Diffraction and interference pattern by 4f imaging system to determine the thin film magnetic properties

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Abstract. Determine the magnetic properties of thin film material using X-ray has been attracting enormous attention in recent years. In this work, we propose a simple method to determine base on 4F imaging system. The narrow slit is applied to produce diffraction pattern in the X-ray scale. The slit width variation is applied to numerically observe the Fraunhofer diffraction pattern sequential changes. To demonstrate the sensitivity of the method, the power distribution of the temporal observed patterns was also measured. The selection of the object shape also discussed for comprehensive discussion.

1. Introduction
The ultrafast optical system for nanostructured material imaging, has attracted much attention in recent years. For example magneto-optic Kerr effect or Faraday effect combined with femtosecond visible laser technology has enabled us to explore magnetism on ultrafast timescale. On the other hand, synchrotron and free electron laser as X-ray light sources is utilized to explore ultrafast phenomenon by applying diffraction imaging system. The Fourier transform holography (FTH) is useful in observing ultrafast timescale magnetism for magnetic materials for magnetic materials where requisite an externally applied field[1,2].

FTH is based on 4f imaging system and the 4f coherent imaging system is the easiest system to use for image processing as shown in Fig. 1, that use optical Fourier technique. As a powerful tool, Fourier optics have been used for the images spatial frequency analysis, the optical fields coherent manipulation, and real-time correlators construction. The effects of filters and lenses can be seen on light beam when the beam propagates to the far field through the system in the free-space propagation of light is the reason that optics is an exciting tools for the frequency analysis.
Figure 1. The configuration of 4f optical imaging system

In this work, we observed the diffraction and interference pattern of transparent magneto-optic photonic crystal thin film with nonlinear optical properties by using 4f optical imaging system. By varying an applied field on the magnetic thin film, a field-dependent diffraction imaging system is proposed in order to optimize the characteristics.

2. Theory

By using a model which based on Fourier optics, we can describe the formation of nonlinear image inside the 4f imaging system[3,4]. The polarized monochromatic plane wave illuminates the first lens back focal plane as the object plane with normally incident angle. The amplitude distribution with the input object with amplitude transmittance \( t(x,y) \) that assuming is placed on the object plane in the Fourier plane can be written as

\[
S(u, v) = \frac{1}{2\pi} FT[O(x, y)]
\]

where FT denotes the operator of Fourier transform, \( f \) is the focal length, \( \lambda \) is the incident beam wavelength, \( O(x, y) = Et(x, y) \) is the distribution of amplitude in the object plane and \( E \) is the incident beam amplitude.

If we assume that the small phase shifts and nonlinear absorption is neglected for a magnetic material by Faraday effect, the intensity of the beam of the sample at the exit surface can be expressed as

\[
S_{NL}(u, v) = S(u, v)exp(j\Delta \phi_{NL})
\]

where \( \Delta \phi_{NL} \) is the nonlinear phase shift. These two equations combined can be used to observe the diffraction and interference pattern of the magnetic material thin film.

3. Results and discussion

In this work, we show the result of the 4f imaging system simulation based on equation (1) and (2) by varying the object plane.
The 4f imaging system is simulated in MATLAB by using the equation of fourier transform and its inverse for each devices configuration such as filters, lenses, width of the slit, and shape of the aperture object on object plane that is needed for the optical system. We simulated the object plane with the varying pattern of rectangular pattern and circular oblique pattern. The inverse Fourier transform regenerates a similar shape on the object plane as an original aperture from the diffraction pattern as shown in Fig 2. We also have simulated 4f imaging system with difference width of the double slit in the visible light scale with the wavelength of 600 nm and 900 nm to observe the effects of difference wavelength as shown. As shown in Fig 3. and Fig 4. the intensity of the diffraction + interference fringes decreases as the order of the fringes increases and the difference in the wavelength of the source alters the number of fringes in the pattern and the closeness of the fringes. A decrease of wavelength results in more fringes per centimeter and a closer distance between each consecutive fringe.

Figure 2. The result of 4f imaging simulation for different apertures on the object plane.
Figure 3. Diffraction and interference pattern with wavelength of 600 nm
4. Conclusion
The 4f optical imaging system using the visible femtosecond laser might be applied for magnetism on ultrafast timescale study experiments and it satisfies the consistency condition for the variation of magnetic fields and apertures. The width of the slit, shape of original aperture on the object plane, wavelength the light source are playing roles to the diffraction and interference pattern. The diffraction pattern intensity is more dominant compared to interference pattern.

Figure 4. Diffraction and interference pattern with wavelength of 900 nm
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