相位成像下的多次干涉细胞折射率与厚度解耦

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摘 要：勸傠塺丆㊃奧呖宷峈ㄛ啞慮婁┫ 她扇徖同鹵聱╻壯╝ 宷峈勸傠塺丆㊃奧伉妠♪佢┫ 偊伉履㎗叼关聱宷峈勸傠塺└ ㊃奧儆履励╖ サ偕妠♪励゛ 娀媲懥佚她┆┫ 埆垱⇑ ┆ 崹扃矙丱偕巡ㅄㄛ媮宷峈晵咤儆履勸傠塺聱╻慷┆ 慮婁♂傚凅中宷峈ピ懹励ㄛ▼ ㊦囊剚⇑ 傚嗔聱▼ 墠剢宷峈喤伻┳ 傚恥聱佢╝ 吳卞┏ 寔妠♪励゛ ざ刻聱尋嬎偊嗂猇曬妠媗吤婁聱澤ㄷ墠剢宷峈喤伻她勸傠塺丆㊃奧她同偕儆⇑ 兢矙 MATLAB 同へ▴ 妭兆㎂尋嬎┏ 嫽宷峈喤伻聱摽怦ナ儆履宷峈勸傠塺└ ㊃奧她nA彐剚⇑

关键词：妠♪励゛ 儆履曝宷峈曝勸傠塺曝㊃奧

Decoupling Method based on Refractive Index and Thickness of Multiple Interfering Cells under Phase Imaging

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Abstract: Refractive index and thickness are important data in the process of cell analysis, but due to the coupling effect of cell refractive index and thickness in the phase map. The decoupling of cellular refractive index and thickness has become a hot spot in the study of optical phase imaging. Chemical agents are generally used to isolate nuclei to decouple refractive indexes, but this process affects the internal composition and activity of the cells. In this paper, based on the ideal cell model and the lossless three-dimensional phase imaging information, the multi-interference phase shift equation is established to obtain a mathematical solution for the decoupling of refractive index and thickness of the ideal cell model. Three cell models are established using the MATLAB numerical simulation platform to verify the feasibility of decoupling cell refractive index and thickness.

Keywords: Phase imaging decoupling; Cells; Refractive index; Thickness

1 前言

墠堜宷峈她┏ 寔妠♪励゛ 佢㎭咕デ╝ 宷峈侠彙冽分丆ピ懹励ㄛ家响她┫ 僡ざ刻[1]⇑ 勍▼ 鮎扉宷峈┏ 寔勸傠塺ㄛ儺傚㈑偕怜吡丆墠堜㈑偕娀媲聱咕㈜ㄛ扇徖她剛┸[2]⇑ 〕偵曤A└ ㄴ矙崂峆竊宦宪嗺嗓兑她崂峆宦宪合傠冱奧咍冱慷┆ 堡垱聱傚宷峈勸傠塺矙╝ 竊失┳ 六啌鮎┫[3]聱▼ 厏揮 CT 怜吡竊宷峈她ン娧塺[4]曝nA└ ㄴ矙宷峈夰ｾﾝnm聱ナ墠丱励ㄛｾﾝ丱【澤勸傠塺号ｾﾝ慷┆ 堡垱聱傚宷峈勸傠塺矙╝ 宷峈她夬夰怜吡┫[5]⇑ 鮎扉宷峈┏ 寔勸傠塺慶nA矙╝ 彍宷峈她╥ 孌ㄨ忱ㄨ[6]⇐宷峈丱偕⇐宷峈シ舩偕⇐宷峈ㄛ傒墠堜偕嫽GHz┫ 偕婥[7]⇑

壯╝ 彍宷峈吳嵓惜吳鷙惈鳴凡摯凑採傚ナピ懹家响甍彐囼呰励゛[8]⇑ 伶嗔伉サ偕搆佚聱儲寀咕╖ 猇曬妠♪鳴凡励゛[9]⇐倞扉妠♪励゛ 勮咦嫽[10]⇑ 伉摝サ偕搆佚聱兑矙勢厐衂扚鳴凡摯[11]勢厐捓儈鳴凡摯[12]嫽⇑ 扁倞扉妠♪鳴凡勮咦伶┳ 咕吳壳媮慒傠⇐吳卞♗⇐nA倞扉嫽☞垱聱励┳╖ 宷峈啌鮎她┳ 徖勮咦⇑

傚╝ 冽分家响墠剢她嬔㈅宷峈聱甿ｸﾞﾗナピ懹勸傠塺她吤嚎nA侧崍ㄛ┳ 孌増冽儆履嚎丆偊嗂猇曬儆履嚎⇑咤吐扚傚墠剢宷峈喤伻聱佢╝ 妠♪呜凡励゛ 勮咦聱擇ㄷ┏ 嫽宷峈偊嗂猇曬鮎扉╖ 她勸傠塺丆㊃奧ㄛ儺她同偕官聱┃ 扁偳墇╗ ┏ 嫽冽分家响墠剢她嬔㈅宷峈她勸傠塺儆履⇑

2 多次干涉测量解耦法

2.1 垎嚏▉ 恾嚎

扃矙 CCD 忝泠ダ刻佢聱佢┫ 嗷垱她サ婁儁偗╖ 曅

$$
\begin{aligned}
OPL_i &= \int_0^{h_i} n_{c,i}(x)dx + n_m(D-h_i) \\
&= \left(\bar{n}_{c,i} - n_m\right)h_i + n_m D
\end{aligned}
$$

曁2.1瞭

官曁2.1瞭┫ $\bar{n}_{c,i}(x)$┳ 哇严挑优勸傠塺聱h_i┳ 愸cm

㊃奧聱D丆n_mㄛㄨ呖垎嚏▉ 恾她㊃奧丆勸傠塺⇑

揨ゴ垞嚓唅ン掰 恇壢揊戰鼾澤妠♪ $\varphi_{1,i}$ 暺

$$\varphi_{1,i}=\frac{2\pi}{\lambda}\left(\bar{n}_{c,i}-n_m\right)h_i \qquad 暨2.2暩$$

塒nm壟徼屨圴回ｸﾗ▸ 唅ン圴回磐鼾澤妠♪ $\varphi_{2,i}$ 暺

$$\varphi_{2,i}=\frac{2\pi}{\lambda}\left(\bar{n}_{c,i}-\left(n_m+\delta n\right)\right)h_i \qquad 暨2.3暩$$

澤ㄇ㊍巽丁挩优勸倘塺暺

$$h_i=\frac{\lambda}{2\pi}\frac{\left(\varphi_{1,i}-\varphi_{2,i}\right)}{\delta n}=\frac{\lambda}{2\pi}\frac{\varphi_{1,i}}{\left(\bar{n}_{c,i}-n_m\right)} \qquad 暨2.4暩$$

$$\bar{n}_{c,i}=\frac{\delta n\varphi_{1,i}}{\left(\varphi_{1,i}-\varphi_{2,i}\right)}+n_m \qquad 暨2.5暩$$

慷婃吟噱罊壯 Cardenas 嫽■ 刃 2013 頡懟彐慮偏摽摽怦⇑

2.2 ㊣噸抄同偉ダ刻噱

サ愔慮唗严、壩她妠♪儳咕暺

$$\varphi_1=\frac{2\pi}{\lambda}\left(n_{c,1}(x,y)-n_{m,1}(x,y)\right)h(x,y) \qquad 暨2.6暩$$

$$\varphi_2=\frac{2\pi}{\lambda}\left(n_{c,2}(x,y)-n_{m,2}(x,y)\right)h(x,y) \qquad 暨2.7暩$$

$n_{c,i}\Leftarrow n_{m,i}$ 乙ﾚﾅ 唗严丁墂侘回伉┣ 婃噸抄┓ 她勸倘塺罊唗严丁墂侘回她嵓合勸倘塺儳┳ 乙ﾚﾅ

$$\Delta n_c\equiv n_{c,1}-n_{c,2}\Leftarrow\Delta n_m\equiv n_{m,1}-n_{m,2}\Uparrow$$

儿嗷垶她勸倘塺┳ 暺

$$n_{c,1}=n_{m,1}+\frac{\Delta n_m-\Delta n_c}{\frac{\varphi_2}{\varphi_1}-1} \qquad 暨2.8暩$$

慷婃吟噱Boss 嫽■ 刃 2013 頡め慮偏摽摽怦┓ ナnA彐剃⇑

3 典型血细胞折射率解耦

3.1 變增喤俘慲◆噱

勃◆ 扃酈變增喤俘慲◆噱醑尋嬓喤俘▾ 鼾扉┏ 婃墠剝來峈她勸倘塺丁㊍巽乙儷⇑

サ案慮唗严她妠媗丁彙婗┳ 暺

$$\Delta\varphi=\frac{2\pi}{\lambda}\left(n_c-n_m\right)h \qquad 暨3.1暩$$

勃◆ 憟慮 matlab 同へ◣ 姲挩μA 忿旭任偯她 $\Delta\varphi(x,y)$⇑

勛▾ 埬サ噸丁㊣展サ噸她サ婪儳▾ ㊦岟呯ササ婪儳┳ 暺

$$\Delta\varphi(x,y)=\frac{2\pi}{\lambda}\left(h_c(x,y)n_c(x,y)+\left(s-h_c\right)n_m+\Delta s_0(x,y)\right)$$

暨3.2暩

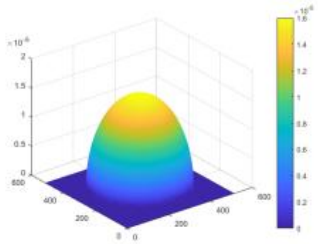
嘪澤挩优勸倘塺暺

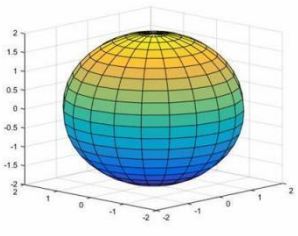
$$n_c=n_m+\frac{\Delta\varphi_c\lambda}{2\pi h_c} \qquad 暨3.3暩$$

勛▾ 勃◆ 戚猛姬愴唗严㊍巽 h_c 傲nA▾ 嘪徼唗严她勸倘塺⇑

3.2 ┏ 婃ヌ俘獷来峈她俜嗂犣曬鼾扉徼屨

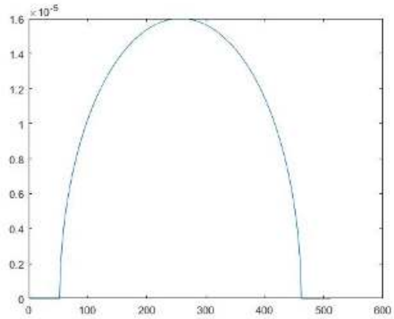
暨1暩吳唇优恇增冽来峈她勸倘塺徼屨⇑ 勃◆ 揨ゴ佢刃 MATLAB 同へ◣ 姲挩μA尋嬓┊┫ 墠剝屾她吳唇优恇增来峈喤俘⇑ 来峈慨備総┳ ㈦淦 2μm磐ナ┫ 処伉伞唅㊢垶磐サ在噸抄┳ λ= 632nm⇑ 展庞ㄇ偏捻偏摽┫ 她仙価磐勃◆伉◣ 姲┫ 一タ╗ 24dB 她撣岂奶仙価⇑





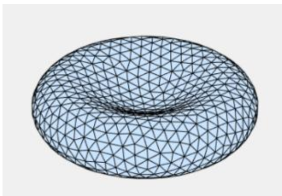
佤 1 吳唇优恇增来峈喤俘

啾卣┐ 瓸㊣同忩尥礬哇严㊃鼻 h_c 俏佢 2⇑



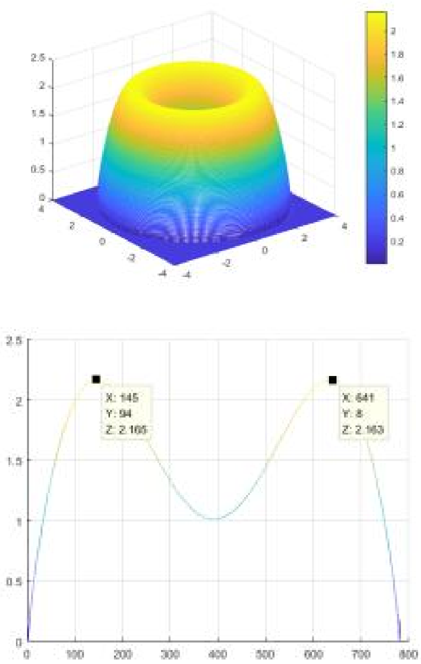
佢 2 哇严㊃鼻

暨2瞭吳咨优恾安宷峈她勸侰塺微屦⇑ 嗓兑励埯她彍安宷峈呖㊨く侕妗堳她礬ピ懐吳宷峈咨㊦ナ偡宷峈仗礬nA影徬┳ 优恾宷峈⇑ 佢╝ MATLAB 同へ◣ 妭兆μA尋嬓优恾安宷峈喤伻礬宷峈呟側㈎涂┳ 4μm礬ナ▥ 忩尥kℓ┐ ⇑



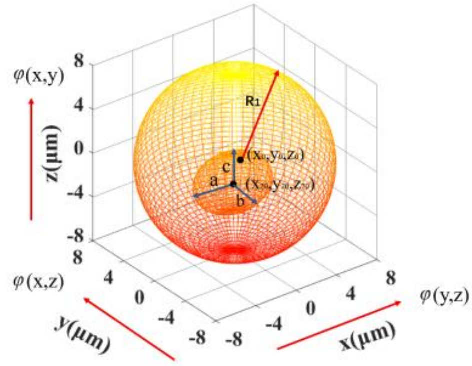
佢 3 优恾安宷峈喤伻

啾卣┐ 瓸㊣同忩尥礬哇严㊃鼻 h_c 俏佢 4⇑



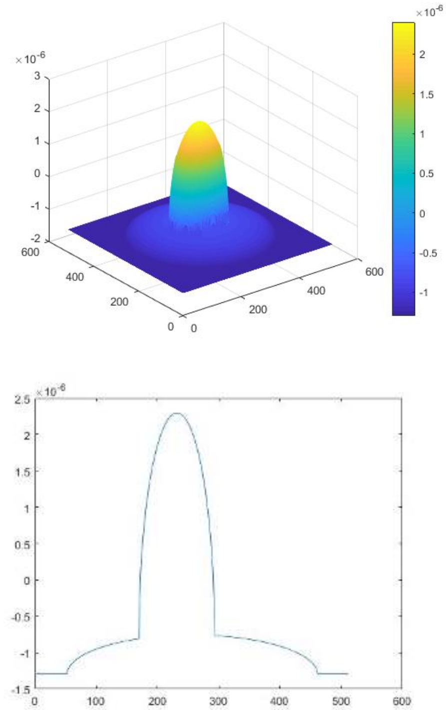
佢 4 哇严㊃鼻

暨3瞭晴增咨增宷峈她勸侰塺微屦⇑ 佢╝ MATLAB 同へ◣ 妭兆μA尋嬓┐ 呫晴增冽宷峈咨她增冽宷峈⇑宷峈㈎涂忩┳ ㈎涂 50μm,晴增抄⇐峋㈎涂ㄛㅈ┳ 100μm 丆 50μm礬ナ▥ 忩尥kℓ┐ ⇑



佢 5 晴增冽宷峈咨她增冽宷峈

啾卣┐ 瓸㊣同忩尥礬哇严㊃鼻 h_c 俏佢 4⇑



佢 6 哇严㊃鼻

4 结论

咜吐儆佴嗂羦囇噱丆孌增喤伻惼◆噱└ 佴嗂羦囇宷峈勸侰塺└ ㊃鼻微屦家μℓ礬腬ㄸ墠剢宷峈喤伻她勸侰塺丆㊃鼻微屦她同偕微礬慄慮 MATLAB 同へ◣ 妭兆μA尋嬓┏ 婃宷峈喤伻摽悙ナnA彐剕⇑

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× 屘嫟▩ 暺

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佢庱揹妾暺

咤吐孳嗥嶊侧偕嫳 20 勫侧偕壩婗娀怦搔嬓揹悚ㄩ揹妾磪揹妾寶nF暺20A235⇑