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"NUMERICAL SIMULATION OF DIFFRACTION PATTERNS WITH DIFFERENT ILLUMINATION LASER WAVELENGTH"

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Numerical Simulation of Diffraction Patterns with Different Illumination Laser Wavelength

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***Abstract* - In this study, a computer simulation program generating Fresnel diffraction patterns from the apertures by using the different illumination wavelength sources has been studied. Changing the aperture-screen distance and the illumination wavelength provides a clear transition of diffraction patterns from the Fresnel to the Fraunhofer region. The diffraction patterns obtained by the Fresnel integral method have been compared with those simulated by the Fraunhofer calculation. There is a good agreement between the results. Certain conditions have been investigated that Fresnel diffraction patterns approach the Fraunhofer diffraction patterns. The simulations have been performed using a personal computer with Matlab software.**

***Keywords* – Diffraction, Optics, Numerical simulation, Micron/nano structures.**

I. INTRODUCTION

OPTICS is one of the important fields of physics that studies the properties of light. It plays an important role in technical applications such as communication and information sciences. In optics, the diffraction of light plays a paramount role in solving optical problems that do not usually reach an agreement with an exact solution. Therefore, numerical methods make it easy to investigate simpler cases. When the optical wave encounters an aperture, diffraction of light occurs [1]. Diffraction is classified known as Fraunhofer (far-field) and Fresnel (near-field) diffraction. The Fraunhofer diffraction pattern occurs when the aperture-observation screen distance is large. However, the Fresnel diffraction pattern appears when the aperture-screen distance is short [2, 3]. Diffraction and propagation of the optical field from an aperture were calculated by using Helmholtz-Kirchhoff [4] and Rayleigh-Sommerfeld integrals [5]. The Fresnel and Fraunhofer diffraction patterns were obtained by using the Fourier transform method [6] and two dimensional Fast Fourier transform method [7].

The calculation of the diffraction integral is possible with minimum effort due to the personal computer and packaged mathematical software. In this paper, the diffraction patterns have been obtained by using Matlab software (R2017b 9.3.0.713579 (x64)) [8] for different input parameters, i.e. wavelengths and aperture to screen distance. The Fresnel and Fraunhofer diffraction patterns have been simulated for micron size aperture by using the radiation source from 4nm to 600nm (corresponding to photon energy from ~310eV to 2eV) [1, 9]. This paper aims to study diffraction phenomena further for small-size structures by using short-wavelength radiation. The "soft x-ray region" of 4nm corresponds to the water window region in which water is transparent to extreme ultraviolet (XUV) radiations. Therefore, the wavelength region has a crucial role in viewing water-dominant biological samples, and the diffraction of light has a vital role in life science. On the other hand, this phenomenon is complex for studies at the short wavelength region, and it is not easy for laboratory experiments. For this reason, the simulation approaches facilitate viable alternatives and bring an idea for pre experiments studies. The contribution of the study to the literature is to investigate the diffraction phenomena by using small size structures at short wavelength regions, i.e. how does the diffraction phenomena behave in short wavelengths, which is important for life science studies?

Over the last 20 years, the optics field including coherent XUV beamlines has brought opportunities studied in several disciplines from biological imaging [10] to material science [11], and astrophysics [12] to high energy plasmas [13]. Also, it is useful to science and engineering students who deal with Fresnel diffraction, especially in short-wavelength regions. Therefore, the implementation of a diffraction model for a small-size aperture by using a short-wavelength source is important.

The diffraction patterns discussed the Fraunhofer diffractions of the single slit at the visible or infrared region, however, the diffraction patterns at the XUV region were not mentioned. The paper introduces a simulation for Fraunhofer and Fresnel diffraction at a wavelength range from XUV to the visible region. The simulation program is compiled by several input parameters, namely the aperture-screen distance and the illumination wavelength. The simulation program demonstrates how a diffraction pattern changes with varying input parameters from the Fraunhofer to the Fresnel region at the short wavelength region.

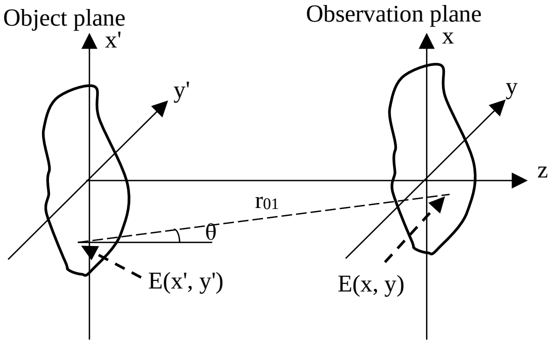

Figure 1 Schematic diagram of diffraction [1, 11]

II. BASIC DIFFRACTION THEORY

Light propagation and diffraction have been described by using the Huygens-Fresnel principle by several researchers [4, 7, 14, 15]. The fundamental calculation of Fresnel diffraction from a rectangular aperture is that a light wave passes through an aperture and the total electric field at any point in the xy-plane can be obtained by the Huygens-Fresnel Principle for rectangular coordinates, Fig. 1 [1, 9]. The diffracted light is observed on the screen located at distance. By using the Huygens-Fresnel principle, the total field (E(x, y)) in the xy-plane is integral of the fields of all the wavelets produced in each part of the aperture in the x'y'-plane [15]

$$E = \frac{-iE_u}{2}\left[C(\mathrm{u}) + \mathrm{i}\,S(u)\right]_{\alpha_1}^{\alpha_2}\left[C(v) + \mathrm{i}\,S(v)\right]_{\beta_1}^{\beta_2} \qquad (1)$$

where E_u is the unobstructed electric field, and *C* and *S* are the Fresnel integrals, and two-dimensional variables are defined $u = y\left[\frac{2(\mathrm{r}_{01}+\mathrm{P}_0)}{\lambda r_{o1}P_0}\right]^{0.5}$ and $v = z\left[\frac{2(\mathrm{r}_{01}+\mathrm{P}_0)}{\lambda r_{o1}P_0}\right]^{0.5}$. λ is the wavelength, and r_{01} is a vector from an aperture point to a parallel screen, θ is the angle between r_{01} and the aperture surface x'. P_0 is the aperture to source distance. *E(x',y')* and *E(x,y)* are electric fields on the aperture and the screen, respectively. There are two approximations: (i) the dimensions of the diffraction geometry are larger than the illumination wavelength (λ). (ii) The observation screen distance is many wavelengths from the aperture ($r_{01} >> \lambda$)

Taking the square of the electric field, Eq. 1 gives

$$I = \frac{I_u}{4}\left\{\left[C(\alpha_2) - C(\alpha_1)\right]^2 + \left[S(\alpha_2) - S(\alpha_1)\right]^2\right\}\times$$
$$\times\left\{\left[C(\beta_2) - C(\beta_1)\right]^2 + \left[S(\beta_2) - S(\beta_1)\right]^2\right\} \qquad (2)$$

I_u is unobstructed intensity corresponding to the square of E_u, and $\alpha = \sqrt{\frac{2}{\lambda z}}(x' - x)$ and $\beta = \sqrt{\frac{2}{\lambda z}}(\mathrm{y}' - \mathrm{y})$ are coefficients.

The derivation of the Fresnel integral method is given in a detailed manner [15]. When the distance between the aperture to the observation screen is increased, the Fresnel diffraction region gradually approaches the Fraunhofer diffraction region. In the simulation part, the Fresnel diffraction integral has been used, Eq. 2. Input parameters namely the aperture to screen distance and the illumination wavelength have been changed, and the diffraction patterns vary with changing input parameters.

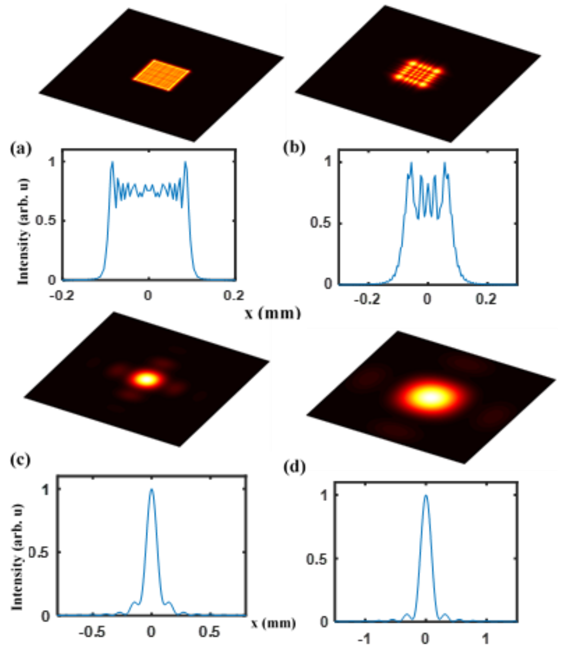

Figure 2 Diffraction patterns for increasing the aperture-screen distance. (a)10mm, (b)70mm, (c)700mm, (d)1400mm. The aperture size is 0.1mm×0.1mm, and the illumination wavelength is 32nm. In (a-d) the upper figures are for 2D diffraction patterns, and lower figures are for 1D normalized intensity distribution.

III. SIMULATION RESULTS

Figure 2 shows the diffraction patterns for the increasing aperture to screen distance. The illumination wavelength and the aperture size are 32nm and 0.1mm×0.1mm, respectively. When the aperture-screen distance is increased, the Fresnel diffraction pattern gradually changes into the Fraunhofer diffraction pattern. Aperture size is about 3100 wavelengths wide, and the screen has been placed from the aperture about 0.3million to 43million wavelength away, Fig. 2 (a) 0.3million, (b) 2.2million, (c) 22milllion, and (d) 43million. Upper figures in Figure 2 present 2D diffraction patterns while lower show the normalized 1D intensity distribution of the diffraction pattern.

Figure 3 presents diffraction patterns (upper figures Fig. 3 (a-d)) for fixed aperture size of 0.1mm×0.1mm and for the apertures to screen distance of 700mm. The illumination wavelength gradually increases from 4nm to 600nm wavelength. Thus, the aperture width varies from 25×10^3 to 160 wavelength size, and the distance between the aperture-observation screen changes from 175 to 1 million wavelengths away, Fig. 3 (a)-(d). When the aperture size and the aperture–screen distances are constant, the Fresnel diffraction patterns are generated at the short wavelength region. An increase in the illumination wavelength generates the Fraunhofer diffraction patterns, Fig. 3. Lower figures in Figure 3 are normalized-1D intensity distributions of diffraction patterns.

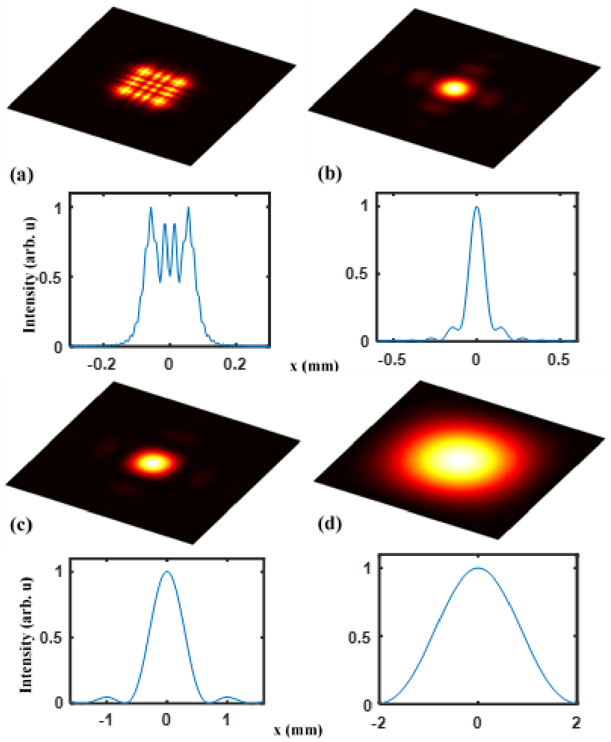

Figure 3 Diffraction patterns for increasing wavelength. (a) 4nm, (b) 32nm, (c) 200nm, (d) 600nm. The aperture size is 0.1mm×0.1mm, and the aperture-screen distance is 700mm. In (a-d) the upper figures are for 2D diffraction patterns, and lower figures are for 1D normalized intensity distribution.

Figures 2, 3 agree with the rule that the aperture-screen distance (r_{01}) and the illumination wavelength (λ) have effects on the diffraction patterns [1, 9]. A practical comparison, if a satisfies the relation of $r_{01} < a^2/\lambda$, the Fresnel diffraction occurs. The relation of $r_{01} > a^2/\lambda$ gives the Fraunhofer diffraction, where r_{01}, a, and λ are the aperture-screen distance, the aperture size, and the illumination wavelength, respectively.

IV. CONCLUSION

This study describes that the generated diffraction images in the Fresnel and the Fraunhofer region by using illumination wavelengths at different illuminating wavelengths and the aperture-screen distance. The basic diffraction theory is described. The simulated 2D diffraction images and 1D diffraction intensity distribution for small size aperture and different wavelength sources (from 4nm to 600nm) are presented in the results. The obtained diffraction result for 600nm illumination wavelengths in this paper is similar to the studies in Refs. [14, 15] which provides the simulated diffraction patterns for the visible wavelength region. The Matlab software simulates the diffraction patterns. The transition from the Fresnel to Fraunhofer region is observed with varying input parameters, namely the aperture-screen distance and the illumination wavelengths.

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PREFACE

International Conference on Engineering Technologies (ICENTE'21) was organized in Konya, Turkey on 18-20 November 2021.

The main objective of ICENTE’21 is to present the latest research and results of scientists related to Biomedical, Computer, Electrics & Electronics, Mechanical, Mechatronics, Metallurgy & Materials and Civil Engineering fields. This conference provides opportunities for the delegates from different areas in order to exchange new ideas and application experiences, to establish business or research relations and to find global partners face to face for future collaborations.

All paper submissions have been double blind and peer reviewed and evaluated based on originality, technical and/or research content/depth, correctness, relevance to conference, contributions, and readability. Selected papers presented in the conference that match with the topics of the journals will be published in the following journals:

- Artificial Intelligence Studies (AIS)
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- International Journal of Automotive Engineering and Technologies (IJAET)
- International Journal of Energy Applications and Technology (IJEAT)
- MANAS Journal of Engineering (MJEN)
- Open Journal of Nano (OJN)
- Selcuk University Journal of Engineering Sciences (SUJES)

At this conference, there are 267 paper submissions. Each paper proposal was evaluated by two reviewers. And finally, 206 papers were presented at the conference from 13 different countries (Albania, Cyprus, United Kingdom, Georgia, Morocco, Macedonia, Mauritania, Mexico, New Zealand, Pakistan, Poland, Tunisia, Turkey) with 134 local and foreign universities and organizations participating,

In particular, to Selcuk University Rector Prof. Dr. Metin AKSOY; we would like to thank the conference scientific committee, session chairs, invited speakers, referees, technical team, participants, and all our colleagues who have contributed. They have made a crucial contribution to the success of this conference. Our thanks also go to our colleagues in our conference office.

Prof. Dr. Sakir TASDEMIR
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