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Research on reflective micro-structures for laser protection

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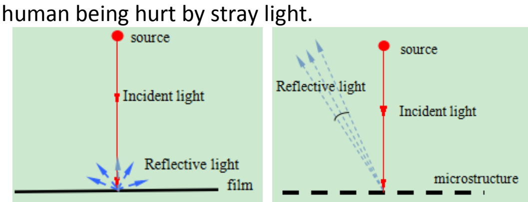
Abstract
With the continuous development of laser technology and the expanded applications of high energy, high-power, short-pulse laser, laser safety to operator and instrument become a major concern. Different wavelengths of lasers would cause different degrees of injury to the eyes. When the laser enters into the eyes, its energy will burn the corneas and may cause blindness. High energy laser will cause skin erythema and blisters which may eventually develop into cancer. The surface of instruments could also be damaged by laser. Therefore, the study of laser safety has received much attention.
This research aims to develop a novel reflective micro-structured surface for protection against laser irradiation based on the latest microstructure design theory to eliminate the damage of the immense heat generated from a high power laser to people and equipment. The approach is novel and has significant application for both civic uses in laser safety as well as in national defence. The characteristic parameters of microstructure are designed on the basis of Fresnel's law and diffractive law. Then microstructure use solidworks and LightTools to make optical simulations. The designed optical microstructure helps to reflect the vertical incidence beam into a tilted emergent beam with a 10 degree angle, to prevent damage to people or instrument.

Keywords: microstructure, design of microstructure, laser protection

1. Introduction

Laser technology and applications has a rapid development, and then it has been combined with a number of disciplines to form multiple application technology. It found that the use of laser will be harmful to the human body and equipment through practice and exploration. [1-3]

Laser protection techniques usually involve absorption, reflecting and complex methods to protect human eye, equipment and environment. [4-7] The project is intended to design a reflective laser protective microstructure element for laser protection glasses. It solves the problem that stores heat for absorptive type. Fig.1 shows the working principle of reflective film and reflective microstructure. Compared with reflective film, the reflective microstructure eliminates echo to avoid laser and optics being effected, as well as environment and human being hurt by stray light.



(a) (b)

Figure 1. (a) The working principle of reflective film. (b) the working principle of reflective microstructure.

2. Design of reflective microstructure

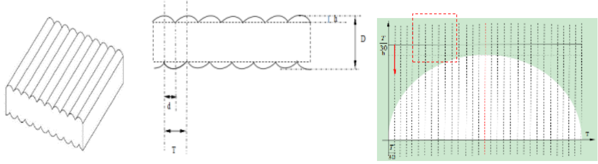
Fig. 2 shows the design of the reflective microstructure. It can eliminate echo to ablate laser, equipment and systems that the design is malposed between the structure of the up and down, and the horizontal spacing is d. Since the laser protective glasses require a relatively smooth surface, so the design uses non-spherical instead of spherical. Combined with Snell's law, optical diffraction basic laws and the above problems, the structural parameters of microstructure is acquired in Table 1. The period of microstructure is 30um. The total thickness is 55.81um. Microstructural unit height is 0.995um. The horizontal spacing is 15um between the structure of the up and down, and its edge meets the following expression:

$$z = \frac{-x^2}{r\left(1+\sqrt{1-(k+1)\times(\frac{x}{r})^2}\right)} \qquad (1)$$

Where r is the radius, k is the conic constant. Grating is a novel design for the microstucture. Fig. 2 demonstrates the details of gratings. The unit is from microstructure in Fig.2(b). Then it will be magnified to a clear unit. The length of the unit is equal to T. Since the grating formula

$$d(\sin\theta_m + \sin\theta_i) = m\lambda (m = 1,2,3,4...) \qquad (2)$$

(Where d is grating space, θ_m is diffraction angle, θ_i is incident angle, m is diffraction grade. Then the grating space t is 1um. So t is equal to $\frac{T}{30}$. The grating should be made from de red line to the horizontal axis).



(a) (b) (c)

Figure 2. (a) Reflective microstructure (b) The front view of reflective microstructure (c) The grating

Table 1 (The characteristic parameters of microstructure)

Title	Code	Size（um）
Priod of microstructure	T	30
Thickness of microstructure	D	55.81
Heightness of microstructure unit	h	0.995
Horizontal spacing between the structure of the up and down	d	15
Parameter 1	k	-1
Parameter 2	r	92
Priod of grating	t	1

3. Simulation of the optical path

The model of the microstructure is built by solidworks, and then Lighttools is used to simulate the light path of optical microstructure. As the characteristics of carbon dioxide laser, the wavelength of the source is 10.6um, its divergence angle is 0.06 ° (Fig.3).[10] The number of rays are 2500, as well as the relative distance L between the microstructure and source is 0.5m. (The following simulation of the optical path to the position of the source, microstructure, incident and reflective light is the same with Fig.3.)

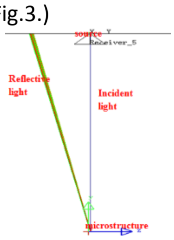


Figure 3. The diagram of light path

When the rays raech the element, there is a light spot on the element. Then the area of the light spot can be got by the following equation,

$$r = L \times \tan 0.06^\circ \qquad (3)$$

Where r is the radius of light spot. The size of microsructure should be bigger than $0.52\text{mm} \times 0.52\text{mm}$ at the moment. But $90mm \times 64mm$ is chosen for further research.

The ray which is perpendicular to the horizontal plane is the referred ray. It will intersect with the microstructure. The crossing point is P. Point of P, the angle between incident and reflective light is produced by the following way for P(Fig. 4). O ' is the center of the emergent light area on the receiving plane. The angle between incident and reflective light can be got by the following equation.

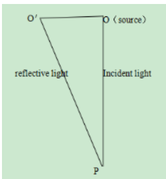
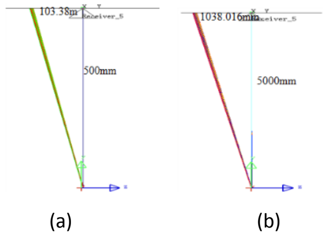


Figure 4. The angle between incident and reflective light

In $Rt\Delta OO'P_1$,

$$\eta = \arctan\left(\frac{OO'}{OP}\right) \qquad (4)$$

The direction of the reflective light is generated by simulation analysis of LightTools. Fig.5 shows that the relative distance between source and microstructure is different, it makes no difference on the angle between incident and reflective light. The relative distance between source and element is 5m in Fig.5 (b), the relative distance between source and element is 0.5m in Fig. 5(a). It is obvious to learn the angle η under the two conditions (Table 2).



(a) (b)

Figure 5. (a) The relative distance between source and element is 0.5m. (b) The relative distance between source and element is 5m.

Table 2 (The angle η under the two conditions)

a	b
11.68°	11.728°

There are five situations about P(Fig. 6). P1 is the top point of microstructure unit. P3 and P4 are the endpoint. Fig.7 indicates the reflective light on these cases and it is easy to gain the angles. The number of rays are 2500, as well as the relative distance between the source and the reflecting microstructures is 0.5m in the Simulating conditions.

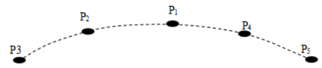


Figure 6. Five situations about P

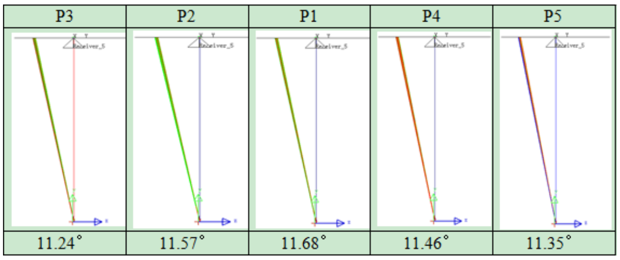


Figure 7. The reflective light on five cases

Conclusion

Reflective microstructure is developed through the research on Snell's law and diffractive law. The period of microstructure is 30um. The total thickness is 55.81um. Microstructure unit height is 0.995um. The horizontal spacing is 15um between the structure of the up and down. Designed optical microstructure services to reflect the vertical incidence beam into a tilted emergent beam with a 10 degree angle. It can be implemented in laser protection glasses very well. The reflective microstructure can also be applied in the research of the laser protective walls and military laser protection. It needs further research and discussion.

References

[1] Urmoneit U, Hotz A, Fröhlich T, et al. Influence of Laser Beam Diameter on the Resistance of Laser Protection Filters to Laser Radiation[J]. Physics Procedia, 2014, 56: 1377-1383.

[2] Sarkar A. Laser protection polymeric materials: U.S. Patent 8,709,305[P]. 2014-4-29.

[3] Ritt G, Walter D, Eberle B. Research on laser protection: an overview of 20 years of activities at Fraunhofer IOSB[C]//SPIE Security+ Defence. International Society for Optics and Photonics, 2013: 88960G-88960G-15

[4] Corbett J, Woods M. UV Laser Radiation: Skin Hazards and Skin Protection Controls[R]. SLAC National Accelerator Laboratory (SLAC), 2013.

[5] Peng Shi, X.H. Fu, Yan Sun. Dual-band infrared laser protective anti-reflection film [J]. CHINESE JOURNAL OF LASERS, 2011, 38(4): 182-186.

[6] B.X. Yang, S.X. Zhang, Bo Yang. Research progress on near-infrared absorbing croconaine dyes for1064nm laser protection [J]. function materials, 2013, 44(22): 3235-3238.

[7] G.H. He. The selection of He-Ne laser protective glasses for operator [J]. Chinese and foreign health abstract, 2013 (24).