Journal of **Kim Il Sung** University
(Natural Science)
Vol. 3 No. 4
Juche103(2014)

The Fraunhofer Diffraction occurring in a Refractive Index Matched GRISM based on HDG

Jo Chon Gyu, Choe Chol Gyu

Abstract We have composed a new type of dispersive element consisting of a refractive index modulation HDG and a prism, and have investigated the Fraunhofer diffraction characteristics of the GRISM disperse system.

First, we have used a high-resolution holographic plate "Лои-2" as the board to form a holographic amplitude grating, and then have processed it with Br_2 to build a refractive index modulation HDG, finally investigating its diffraction efficiency characteristics.

We have found a reasonable refractive index matching condition to attach the HDG and glass prism to each other, thus composing a new type of GRISM dispersive system and investigating its Fraunhofer diffraction characteristics.

Key word holographic refractive grating

Introduction

The great leader Comrade **Kim Il Sung** said as follows.

"Today scientists and technicians are faced with a very important task. They must forge ahead more energetically with scientific research work in order to make a great contribution to raising the scientific and technological level of the country to a higher stage and developing the national economy at a rapid pace."("**KIM IL SUNG** WORKS" Vol. 37 P. 359)

Using a GRISM which is composed of an HDG and a prism attached to each other under the condition of refractive index matching, we study the characteristics of the Fraunhofer diffraction occurring in the GRISM. The GRISM is a new disperse element which is a combination of a diffraction grating and a prism. Research is mainly performed on improving the characteristics of the diffraction grating which gives the main effect of divergence [2－4].

But there were no former investigations on a GRISM designed in a phase matching method based on a refractive index modulation HDG.

This paper presents the implementation of the refractive index matching of a phase HDG and a prism which has been produced from a high resolution holographic plate "Лои-2" by processing with Br_2, thus gives solution to the stabilization problem of the grating and elucidates the Fraunhofer diffraction characteristics.

1. Fraunhofer Diffraction in a Prism-Slit Disperse System

First, we will discuss the phenomena occurring in an optical system consisting of a slit and a prism, instead of HDG.

Consider an optical system like Fig. 1 where a slit of width a_0 is attached to a wedge type crossed prism and let the incident light be a plane light wave.

In this case the light wave entering this system is bound to undergo a continuous phase-change along the slit face.

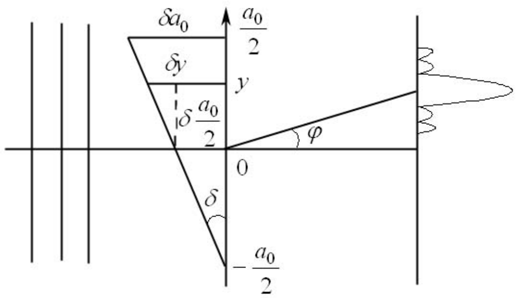

Fig. 1. Fraunhofer diffraction in a prism-slit optical system

Let the center of slit 0 be the origin of coordinates and assume that the apical angle δ of the prism is not large. Now then, at coordinate y the prism's geometric thickness is $\delta\frac{a_0}{2}+\delta y$ and its optical thickness is $\left(\delta\frac{a_0}{2}+\delta y\right)n$ where n is the refractive index of the prism's material.

Thus, the according phase change is

$$\Delta\alpha = kn\left(\delta\frac{a_0}{2}+\delta y\right)+k\left[\delta a_0-\left(\delta\frac{a_0}{2}+\delta y\right)\right] \quad (1)$$

where $k=2\pi/\lambda$.

The first term of (1) is the phase change through the prism and the second term is the phase change caused by the optical path δa_0.

Meanwhile, according to Huygens-Fresnel's principle the amplitude distribution of the diffraction pattern in the Fraunhofer area can be described as [1],

$$\Phi(x', y') = \int_S \Psi(x, y)e^{ik(xx'+yy')}dxdy \quad (2)$$

thus assuming that the slit is infinitely long, we can consider the light area distribution Ψ as one-dimensional and describe it as

$$\Psi(y) = \frac{A_0}{a_0}e^{i\Delta\alpha}. \quad (3)$$

In the absence of a prism, the light's complex amplitude gained by the slit can be described as

$$A = \int_{-a_0/2}^{a_0/2}\Psi(y)e^{-iky\sin\varphi}dy. \quad (4)$$

If we put (3) into (4), the amplitude of the diffracted light wave can be calculated as

$$A_\varphi = \int_{-a_0/2}^{a_0/2}\frac{A_0}{a_0}e^{i\Delta\alpha-iky\sin\varphi}dy = \frac{A_0}{a_0}e^{ik(n+1)\delta a_0/2}\int_{-a_0/2}^{a_0/2}e^{-i[k\sin\varphi-k(n-1)\delta]y}dy. \quad (5)$$

According to the Fraunhofer diffraction formula in a rectangular area, the (5) can be put into

$$|A_\varphi| = |A_0| \frac{\sin\{ka_0[\sin\varphi - (n-1)\delta]/2\}}{ka_0[\sin\varphi - (n-1)\delta]/2}. \tag{6}$$

If we turn into account the fact that in the absence of a prism the primary maximum of the diffraction pattern appears on the primary optical axis, we can see that according to (6) in case of a prism present the primary maximum of the diffraction pattern will be biased by

$$\varphi \approx (n-1)\delta \tag{7}$$

from the primary optical axis.

2. Fraunhofer Diffraction in a Refractive Index Modulation HDG

We have implemented refractive index modulation by treating an amplitude modulation HDG with Br_2. The amplitude modulation HDG has been obtained from a high resolution holographic plate "Лои-2".

If the amplitude grating consisting of silver halide emulsion is processed with Br_2, hardening of the emulsion by tanning[5] doesn't occur. Only an oxidation reaction $2Ag+Br_2 \rightarrow 2AgBr$ occurs which forms $AgBr\,(n=2.25)$ which has a refractive index greater than that of gelatin $(n=1.52)$, thus implementing refractive index modulation.

Investigation of the Fraunhofer diffraction characteristics by this 600mm^{-1} grating shows that Bragg effect is ostensible(Fig. 2).

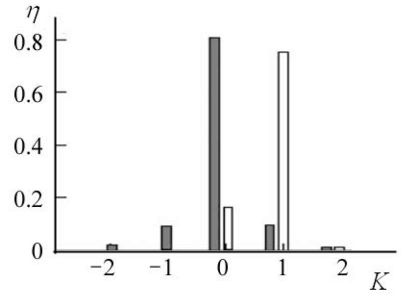

Fig. 2. Fraunhofer diffraction of a 600mm^{-1} grating processed with Br_2
Black bar- vertical incident light, white bar-bragg incident light

Fig. 2 shows that in case of normal incident light the first order efficiency amounts to only a few percentages, while 78%, most of the incident flow of light concentrates on the primary maximum. In case of Bragg angle incident light most of the incident flow of light concentrates on the first order and only 13% is allocated to the primary maximum. This fact gives the result that the distribution of light intensity depends strongly on the incident angle and if the incident light enters at Bragg angle the first order diffraction efficiency gets to the maximum of about 70%.

According to such experimental results we can conclude that it is reasonable to use a phase type HDG processed with Br_2 in a GRISM.

3. Fraunhofer Diffraction in a Refractive Index Matched GRISM Dispersive System

Fig. 3 shows the outline of our GRISM disperse system.

We have balanced the polarization angle φ in equation (7) with the diffraction angle φ_1 which is the angle of the first order spectrum which is of the greatest intensity, thus satisfying the condition $\varphi = \varphi_1$.

Meanwhile, the maximum condition of a refractive index modulation HDG is satisfied if the incident light enters at Bragg angle. At that time the Bragg angle can be expressed as

$\theta_B = \arcsin[\lambda/(2\Lambda)]$ where Λ is the spatial period and θ_B is the Bragg angle(Fig. 4).

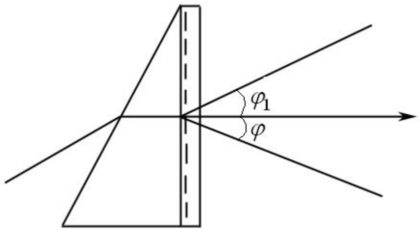

Fig. 3. Polarization of light in a GRISM disperse system

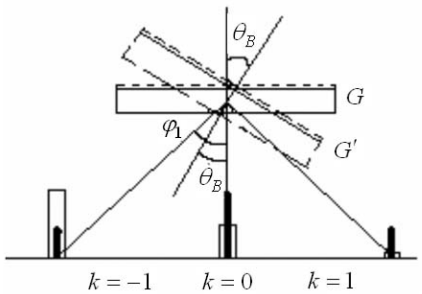

Fig. 4. Bragg diffraction in the HDG

So for the given GRISM disperse system the following expression holds true.

$$\varphi_1 = 2\theta_B = 2\arcsin[\lambda/(2\Lambda)] = (n-1)\delta \tag{8}$$

According to expression (8), the relationship between the spatial period of the HDG and the prism's apical angle should be expressed as

$$\Lambda = \frac{\lambda}{2\sin[(n-1)\delta/2]}. \tag{9}$$

According to equation (9) the relation between HDG spatial period and the prism's apical angle is shown in Fig 5.

As shown in Fig.5 in case that the spatial frequency is $\nu = 300\text{mm}^{-1}$, thus the spatial period is $\Lambda = 3.33\mu\text{m}$, a prism with the apical angle $\delta=17^\circ$ is the best choice for the GRISM. If the spatial frequency is $\nu = 600\text{mm}^{-1}$, thus if the spatial period is $\Lambda = 1.67\mu\text{m}$, a prism with the apical angle of $\delta = 33°$ is the best choice.

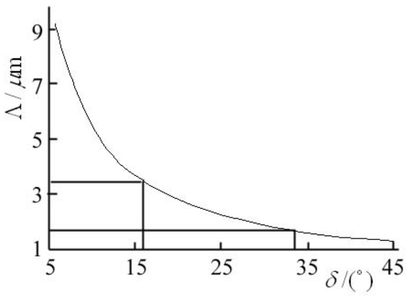

Fig. 5. Change of HDG spatial period according to the prism's apical angle

Refractive index matching is implemented by Canadian balsam $(n = 1.52)$.

The consequent GRISM has excellent disperse characteristics, is much stable against dampness and no change in photochemical sensitivity has been detected in the ultraviolet exposure experiment with EHV mercury lamp “ДРЩ-250”.

The experimental results show that GRISM based on a refractive index modulation phase HDG is a new and reasonably good combination method of dispersive elements.

Conclusion

On the basis of investigation of the Fraunhofer diffraction characteristics in a slit-prism optical system, we have found a reasonable refractive index matching condition for the composition of a GRISM, a new style of dispersive element.

Since the refractive index of the HDG's emulsion is $n=1.52$ and the refractive index of the prism material is $n=1.52$, phase-matching with Canadian balsam of the refractive index $n=1.52$ is an effective way to compose a GRISM as a new direct-view dispersive element.

And we have found evidence that it is a reasonable solution to the problem of dispersive system stabilization to compose a GRISM disperse system by phase-matching based on refractive index modulation HDG.

References

[1] J. W. Goodman; Introduction to Fourier Optics, McGraw Hill, 361～367, 1996.

[2] B. Kilosanidze et al.; Appl. Opt., 52, 5, 1006, 2013.

[3] Ho-Chiao Chuang et al.; Opt. & Laser. Technology, 44, 2182, 2012.

[4] T. Hieta et al.; Optics Communication, 282, 3119, 2009.

[5] I. Banyasz; Optics Communication, 267, 356, 2006.