Wavefront distortion

1. What is wavefront?

The wavefront is the wave vibration surface, also known as the mesophase surface, which refers to the surface composed of points with the same phase of light wave vibration. At first, the wavefront that runs in the front of the wavefield is called the wavefront. In modern optics, wavefront refers to the light field that directly contacts the receiving plane.

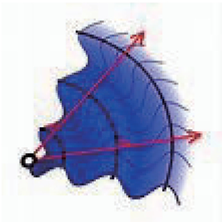

Fig.1 Wavefront diagram

2. What is wavefront distortion?

According to Marius' Law: the optical path between the corresponding points of the outgoing wave surface and the incident wave surface is equal, but due to the existence of aberration, the equal optical path surface of the outgoing wave surface deviates from the ideal wave surface, and the offset of the two is the optical path difference. Wavefront distortion means that if the wavefront changes after passing through a certain transmission medium, for example, it is no longer a spherical wave or a plane wave, it is called wavefront distortion.

3. What are the effects of different concentrations on the crystal?

3.1 Transmission wavefront distortion (TWD)

The reason for transmission wavefront distortion is that the time path n*d of a beam of light passing through the part is not equal, n is the refractive index of the material and d is the distance traveled by the light in the part. It is a specification describing the deviation between the transmission component of incident light and a completely flat plane wave.

3.2 Reflected wavefront distortion (RWD):

Reflected wavefront distortion refers to the wavefront deformation of a beam of light wave after reflection caused by the defect of the surface shape of the part. Used to describe the deviation of the reflected component of incident light from a completely flat plane wave. The incident plane wave is distorted when reflected on the incident side. We call it reflected wavefront distortion or RWD.

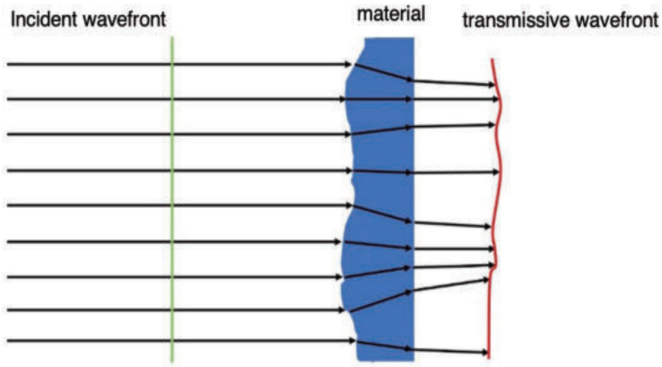

Fig. 2 transmitted wavefront distortion

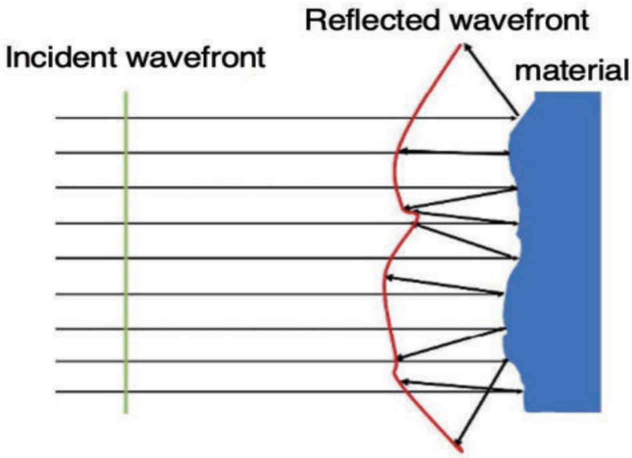

Fig. 3 reflected wavefront distortion

4. What causes wavefront distortion?

There are many reasons for wavefront distortion. The intuitive performance is determined by the surface shape, parallelism, and material uniformity. Take the measurement of optical elements as an example:

4.1 Internal factors:

(1) Material quality
In the process of crystal growth, there are often a variety of defects, such as impurities, bubbles, lattice defects, and so on. It will greatly affect the optical properties of the material, and the fringes and bubbles in the material will cause the distortion of the wavefront.
(2) Machining
The flatness and parallelism of the material surface during polishing; the stress of the film during coating; the support force of the outer frame of the element.
3.2 External factors:
(1) System
After the light passes through optical elements such as lenses and samples, due to the unsatisfactory design and placement of imaging elements and the uneven refractive index of samples, the light deviates from the ideal optical path and produces wavefront distortion.
(2) Environmental effect
Temperature and airflow will make the air density uneven in the local area, cause local deflection to the measurement beam, change the measurement wave surface and affect the measurement results. The influence of environmental vibration on the interferometer is that it causes random phase change between two coherent wavefronts, which is mainly manifested in the jitter of interference fringes, resulting in fringes blurring.

5. What affects the wavefront distortion?

The wavefront distortion is comprehensively determined by the incident surface, the exit surface, and the uniformity of the medium. If the internal fringes and envelopes of optical materials (especially in the case of faults and dislocations in the crystal) are serious, the wavefront distortion cannot be done well no matter how good the surface shape is.
The following is some examples of a single substrate material:
(1) Incident surface: flat; Exit surface: flat; Base material: homogeneous
TWD: low
RWD: low

Fig 4: flat, parallel and homogeneous substrate

(2) Incident surface: curved; Side B: curved (same as side A); Basic material: homogeneous
TWD: low
RWD: high

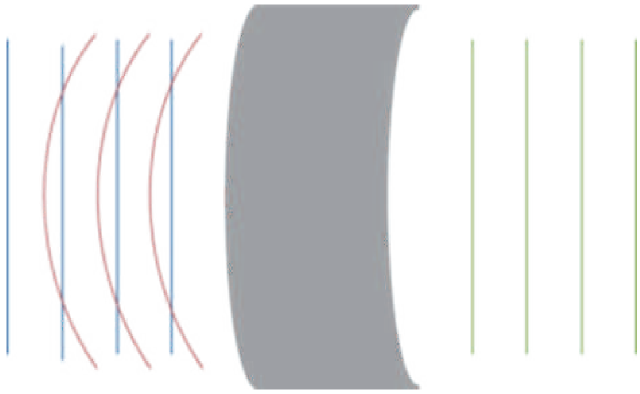

Fig 5: curved, parallel and homogeneous substrate

(3) Incident surface: curved; Exit surface: different from surface A; Basic material: homogeneous
TWD: high
RWD: high

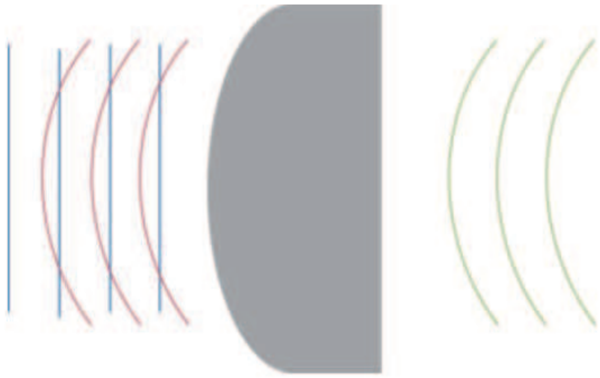

Figure 6: curved, non-parallel and homogeneous

(4) Incident surface: flat; Exit surface: flat; Basic material: inhomogeneous
TWD: high
RWD: low

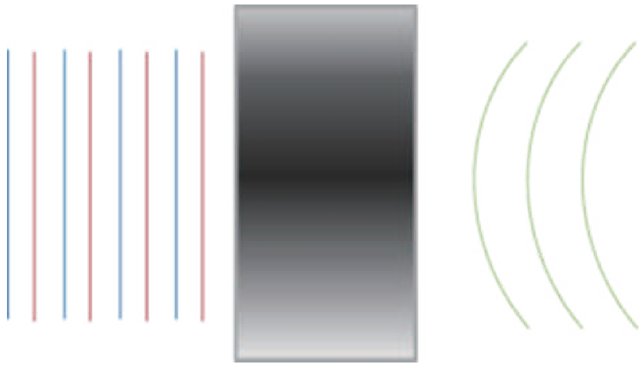

Fig 7: flat, parallel and inhomogeneous substrate

6. Why measure transmitted wavefront distortion?

Because the transmitted wavefront distortion TWD reflects the optical uniformity of the material. As for the relationship between optical uniformity and wavefront distortion, it can be said that if the crystal with poor optical uniformity, it is difficult to obtain ideal wavefront distortion (PV value) through processing. Simply look at the face shape after processing, and use a standard plate.

Transmitted wavefront distortion (TWD) or equivalent transmitted wavefront error (TWE) is a specification to describe the deviation between the transmitted component of incident light and a completely flat plane wave. TWD is usually specified as the "per/λ" value ratio (usually 633 nm) of the nominal wavelength used to characterize the surface map. TWD is particularly important in imaging applications, because the distortion of the transmitted beam may lead to the image distortion of the detector, or the change of the light intensity of the detector is not caused by the measured sample, but by the result of its own influence. The TWD is mainly affected by the characteristics of the bare substrate before coating. The substrate parallelism specification defines TWD to a great extent, but due to the change of effective optical refractive index caused by material characteristics, the non-uniformity in the substrate material will also affect the transmitted wavefront. Similarly, the influence of coating uniformity change will also affect TWD, although the influence of coating and substrate heterogeneity on TWD is almost always submerged by the physical substrate specification.

7. Why measure the reflected wavefront distortion?

Reflected wavefront distortion (RWD) or equivalent reflected wavefront error (RWE) is a specification used to describe the deviation of the reflected component of incident light from a completely flat plane wave. RWD is usually specified as the "per/ λ" value ratio (usually 633 nm) of the nominal wavelength used to characterize the surface map. RWD is suitable for applications where the reflected beam is used for imaging or detection because the direction and distortion of the reflected wavefront are important. Like TWD, RWD is affected by the characteristics of the bare substrate before coating, but unlike TWD, the influence of coating stress usually makes a very important contribution to RWD. The flatness of the primary reflective surface largely determines the RWD, so the flatness of the incident surface of the substrate is very important. However, due to the stress caused by the complex coating, the curvature of the surface is always changed by the coating itself. The completely flat substrate surface can be bent (raised) by the filter coating but can be at least partially flattened using the back coating (stress balance coating) with equivalent stress. The non-uniformity in the substrate material is largely irrelevant because the reflected beam will not reach the substrate material itself, but the change of coating uniformity will affect RWD.

At a normal incidence rate, the difference between flatness and RWE is only 2 times:

RWE = 2 × flatness

Flatness = 1/2 × RWE

In the case of non-normal incidence, the relationship between flatness and RWE depends on the incidence angle θ:

RWE = [2cos(θ)] × Flatness

Flatness = RWE / [2cos(θ)]

8. What are the measurement methods of wavefront distortion?

According to the detection principle, there are two main methods: one is to use the wavefront detector to detect directly, mainly including shack Hartmann wavefront sensor and so on; The other is indirect detection based on the principle of interference, that is, the light intensity distribution of the wavefront to be measured on some characteristic surfaces is obtained first, and the wavefront distribution is obtained by reverse solution through further processing.

8.1 Interferometry

Interferometry is a technology to obtain information through the interference phenomenon caused by the superposition of waves (usually electromagnetic waves). The interferometer is widely used in scientific research and industrial production to measure micro displacement, refractive index, and surface flatness. In the interferometer, the light emitted from a single light source will be divided into two beams, passing through different light paths and finally intersecting to produce interference. The generated interferogram can reflect the optical path difference between the two beams. According to the superposition principle, the result of wave convergence can reflect the original state of the wave. Interferometry is based on this. When two beams of light with the same frequency are superimposed, their fringes depend on their phase difference: the same phase will produce enhanced fringes, on the contrary, they will produce weakened fringes. Between the two cases, there will be stripes of intermediate intensity. These fringes can be used to analyze the relative phase correlation of the two beams.

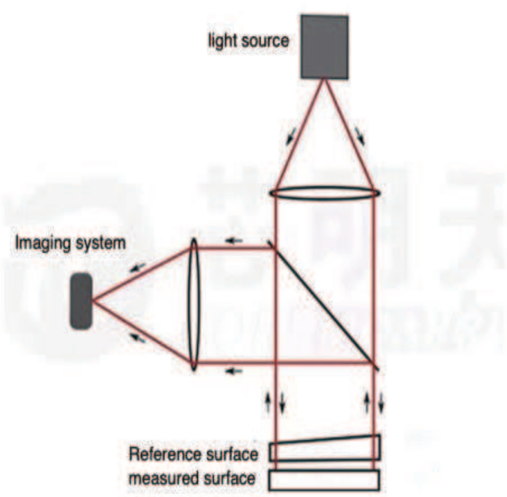

Fig 8. Fiso interferometer

Optical measurement is usually completed by Fiso interferometer. A reference plane is placed on the plane to be inspected. There is a narrow gap between the two planes. The upper surface of the reference plane is slightly inclined (the inclination angle is within one degree) to avoid interference with the rear surface. The gap between the plane to be inspected and the reference plane enables the two planes to form a certain inclination. This inclination can add a controllable phase gradient to form interference patterns. People can control the arrangement and direction of the interference pattern, and get a nearly parallel interference pattern sequence instead of a complex contour vortex. However, the separation of planes requires the collimation of illumination light.

8.2 Sensor measurement

Taking shack Hartmann sensor as an example, the incident beam is focused on the CCD array by a group of microlenses. Each lens element has many CCD pixels. The spot position was measured before and after inserting the sample. The wavefront distortion caused by the sample causes the spot to move. The number of deformation waves is calculated by the change of spot position. Low cost laser sensors are widely used in metrology, astronomy, life science and other fields.

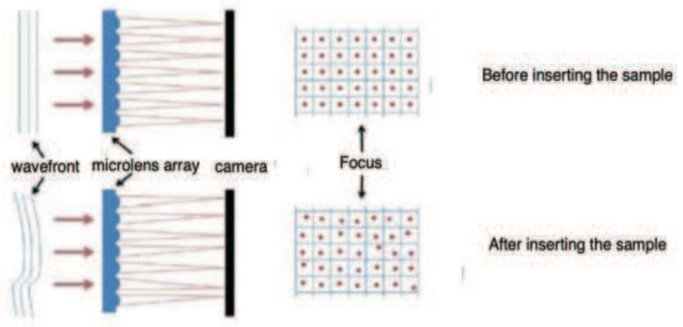

Fig 9. Shack Hartmann sensor

9. What are the precautions in the measurement?

9.1 Precautions for optical inspection

- Do not touch the surface of the optical lens by hand.
- When there is dirt on the lens surface, do not wipe it directly by hand; The dust should be blown off with a blowing balloon first; then wipe it with a flannelette. If necessary, dip a cotton rod with the mixture of alcohol

and ether.

- When installing or removing parts, handle them with care to avoid damaging the instrument or product.
- The measurement shall be patient and meticulous to avoid reading error.
- For the measurement with high accuracy requirements, it shall be measured three times and the average value shall be taken.
- The optical testing equipment shall be cleaned and maintained regularly.
- The testing laboratory shall be kept clean, tidy, dry, and well ventilated.

9.2 Precautions for use of an interferometer

- The instrument should be placed in a dry, clean, and vibration-free environment.
- When moving the instrument, in order to prevent the guide rail from deformation, hold the base before moving.
- When the optical parts of the instrument are not in use, they should be stored in clean and dry vessels to prevent mildew.
- Try not to wipe the reflector and spectroscope of the instrument. If they must be wiped, they should be wiped carefully and cleaned by scientific methods.
- Transmission parts such as guide rail, screw rod, nut, and shaft hole shall be well lubricated. Therefore, precision instrument oil shall be used for lubrication when necessary.
- During use, strong rotation and hard pulling shall be avoided, and the components shall be adjusted reasonably and properly.
- Avoid scratching or corroding the guide rail surface screw rod and keep it free of oil loss.
- Avoid using in an environment with large temperature changes, wind and humidity, otherwise, the test results will be greatly affected.

9.3 Precautions for sensor use

- The sensor should not be installed in direct sunlight, high temperature, possible frost, and corrosive gas.
- The connecting wire shall not use the same wiring pipe or wiring slot as the power line and power line or use shielded wire.
- The connecting wire shall not be too thin and the length shall not be too long.
- After the power is turned on, it is necessary to wait for a certain time before testing.

10. How to choose the right product?

While it may be tempting to specify all flatness, TWD, and RWD as part of the specification, it is important to ensure that functionally irrelevant parameters are not specified, as this will unnecessarily increase costs.
Here are some guidelines on when to specify TWD and RWD:
(1) Filter used at normal (0°) incidence angle:
Typical application: imaging
In these optical designs, for almost all cases, only the transmission wavelength is used, and all other light can be considered "blocked" (rather than reflected, even if this is the way to achieve blocking)
RWD (reflected light not recovered) should not be specified
If it is important for the application to retain the wavefront or direction of the transmitted light, TWD should be specified
(2) Filters used at abnormal (usually 45°, but any value > 0°) incidence angles:
Typical applications: multi-wavelength imaging, beam control
In these optical designs, the transmission wavelength and reflection wavelength are usually used at the same time (or only the reflection wavelength in the case of a mirror)
If the reflected light is to be restored/used, the RWD should be specified
In the case of a beam splitter, if the direction of the retained wavefront or transmitted light is important for the application, TWD should be specified

Reference

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