The research on making large-size aspherical mirrors by vacuum evaporation technique

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ABSTRACT

Along with development and progress of modern optics manufacturing technology and optical test technology, there are a series of modern polishing technologies based on the application of computer software and hardware, such as CCOS(Computer Controlled Optical Surfacing), Stress Lap Polishing, Magnetorheological Finishing, Ion Beam Milling, etc. The emergence of these new technologies promotes aspherical mirrors widely used in optical system. Vacuum evaporation technique is applied widely on making optical coating. In this paper, we discuss the feasibility on applying vacuum evaporation technique to making large-size aspherical mirrors. The technology is to take original sphere as substrate, deposit film of certain thickness distribution on the surface, then get aspherical mirror. This technology has a special advantage and tremendous development space in the off-axis aspheric processing, silicon carbide aspheric surface processing and modification, super-glossy aspheric processing and great telescope mirror batch processing.

Keywords: vacuum evaporation, original sphere

1. INTRODUCTION

Aspheric optical system, not only increase the degree of freedom of optical design, reduce the number of optical components used and improve the image quality, but simplify the apparatus structure and reduce the instrument size and weight. This point in the application of space optical systems is particularly important significance.

Compared with traditional spherical component processing, processing of aspheric component is much more difficult, especially off-axis aspheric. It is because of the aspheric processing difficulties, and thus in a very long period of time to limit the application of aspheric optical components in optical systems. With the development and progress of modern optical manufacturing technology and optical testing technologies, there are a series of modern polishing technologies based on the application of computer software and hardware, such as CCOS(Computer Controlled Optical Surfacing), Stress Lap Polishing, Magnetorheological Finishing, Ion Beam Milling, etc. The emergence of these new technologies promotes aspherical mirrors widely used in optical system.

Traditional classical polishing method and modern polishing techniques(CCOS, Stress Lap Polishing, Magnetorheological Finishing, Ion Beam Milling, etc.) achieve aspherical surface error correction by removing the surface material. If vacuum evaporation technique can be applied to achieve aspherical surface error correction by covering certain material, it will be completely different from the previous polishing technology and also have its unique advantages.

Vacuum evaporation coating is under vacuum conditions, the coating material is heated and vaporized by electric gun etc, so the evaporation stream of particles is directly transported to the substrate and form the solid thin film on the substrate, which is the resistance heating evaporation method. In recent years, with the introduction of the ion beam assisted deposition, enhanced the film adhesion, reduced film internal stress, at the same time can increase the packing density, improve the density of the film, eliminate columnar crystals, therefore, the film quality is improved, the properties have been close to the solid materials. The modern vacuum evaporation equipment have stable performance, good repeatability of thickness distribution, assisted by special design of the mask plate, can realize special distribution on plated components.

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2. PRINCIPLES OF THE METHOD

Vacuum evaporation aspheric technology can be subdivided into the following three key elements:

2.1 thickness distribution of deposition material

Film thickness at any point on the substrate depends on the emission characteristics and the geometric configuration of the evaporation source, known as the emission characteristics and the geometric configuration of evaporation source, can be theoretically calculated and gain the law of film thickness distribution.

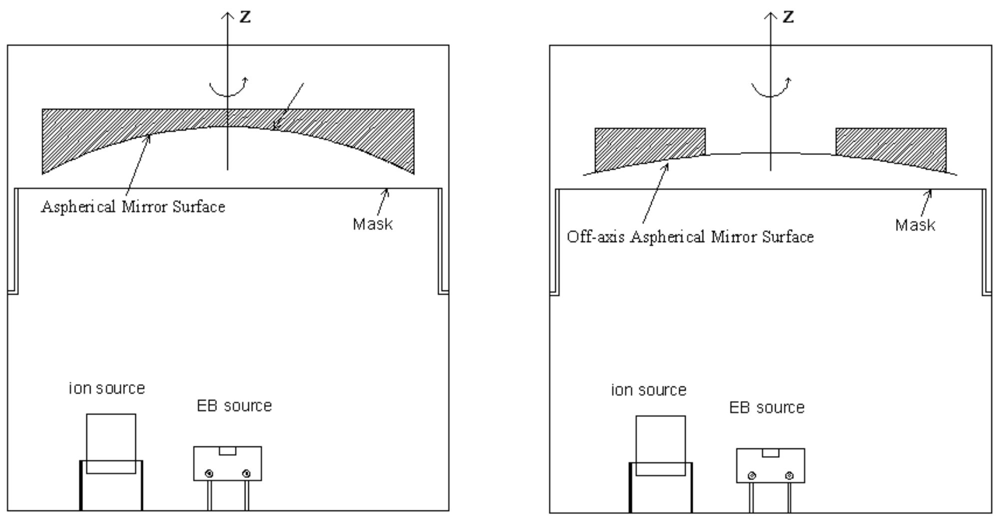

Fig.1.a Fig.1.b

Fig.1.a is diagram for making large aperture aspheric by vacuum evaporation, Fig.1.b is diagram for off-axis aspheric by vacuum evaporation. Mask is mask plate, its shape is decided by the thickness difference of desired aspheric and original spherical and film thickness distribution. Ion source assisted deposition material, EB is electron beam evaporation source.

2.2 derivation of thickness distribution for evaporating aspheric

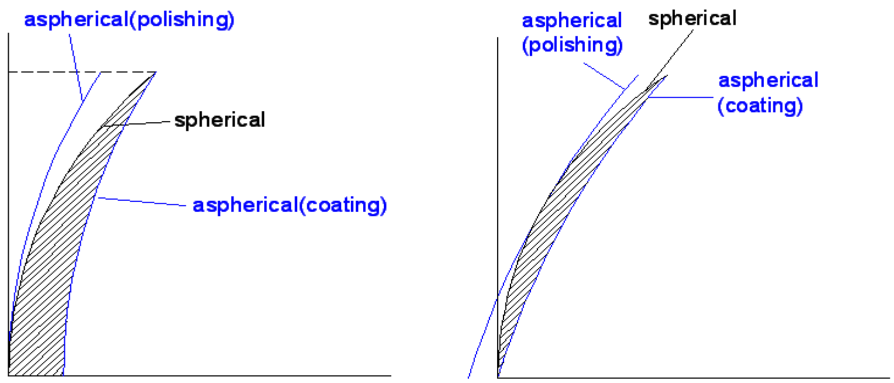

Fig.2.a Fig.2.b

Fig.2.a is the original spherical for deposition with a vertex center of curvature for the center of the sphere; Fig.2.b is the original spherical for deposition with the closest comparison of spherical. The shaded area is film thickness distribution required for deposition.

In the conventional aspherical surface processing method, the selection of appropriate original surface can reduce the amount of grinding, play a multiplier effect. Original spherical selection for vacuum evaporation aspherical can also refer to the classic aspheric optical technology, according to the characteristics of vacuum evaporation, can choose the closest comparison based on spherical surface, can also choose to vertex curvature center as the center spherical surface based on spherical surface.

Determined the original spherical, combined with the required aspheric type can determine the deposition thickness distribution of the aspheric.

2.3 the mask shape (control of film thickness distribution)

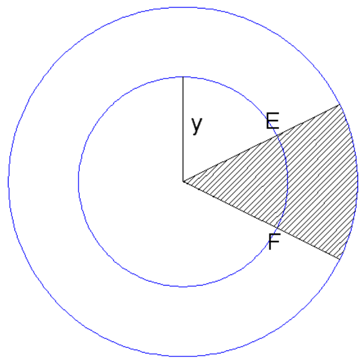

Fig.3 mask diagram

The mask between the optical component and evaporator can change the film thickness distribution. Figure, wedge-shaped shadow express the mask that is located before the optical components, $t_m(y)$ is film thickness with the mask, $t_n(y)$ is film thickness without the mask, for a given y value, the relationship can be expressed as:

$$t_m(y) = t_n(y)\left[1 - \frac{M(\overset{\frown}{EF})}{2\pi y}\right]$$

$t_m(y)$ express the required thickness difference distribution between spherical and aspheric; $t_n(y)$ express thickness distribution distribution on the initial sphere without mask. Therefore, the shape of the mask expression:

$$M(\overset{\frown}{EF}) = 2\pi y\left[1 - \frac{t_m(y)}{t_n(y)}\right]$$

3. THE APPLICATION

3.1 For ultra-smooth aspheric processing

With the development of science and technology, the ultra-smooth surface of optical components are demanded more and more. Such as intense laser, shortwave optics as the representative of Engineering Optics is rapidly developing, the optical components of the laser fusion system, ultraviolet optical system, X ray systems are put forward more and more requirements on machining precision. The developing direction of optical component is working towards the ultra smooth, complicated surface, no damage [1]. At present, the roughness of ultra-smooth optical plane and spherical surface can get to 0.1nm , but the ultra-smooth aspheric processing is much more difficult [2]. Such as the off-axis aspheric mirror in extreme ultraviolet lithography (EHVL) system is closer to the ideal shape and sub-nanometer surface roughness, has reached the limit of polishing technology.

In ultra-smooth aspheric processing, W . C. Sweatt and E . Spiller studied the influence of the deposition film on the substrate roughness, indicated the deposited film can obviously improve the substrate of high frequency error, and proposed it can be used for aspheric mirror processing of extreme ultraviolet lithography (EHVL) system. It will be much easier If can use the ultra-smooth spherical assisted by the vacuum evaporation technique to achieve ultra-smooth aspheric [3].

3.2 For silicon carbide aspheric surface processing and modification

SiC materials exhibit many outstanding properties, such as good chemical and thermal stability, good oxidation resistance, low thermal expansion, high hardness, high thermal conductivity and good radiation resistance. These excellent properties make SiC a prime candidate material for instrumentation applications in fields such as mirrors in space and ground astronomy. Due to the special structure of the silicon carbide, manufacturing of silicon carbide mirror is very challenging: close to the hardness of the diamond makes the grinding inefficiently; stable chemical properties can not "soften" the surface to improve the polishing process in surface roughness and surface removal efficiency; the surface of the grain structure is difficult to achieve high-quality surface roughness.Therefore, the surface roughness of SiC mirror is usually improved by the surface modification. The so-called SiC modification technology is coating a dense layer such as Si, SiC to cover the surface defects, and then polishing the modified layer to the required accuracy. The silicon carbide substrate surface modification methods have chemical vapor deposition and physical vapor deposition [4-7]. In silicon carbide aspheric mirror processing, if only the processing of silicon carbide surface to the initial surface, and then completing the aspheric shaping and modification through the vacuum evaporation technology, then optical precision polishing for the modified layer will greatly improve the processing efficiency of silicon carbide aspherical mirror.

3.3 For off-axis aspheric processing

In the optical system off-axis aspheric is a partial axis asymmetry optical components. Due to the adoption of the aspheric surface, not only can overcome the central obscuration, enlarge the effective aperture, and can avoid the resulting diffraction phenomenon, improve the image quality, simplify the structure of the apparatus. In the past in order to obtain the off-axis aspheric surface was usually used to process a complete full aperture aspheric mirror, and then the cut needed for off-axis component of the so-called "big cut small" method. As a result of processing difficulty and high cost, are generally not easily using this method. For off-axis aspheric processing, using vacuum coating equipment rotation, with the closest comparison spheric as initial spheric, according to off-axis determine component position, design reasonable thickness correction mask, through vacuum evaporation technology can obtain the off-axis aspheric mirror [8].

3.4 For great telescope mirror batch processing

The current international great telescope program are: China 30-100 meter telescope (CFGT); America 's thirty Meter Telescope (TMT); the European extremely large telescope (ELT). Each of the great telescope program involving hundreds of pieces of sub-mirror processing tasks, such as China CFGT plan in the 30m diameter primary mirror consists of about 600 fan-shaped non-spherical face mirrors. At present, very large telescope for large quantities processing off-axis aspherical mirror technology is immature, processing cycle is very long. How in a short time high quality completion of hundreds of mirror manufacture, is the first thing to consider in the development of great telescope. Supported by the National Natural Science Foundation, carried out in the Nanjing Institute of Astronomical Optics & Technology “aspheric optics replication technology” can only achieve a diameter of 400mm caliber.

Aspherical optical replication technology in optical aspheric batch processing achieved good results, but at present only for small caliber of the element, and as a result of the separation of aspheric mirror need optical component have a substantial thickness. Vacuum evaporation aspheric mirror technology is not affected by the restrictions of shape and size, can be seen as the" non-contact replication technology". For more than one meter caliber, the same type of the sub-mirror could be considered in the future by vacuum evaporation forming technology for batch processing[9-10].

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