Spectral domain characteristics of partially coherent illumination on grating imaging system

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ABSTRACT

The grating imaging system has the advantages of high resolution, high sensitivity and strong anti-interference ability, and has been widely used in machine vision, biomedicine and imaging spectroscopy and other fields. The coherence and polarization properties of the light field have different effects on the grating imaging system. This paper studies the polarization system of the grating illuminated by partially coherent light based on the unified theory of polarization and coherence. The experiment is carried out using a sinusoidal amplitude grating of 20 lines per mm. The experimental results show that when the coherence is fixed, as the normalized intrinsic frequency of the grating increases, the second harmonic disappears, leaving only the direct current (DC) component and the first harmonic component, which is consistent with the theoretical result.

Keywords: coherence; polarization properties; spectral components

1. INTRODUCTION

In recent years, many researchers have conducted in-depth research and analysis on various aspects of the grating imaging system[1][2]. Through these research and analysis, people can better understand and optimize the imaging performance of the grating imaging system, so it is necessary to study it deeply[3]. However, many current studies on the grating imaging system only consider either property of the light field coherence or polarization, while those two properties of the light field have different effects on the grating imaging system. Therefore, it is not enough to only consider one properties of the light field[4].

In this paper, based on the coherent polarization unified theory[5], we have studied the polarization imaging system of the grating illuminated by partially coherent light[6]. In the theoretical analysis, we establish the mathematical model of the grating polarization system illuminated by partially coherent light, design and build an experimental platform, obtain and

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process experimental data, compare the theoretical and experimental results, and establish the influence of the normalized intrinsic frequency of the grating on the imaging system is obtained.

2. THEORECTICAL ANALYSIS OF GRATING IMAGING SYSTEM

The mathematical model for the image intensity of a sinusoidal amplitude transmittance grating in the spatial domain formed by partially coherent polarization imaging system is expressed as:

$$\mathrm{S}_i^{im}(x) = A_i + B_i \cos 2\pi f_{x_0} x + C_i \cos 2\pi 2 f_{x_0} x \quad i = 0,1,2,3 \tag{1}$$

where f_{x_0} is the intrinsic frequency of the grating, and A_i, B_i and C_i are the coefficients of the three components of the output signal in the partially coherent imaging system, namely the DC component, the sinusoidal component with the frequency of f_{x_0}, the sinusoidal component with the frequency of $2f_{x_0}$ that is introduced when the field amplitude distribution changes to the intensity distribution at the detector, and $i = 0,1,2,3$ are the Stokes' parameters.

The Fourier transform of Eq. (1) gives the spectral domain representation of the image intensity as follows:

$$S_i^{im}(f_x) = A_i\delta(f_x) + \frac{1}{2}B_i\left[\delta\left(f_x - f_{x_0}\right) + \delta\left(f_x + f_{x_0}\right)\right] + \frac{1}{2}C_i\left[\delta\left(f_x - 2f_{x_0}\right) + \delta\left(f_x + 2f_{x_0}\right)\right] \tag{2}$$

This paper uses the parameter σ from microelectronic lithography to evaluate whether the system is close to fully coherent or fully incoherent. This parameter is defined as follows:

$$\sigma = \frac{NA_i}{NA_o} = \frac{\alpha_0}{z_i} \Big/ \frac{\beta_0}{z_0} = \alpha_0 z_0 / \beta_0 z_i \tag{3}$$

here NA_i is the numerical aperture of the imaging lens, NA_o is the numerical aperture of the condenser, z_0 is the distance between the light source and the sinusoidal amplitude grating, z_i is the distance between the imaging lens and the image plane, β_0 is the size of the radius dimension of the light source, and α_0 is the radius dimension of the imaging lens.

The parameter σ is used to evaluate the coherence of the optical imaging system. When $\sigma = 0$, the system can be regarded as a fully coherent optical imaging system; when $\sigma \gg 1$, the system can be regarded as a fully incoherent optical imaging system. The simulation and experimental results in this paper are also based on the value of the parameter σ to evaluate the coherence property of the system.

3. EXPERIMENTAL STUDY ON IMAGING SYSTEM OF GRATING

In the experiment, a sinusoidal amplitude grating with a line density of 20 line per mm is selected as the grating object. The experimental optical platform is designed, built and shown in Figure 1.

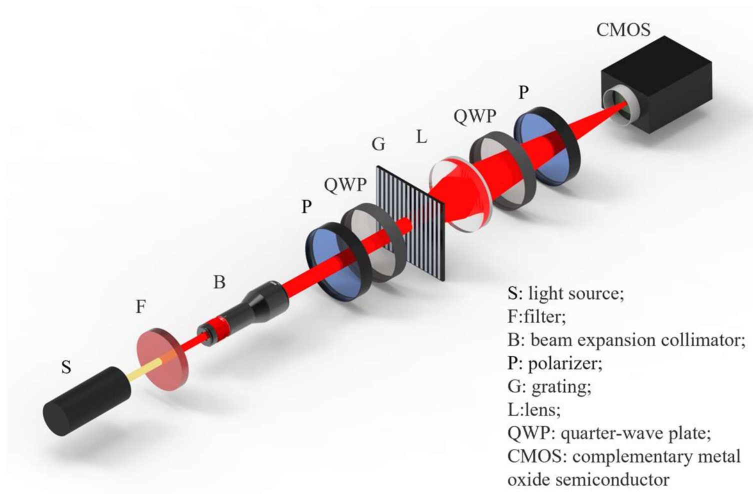


Figure 1. Experimental optical path diagram

Parameters $\sigma = 1$, $T(f_{x_0}) = 0.4$ and $\sigma = 1$, $T(f_{x_0}) = 0.6$ were studied by using a 20 line per mm grating, here $T\left(f_{x_0}\right)$ is the normalized intrinsic frequency of the grating. The experimental results of parameters $\sigma = 1$ and $T(f_{x_0}) = 0.4$ are shown in Figure 2(1). First, six sets of images for measuring Stokes parameters are obtained, where (a) is horizontal polarization information, (b) is vertical polarization information, (c) is 45° direction polarization information, (d) is right-handed polarization information, (e) is 135° direction polarization information, and (f) is left-handed polarization information. The results of parameters $\sigma = 1$ and $T\left(f_{x_0}\right) = 0.6$ can be obtained without changing the polarization state of the grating in the optical platform. Similarly, six images are measured and shown in Figure 2(2).

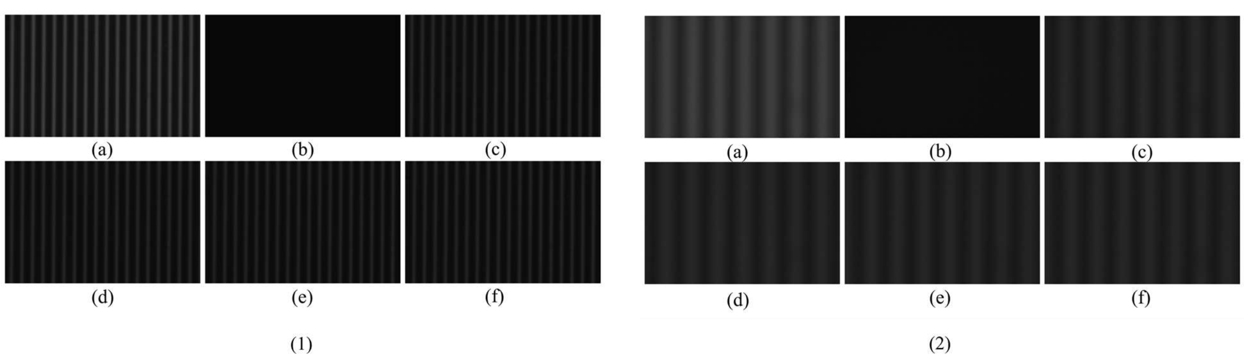
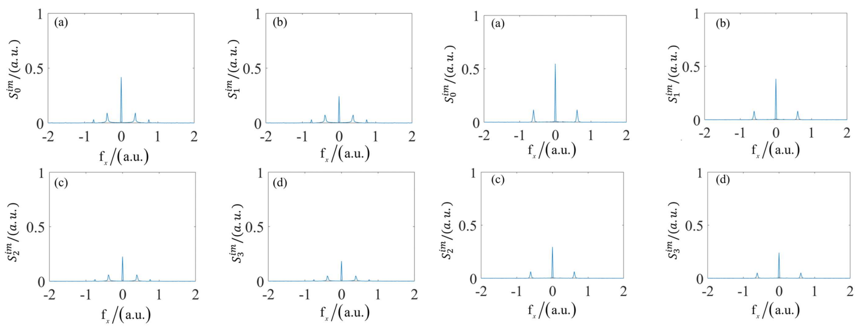


Figure 2 Experimental diagram of Stokes parameter measurement for parameters $\sigma = 1$. (1) and (2) are experimental diagrams when $T\left(f_{x_0}\right) = 0.4$ and $T\left(f_{x_0}\right) = 0.6$

Using MATLAB to add and subtract the six images in Figure 2(1) ($S_0 = (a) + (b)$, $S_1 = (a) - (b)$, $S_2 = (c) - (e)$,

$S_3 = (d) - (f)$), and reading the one-dimensional information of Stokes intensity map, we can obtain the Stokes one-dimensional map. The spatial domain information is converted to the spectral domain by using Fourier transform, and the Stokes spectral graph under this parameter is obtained. Its spectrum diagram is shown in Figure 3(1). We perform the same image processing of Figure 2(2), and shown the result in Figure 3(2).



(1) (2)

Figure 3 Stokes spectrogram of parameters $\sigma = 1$. (1) and (2) are experimental diagram when $T(f_{x_0}) = 0.4$ and $T(f_{x_0}) = 0.6$

Figure 3(1) shows the experimental results of parameters $\sigma = 1$ and $T(f_{x_0}) = 0.4$ have DC components, first harmonic components and second harmonic components. Similarly, it is obvious that the experimental results of parameters $\sigma = 1$ and $T(f_{x_0}) = 0.6$ shown in Figure 3(2) have DC component and first harmonic component, while the second harmonic component has disappeared.

4. CONCLUSION

This paper is based on the coherent polarization unified theory, and studies the polarization system of a grating illuminated by partially coherent light. The imaging regularity are studied by using a 20 lines per mm sinusoidal amplitude grating, and the experimental results show that with parameters $\sigma = 1$ and $T(f_{x_0}) = 0.4$, the experimental results have direct current components, first harmonic components and second harmonic components, which is consistent with the theoretical analysis. On the other hand, with parameters $\sigma = 1$ and $T(f_{x_0}) = 0.6$, the experimental results have direct current components and first harmonic components, and the second harmonic components disappear, which is consistent with the expectations.

REFERENCES

[1] Chekhova Maria,Banzer Peter. Polarization of Light:In Classical, Quantum, and Nonlinear Optics[M].De Gruyter:2021-03-17.

[2] Goldstein Dennis H.. Polarized Light, Third Edition[M].CRC Press:2017-12-21.

[3] Whitehead L W, Williams G J, Quiney H M, et al. Diffractive imaging using partially coherent x rays[J]. Physical

review letters, 2009, 103(24): 243902.

[4] Sanchez-Brea L M, Alonso J, Bernabeu E. Quasicontinuous pseudoimages in sinusoidal grating imaging using an extended light source[J]. Optics communications, 2004, 236(1-3): 53-58.

[5] Quiney H M. Coherent diffractive imaging using short wavelength light sources[J]. Journal of modern optics, 2010, 57(13): 1109-1149.

[6] Becherer R J, Parrent G B. Nonlinearity in optical imaging systems[J]. JOSA, 1967, 57(12): 1479-1486.