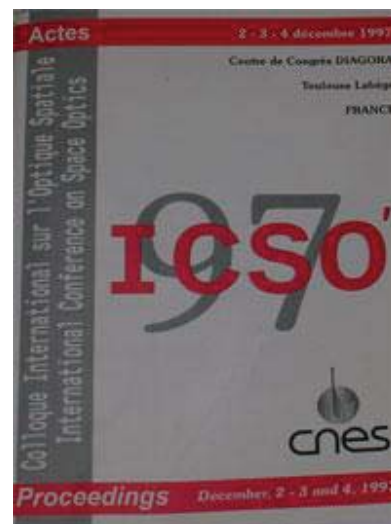


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New Idea For Recording X-Ray Imaging Holography

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ABSTRACT

In this paper, a new recording method named X-ray image holography is proposed, and The new idea employs two micro zone plates, one for imaging, the other for producing the reference. Main advantage over the traditional X-ray in-line and lensless Fourier transform holography is that the requirement of the spatial for X-ray beam is reduced. Consequently, the method for selecting the experimental parameters is given.

Keywords: X-ray, image holography.

1. INTRODUCTION

X-ray holography can offer the possibility of three dimensional micromolecular structure in live cells in biology and provide resolving power reaching wavelength range. Moreover, this capability should be applicable to cells and subcellular structures in something closely related to their natural state: that is without dehydration, sectioning or staining. Although there are higher resolving power than soft X-ray due to short wavelength in electron microscope and electron holography, they require thin sectioning and fixation of the specimen. This can result in partial structural disassembly and precludes the investigation of structural changes resulting from genetic or environmental manipulation. Therefore, soft X-ray holographic method has specially advantageous for biological samples if X-ray in the wavelength region between the carbon and oxygen K edges are used.

X-ray holographic microscopy was first suggested in 1952 by Baez. Until 1974, Gabor holograms of chemical fibers and red blood cells were recorded by Aoki and Kikuta et al.^[1] using both microfocus x-ray tubes and synchrotron radiation sources at 4 μ m resolution. In recent years, X-ray holography has received much renewed attention due to recent advances in X-ray lasers, synchrotron radiation sources and optics. In 1986, an X-ray hologram was taken by Trebes et al.^[2] by means of an X-ray laser and a Gabor in-line type at 5-10 μ m resolution. The holograms were recorded on photoresist using 25.7 \AA soft X-ray from an undulator at the National Synchrotron Light Source at Brookhaven National Laboratory at 560 \AA resolution in 1990.^[3] The lensless Fourier transform holograms were recorded by I. McNulty.^[4] In 1992, a digital twin imaging elimination method in soft X-ray in-line holography was developed by Joylux et al at Orsay, France and resolution as high as 60nm has been achieved.^[5]

However, up to now, two main approaches have been used to record X-ray holograms, i.e. Gabor and lensless Fourier transform holograms. In this paper, a new recorded method named x-ray image holography is proposed. The method employs two micro-zone-plates, one for imaging, the other for producing the reference. X-ray image holography has main advantage over the traditional X-ray in-line holography and lensless Fourier transform holography, i.e. the requirement of the spatial and temporal coherence for the X-ray beam is reduced.

As we know, the main limiting factor for realizing holography with high resolution is represented by the limited spatial coherence of synchrotron radiation sources. In optical and electron holography, the problems of the finite sources dimension has already been solved by using the image holography method. That is, making the object on image in the recording plane of the hologram.

The main propose of this paper is to fill this gap and give the method for selecting experimental parameters

2. THE PARAMETER-SELECTION METHOD IN X-RAY IMAGE HOLOGRAPHY

Suppose the X-ray image hologram can be recorded in digital form by CCD camera. The resolution limit of CCD is about 5 μ m. Let the minimum spacing d is 6 μ m, thus the include angle θ between the reference beam and the imaging beam is

$$\theta = 1 / d. \quad (1)$$

Image separation requires

$$g \geq 3\alpha' \quad (2)$$

where α' is the angular radius of the imaging light cone. Suppose s' is the imaging distance, ρ_k is the radius of the zone plate, we have

$$\rho_k = s' \alpha' \leq s' \lambda / 3d \quad (3)$$

Therefore, the radius δ' of an image spot (pixel) must satisfy

$$\delta' = 0.61\lambda s' / \rho_k \geq 0.61\lambda / (\lambda / 3d) = 1.83d \quad (4)$$

Suppose

$$\delta' = 2d = 12 \mu m \quad (5)$$

The radius δ of an object spot (resolution element) is 60nm, so the magnification m of the zone plate is

$$m = \delta' / \delta = 200. \quad (6)$$

Suppose the imaging distance s' is 200mm, thus the object distance s is 1mm. And if the wavelength λ is 3.3nm, the radius ρ_k of the zone plate is

$$\rho_k = 0.61\lambda s' / \delta' = 33.55 (\mu m), \quad (7)$$

the focal length f of the zone plate is

$$f = [(1/s) + (1/s')]^{-1} = 0.995 (mm), \quad (8)$$

the first zone radius ρ_1 is

$$\rho_1 = \sqrt{f\lambda} = 1.81 (\mu m) \quad (9)$$

and the total number k of zones is

$$k = (\rho_k / \rho_1)^2 \approx 344 \quad (10)$$

The focus-to-focus spacing t between the two zone plates is

$$t = (s' - f)\lambda / d = 109.5 (\mu m) \quad (11)$$

Now we discuss the requirement of the spatial coherence for the X-ray beam. Suppose the radius r_0 of the X-ray source is 21mm. According to van Cittert-Zernik theorem^[6], the degree of spatial coherence will be equal to or bigger than 0.88, if the distance z_0 satisfies

$$z_0 \geq r_0 t / 0.161 = 414.8 (mm) \quad (12)$$

Thus the center-to-center spacing T between the two diffraction disks of the two zone plates on the hologram, can be given by

$$T = t(z_0 + s') / (z_0 + f) = 162 (\mu m). \quad (13)$$

The radius R' of the diffraction disk on the hologram is

$$R' = 0.61(s' - f)\lambda / \delta = 6.677 (mm), \quad (14)$$

and the superimposed width W of the two diffraction disks is

$$W = 2R' - T = 13.2 (mm) \quad (15)$$

Now we discuss the requirement of the temporal coherence for the X-ray beam. The path of a reference ray from the X-ray source to the hologram is

$$L_o(R, \phi) = z_o + [s' / (s' - f)] [(s' - f)^2 + R^2 - T^2 - 2RT \cos \phi]^{1/2}$$

$$\approx (z_o - s) + s + s' (R^2 + T^2 - 2RT \cos \phi) / 2(s' - f)^2 \quad (16)$$

and the path of object rays passing through a zone with the radius ρ is

$$L_o(R, \phi, \rho) \approx (z_o - s) + [s' / (s' - f)] [(s' - f)^2 + R^2]^{1/2} + \rho^2 / 2s - \rho^2 / 2s'$$

$$\approx (z_o - s) + s + s' - (1 - 1/m) R^2 / 2s' + \rho^2 / 2f \quad (17)$$

Because the relationship between the spatial frequency v of object rays and the radius ρ of a zone is

$$v = \rho / s\lambda \quad (18)$$

Therefore, the path difference between the reference ray and the object rays with $0.61v\lambda$ resolution is

$$\Delta L(R, \phi, v) = L_o(R, \phi) - L_o(R, \phi, v)$$

$$\approx (R^2 + T^2 - 2RT \cos \phi) s' / 2(s' - f)^2 - (1 - 1/m) R^2 / 2s' - (vs\lambda)^2 / 2f \quad (19)$$

The cut-off spatial frequency v_c of the imaging zone plate is

$$v_c = \rho_c / s\lambda = 0.61 / \delta \approx 10^7 (\text{nm})^{-1} \quad (20)$$

and the path difference between the reference ray and the rays with 60nm resolution from an object spot is

$$\Delta L(R, \phi, v_c) \approx (R^2 + T^2 - 2RT \cos \phi) s' / 2(s' - f)^2$$

$$- (1 - 1/m) R^2 / 2s' - (v_c s\lambda)^2 / 2f \quad (21)$$

So the path difference between the reference ray and the rays with 60nm resolution from the object spot on the axis of the imaging zone plate is

$$\Delta L(0, \phi, v_c) \approx T^2 s' / 2(s' - f)^2 - (v_c s\lambda)^2 / 2f = 0.49 (\mu\text{m}) \quad (22)$$

If the object spot is at $(r, \phi) = [5(\text{mm}), 0]$ or $(r, \phi) = [5\mu\text{m}, \pi]$, the image spot will be at $(R, \phi) = [100\mu\text{m}, 0]$ or $(R, \phi) = [100\mu\text{m}, \pi]$ respectively, as shown in Fig.2. So the path difference, between the reference ray and the rays with 60nm resolution from the object spot at $(r, \phi) = [5(\text{mm}), 0]$, is

$$\Delta L[1000(\text{mm}), 0, v_c] \approx (R^2 + T^2 - 2RT \cos \phi) s' / 2(s' - f)^2$$

$$- (1 - 1/m) R^2 / 2s' - (v_c s\lambda)^2 / 2f = 1.3(\text{mm}) \quad (23)$$

And the path difference, between the reference ray and the rays with 60nm resolution from the object spot at $(r, \phi) = [5\mu\text{m}, \pi]$, is

$$\Delta L[1000(\mu\text{m}), \pi, v_c] = 0.3(\mu\text{m}) \quad (24)$$

According to the above calculation, the X-ray image hologram with 60nm resolution can be recorded by a CCD camera at synchrotron rely on the technology of the zone plate and aperture at present. In addition, the device of taking the X-ray image hologram can also be used as an X-ray interferometer, we call it double-zone-plate X-ray interferometer.

ACKNOWLEDGEMENT

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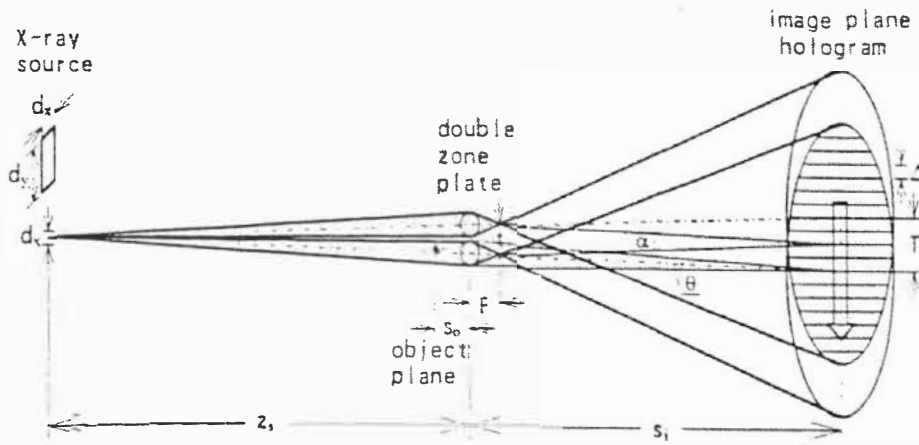


Fig.1 Schematic of recording an X-ray image hologram.

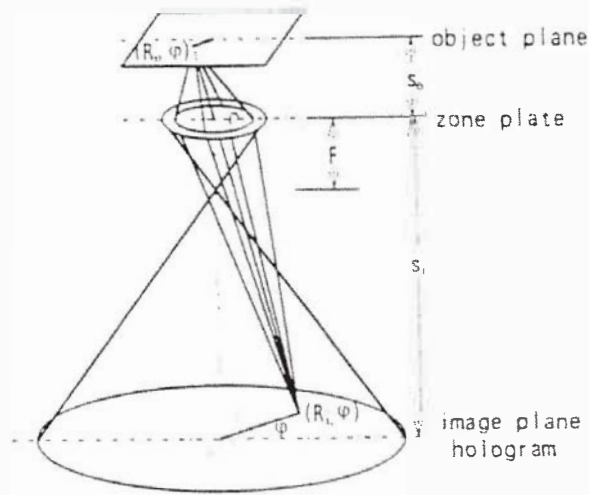


Fig.2 Schematic diagram of calculating the path of X-rays from an object spot to its image spot.