Optical Diffraction Method for Disk-memory Groove Parameters Testing

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Abstract

The optical disk-memory has very fine grooves. The widely applied Fraunhofer theory fails to describe the diffraction since large diffraction angle should be taken into account and the Fresnel coefficients at the grooves are no longer constant. Under the circumstances, a method has been developed to study this diffraction problem; furthermore, some essential factors, such as the influence of the groove form, the contribution of the multiple reflection at the substrate surfaces to the diffraction patterns, particularly when the substrate is not perfectly parallel, and so on, have been discussed. Finally a diffraction technique for testing groove parameters has been established.

1. Introduction

Optical disk-memory which promises high storage bits is widely applied in scientific research and industries. It's essentially necessary to test and to inspect the parameters(such as the pitch, width, depth, even the form of the grooves) carved prior to the data writting process[1,2]. It's even a fairly challenging task. For the state-of-the-art highdensity optical disk, the fine structure of such grooves is near or even beyond the Rayleigh resolution limit(for visible wavelength, e.g. the pitch, width, and depth are n the order of 2, 0.5 and 0.1μm, respectively[2]). Since the disk-memory has a quite large area should be tested, the optical diffraction method promises a real-time, non-contact, large area possible testing or inspection which can determine groove parameters and discriminate defects individually, and can be applied both to reflection and transmission testing; however since the large diffration angle should be considered, the Fraunhofer theroy, which was employed in the reference[2], is no longer valid to describe the diffraction here. In this paper the diffraction method has been investigated in very detail.

2. Theory

Consider the diffraction measurements (reflection as well as transmission) as shown in Fig. 1, a incident beam with wavelength λ, incidence angle θ_i, illuminates the optical disk-memory under test which has N grooves, each one has the same definite form with pitch p, width d, and depth h, respectively; the refractive index of the groove material is n. From the Kirchhoff-Helmholtz theory, the far-field $E_2(s)$ could be obtained from the near-field $E_1(\rho)$ in the area S:

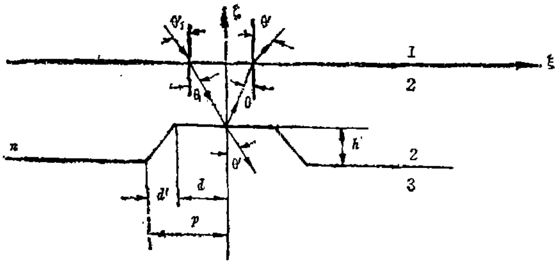

Fig. 1 Geometry of the diffraction measurements

$$E_2(s) = E_0 \frac{i \exp(iks)}{\lambda_0} q(\theta_i, \theta, \varphi) \iint_S \exp[-i(k-k_i)\cdot\rho] d\xi d\eta \tag{1}$$

with

$$\left.\begin{aligned} \rho &= \hat{x}\xi + \hat{y}\eta + \hat{z}\zeta(\xi,\eta) \\ s &= \hat{x}x + \hat{y}y + \hat{z}z \end{aligned}\right\} \tag{2}$$

representing the near-field and the far-field coordinates, respectively. The q factor could be expressed

$$q(\theta_i, \theta, \varphi) = q_r(\theta_i, \theta, \varphi) = \frac{\lambda[(1+r)k + (1-r)k_i]\cdot(k-k_i)}{4\pi(k-k_i)\cdot\hat{z}} \tag{3}$$

for reflection testing; and

$$q(\theta_i, \theta, \varphi) = q_t(\theta_i, \theta, \varphi) = \frac{\lambda t(k+k_i)\cdot(k-k_i)}{4\pi(k-k_i)\cdot\hat{z}} \tag{4}$$

for transmission testing, respectively.

Since the grooves have a regular one dimensional periodical structure, it's reasonable that the diffraction patterns will be limited in the incident plane, i.e. $\varphi = 0$ and the problem reduces to a one dimensional one. Define the near-field aperture function

$$u_1(\xi) = [u_{10}(\xi) * \mathrm{comb}(\xi/p)]\mathrm{rect}(\xi/L) \tag{5}$$

with

$$u_{10}(\xi) = \begin{cases} \exp[-i(k-k_i)\cdot\hat{z}\zeta(\xi)] & 0\leqslant\xi\leqslant p \\ 0 & \text{else where} \end{cases} \tag{6}$$

representing the contribution of each groove, the comb function

$$\mathrm{comb}(\xi/p) = \sum_{n=-\infty}^{\infty} \delta(\xi - np) \tag{7}$$

and the rect function

$$\mathrm{rect}(\zeta/L) = \begin{cases} 1 & |\zeta| \leqslant L/2 \\ 0 & \text{else where} \end{cases} \tag{8}$$

where $L = np$ is the illuminated length of the disk-memory, the symbol "$*$" denotes the convolution. With the definition of the spatial frequencis

$$\left.\begin{aligned} u &= \frac{(k-k_i)\cdot\hat{x}}{2\pi} = \frac{\sin\theta - \sin\theta_i}{\lambda} \\ w &= \frac{(k-k_i)\cdot\hat{z}}{2\pi} = \frac{\cos\theta + \cos\theta_i}{\lambda} \end{aligned}\right\} \tag{9}$$

we can express the far-field intensity distribution

$$l_2(\mathrm{u}) = |E_2(u)|^2 = l_{20}(u)H(N,\pi pu)Q(\theta_i,\theta) \tag{10}$$

with

$$l_{20}(u) = \frac{|E_o|^2}{(\lambda_s)^2}\left|\int_{-\infty}^{\infty} u_{10}(\xi)\exp(-i2\pi u\xi)\,d\xi\right|^2 \tag{11}$$

representing the contribution of the groove form;

$$H(N,\pi pu) = \left(\frac{\sin\pi Npu}{\sin\pi pu}\right)^2 \tag{12}$$

representing the contribution of the finte length of the comb function that indicates the influence of the groove number N, which will determine the width of each diffraction spectrum, and the pitch of the groove, p, which will determine the position of each spectrum; and the Q-factor

$$Q(\theta_i,\theta) = |q(\theta_i,\theta)|^2 \tag{13}$$

representing the influence of the Fresnel coefficients at the disk-memory surface, respectively.

According to the actual fabrication process, we consider the grooves have the trapzodic form, in some case will have the circular form. Their contribution could be calculated by E_q.(11). For the trapzodic form, we have

$$l_{20}(u) = \sum_{i,j=1}^{5} B_i B_j K_{ij} \tag{14}$$

$$\mathrm{sinc}(x) = \sin\pi x/(\pi x) \tag{15}$$

$$\left.\begin{array}{ll} B_{1,3}=d'\operatorname{sinc}(ud'+wh), & B_2=(d-2d')\operatorname{sinc}[u(d-2d')] \\ B_{4,5}=[(p-d)/2]\operatorname{sinc}[(u/2)(p-d)] & \end{array}\right\} \tag{16}$$

$$\left.\begin{array}{ll} K_{ij}=\cos\pi(F_i-F_j) & \\ F_{1,3}=\pm u(d-d'), & F_2=0 \\ F_{4,5}=2wh\pm(u/2)(p+d) & \end{array}\right\} \tag{17}$$

when the parameter d′ is set to be d/2 and O, Eqs. (14) to (17) automatically reduce to the expressions for the triangular and the rectangular form, respectively. In the case the circular form with radius a, its contribution can still be expressed by Eq. (14), only with

$$\left.\begin{array}{ll} B_{1,3}=\sqrt{a/(\pi w)}\displaystyle\int_{d_1}^{d_2}\begin{Bmatrix}\cos\xi^2\\ \sin\xi^2\end{Bmatrix}d\xi & B_2=0 \\ d_{1,2}=\sqrt{(\pi w)/a}\left(\dfrac{ua}{w}\mp\dfrac{d}{2}\right) & \end{array}\right\} \tag{18}$$

$$F_1=(a/w)u^2, \qquad F_3=F_1-1/2 \tag{19}$$

the other B_4, B_5, F_2, F_4, and F_5 are just the same as those of the trapzodic form.

For the metal substrate the reflection testing is preferable, the previous discussion is enough to describe the diffraction. However when we use the semiconductor or dielectric substrate, the multiple reflection at their surfaces couldn′t be ignored, especially when the substate is not perfectly parallel. Consider the reflection testing as shown in Fig. 1, the beam with angle θ_i' arrives at the interface (1,2) without groove, it gets through the substrate and hits the interface (2,3) which is carved with grooves, thus it is diffracted, and the actual incident angle at the grooves is θ_i, satisfying the Snell′s law with θ_i'. The diffracted beam reflects back, gets through the substrate, and hits the interface (1,2) again; the main part will penetrate it and be received, some of the beam (about 10%) is reflected back which is turned to be the multiple reflection. Accumulating all orders of multiple reflection, we should add factor to Eq. (10) to include their contribution

$$l_2(u)=l_{20}(u)Q(\theta_i,\theta)H(N,\pi pu)\sum_{j=0}^{\infty}\left[\prod_{j-0}^{J}R_1(\theta+ja)\,R_2(\theta+2ja)\right]\times [1-R_1(\theta+2ja+a)] \tag{20}$$

similarly for the transmission testing, we have

$$l_2(u)=l_{20}(u)H(N,\pi pu)\left\{\left[1-R_2(\theta_i)\right]Q(\theta_i,\theta)+\sum_{J=1}^{\infty}\left[\sum_{j=1}^{J}R_1(\theta+ja)\right]\times\left[\prod_{j\ 1}^{J-1}R_2(\theta+2ja)\right]\left[1-R_2(\theta+2ja)\right]\right\} \tag{21}$$

where α is the wedge angle of the substrate, from Eqs.(20) and (21), which is obviously to make the multiple reflection shifted; and R_1, R_2 denote the reflectances at the interface (1,2), and (2, 3) respectively.

3. Results and Discussions

A CCD image processing system[3] has been employed to measure the diffraction spectra, the light wavelength is $\lambda = 0.6328\mu m$, while the pitch, the width, and the depth of the grooves are calculated from the spectra, they are 1.6, 0.5, and $0.07\mu m$, respectively. The influence of the groove form is shown in Fig.2

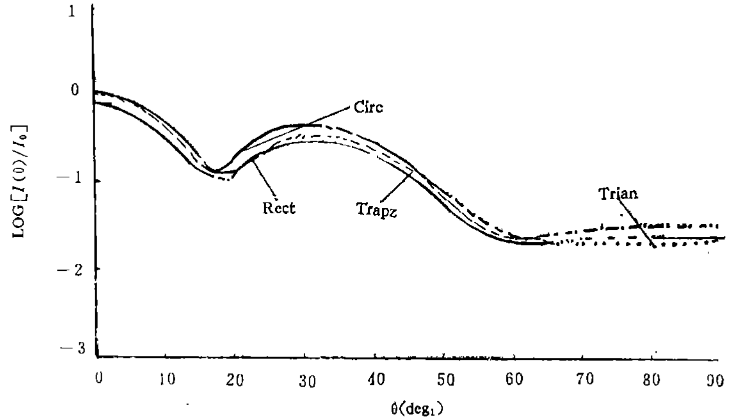

Fig. 2 Illustration of the influence of the groove form

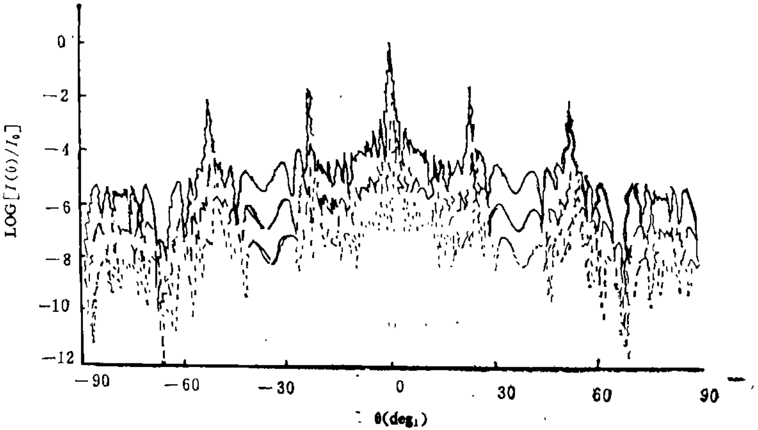

Fig. 3 Influence of the multiple reflection at the substrate surfaces

it shows the circular and the rectangular form have the maximal and the minimal diffraction, respectively. Further, the difference between the trapzodic and the rectangular form is so small that the rectangular form is quite a good approximation. Fig.3 shows the contribution of the multiple reflection, in the event the substrate is not parallel with wedge angle 1 degree, the piot shows the first and second multiple reflection shifted, which make the zero order spectra lower, simultaneously make the other spectra higher and wider. Finally the measured and the calculated results are shown in the Table 1.

Table 1 Relative intensity distribution of the measured and calculated diffraction spectra

	Diffraction order		
	0	1	2
Reflection testing	1	0.01107	0.00332
Calculation	1	0.01115	0.00470
Transmission testing	1	0.01408	0.00474
Calculation	1	0.01400	0.00470

4. Conclusion

The results demonstrate that the pitch of the grooves can be simply determined by the H($N,\pi pu$) function, which is shown in the diffraction patterns as the positions of all orders of spectra; next, all the factors of the width, depth, and form of the grooves have influences on the intensity of the spectra, particularly determine the ratios of the intensity between the zero order to the firsr order, and the zero order to the second order spectra, respectively; further the multiple reflection of the substrate surfaces has also a strong influence on the spectra, especially the measurements show that the first and the second order spectra in transmission are larger than those of the reflection testing, which could only be induced by the multiple reflection, while under the circumstances the parameters of the grooves are just the same, the only factor to make such difference is the contribution of the reflectance and the transmittance, which are different in the reflection and the transmission testing, too.

References

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用于光盘存贮器沟槽参数测试的光学衍射方法

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摘要：光盘存贮器有非常精密的沟槽。用衍射法进行测量，由于要引用大衍射角计算，沟槽的菲涅尔系数不再恒定，因此应用很广的弗朗和费理论不适于描述光盘沟槽的衍射。这种情况下，我们提出了一个研究此种衍射的方法，进一步讨论了一些基本因素。例如：沟槽形状的影响，基底多重反射对衍射图样的影响，特别是当基底不完全平行时的影响等等。最后，建立了一种测量沟槽参数的技术。