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Final Diffraction Patterns of the Beam Splitters used in the Soft X-Ray Interferometer by a He-Ne Laser

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The soft x-ray(10nm-100nm) interferometer is a modified Mach-Zehnder type interferometer and it consists of two beam-splitters and four totally reflecting mirrors. The beam-splitters used here are 50% transmission and 50% reflection grating type. The diffraction patterns of beam splitters(1st B. S.) were investigated with a He-Ne laser. The diffraction patterns produced by the soft x-ray interferometer(2nd B. S.) were also investigated in intensities and positions. The diffraction patterns of 20 degree grazing incidence on the beam splitters(1st B. S.) show a circular array of spots. Both the reflected and the transmitted beams show the same patterns but symmetric circles on the screen. The maximum intensity appears roughly when n is in the zeroth and odd orders and the suppressed peak(missing order) appears when n is in the even orders. Intensities of 3 center fringes($n = 0, \pm 1$) are stronger than others. These results confirm the reduced grating equation and make agree with the intensity distribution function. It was found that the final patterns produced by the soft x-ray interferometer(2nd B. S.) consisted of fine fringes which were caused by two of three diffraction beams that were arrived at the second beam-splitter.

I. INTRODUCTION

To achieve a higher resolving power of a spectrometer, an approach other than the traditional, grating-based spectrometer must be used. [1] It has been known in optics for a long time that an interferometer can always, in principle, outperform a grating in terms of maximum resolving power or phase-space acceptance for equivalent resolving power. The theoretical maximum resolving power of a typical spherical grating monochromator (~64,000) has been nearly achieved. [1–3] In practice, interferometery with x-rays is very difficult, due to the short wavelength. Only recently have the mechanical, optical, and metrological technology advanced enough to practically build a soft x-ray interferometer for a spectrometer. [1–3]

A spectrometer is designed for ultra high-resolution (theoretical resolving power $E/\Delta E \sim 10^6$) in the photon energy region of 60~120eV. The key component of the spectrometer is a soft x-ray interferometer [2,3]. The interferometer consists of two beam-splitters and four reflecting mirrors. It is a modified Mach-Zehnder type interferometer. The beam splitters used here are 50% transmission and 50% reflection grating type.

In this research, the diffraction patterns of each beam-splitter(1st) and the soft x-ray interferometer [3] (2nd B. S.) were investigated with He-Ne laser at 20° grazing incidence to the beam-splitter so that the diffraction patterns of the same interferometer with soft x-ray is preestimated. The diffraction patterns of grazing incidence confirm the grating equation, and make agree with the intensity distribution function. The final patterns produced by the soft x-ray interferometer(2nd B. S.) consisted of fine fringes caused by two of three diffraction beams that arrived at the 2nd beam-splitter.

II. CONICAL DIFFRACTION THEORY

Experience has shown that by far the easiest approach to dealing with the geometry of conical diffraction is the use of a simple spherical coordinate system [4,5] such as that shown in Fig. 1.

If the poles of the coordinate system are defined by the direction, in space, of the ruling on the grating, the direction of the incoming ray can be described by just two parameters, the altitude and the azimuth. Called

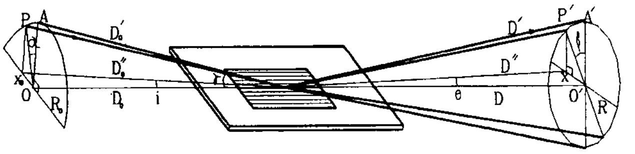

FIG. 1. Notation for the geometry of conical diffraction by beam-splitter.

γ it defines the half-angle of the cone into which light is diffracted; all light leaves the grating at the same altitude angle at which it approached. The azimuth of the approaching ray α is defined to be zero if it lies in the plane which is perpendicular to the surface of the grating and parallel to the rulings. R is the radius of the conical diffraction circle on the diffraction plane. Azimuth of diffracted light is β.

The grating equation of a transmission grating is

$$n\lambda = d\cos\gamma(\tan i + \tan\theta) \qquad (1)$$

Sometimes it is convenient to write the above equation in α, β(Fig. 1). [4,5] Then, the resulting form is

$$n\lambda = d\sin\gamma(\sin\alpha + \sin\beta) \qquad (2)$$

The value of β can be calculated for any wavelength λ and order n by the grating equation where d is the ruling spacing of the grating. If we consider the case of N long, narrow slits, with width b and center-to-center separation d. The intensity distribution function [6] is

$$I \cong A^2 = A_0^2\left(\frac{\sin^2\psi}{\psi^2}\right)\left(\frac{\sin^2 N\xi}{\sin^2\xi}\right) \qquad (3)$$

where $\psi = \frac{\pi b}{\lambda}\{\sin\gamma(\sin\alpha + \sin\beta)\}$ and $\xi = \frac{\pi d}{\lambda}\{\sin\gamma(\sin\alpha + \sin\beta)\}$ are modified functions according to Eq. (2).

III. EXPERIMENT

The horizontal length of beam-splitter is 16mm and its width is 6mm. Two 50% reflection - 50% transmission - grating beam splitters(B. S.) are used in the soft x-ray interferometer. The experimental setup of grazing incidence on the beam splitters is shown in Fig. 2.

The angle between direction of laser beam and the beam splitter is 20°($\gamma = 20°, \alpha = 0$), and the distance(D) between the beam splitter and the screen is 280cm. The intensity distribution of diffraction patterns were measured with a photo detector(ORIEL 70260, 70261). The schematic diagram of the soft x-ray interferometer and its optical path are shown in Fig. 3. The soft x-ray interferometer is designed with an angle of 20° (grazing) on the beam splitter and 10° on each mirror.

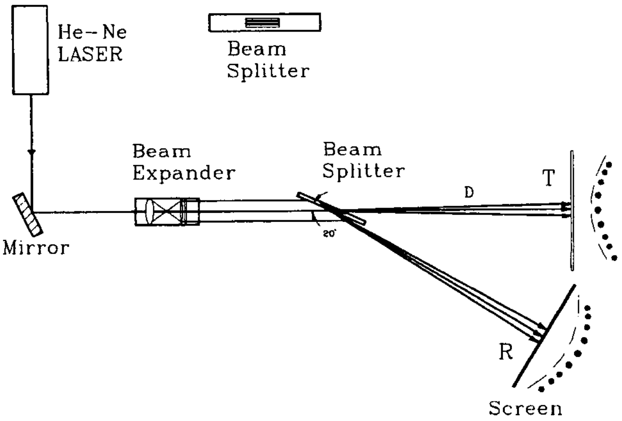

FIG. 2. Experimental setup of grazing incidence to B. S.

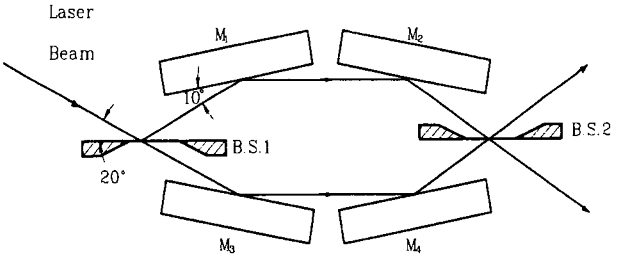

FIG. 3. The schematic diagram of the interferometer and its optical path.

Molybdenum coated mirrors and beam splitters with these incident angles provide a good reflectivity for soft x-rays. The diffraction patterns produced by the 2nd beam splitter(soft x-ray interferometer) were also measured. The He-Ne laser(20mW, 632.8nm) was used as a light source to investigate the diffraction patterns produced by the special grating type beam splitters and their intensities.

IV. RESULT AND DISCUSSION

From Eq. (2), the fringe intervals are 1.7 cm, and the experimental data show 1.65cm in average. The diffraction fringes of grazing incidence confirm a grating Eq. (2), and make agree with the intensity distribution function(3). The final diffraction patterns produced by the soft x-ray interferometer(2nd B. S.) with normal incidence and grazing incidence are shown in Fig. 4. Figs. 4, 5 and 6, are all patterns observed with He-Ne Laser.

It was found that each pattern consisted of fine fringes which were caused by two of three diffracted beams of the 1st B. S. that arrived at the 2nd beam splitter(Figs. 4 and 5). Fig. 5 shows the diffrac-

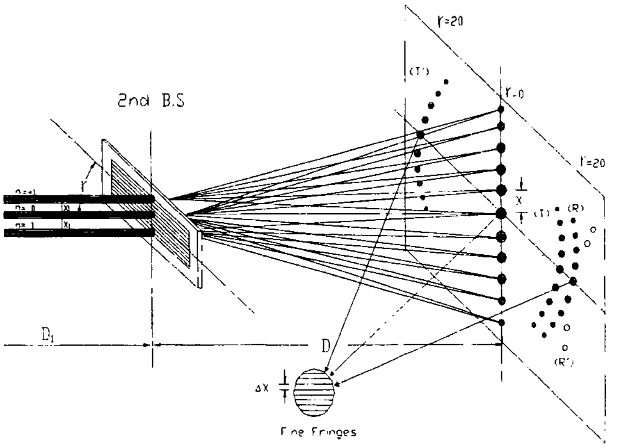

FIG. 4. Final diffraction patterns of interferometer(2nd B. S.).

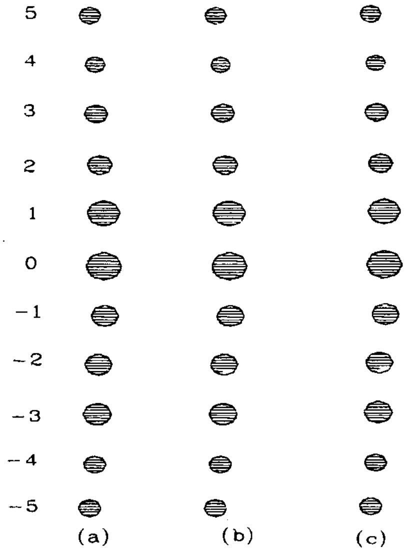

FIG. 5. Diffraction fringes through the interferometer(2nd B. S.), (a) transmitted fringe, (b) transmitted and reflected fringe, (c) reflected fringe.

tion fringes through the interferometer(2nd B. S.), (a) transmitted (b) both transmitted and reflected (c) reflected fringe respectively.

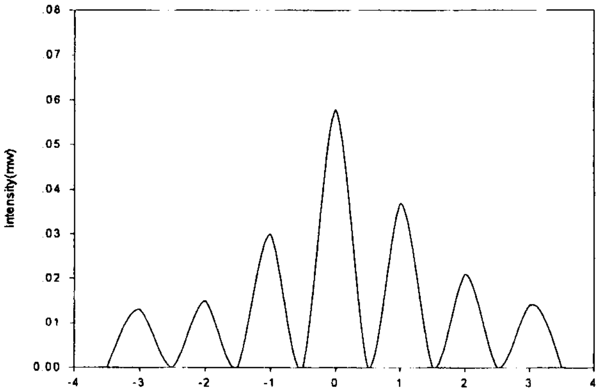

FIG. 6. Intensity of final diffraction fringe through the interferometer(2nd B. S.) made by both transmitted and reflected fringes(b) in Fig. 5.

The intensity of final fringes through the interferometer(2nd B. S.) made by both transmitted and reflected fringes (b) in Fig. 5 was shown in Fig. 6. As the order increased, the intensity of fringes decreased according to the combined intensity theory.

We have calculated the fringe intervals by the theory for both the cases of the He-Ne laser and the soft x-rays and compared them with the experimental data for the case of He-Ne laser.

The equation of fringe intervals for theoretical calculation is $x = n\lambda R/d\sin\gamma$ from equation [2]. In the soft x-ray interferometer, the optical path length between the 1st beam splitter and the 2nd beam splitter is 29.5cm.

The results shows good agreement in the case of He-Ne laser. Even in soft the x-ray case, the calculated values of fringes are also predicted and strong enough to measure with the recent CCD camera.

V. CONCLUSION

The diffraction patterns of 20° grazing incidence on the beam splitters(1st B. S.) show a circular array of spots. Both the reflected and the transmitted beams show the same patterns but symmetric circles on the screen. The maximum intensity appears roughly when

TABLE 1. Fringe intervals of 1st B. S., 2nd B. S. calculated by He-Ne Laser(632.8nm) and soft x-ray(10nm) and experimental values by He-Ne Laser only.

		Theoretical Data	Experimental data
He-Ne Laser (632.8nm)	Fringe interval	2.00mm(D, screen)	1.99mm(D, screen)
	1st B. S. (2nd B. S. surface)	1.77mm (2nd B. S.)	1.80mm (2nd B. S. surface)
	2nd B. S.(D, screen)	0.929mm(D, screen)	0.93mm(D, screen)
X-ray (10nm)	Fringe interval	0.0314mm	expected
	1st B. S.	0.28mm	expected
	2nd B. S.(D, screen)	0.104mm	expected

n is in the zeroth and odd orders and the suppressed peak(missing order) appears when n is in the even orders. Intensities of the 3 center fringes($n = 0, \pm 1$) are stronger than others. These results confirm the grating equation and make agree with the intensity distribution function.

The fringe intervals for both the cases of the He-Ne laser and the soft x-ray were calculated and compared with the experimental results. The results show good agreement in the case of the He-Ne laser. It is also expected to measure the fringe intervals and intensities of soft x-ray case with the recent CCD camera.

It was found that the final patterns produced by the soft x-ray interferometer(2nd B. S.) consisted of fine fringes which were caused by two of three diffraction beams that were arrived at the second beam-splitter.

REFERENCES

[1] G. Kaindl, *International Seminar on Atomic and Molecular Photoinoization*, (Tsukuba, Japan, 1995).

[2] M. R. Howells et al, Nuclear Instruments and Methods in Physics Research A **347**, 182 (1994).

[3] E. J. Moller, Ph. D. Thesis, (LBNL-38901, Advanced Light Source, Lawrence Berkeley National Laboratory, p. 53, 1996).

[4] J. Chamberlain, (John Willey and Sons, Chichester, 1979).

[5] Webster Cash, Appl. Opt. **24**, 710 (1982).

[6] E. Hecht, *Optics* 2nd ed., (Addison-Wesley Publishing Co., New York, 1987) p. 410.