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博士論文

穿透式 X 光顯微鏡中的相位影像

Phase Imaging in Transmission X-ray Microscope



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## 摘 要



X 光影像在生物以及醫療應用上有著非常重要的角色。而相位對比在高解析度的 X 光影像是一個很重要的工具，因為相位的對比較傳統的吸收造成的對比要能提高個二至三個數量級，並且非常有效的減少 X 光影像帶來的輻射劑量。相位對比在於我們目前注重的高解析度的細胞影像，以及其他軟物質有非常重要的貢獻。

這篇論文，最主要的目的是要在穿透式 X 光顯微鏡中發展相位對比的方法。利用同步輻射所提供的光源，我們所使用的穿透式 X 光顯微鏡(TXM)在吸收的對比下能夠達到具有數十奈米的解析度。對相位對比，我們使用發展出兩種不同的方式來觀察相位。第一種是利用光波傳遞的方式紀錄不同位置的繞射的條紋，第二種是利用 Zernike 的相位方法來觀察干涉的相位圖樣。第一種方法我們利用合併以往兩種分別使用在高解析度電子顯微鏡(TEM)的迭代方法(SCWP)，以及以往利用在低解析度 X 光影像的(TIE)方法來解出 X 光顯微鏡中的相位。第二種方法我們使用一個疊代的方式解 Zernike 的相位方法，並且可以只用一張影像解出相位的資訊。這個方法將可以應用在立體的相位對比斷層掃描(phase tomography)上。理論方法和實驗的結果都呈現在論文之內。此兩種方法，都可以應用在 X 光顯微鏡之內，並且有效的回覆相位資訊。此項技術將對三維高解析度的生物醫學影像帶來很大的貢獻。

**Phase Imaging  
in  
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**ABSTRACT**

The phase imaging in X-ray is a powerful tool for non-destructive investigation at nanometer scale. The phase image enhances the contrast for 2 to 3 orders of magnitude higher than the absorption contrast at the hard x-ray region. Furthermore, with the high penetration deep, the phase imaging in hard x-ray is good for the soft material like a cell or bio-medical tissue.

This thesis describes the development of the x-ray phase imaging technique using transmission X-ray microscope (TXM) at a synchrotron source National Synchrotron Radiation Research Center (NSRRC). The TXM has the spatial resolution of several tens of nanometer by using absorption contrast. For phase contrast imaging, the combination method of transport of intensity equation (TIE) and self-consistent wave propagation (SCWP) is applied to retrieve the pure phase information and a resolution of tens of nanometer resolution at hard x-ray region is demonstrated experimentally. To realize the phase tomography, an iterative method (iterative phase retrieval for common path interferometer, IPR-CPI) to calculate the phase image from the Zernike phase contrast method is proposed. It is realized that by using only one x-ray image and a known structure of Zernike phase plate, the phase image can be retrieved and the new methodology was verified by both computer simulation and TXM experiment.

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# Table of contents

Abstract in Chinese.....	i
Abstract in English.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
List of Tables.....	vi
List of Figures.....	vii
<b>Chapter 1: Introduction.....</b>	<b>1</b>
<b>1.1 Matter, Light and their Interactions.....</b>	<b>3</b>
1.1.1 The complex reflection index of X-rays .....	3
1.1.2 The absorption and phase shift.....	6
1.1.3 The free space wave equation.....	7
<b>1.2 The X-ray Phase Imaging – a literature survey.....</b>	<b>8</b>
<b>1.3 The Progress of X-ray Microscope.....</b>	<b>9</b>
<b>1.4 Current Issue- towards living cell tomography.....</b>	<b>11</b>
<b>Chapter 2: Transmission X-ray Microscope (TXM) at NSRRC.....</b>	<b>14</b>
<b>2.1 NSRRC Storage Ring and Superconducting Wavelength Shifter.....</b>	<b>14</b>
<b>2.2 NSRRC's TXM.....</b>	<b>16</b>
<b>2.3 Absorption Contrast Image.....</b>	<b>24</b>
<b>2.4 Third Order Image.....</b>	<b>26</b>
<b>2.5 Dark Field Image.....</b>	<b>35</b>
<b>2.6 Tomography.....</b>	<b>42</b>
2.6.1 The principle of x-ray tomography.....	42
2.6.1.1 Projections.....	42
2.6.1.2 Fourier Slice Theorem.....	44
2.6.1.3 The Filtered Back Projection Algorithm.....	45
2.6.2 Nano Tomography.....	48
2.6.2.1 Synchrotron Radiation (SR)-based micro tomography.....	48
2.6.2.2 Nano-Tomography by TXM.....	49
<b>2.7 Summary.....</b>	<b>54</b>
<b>Chapter 3: Phase Retrieval of Wave Propagation in TXM.....</b>	<b>55</b>
<b>3.1 Transport of Intensity Equation (TIE).....</b>	<b>57</b>
<b>3.2 Self-Consistent Wave Propagation (SCWP).....</b>	<b>60</b>

<b>3.3 Combination of TIE and SCWP for Phase Retrieval.....</b>	<b>62</b>
<b>3.3.1 The different response of TIE and SCWP.....</b>	<b>62</b>
<b>3.3.2 The Applicable range of TIE and SCWP.....</b>	<b>66</b>
<b>3.3.3 Phase retrieval by combination of TIE and SCWP.....</b>	<b>68</b>
<b>3.4 The Quantitative Phase Retrieval in Transmission X-ray Microscope.....</b>	<b>69</b>
<b>3.4.1 Applying phase retrieval in TXM.....</b>	<b>69</b>
<b>3.4.2 Experimental result and analysis.....</b>	<b>71</b>
<b>3.5 Summary .....</b>	<b>76</b>
<b>Chapter 4:    Zernike’s Phase Imaging and Phase Tomography.....</b>	<b>77</b>
<b>4.1 Zernike’s Phase Contrast .....</b>	<b>78</b>
<b>4.2 Iterative Phase Retrieval for Common Path Interferometry (IPR-CPI).....</b>	<b>81</b>
<b>4.2.1 The process of common path interferometer (CPI).....</b>	<b>81</b>
<b>4.2.2 The iterative way of phase retrieval from CPI.....</b>	<b>85</b>
<b>4.2.3 Analysis of IPR-CPI.....</b>	<b>87</b>
<b>4.2.4 The experimental result.....</b>	<b>95</b>
<b>4.2.5 Summary for IPR-CPI.....</b>	<b>100</b>
<b>4.3 The Phase Tomography.....</b>	<b>101</b>
<b>4.3.1 Phase tomography by Zernike’s phase contrast.....</b>	<b>101</b>
<b>4.3.2 Phase tomography by combined method of TIE and SCWP.....</b>	<b>105</b>
<b>4.3.3 Phase tomography by IPR-CPI.....</b>	<b>106</b>
<b>4.4 Summary.....</b>	<b>110</b>
<b>Chapter 5:    Conclusions.....</b>	<b>111</b>
<b>References.....</b>	<b>115</b>

# Table Index

Table 1-1 The simulated parameter(for biology sample).....	11
Table 2-1 Specification of the three zone plates in NSRRC-TXM .....	24





# Figure Index

Figure 1-1 The schematic view of (a) TXM and (b) STXM .....	10
Figure 1-2 The simulation of the projection of the cell in the micro tube .....	12
Figure 1-3 Radiation dose calculated for minimal exposure imaging.....	13
Figure 2-1 The optical layout of BL01B.....	15
Figure 2-2 The measured flux for BL01B.....	15
Figure 2-3 The schematic drawing of the TXM .....	16
Figure 2-4 The images of TXM in BL01B hutch.....	17
Figure 2-5 The reflectivity versus incident grazing angle for the glass (SiO <sub>2</sub> ) capillary for photon energy of 8 keV .....	19
Figure 2-6 The optical layout of the condenser .....	19
Figure 2-7 The capillary condenser use to focus X-ray .....	20
Figure 2-8 The zone plate image by SEM.....	22
Figure 2-9 (a) The CCD .(b) the schematic of the internal design of the microscope .....	23
Figure 2-10 The calculated magnification versus energy from 8-11 keV .....	25
Figure 2-11 Image is taken at 8.4 keV (a) and 9.5 keV (b) .....	26
Figure 2-12 The cross-section profile of the outmost zone of the zoneplate .....	28
Figure 2-13 The setup of third order image .....	29
Figure 2-14 The spoke pattern are imaged under different image mode .....	33
Figure 2-15 The modulation transfer functions for third order and first order image.....	34
Figure 2-16 Two methods implement the dark field in TXM.....	36
Figure 2-17 The frequency response for the dark field and bright field .....	37
Figure 2-18 The image of a siemen's star in (a) bright field and (b) dark-field.....	38
Figure 2-19 A Siemens star in (a) Bright field and (b) Dark-field after 2D Fourier transform .....	39
Figure 2-20 The dark field of used zone plate in (a) Bright field and (b) Dark-field.....	40
Figure 2-21 The dark field image of a tungsten plug in the memory chip.....	41
Figure 2-22 The schematic of projections of the object.....	43
Figure 2-23 The projections of a half-zone plate model .....	43
Figure 2-24 The reconstructed slice of tomography .....	47
Figure 2-25 The setup for SR-based tomography .....	48
Figure 2-26 The projection images from IC before process .....	50
Figure 2-27 The projection images from after align and reference processes.....	50
Figure 2-28 3D rendering of tungsten plug with “key hole” .....	50
Figure 2-29 The 3D rendering of tungsten plug is plotted with higher threshold .....	51
Figure 2-30 The top-view and side view of the tungsten plug displayed in voxel mode (top) and iso-surface (bottom) mode .....	52
Figure 2-31 The cross-section plot of orange line in the 2-30 .....	53

Figure 3-1 The scheme of the SCWP .....	61
Figure 3-2 The intensity simulation of a wave concentric phase retardation with propagation different position .....	64
Figure 3-3 The retrieved phase by TIE for a zone-plate-like pattern .....	65
Figure 3-4 The retrieved phase by TIE (blue), SCWP (red), and Combine (green) method .....	66
Figure 3-5 The applicable range for TIE and SCWP. For SCWP .....	68
Figure 3-6 The optical system of a single lens system.....	70
Figure 3-7 A plastic zone plate is used as the sample for testing .....	72
Figure 3-8 The experimental and simulated images of TXM .....	73
Figure 3-9 The results of three phase retrieval methods.....	74
Figure 4-1 The schematic drawing of Zernike's phase contrast in TXM .....	79
Figure 4-2 The out look of the phase ring.....	80
Figure 4-3 The biology images under Zernike's phase contrast.....	81
Figure 4-4 The common path interferometer in the microscope.....	83
Figure 4-5 The modulation of the phase ring in the back focal plane (BFP) .....	85
Figure 4-6 The scheme of the iterative phase retrieval form Zernike's Phase contrast.....	86
Figure 4-7 The derivation of normalized intensity of the CPI.....	88
Figure 4-8 The initial condition of IPR-CPI.....	91
Figure 4-9 The phase is retrieved with different width of phase ring .....	92
Figure 4-10 The phase is retrieved with different thickness of phase ring.....	93
Figure 4-11 The error value in the iteration in IPR-CPI .....	94
Figure 4-12 The cross-section plot of the retrieved phase with initial phase of zero value.....	95
Figure 4-13 Plastic zone plate measured by Zernike's phase contrast .....	96
Figure 4-14 The Zernike's phase contrast image and its simulation image .....	97
Figure 4-15 The Zernike's phase contrast image and its retrieved phase image.....	99
Figure 4-16 The plastic zoneplate for verifying the IPR-CPI method for smaller line width.....	100
Figure 4-17 The reconstructed slice of tomography from the object shown in the left .....	103
Figure 4-18 The phase tomography by the FBP and Zernike's Phase contrast of the filter material with Os stained .....	104
Figure 4-19 The phase retrieved by SCWP and TIE method.....	105
Figure 4-20 The reconstructed slice from Zernike's Phase contrast and IPR-CPI.....	106
Figure 4-21 The image of Zernike's phase contrast of the AGS cell (a) and its retrieved phase (b)....	108
Figure 4-22 The rendering of the phase tomography of the outer shell of the stained AGS cell.....	109
Figure 5-1 The phase image of the biology cell in the capillary.....	112
Figure 5-2 (a) the 3d rendering of the original cell in the capillary (b) the 3d rendering of the reconstruct phase tomography of cell in the capillary .....	113