Light propagation through etalons and other components with internal multiple reflections

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Component, e.g. Fabry-Perot etalon , with internal multiple reflections plays an important role in laser technology. Its optical functionality is based on multiple reflections inside the component and the interference effect. In this paper, two electromagnetic concepts that allow the modeling of such components for general incident light are proposed. The first one is based on an iterative field tracing approach. The other one is based on the matrix method for stratified media. We present the details, demonstrate various examples and also discuss sampling issues due to the internal multiple reflections.

1 Introduction

The components with internal multiple reflections are widely used in optical field, especially in laser technology. Nowadays there are lots of modeling methods to handle this kind of optical components, rigorous as well as approximate numerical methods. For rigorous solvers, the numerical efforts increase rapidly as the feature size of structure increases. Hence, the well-approximated methods, which not only reduce the numerical effort effectively but also keep modeling accuracy, are used instead of the rigorous methods. What's more, according to concept of field tracing [1], the combination of diverse modeling techniques is feasible.

Generally, internal multiple reflections occur between two or more surfaces. Therefore, in principle the determination of modeling approach depends on the structure of surfaces. In this paper, we divide situations into two classes: component with parallel planar surfaces and component with non-parallel curved surfaces. For the first class, one typical example is Fabry-Perot interferometer. The mature matrix method for stratified media [2], which is a rigorous method, is determined to use. In the second case, the component contains non-parallel curved surfaces, a famous application is Newton's rings device. An iterative field tracing approach, which is based on thin element approach (TEA) [3] and iterative approach, is proposed to use.

2 Component with parallel planar surfaces

2.1 Fabry Perot interferometer

In Fig. 1 the equipment diagram of a typical Fabry Perot interferometer is shown. This device contains a parallel glass plate with anti-reflective (AR) coating and a collimating lens. Due to the use of anti-reflective coating, the multiple internal reflections between two plates become very strong and can't be ignored.

In Fig. 2 we present the simulation results of Fabry Perot interferometer. The input field is a general Gaussian beam with divergent angle $0.1°$ and field size ($110\mu m \times 110\mu m$). After the parallel plate the field size become ($5mm \times 5mm$), even though the thickness of plate is just about $7mm$. Finally on focal plane, the field is focused to ($4mm \times 4mm$). On focal plane we can observe the interference pattern, which contains several concentric rings.

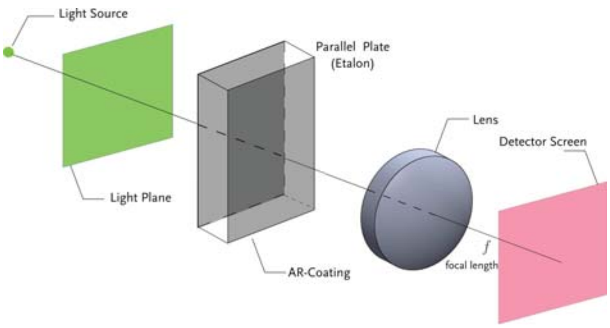


Fig. 1 *Set-up of Fabry Perot Interferometer, using a pair of parallel plates with anti-reflection coating.*

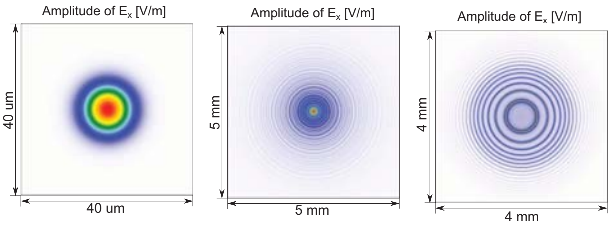
2.2 Analysis of sampling issue

Figure (b) is field directly after etalon which locates before lens. And figure (c) is pattern on focal plane. According to Fourier optics knowledge, 1-f system is a Fourier operator. It means that figure (c) is the Fourier transformation (angular spectrum) of (b). Meanwhile, considering input angular spectrum, as we mentioned the input field (a) is Gaussian profile. So its angular spectrum should be still Gaussian profile. Therefore, comparing these two spectra, we find that Fabry Perot device modulates the spectrum of field. The multiple internal reflections introduce lots of high frequencies components. As we all known. the most common application of Etalon is mode selection. Similarly in our case we can regard

DGaO Proceedings 2015 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2015-P022-8
submitted: 07.Jul.2015 - published: 19.Aug.2015

the Etalon as a spectral filter. Then we can understand why the angular spectrum of output field contains so many ring's structures.

Solution: Obviously output field requires more sampling points than input field. In simulation process. Therefore, the sampling parameter of input field and output field should be keep same. In other words, we need embed the input field as large as output field.



(a) Incident field (b) Field after etalon plate (c) Field on focal plane

Fig. 2 *Simulation results. (a) is input field of this test. (b) shows the output field directly after the Fabry Perot Etalon. (c) is the output pattern on focal plane.*

3 Component with non-parallel curved surfaces

In this section we will discuss another case, that the component contains non-parallel surfaces. Obviously under this situation, we can't use matrix method any more. Therefore we propose another famous scalar geometrical approach [4], Thin Element Approximation (TEA).

3.1 Newton's rings simulation

As a famous optical phenomenon, the principle of Newton's rings is also about internal multiple reflections. The related equipment consists of a convex lens and a flat surface, Fig. 3. The light fields are reflected multiple times between the spherical surface and an adjacent flat surface. The output fields is the sum of all iterative rays. Since we regard the device as "Thin element", the refraction on spherical surface is ignored. Due to the constructive interference between the light reflected from both surfaces, we can observe the interference pattern.

The numerical test of Newton's rings has been done. Simulation parameters and corresponding results are presented in Fig. 4.

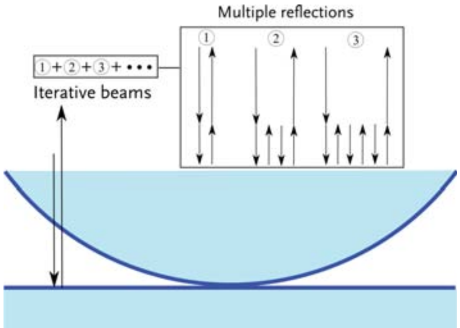
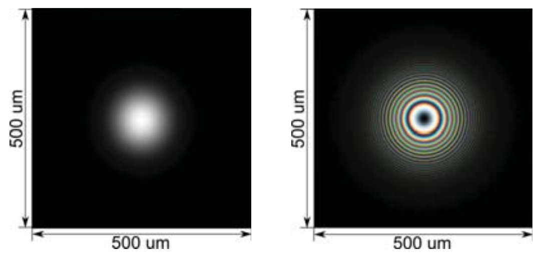


Fig. 3 *Schematic diagram of Newton's rings device: the internal multiple reflections between two surfaces.*



(a) Input white light field (b) Output Newton's rings pattern

Fig. 4 *Newton's rings simulation for white light source. The curved radius of spherical lens is $r = 5mm$. The white light source contains three monochromatic light, @ 473nm, 532nm and 635nm.*

3.2 Analysis of simulation result

Comparing the input field and output field, it is easy to see that the size of field doesn't change. It is because that we use TEA as modeling approach. What's more, in principle the iterative number should be infinite. But in practice we find that the simulation result is convergent when the iterative number is larger than a critical number. This number is related to the reflectivity/ transmissivity of the field at the interface.

4 Conclusion

In this paper, we proposed two modeling approaches: iterative geometrical field tracing approach (combined with TEA) and diffractive field traicng approach (based on transfer matrix method). They have different features: iterative geometrical field traing is approximated but has very fast computational rate. On the other hand, diffractive field tracing is rigorous but only can be used for component with parallel planar surfaces. What's more, for diffractive field tracing we need pay more attention on the sampling issue.

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DGaO Proceedings 2015 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2015-P022-8
submitted: 07.Jul.2015 - published: 19.Aug.2015