Research on Electromagnetic Wave Propagation and Optical Characteristics Based on Optical Transfer Matrix Method

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Abstract. The processing of electromagnetic waves by means of optical transmission matrix can be applied through multi-layer homogenization media, and finally real-time transmission can be realized. After that, it can derive the transmission matrix based on the interface and propagation matrix construction, and finally obtain the reflection and permeability coefficients. This article summarizes the content of the transmission matrix method based on previous work experience. The author discusses the propagation and optical characteristics of physical electromagnetic waves based on the optical transmission matrix method from four aspects: reflection-increasing film analysis, DBR design, reflectance calculation of fiber multi-directional laminates, plane wave propagation and reflection in the medium.

1. Introduction
Generally speaking, optics belongs to the category of basic subjects. People's previous research mainly focused on light generation and propagation. At this stage, optics is still one of the cutting-edge subjects, including photonics and information optics. Among them, the main content involved in wave optics is light interference, diffraction and so on. In contrast, the transfer matrix method has strong advantages in itself. It not only has been fully applied in the processing of optical properties of thin-film optical multilayer media, but also has value in the design of optical devices. The transmission matrix method and the specific matrix form all have to go through the multi-light output superposition interference process, and carry out appropriate processing. Only in this way can the electromagnetic wave amplitude and phase level effects be adjusted, making the display of optical principles more intuitive. This will ensure that the physical properties and significance of the coherent superposition of physical electromagnetic waves are fully clarified, creating favorable conditions for the development of subsequent research work.

2. Transfer Matrix Method
The transmission matrix method can calculate the reflectance and transmittance of a multi-layer structured medium formed of materials with different refractive indexes, and the specific distribution of the light field inside the medium. If the transmission matrix is small and there are not many matrix elements, the actual calculation amount will drop significantly, but the calculation accuracy can be guaranteed not to be affected in any way. First of all, researchers can realize layer-by-layer use of the equation form of a single medium layer in the multi-layer medium transmission data matrix, as well as a predetermined order, to clarify the product of the transmission matrix. This is also the multi-layer media transmission matrix that people often say. It is of great significance at the physical level of the transmission matrix. It can pass through one end of the multi-layer medium, and perform the
transmission operation of the light wave electromagnetic field strength and the tangential component of the magnetic field strength, so that it is distributed on the other end of the multi-layer medium.

Secondly, when light is in a multi-layered medium transmission state in the study of reflectance and transmittance, relevant staff can conduct a comprehensive study on the reflectance and transmittance of light waves. This can make physical electromagnetic wave propagation and optical properties research more scientific.

More importantly, the transmission line theory is mainly derived from the analogy of the transmission line equation in microwave technology. Throughout the entire implementation process, the intuitiveness of actual recursive iterative programming is very limited. The transmission matrix method can propagate the electromagnetic wave field components forward and backward in two adjacent layers of media. Then, we can link them together through a simple matrix, and finally use the matrix product to make a relationship between the known quantity and the quantity to be calculated. In contrast, the transmission line theory can better reflect the wave propagation process, making the program implementation process easier. The transfer matrix method can also be popularized and used between adjacent interfaces of fiber multi-directional laminates, and its effect is also obvious [1].

3. Research Principle

3.1. The Propagation of Electromagnetic Waves in Free Space
Electromagnetic waves are mainly produced by the propagation process of changing electric and magnetic fields in space. When several trains of electromagnetic waves propagate in the same coal quality, they can each maintain their own characteristics and pass through the coal quality at the same time, combining in the wave meeting and superposition work. Vibration at any point can be synthesized for the vibrations generated by each wave individually at that point. If the wave source vibration, frequency, etc. are kept in sync, there will be some points of vibration that are always in a strengthened state when they are superimposed. Obviously, there are also some points that completely cancel or weaken, and eventually interfere. Interference is an important characteristic of electromagnetic waves. We can use specific interference principles to realize in-depth exploration of electromagnetic wave propagation characteristics. Among them, the most typical case is standing wave. In the same coal quality, if there are two rows of coherent waves with the same amplitude, standing waves will be formed when they propagate back on the same line. Researchers can use the Michelson interference concept to measure the wavelength of electromagnetic waves of known frequencies, and then determine the propagation velocity of electromagnetic waves.

3.2. Reflection and Refraction of Electromagnetic Waves
There are also differences in the reflection and refraction angles of electromagnetic waves when they are incident on different media obliquely. Besides, in the application of the dielectric plate, the actual transmitter and receiver can be transferred into a parallel polarization state, and then the incident angle can be changed. When the reflected wave field strength is confirmed, people can transfer the transmitter and receiver to the vertical polarization state and repeat the specific observation process to see if there is reflection. In addition, the staff also needs to move the transmitter to any direction and use the receiver to measure horizontally polarized waves and vertically polarized waves. The staff needs to record the final experimental results and understand the best reflection and refraction of electromagnetic waves.

4. Physical Electromagnetic Wave Propagation and Optical Characteristics Based on Optical Transfer Matrix Method
Researchers can clarify the Matlab programming process based on the concept of optical transmission matrix. In addition, researchers can also visually characterize the reflectance and transmittance of the antireflection film for specific reflectance and transmittance, especially to observe the specific changes that can occur under the influence of incident wavelength and dielectric film thickness. The most
common content is to choose air, dielectric film, glass and air for the reflection-increasing film structure. Among them, the most common refractive index of air is 1, the refractive index of dielectric film is 2.46, and the refractive index of glass is 1.51.

4.1 Changes in Reflectance and Transmittance Under the Influence of Wavelength
In this research, the staff needs to select the visible light band from 400 to 750nm, the incident angle is 30°, the dielectric film thickness is 152nm, and the glass thickness is 5mm. After the incident angle and the thickness of the dielectric film are clarified, the reflectance of the reflector film will increase first and then decrease under the influence of the reflection wavelength. When the wavelength is concentrated around 470nm, the reflectivity will reach the highest state, and the specific value is 0.59. Under the influence of the reflected wavelength, the transmittance appears to be significantly reduced first and then increased. When the wavelength is around 470nm, the transmittance will be at the lowest state, and the specific value is 0.41. In general, the reflectance and transmittance changes are just in the opposite state, but the sum of the two is always 1[2].

4.2 Changes in Reflectance and Transmittance Under the Influence of Dielectric Film Thickness
In order to facilitate research, researchers can assume that the wavelength is 610nm, the incident angle is 30°, and the thickness of the dielectric film varies from 100 to 200nm. Since changes in reflectance and transmittance are easily affected by the thickness of the dielectric film, researchers need to fully grasp the specific changes. Only in this way can we ensure the effective development of follow-up research work. The specific situation is shown in Figure 1 and Figure 2.

![Figure 1. Change in Reflectance](image1.png)

![Figure 2. Change in Transmittance](image2.png)

It can be seen from the data in Figure 1 that under the influence of the thickness of the dielectric film, the reflectivity characterization will first shrink and then increase. When the dielectric film thickness is 117nm, the reflectivity is at the lowest state. When the thickness of the dielectric film is between 117 and 184 nm, if the thickness of the dielectric film increases, the corresponding reflectivity will also increase. When the thickness of the dielectric film reaches 184nm, the reflectance is at the highest state, and the specific value is 0.52. When it is at 185 to 200nm. As the thickness of the dielectric film increases, the reflectivity gradually decreases. It can be understood from the
information in Figure 2 that the change trend of transmittance and reflectance are in the opposite state, and the sum of the two is always 1.

4.3 DBR Design

4.3.1 DBR Design

In order to realize the comprehensive calculation and analysis of the DBR mirror and clarify the reflectance and light field distribution, people can use the transmission matrix to calculate and process the DBR of different levels. Generally speaking, high and low reflectivity materials can choose GaAs multilayer film structure, and AlAs multilayer film structure. For the convenience of research, we can use E to represent the positive vector of the wave amplitude of the dielectric material, and design the growth center wavelength with the aid of the device MBE. This is also the manifestation of the mirror, and then the thickness of the structure is checked with the aid of a scanning electron microscope [3].

4.3.2 Result Analysis

After calculating the specific transmission matrix, we can obtain specific DBR reflectance spectra, namely 10, 20, and 30, where the specific center wavelength is 920 nm. Through relevant calculations, we can understand that the reflection spectra of multilayer film structures with different numbers can also show similar shapes. When the number of structural layers is increasing, the maximum reflectivity will be close to 1. Among them, the maximum reflectivity ratio of DBR under 10 logarithms is 97.5%, and the reflectivity of 30 pairs will directly exceed 99.9%. Otherwise, as the number of multilayer films gradually increases, the range of high reflectance width will continue to shrink. Among them, 10 pairs of structures have a width of approximately 200 nm, and 30 pairs of structures have a width of approximately 125 nm.

In contrast, the center wavelength of the entire MEB growth is 920nm. Among them, 10 pairs of experimental emission spectra, the thickness of the AlAs layer under the structure is 76.9nm, and the thickness of the GaAs layer is 64.3nm. Related research shows that when the center wavelength is 915nm, the reflectivity is the largest, and its specific value is 95.9%. At the same time, there is still a significant difference between the test spectrum results and the calculated spectrum results. The difference between the center wavelength of the test spectrum and the expected wavelength is mainly due to the fact that the designer did not correctly grasp the specific thickness of the control layer when designing the multilayer DBR mirror. Related calculation studies have shown that in a 10-layer DBR mirror, if the thickness deviation of each layer is about 3nm, it will cause the entire center wavelength to shift, and the specific shift distance is about 20nm. Therefore, in the specific design and growth process, people need to strictly control the Al and Ga beam currents. If it is in an unstable state, it will cause the thickness error to become more and more obvious. It can be seen from this that when the period thickness is reduced, the center wavelength of the structure can be significantly shifted. This can be fully verified by the SEM test chart.

When the reflectivity exceeds 90%, the width of the high-reflection band is very narrow, and there are obvious fluctuation problems. This is mainly due to the fact that the interface between the AlAs and GaAs layers has not reached the ideal state. The interface described by the actual transfer matrix method is mainly idealized and smooth interface of the medium. The display of the roughness of the actual interface not only easily leads to changes in the angle of incidence of light, but also scattering problems, and the problem of reflectivity fluctuations will become more and more obvious. When the bandwidth is in a narrow state, it is mainly due to the obvious diffusion of Al and Ga components in the interface position, which leads to diffusion and chaotic growth. During actual MBE growth, Al and Ga in the interface position of the AlAs and GaAs layers can be switched and opened and closed. At this time, the beam current will also change gradually through a gradual change, always moving towards a stable state. As a result, in the interior of the region, we can build an AlGaAs layer to ensure that the effective refractive index change is within a reasonable range [4].
If the wavelength of the test spectrum exceeds 950nm, the reflectivity will also drop rapidly, which is mainly caused by the inconsistency of the GaAs layer thickness and the expected design value. When researchers perform layer thickness calculation simulations, the difference in thickness of materials with different refractive indexes will also increase, which will cause the high reflection band to gradually tilt to the right. For this reason, people need to conduct a comprehensive calculation and analysis of the reflection spectrum of the DBR mirror, and realize a comprehensive design of the entire growth process parameters. When the center wavelength is 980nm, the calculated spectrum results of 30 pairs of structure reflectance are shown in Figure 3.

![Figure 3. Reflectance Calculation Spectrum Result](image)

Wherever possible try to ensure that the size of the text in your figures (apart from superscripts/subscripts) is approximately the same size as the main text (11 points). It can be seen from the information in the figure that the thickness product of AlAs and GaAs under the 980nm structure is 82.3nm and 68.7nm. Different from 920nm, the maximum emissivity of DBR can reach 99.6%. Although there is a big difference from the calculated spectrum structure, the high reflectivity range has a good smoothness without too obvious fluctuations. This also proves that the interface state of the material is in a good state, which can be significantly improved so that the center wavelength is as close as possible to the expectation.

4.4 Calculation of Reflectivity of Fiber Multi-directional Laminate

First of all, in the model design process, we can extend the matrix method to the adjacent interface between the fiber multi-directional laminates. So that it is convenient for the staff to calculate the reflectivity of the laminate fiber composite board in any direction. Then the laminate design of structure-type absorbing materials under the form can provide basic conditions. It can be seen from this type of method that we need to apply the magnetic parameters of various materials and design the calculation model of the laminated plate structure absorbing material, so as to facilitate the implementation of subsequent research work. In the calculation of actual carbon fiber reinforced resin composite multi-directional laminates, the electrical loss absorbent application contains a large amount of carbon black glass fiber reinforced plastic, but its absorbing effect is very limited. The reflectivity of FRP is about -8dB. In the calculation model design, we generally do not fully consider the conductor reflection bottom plate. This is the fundamental reason why the incident wave energy can penetrate the entire plate structure. In order to achieve better absorption, people need to redesign the calculation model, which mainly includes a wave-transmitting layer, an absorbing layer, and a reflective layer. Among them, the wave-transmitting layer contains carbon black, the material is mainly glass steel, and the thickness is about 3mm. In the design of the absorbent layer, it mainly contains 2mm absorbent. In the design of the reflective layer, there are mainly carbon fiber reinforced resin composite materials, with a single layer of 6 layers. The thickness of each layer is about 0.5mm, and the planned direction of the specific incident electromagnetic wave electric field is 0°. More importantly, the model has a peak reflectivity of electromagnetic waves between 8 and 12 GHz at about -18dB. Among them, the bandwidth corresponding to -10dB can reach 3.8GHz.

Secondly, it can be seen from the study on the influence of the structure thickness that the thickness has a great influence on the reflectivity of the laminate structure. For the incident wave of a certain frequency, the thickness is different, and the reflectivity is also different. Generally speaking, the relationship between the total thickness of the model and the reflectivity is complicated. Each
frequency involves a minimum reflectivity point, and the corresponding thickness is also different. And it is not that the greater the thickness, the lower the reflectivity. When the electromagnetic parameters are accurately measured, the relevant staff can also display the reflectance of each frequency point along with the thickness change and mark it in a chart to create favorable conditions for the subsequent determination of the optimal thickness. Generally speaking, the reflectance effect is better when the thickness is between 7-8mm [5].

4.5 Propagation and Reflection of Plane Wave in Medium

Based on the study of physical electromagnetic wave propagation and optical characteristics based on the optical transmission matrix method, the radome is an important device, and the core of the device is often composed of medium. In consequence, when electromagnetic waves are reflected and propagated in a single-layer or multilayer medium, we can conduct in-depth analysis of electromagnetic characteristics. If the radius of curvature of the radome is larger than the wavelength, the electromagnetic wave in the local plate can be approximately regarded as a plane wave. For the study of reflection coefficient and transmission coefficient, one is the sum of multiple reflections, and the other is the equivalent transmission line method. First of all, on the superposition of multiple reflections, researchers need to derive the total reflection coefficient of a single-layer dielectric plate, so as to facilitate the subsequent transmission and reflection of a single-layer uniform isotropic medium plate. Moreover, electromagnetic waves can continuously multiply in the medium, and after multiple reflections and refractions, the electric field vectors can be effectively superimposed. Secondly, researchers can make assumptions about the permeability of each layer of media. For any adjacent dielectric structure in the multilayer dielectric board, the dielectric constant must be clear. What’s more, we also need to clarify from the electromagnetic field boundary conditions and Snell’s law that electromagnetic waves in any polarization form can be decomposed into parallel polarized waves and vertically polarized waves. As the number of layers increases, the staff needs to perform recursive calculations for N-1 times. But the process is very complicated, and researchers only need to give approximate values to solve.

5. Conclusion

To sum up, by facing the anti-reflection film and DBR, and the transmission matrix in all directions, people can calculate the fitting reflectivity and transmittance, and achieve a comprehensive display of the physical electromagnetic wave propagation properties and optical characteristics. For the calculation of the reflectance curve of the DBR mirror by the transmission matrix method, we should design the growth center wavelength and high reflectivity DBR mirror. The final result shows that based on Matlab programming and transmission matrix method, the mathematical algorithm of multi-layer homogenization medium matrix can be realized. Furthermore, with the help of reflectance and transmittance, we can understand the specific propagation of physical electromagnetic waves.

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