig.2: The refraction of the microwaves passing through the prism

We filled the prism model with Styrofoam balls and rotated the arms of Goniometer to find the refraction angle and determine the Snell's Law.

The third part was to observe the polarization of microwaves. We first fixed the source of microwaves and receiver on Goniometer and rotated the direction of receiver. By measuring the rotated angle θ and recording the data M to plot the graph of M versus θ. Then we fixed the polarizer on the center of rotational axis for Goniometer and let the receiver parallel to the source of microwaves. Determine the wave is spherical wave by rotating arms of Goniometer. In additions, we made the direction of diode for the receiver parallel to the source and fixed the polarizer on the center of Goniometer to keep the direction of the metal strips was horizontal. Rotating the receiver and recording the angle when the data M is the minimum. Repeated this step by placing the metal strips at different angles (22.5°, 45°, 67.5°, 90°). Finally, we recorded the data for the direction of metal strips being horizontal and vertical.

The fourth part was to study double-slit interference and single-slit diffraction. We first fixed the double-slit metallic plane on the center of rotational axis for Goniometer. Recording the data on the receiver with changing rotating angle of Goniometer and repeating step by replacing double-slit with single-slit metallic plane.

The fifth part was to study the Lloyd's Mirror. We first set up the apparatus as shown in Fig.3

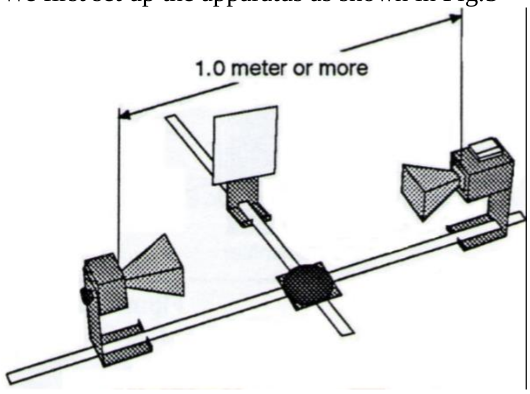

Fig.3: Lloyd's Mirror

Keep changing the position of reflecting mirror to find the maximum data on the receiver, and then calculate the optical path difference between the reflection and the incident wave and compare with its wavelengths.

The sixth part was to study the Fabry－Pérot Interferometer. We set up the apparatus as shown in Fig.4

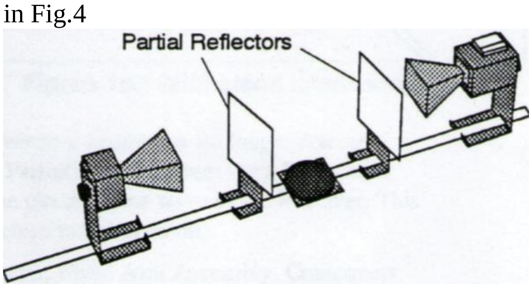

Fig.4: Fabry－Pérot Interferometer

Find the relation between the data from the receiver and the distance of two semi-reflecting mirrors by changing the distance of two

semi-reflecting mirrors and compare the positions with the extreme value of data to its wavelength.
The seventh part was to study the Michelson Interferometer. We first set up the apparatus as shown in Fig.5

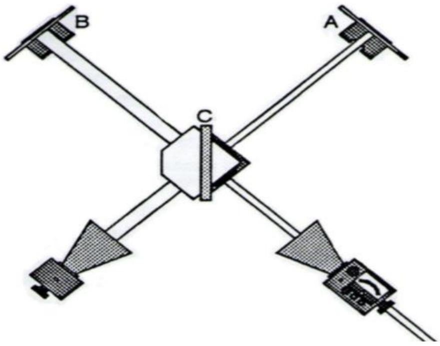

Fig.5: Michelson Interferometer

Find the relation between the data on receiver and the position of the reflecting mirrors by changing the position of the reflecting mirrors. Besides, we recorded the two positions of the reflecting mirrors with the extreme value of data on the receivers.

The last part was to study the Bragg Diffraction. We first set up the apparatus as shown in Fig.6

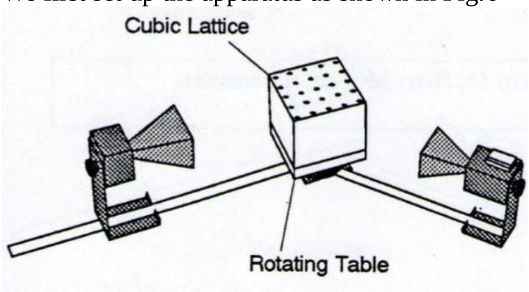

Fig.6: Bragg Diffraction

Then we rotated the cubic lattice at a degree and Goniometer at 2a degree, recording the data on the receiver and plotting the graph for the angle of Goniometer versus the data on the receiver.

Finally, determine the Bragg's Law when the value of data was the maximum and repeat the following above step by changing the atomic planes with different Miller index, as shown in Fig.7

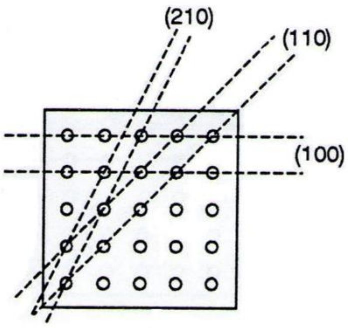

Fig.7: The atomic planes for Bragg Crystal

3.Result and Discussion

For the first part, we record the data of M, R, and pick the peak in our data, then we graph out the figure which describe the relation between intensity and distance. Finally, we fit the curve with the equation as follows:

$$y = a\frac{1}{(x+b)^2} + c \quad (1)$$

$$y = a\frac{1}{x+b} + c \quad (2)$$

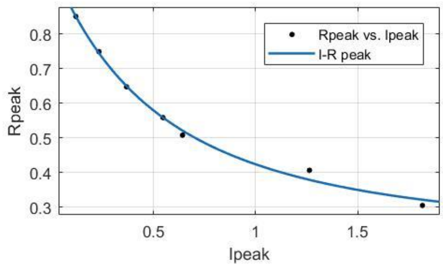

Fig.8: M-R relation by equation (1)

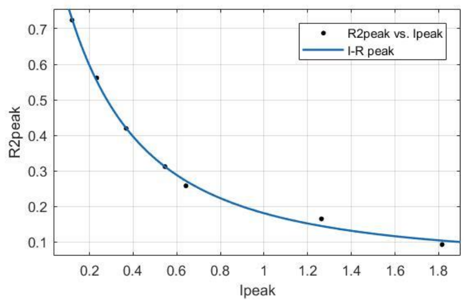

Fig.9: M-R^2 relation by equation (1)

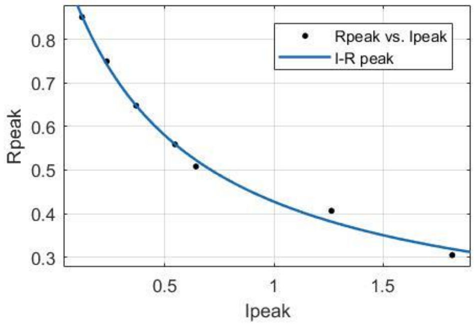

Fig.10: M-R relation by equation (2)

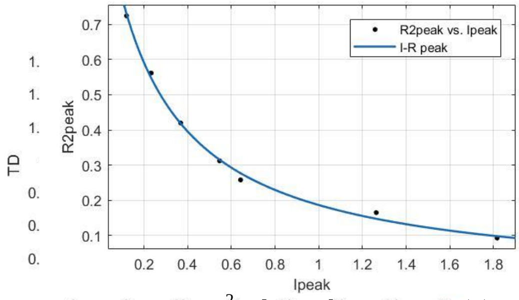

Fig.11: M-R^2 relation by equation (2)

We can see that the reading is decaying while the distance is increasing, but it is almost the same when I fit the data with these two equations, therefore, we can't decide that whether it is spherical wave or plane wave by this method.

For the second part, by Fig.2, we measure that the reflection angle was 40˚ and we use Snell's law, find out that the maximum reading was at 22degree and 40degree, and the index of refraction is 1.716, it satisfies our expectation, and it also tell us that Snell's law is correct.

For the third part, we fix the source first, and we get the figure as below:

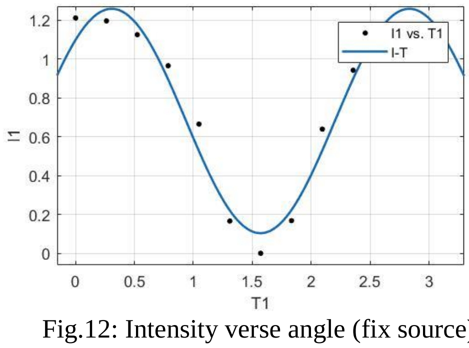

Fig.12: Intensity verse angle (fix source)

And we fix the receiver, change the angle of the source, and we got the below figure:

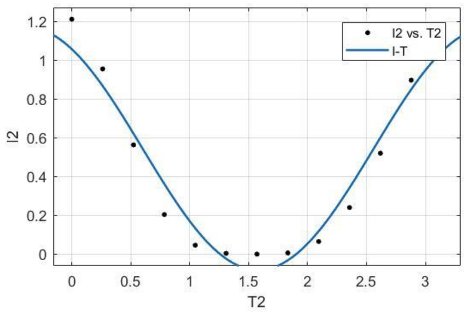

Fig.13: Intensity verse angle (fix receiver)

We had fit the two curves with the function $y = a\cos^2(bx + c) + d$, and we can see that it can fit the data spot smoothly.

Now we will determine the relation between intensity and distance that include a polarizer, and the result was as follows:

Fig.14: Intensity verse distance with a polarizer

Of course, we also record the relation between the intensity and angle, and the result was as follows:

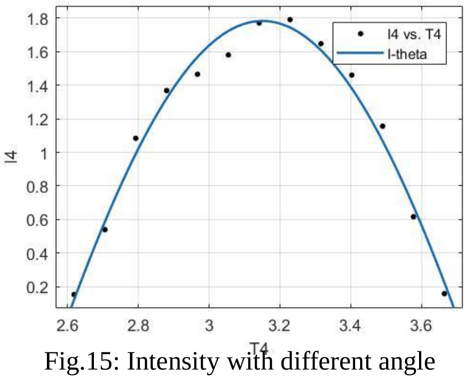

Fig.15: Intensity with different angle

From Fig.15, we observe that intensity was decrease suddenly, and it told us that it was a plane wave, because intensity was dependent on the angle.

For the fourth part, we only finished the single slit diffraction. For the site, we can assume the function of slit is define as:

$$f(x) = \begin{cases} 1, & 0 < x < w \\ 0, & other \end{cases},$$

and we find the Fourier transform of this function F(w), we know that it will become sinc function [1]. Therefore, we expect that the data spot can be fitted by a sinc function, and our data was as follows:

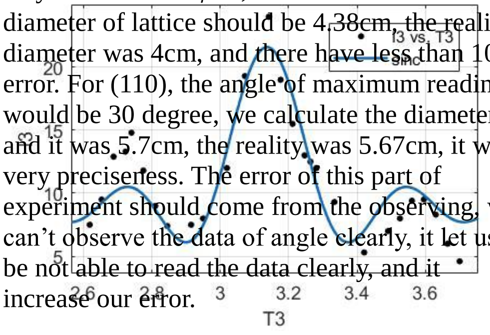

Fig.16 Single slit diffraction

Since we expect that will become a sinc function, we fit the data spot with the function:$y = a\mathrm{sinc}(bx + c) + d$, and we can see that the it can be fitted smoothly, except the left-hand side. During the experiment, we can saw that the reading was unsteady, such that we can't read the data exactly, and it cause the error.

For the fifth part, we know that the half-wavelength is $1.425\mathrm{cm}$, we fix that $d = 19\mathrm{inch} = 48.26\mathrm{cm}$, and measure three optical path different with different h. And the result was as follows:

h(cm)	path different(cm)	times
14.6	4.32	3.03
19.0	7.21	5.06
20.6	8.43	5.91

Table.1 Optical path different

We can see that the optical path different is very similar to the integer times of half-wavelength, and it satisfy our expectation.

For the sixth part, they be apart 20cm, and we measure that whatever maximum or minimum, the reading both 1.5, and the half-wavelength was 1.425cm. The reading was the most accurate one and is also can display 1 number after decimal point. Therefore, I decided that the experiment was success.

For the seventh part, we outcrop that the data will be changing all the time, when we move a little, the "average" of the reading won't change, and it will increase our error, because we don't know where is the "maximize point" actually. We measure that the distance R is 1.5cm, and it is close to half-wavelength.

For the last part, the angle of maximum reading of (100) would be 19~20degree, we measure that they are both 16.5 μA, and we calculate that the diameter of lattice should be 4.38cm, the reality diameter was 4cm, and there have less than 10% error. For (110), the angle of maximum reading would be 30 degree, we calculate the diameter and it was 5.7cm, the reality was 5.67cm, it was very preciseness. The error of this part of experiment should come from the observing, we can't observe the data of angle clearly, it let us be not able to read the data clearly, and it increase our error.

Reference

[1] Erwin Kreyszig, Advanced Engineering Mathematics, 10th Ed, John Wiley & Sons(2011)