第22卷 第3期 激 光 技 术 Vol. 22, No. 3
1998年6月 LASER TECHNOLOGY June, 1998

Optimization of scanning beam in optical disk storage system

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Abstract: In order to acquire a high intensity and minimal scanning beam spot, diffraction analysis and optimal results have been presented. The theory can be applied to CD, CD-ROM, WORM, MOD and other optical disk storage systems.

Key words: laser optical disk diffraction Gaussian beam scanning beam

光盘存储系统中扫描光束的优化设计

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摘要: 利用衍射分析方法, 优化扫描光束参数, 获得高强度、高质量扫描光点。该理论分析及结论广泛适用于CD, CD-ROM, WORM, MOD及其光盘存储系统。

关键词: 激光 光盘 衍射 高斯光束 扫描光束

Introduction

To achieve the highest recording density promised by optical disk storage technology, specially in the magneto-optical disk (MOD) system, it's essential to reduce the scanning beam spot size and increase the central peak intensity. In other words, the optical system must be optimized to produce the smallest spot and use the laser power efficiently[1]. As laser diode is a new type of laser device with many advantages: the smallest size, lowest working voltage and power consumption, and can be directly modulated at high frequency. It has been widely used in optical disk

加强气体对透镜的冷却, 也可明显改善其热效应。

参 考 文 献

1 陈清明, 张永方, 李再光. 中国激光, 1989; 16(8): 459
2 杨宝春, 程兆谷, 陈 刚 *et al*. 中国激光, 1995; 22(4): 271
3 丸尾 大, 宫本 勇(日). 溶接学会论文集, 1992; 10(2): 258
4 李力钧. 现代激光加工及其设备. 北京: 北京理工大学出版社, 1993: 47, 198
5 肖 敏, 胡伦骥, 陈祖涛 *et al*. 焊接学报, 1992; 13(2): 73
6 朱伯芳. 有限单元法原理及应用. 北京: 水利电力出版社, 1979; 251~ 261

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收稿日期: 1997-02-28 收到修改稿日期 1997-05-11

systems: CD, CD-ROM, write once read many (WORM), and erasable optical disk systems. But the laser beam's radiation angles on prependicular to the junction plane is several times biger than that on the parallel to the junction plane. In CD, CD-ROM and some WORM, MOD systems, the scanning beam is an elliptical Gaussian beam, the optical system is simple and low cost. In other systems, the laser beam has been shaped to circular Gaussian beam, the scanning beam is a circular symmetric Gaussian beam. Then, it's important to optimize the optical systems, and compare them for high performance optical disk systems[2].

ⅳ. Diffraction analysis of the scanning beam[3,4]

1. Circular symmetric Gaussian scanning beam

Laser beam from the laser diode has been collimated and shaped to a circular symmetric Gaussian beam, then it's diffracted by objective lens, as in Fig. 1.

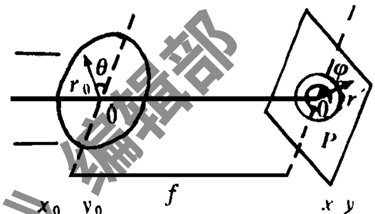

Fig. 1 Laser beam diffracted by Obj.

If the amplitude distribution function on the X_0-Y_0 plane is $A(r_0, \theta)$, then

$$A(r_0, \theta) = A(r_0) = A_0\exp(-\sigma r_0^2/2) \quad (1)$$

Where, A_0 — amplitude of the central beam, σ — Gaussian parameter, $2r_0$ — aperture of the Obj. Let $r_0 = 1$

The intensity discribution on the focal plane is given by

$$I(r) = \{A_0 \frac{2\pi}{\lambda/NA}\int_0^1 r_0\exp(-\sigma r_0^2/2) J_0[2\pi r_0 r/(\lambda/NA)]\,dr_0\}^2 \quad (2)$$

Where NA — numerical aperture of Obj., λ — wave length of laser, f — focal length of the Obj.. A_0 is depended on the laser power, Gaussian parameter σ. Since laser beam is limited by aperture of the Obj., the laser power on the X_0-Y_0 plane can be written as

$$P_w = \int_0^\infty A_0^2\exp(-\sigma r_0^2)\,2\pi r_0 dr_0 = A_0^2\pi/\sigma \quad (3)$$

Laser power collected by the Obj., or laser power of the scanning beam is

$$P_c = \int_0^1 A_0^2\exp(-\sigma r_0^2)\,2\pi r_0 dr_0 = A_0^2\frac{\pi}{\sigma}[1-\exp(-\sigma)] \quad (4)$$

Central intensity of the beam is in proportion to laser power and Gaussian parameter, when $\sigma\to 0$, $A_0\to 0$, $I(r)\to 0$, laser power is expended on the full X_0-Y_0 plane.

In order to optimized the optical system, $I_w(r)$, $I_c(r)$ are defined as

$$I_w(r) = I(r)/P_w = \sigma\pi[\frac{2NA}{\lambda}\int_0^1 r_0\exp(-\frac{\sigma}{2}r_0^2) J_0(2\pi r_0 r\frac{NA}{\lambda})\,dr_0]^2 = CI_{w0}(r) \quad (5)$$

Where $C = \pi(2NA/\lambda)^2$

$$I_{w0}(r) = \sigma[\int_0^1 r_0\exp(-\frac{\sigma}{2}r_0^2) J_0(2\pi r_0 r\frac{NA}{\lambda})\,dr_0]^2 \quad (6)$$

$$I_c(r) = \frac{I(r)}{P_c} = \frac{\sigma\pi}{1-\exp(-\sigma)}[\frac{2NA}{\lambda}\int_0^1 r_0\exp(-\frac{\sigma}{2}r_0^2) J_0(2\pi r_0 r\frac{NA}{\lambda})\,dr_0]^2 = CI_{c0}(r) \quad (7)$$

Where $I_{c0}(r) = \frac{\sigma}{1-\exp(-\sigma)}[\int_0^1 r_0\exp(-\frac{\sigma}{2}r_0^2) J_0(2\pi r_0 r\frac{NA}{\lambda})\,dr_0]^2 \quad (8)$

2. Elliptical Gaussian scanning beam

Elliptical Gaussian beam from laser diode has been collimated by lens.

If amplitude distribution function of Gaussian beam on the X_0- Y_0 plane is $A(x_0, y_0)$.

$$A(x_0, y_0) = A_0 \exp(-\sigma_x x_0^2/2 - \sigma_y y_0^2/2)$$

The intensity distribution on the focal plane is given by

$$I(x, y) = [A_0 \frac{NA}{\lambda}\int_{-1}^{1} dy_0 \exp(-\frac{\sigma_y}{2}y_0^2)\exp(-j\frac{2\pi}{\lambda/NA}yy_0) \cdot \int_{-\sqrt{1-y_0^2}}^{\sqrt{1-y_0^2}} dx_0 \exp(-\frac{\sigma_x}{2}x_0^2)\exp(-j\frac{2\pi}{\lambda/NA}xx_0)]^2 \qquad (9)$$

Where, σ_x, σ_y are Gaussian parameters on the X_0 axis and Y_0 axis.

The power on the X_0- Y_0 plane can be written as

$$P'_w = A_0^2\int_{-\infty}^{\infty} dy_0 \exp(-\sigma_y y_0^2)\int_{-\infty}^{\infty} dx_0 \exp(-\sigma_x x_0^2) = A_0^2\frac{\pi}{\sqrt{\sigma_x \sigma_y}} \qquad (10)$$

The laser power collected by the objective lens, or laser power of the scanning beam spot is

$$P'_c = A_0^2\int_{-1}^{1} dy_0 \exp(-\sigma_y y_0^2)\int_{-\sqrt{1-y_0^2}}^{\sqrt{1-y_0^2}} \exp(-\sigma_x x_0^2)\, dx_0 \qquad (11)$$

Then $\quad I_w(x, y) = I(x, y)/p'_w, \quad I_c(x, y) = I(x, y)/p'_c$

㈦. Peak intensity of scanning beam and its dimension

Let $r = 0$, or $x = 0, y = 0$, central intensity $I_w(0)$, $I_c(0)$, $I_w(0,0)$, $I_c(0,0)$ are obtained from $I_w(r)$, $I_c(r)$, $I_w(x, y)$, $I_c(x, y)$. In erasable optical disk systems, the laser power for erasing or writing is high. More accurately, the central intensity must be high enough to ensure the information bit correct and reliable, the dimension of the information bit depends upon the scanning beam spot, when information bits are smaller, discriminablity and signal-to-noise rate (SNR) increase. Therefore, $I_w(0)$, $I_c(0)$, $I_w(0,0)$, $I_c(0,0)$ are key parameters of the scanning beam.

$$I_{w0}(0) = \sigma[\int_0^1 r_0 \exp(-\frac{\sigma}{2}r_0^2)\, dr_0]^2 = [1-\exp(-\frac{\sigma}{2})]^2/\sigma \qquad (12)$$

$$I_{c0}(0) = \frac{\sigma}{1-\exp(-\sigma)}[\int_0^1 r_0 \exp(-\frac{\sigma}{2}r_0^2)\, dr_0]^2 = \frac{[1-\exp(-\sigma/2)]^2}{[\sigma(1-\exp(-\sigma)]} \qquad (13)$$

$$I_w(0,0) = \frac{\pi}{\sqrt{\sigma_x \sigma_y}}[\frac{NA}{\lambda}\int_{-1}^{1} dy_0 \exp(-\frac{\sigma_y}{2}y_0^2)\int_{-\sqrt{1-y_0^2}}^{\sqrt{1-y_0^2}} dx_0 \exp(-\frac{\sigma_x}{2}x_0^2)]^2 \qquad (14)$$

$$I_c(0,0) = \frac{[\frac{NA}{\lambda}\int_{-1}^{1} dy_0 \exp(-\frac{\sigma_y}{2}y_0^2)\int_{-\sqrt{1-y_0^2}}^{\sqrt{1-y_0^2}} dx_0 \exp(-\frac{\sigma_x}{2}x_0^2)]^2}{\int_{-1}^{1} dy_0 \exp(-\sigma_y y_0^2)\int_{-\sqrt{1-y_0^2}}^{\sqrt{1-y_0^2}} dx_0 \exp(-\sigma_x x_0^2)} \qquad (15)$$

The central peak intensity $I_{w0}(0)$, $I_{c0}(0)$ vs. Gaussian parameter σ are shown in Fig. 2a, $I_{w0}(0,0)$, $I_{c0}(0,0)$ vs. Gaussian parameter σ_x, are shown in Fig. 2b($\sigma_y = 9\sigma_x$).

When $\sigma = 0$, or $\sigma_x = 0$, $I_w(0) = 0$, $I_w(0,0) = 0$, little energy is collected by Obj., but $I_c(0)$,

$I_c(0,0)$ are maximum, therefore, if the beam onto the X_0- Y_0 plane is a plane wave, the energy of scanning beam is concentrated. $\sigma = 2.5$, $I_w(0)$ is maximum, $\sigma_x = 0.7$, $I_w(0,0)$ is maximum, $I_c(0)$, $I_c(0,0)$ decrease as σ, σ_x increase, the width of the beam spot increases some.

Increasing the power of the scanning beam and decreasing the width of beam spot can' t be satisfied simultaneously. Diffraction-limited beam spot requires that central peak intensity $I_c(0)$, $I_c(0,0)$ decrease less than 20%. When $\sigma = 1.5 \sim 2$, or $\sigma_x = 0.6 \sim 0.7$ ($\sigma_y = 9\sigma_x$), $I_w(0)$, $I_w(0,0)$ are almost maximum, and $I_c(0)$, $I_c(0,0)$ decrease less than 20%.

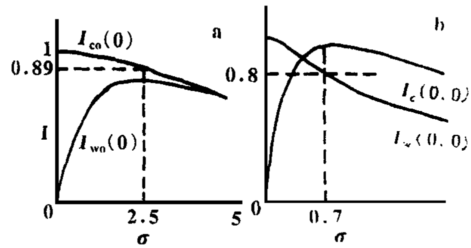

Fig. 2 Central peak intensity vs. Gaussian parameter

The width of scanning spot (half-maximum intensity point) D_r (on the radial), D_x (on X axis), D_y (on Y axis) canbe obtained by let:

$$I_c(D_r/2) = 1/2 I_c(0), \quad I_c(D_x/2, 0) = 1/2 I_c(0,0), \quad I_c(D_y/2) = 1/2 I_c(0)$$

D_r, D_x, D_y have been given by softwares as following table 1, table 2.

Table 1 Relationship between diameters of the spot D_x, D_y and Gaussian parameters σ_x ($\sigma_y = 9^2{}_x$)

σ_x	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
D_x (λ/NA)	0.58	0.58	0.58	0.58	0.59	0.59	0.59	0.60	0.60	0.60	0.61	0.61	0.62
D_y (λ/NA)	0.58	0.60	0.63	0.66	0.69	0.73	0.77	0.81	0.85	0.89	0.93	0.97	1.01

Table 2 Relartionship between diameters of the spot D_r and Gaussian parameters σ

σ	0	0.5	1	1.5	2	2.5	3
D_r (λ/NA)	0.58	0.60	0.60	0.62	0.64	0.66	0.68

㈣ Tridimensional (3D) intensity distribution

Softwares for optical system designing and analyzing have been developed. If required parameters are given, optimized results are gotten immediately, 3D intensity distribution of beam through each optical device can be shown on screen. It′s easy to check the quality of every device and optimize optical parametres. The softwares are applicable for other optical systems.

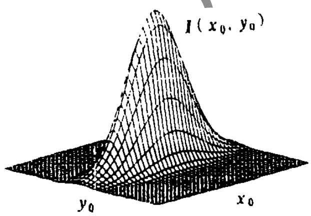

Fig. 3 The intensity distribution on the X_0- Y_0 plane ($\sigma_y = 9\sigma_x$)

Fig. 3, Fig. 4 show the intensity distribution on the X_0- Y_0 plane ($\sigma_y = 9\sigma_x$) and focal plane (X- Y plane). When the beam on the X_0- Y_0 plane is a plane wave, $\sigma \to 0$, or $\sigma_x \to 0$, the intensity distribution of scanning beam spot is circular symmetric, its diameter is minimum. A diffraction ring can be seen clearly. When $\sigma = 2$, the intensity distribution of scanning beam spot is circular symmetric, the diffraction ring can' t be seen clearly.

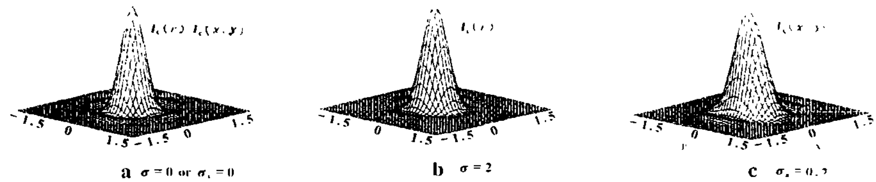

Fig. 4 Unitized intensity distribution on the focal plane

When $\sigma_x = 0.7$ ($\sigma_y = 9\sigma_x$), an elliptical scanning beam is on the focal plan, the ±1 order diffraction beam spots on the X axis can be seen clearly, beam expended a little on the Y axis, no ±1 order diffraction spot can be seen on the Y axis, D_x/D_y is about 1∶1.35, since elliptical long axis is prependicular to track, it has little influnce on the performance of the optical disk system.

㈤ Experment and conclusions

While Gaussian parameters σ, σ_x changed, a frequency analyzer (Tek Tronix 2717) and a 50MHz pluse/function generator (Wave Tek Model 51) are used to test the SNR of MO disk storage system, and approise the quality of the scanning beam spot.

Fundamental parameters of the recording system as following: MO disk 5.25″ 650MB, disk rotational frequency 40Hz, laser wave length 0.78μm, NA(Obj) 0.55, NA(collimation lens) 0.1 ~ 0.35, laser output(writing) 20mW, laser output(erasing) 25mW, laser output(reading) 3mW, signal frequency 2.5MHz.

When σ= 2, transmissivity of the optical system is about 40%. $\sigma_x = 0.7$, transmissivity of the optical system is about 35%. SNR is over 50dB. $1.5 < \sigma < 2.5$, or $0.5 < \sigma_x < 0.9$, SNR is over 45dB. $\sigma > 3$, or $\sigma_x > 1$, the scanning beam spot expands, crosstalk increases, and SNR decreases deeply. $\sigma < 1$, or $\sigma_x < 0.4$, the central peak intensity decreases rapidly, the recording marks can't be stable and reliable.

In circular symmetric scanning optical system, the scanning beam spot is in general more perfect, and the laser power can be used more efficiently, but the optical head is complex. In elliptical scanning optical system, the optical head is simple and minimized. σ= 1.5~ 2, or $\sigma_x = 0.6 \sim 0.7$ ($\sigma_y = 9\sigma_x$), high central peak intensity and small diameter scanning beam spot that is sufficient for MOD storage are acquired, the SNR is over 50dB.

So, a MO disk system for color video recording and a MO disk driver have been developed successfully in which circular scanning beam spot and elliptical scanning beam spot are used[5].

References

1 Bouwhuis G, Brat J, Huijser A *et al*. Principles of optical disk storage, Bristol and Boston, Adam Hilger Ltd, 1986
2 Asnett M W, Johnston Jr T F. SPIE, 1991; 1414: 21~ 34
3 Ooki H. Optik, 1988; 80: 101~ 112
4 Opkins H H, J O S A, 1979; 69: 4~ 24
5 Luo Y, Gao Zh P, Cheng H Y. SPIE, 1996; 2931: 29~ 32

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收稿日期: 1997-03-18