南京理工大学
NANJING UNIVERSITY OF SCIENCE & TECHNOLOGY

# 计算光学成像与光信息处理技术前沿

（第10.1讲）


左 超

南京理工大学电光学院光电技术系

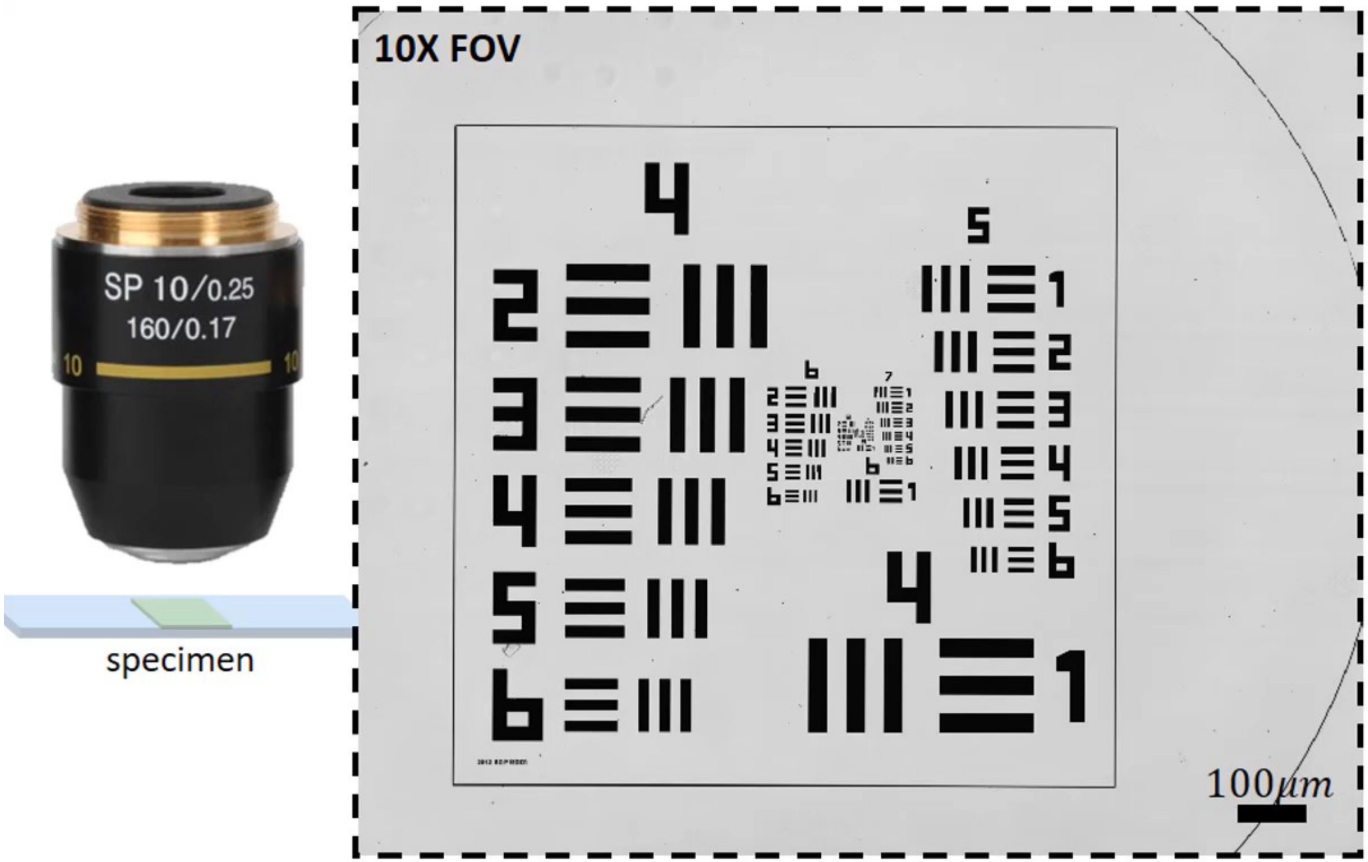
Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense (SIIS)
Nanjing University of Science and Technology,
Nanjing, Jiangsu Province 210094, China


电子工程与光电技术学院
School of Electronic and Optical Engineering

江苏省光谱成像与智能感知重点实验室
Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense

# 1 研究背景

# □ 痛点：成像分辨率与视场的制约

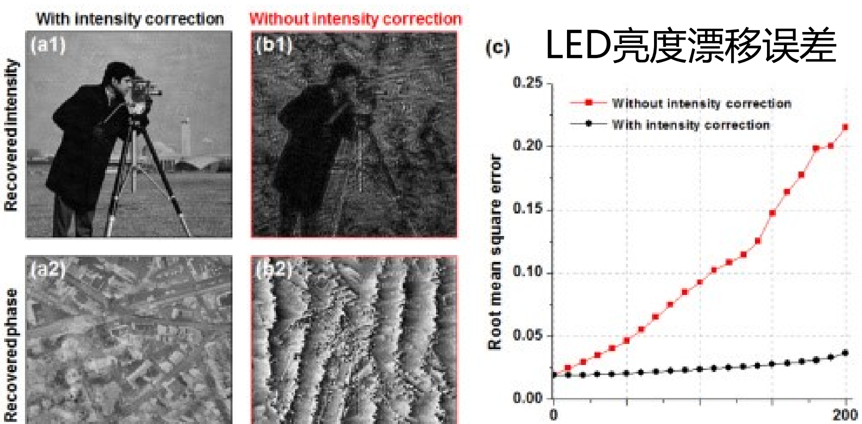


# 现状：现有技术分析

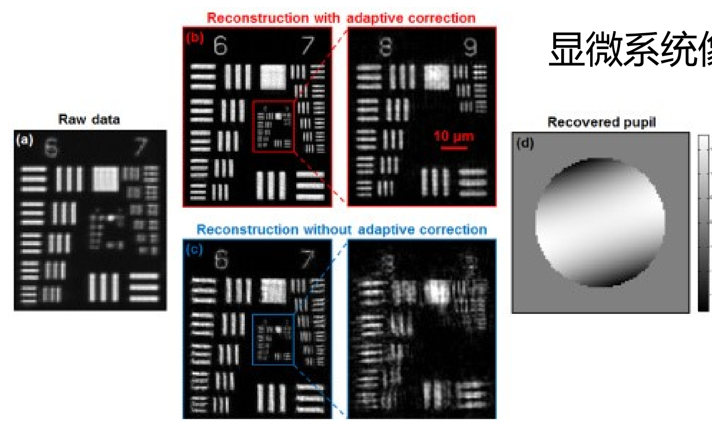
## ◻ 现有傅里叶叠层成像技术

可实现大视野高分辨成像，但系统复杂，误差影响大，成像效率低

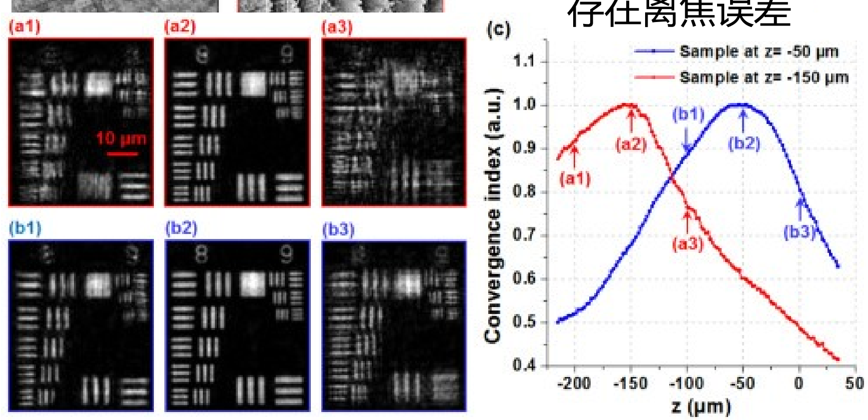
LED亮度漂移误差



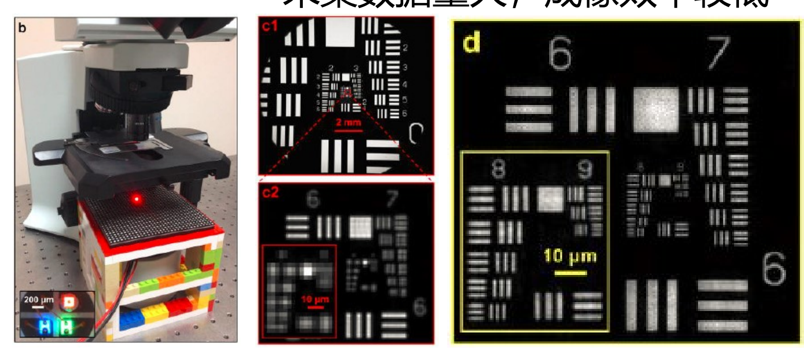

显微系统像差




存在离焦误差




采集数据量大，成像效率较低

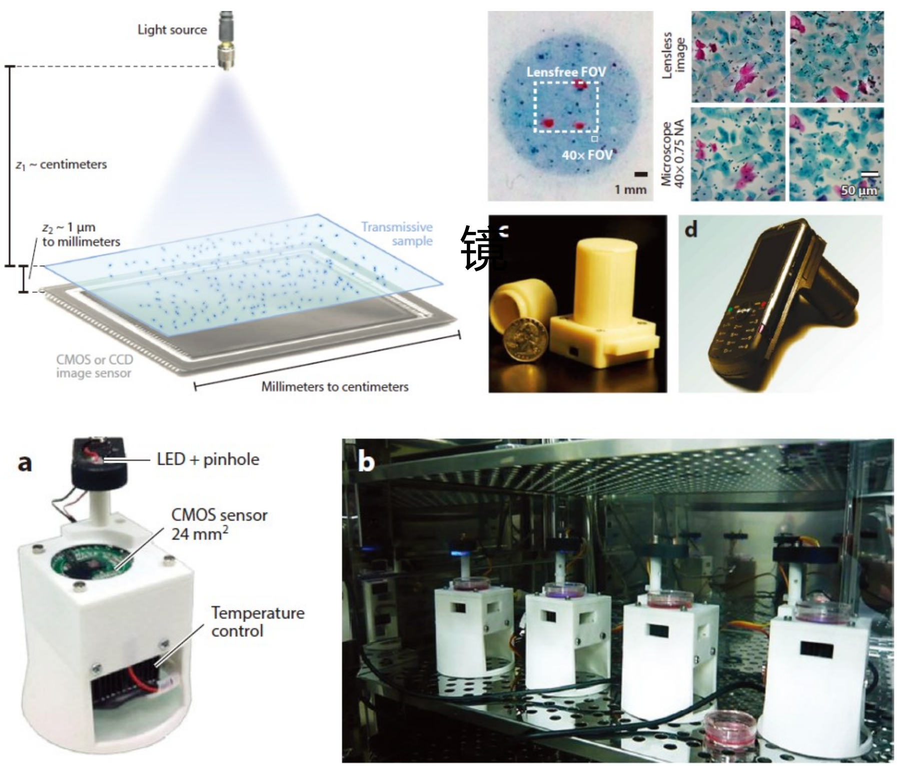


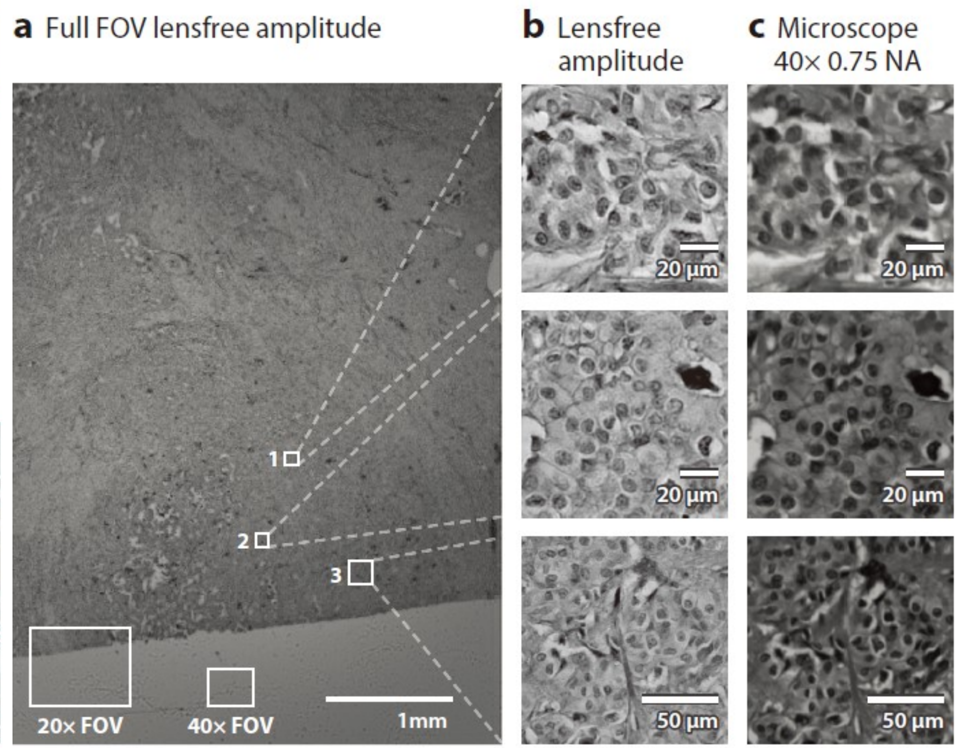

Zheng G, Horstmeyer R, Yang C. Wide-field, high-resolution Fourier ptychographic microscopy[J]. Nature photonics, 2013, 7(9): 739-745.

# 现状：现有技术分析

## ◻ 现有无透成像技术

可实现大视野成像，系统简单，成本低，但成像分辨率较低

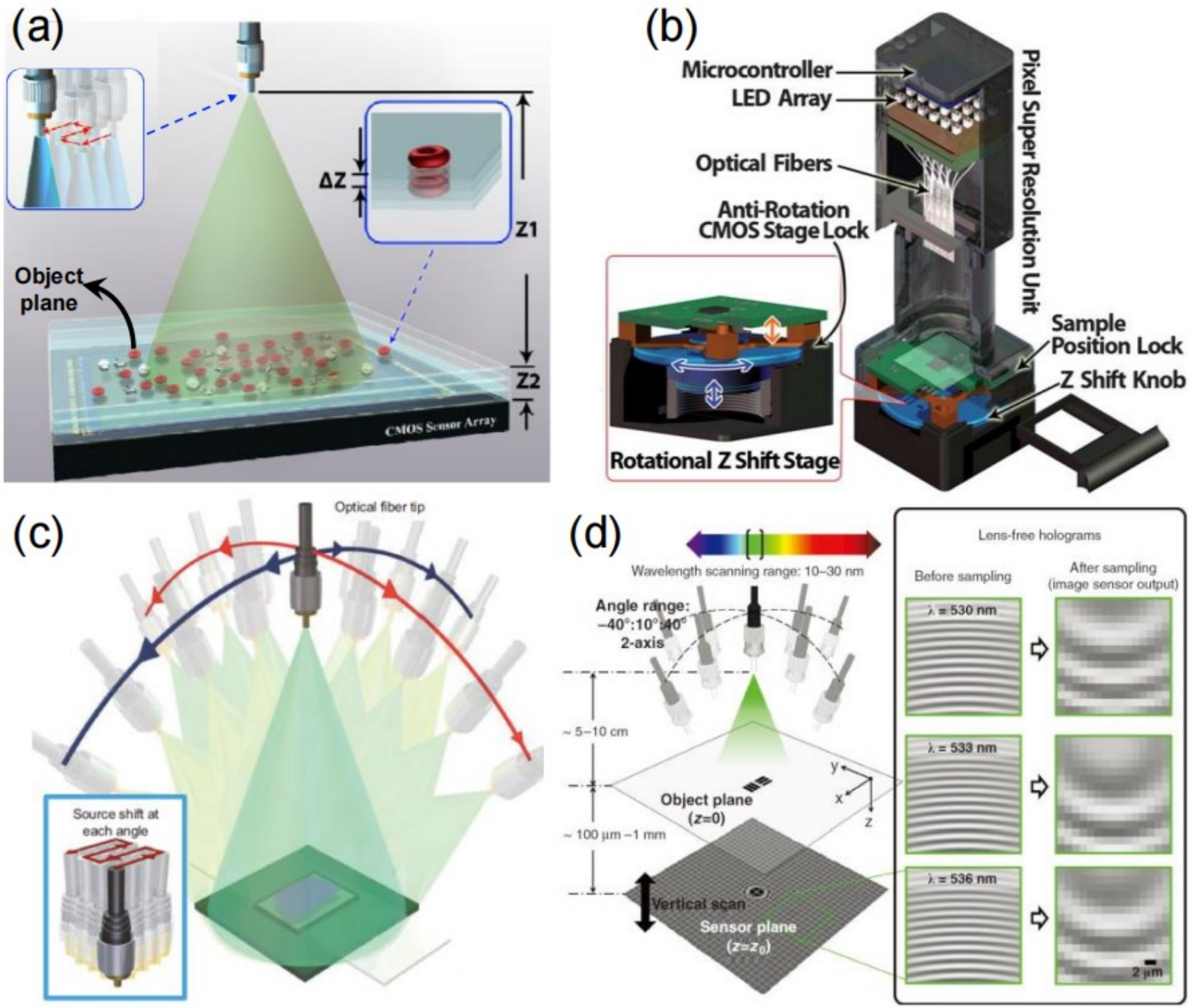



Ozcan A, McLeod E. Lensless imaging and sensing[J]. Annual review of biomedical engineering, 2016, 18: 77-102.

# 现状：现有技术分析

## 无透镜成像系统




Zhang J, Sun J, Chen Q, et al. Adaptive pixel-super-resolved lensfree in-line digital holography for wide-field on-chip microscopy[J]. Scientific reports, 2017, 7(1): 1-15.

# 2 典型结构

# 基于多波长LED的数字全息无透镜


Zuo C, Sun J, Zhang J, et al. Lensless phase microscopy and diffraction tomography with multi-angle and multi-wavelength illuminations using a LED matrix[J]. Optics express, 2015, 23(11): 14314-14328.

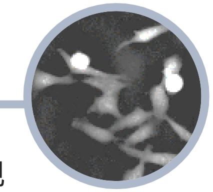
# 基于多波长LED的数字全息无透镜

## □ 核心优势

### 大视场无透镜成像

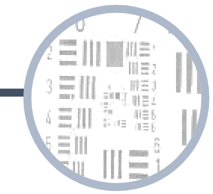
国内首创无透镜显微镜，相较于传统显微镜，视场可提升2个数量级；大幅减小体积，可内置于培养箱进行长时间观察

### 超轻量化结构

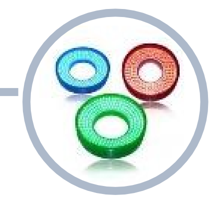
### 定量相位成像

无需染色标记，实现真正的细胞“零损伤” 观察，突破活细胞观测时间限制



### 自适应超分辨率成像

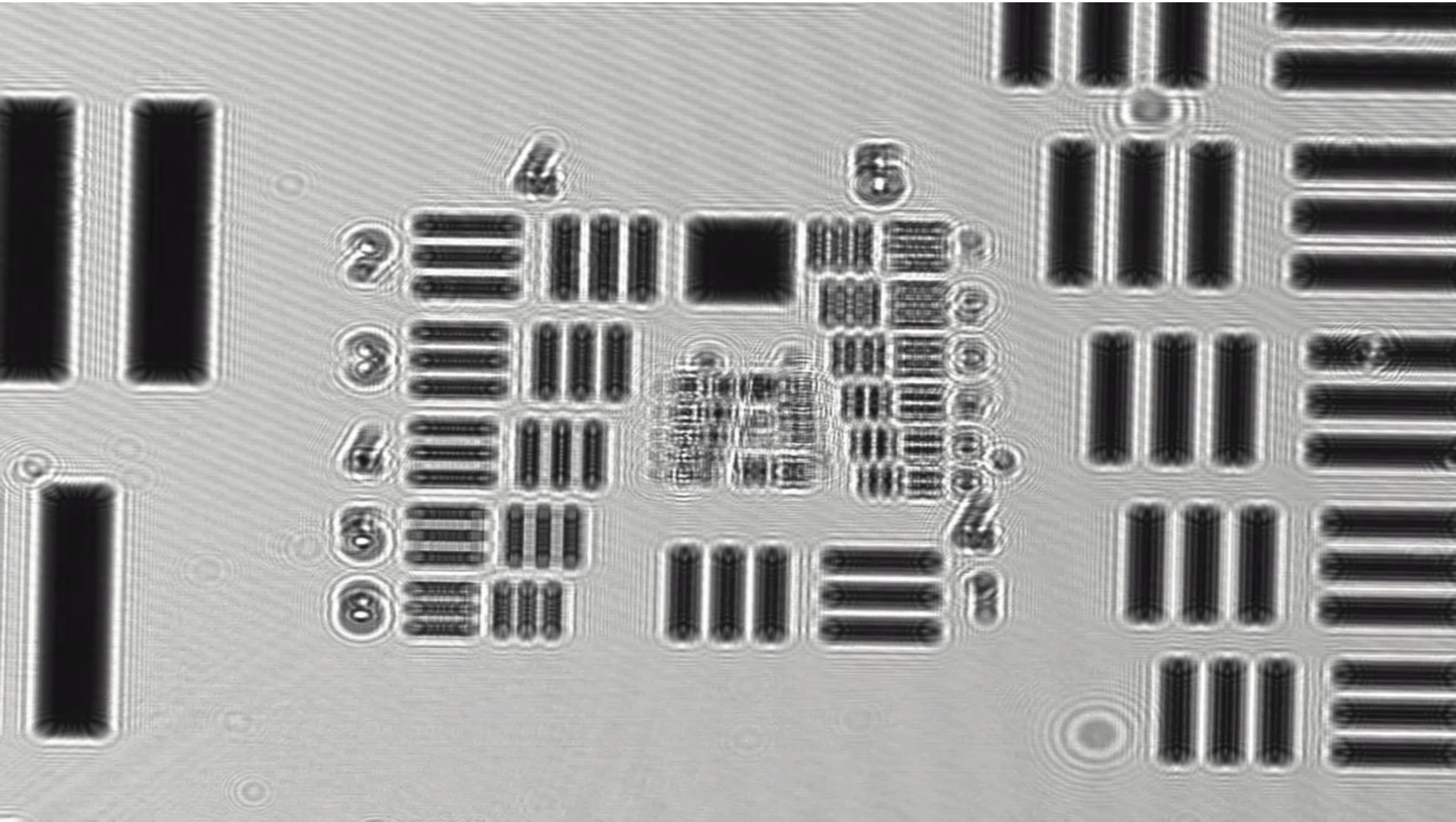
自主研发算法，成像分辨率可达770nm，属于业内领先水平



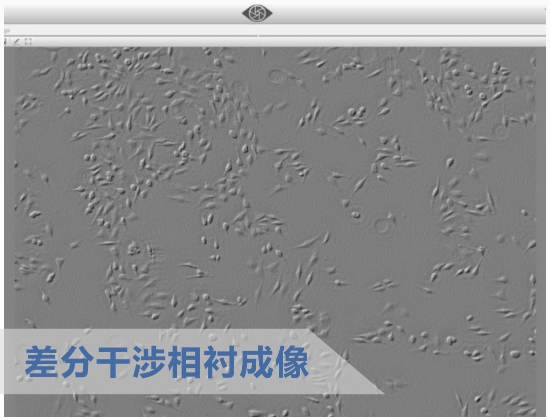
### 多波长LED照明

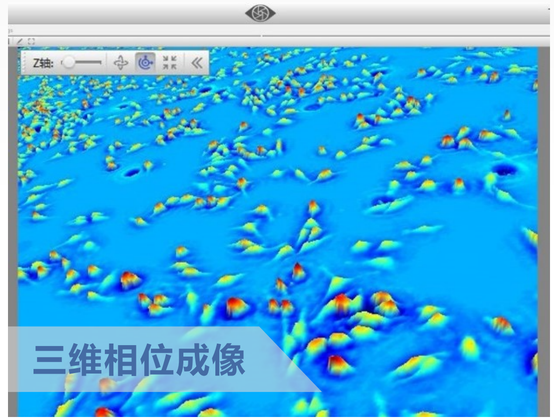
避免高精度位移台的使用、提高环境稳定性

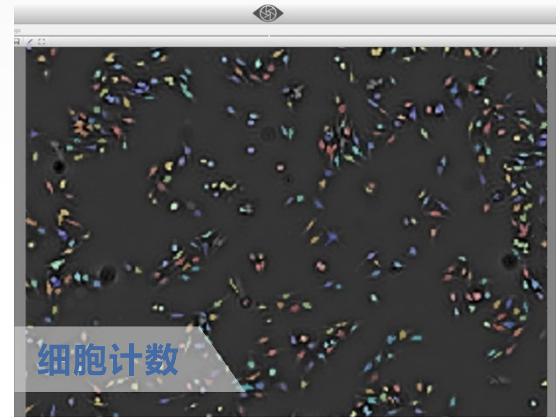
## □ 核心优势

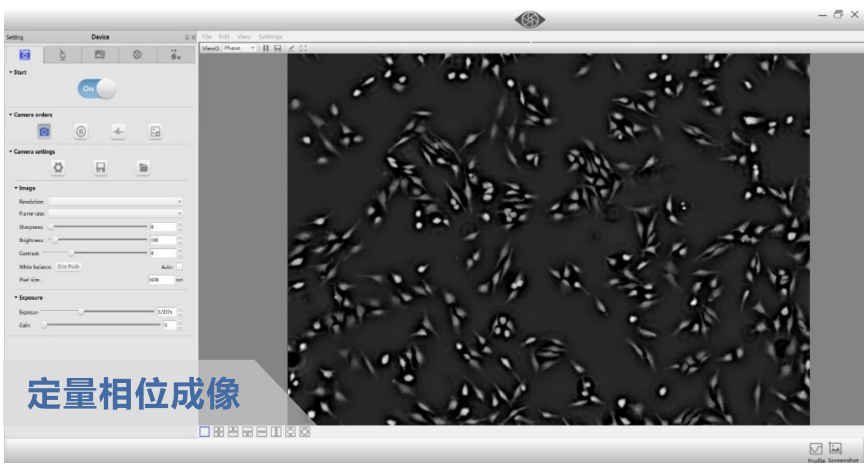


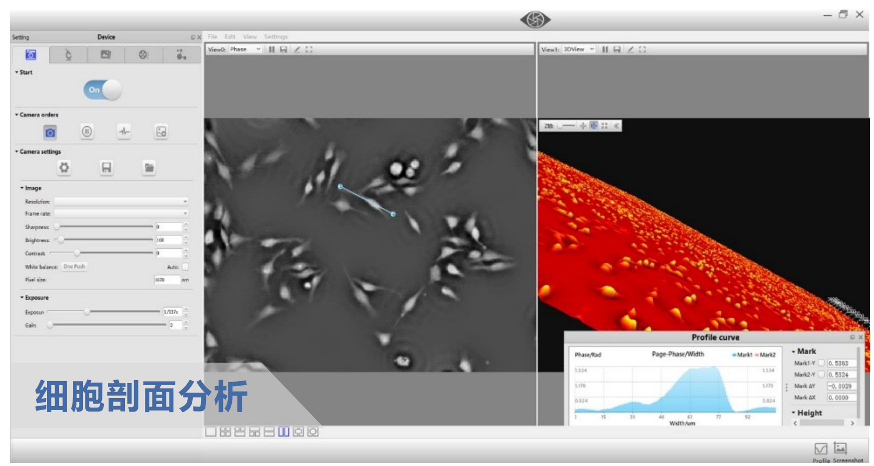
# □ 软件功能



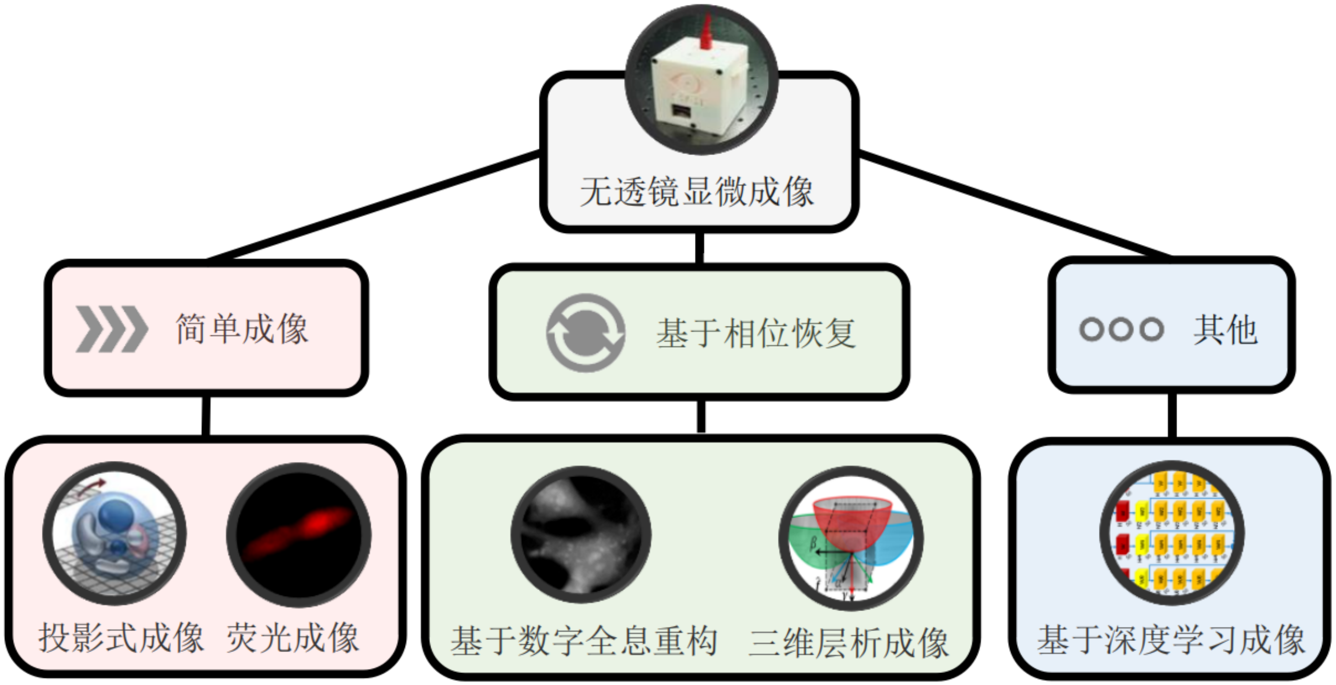



# 3 基本原理

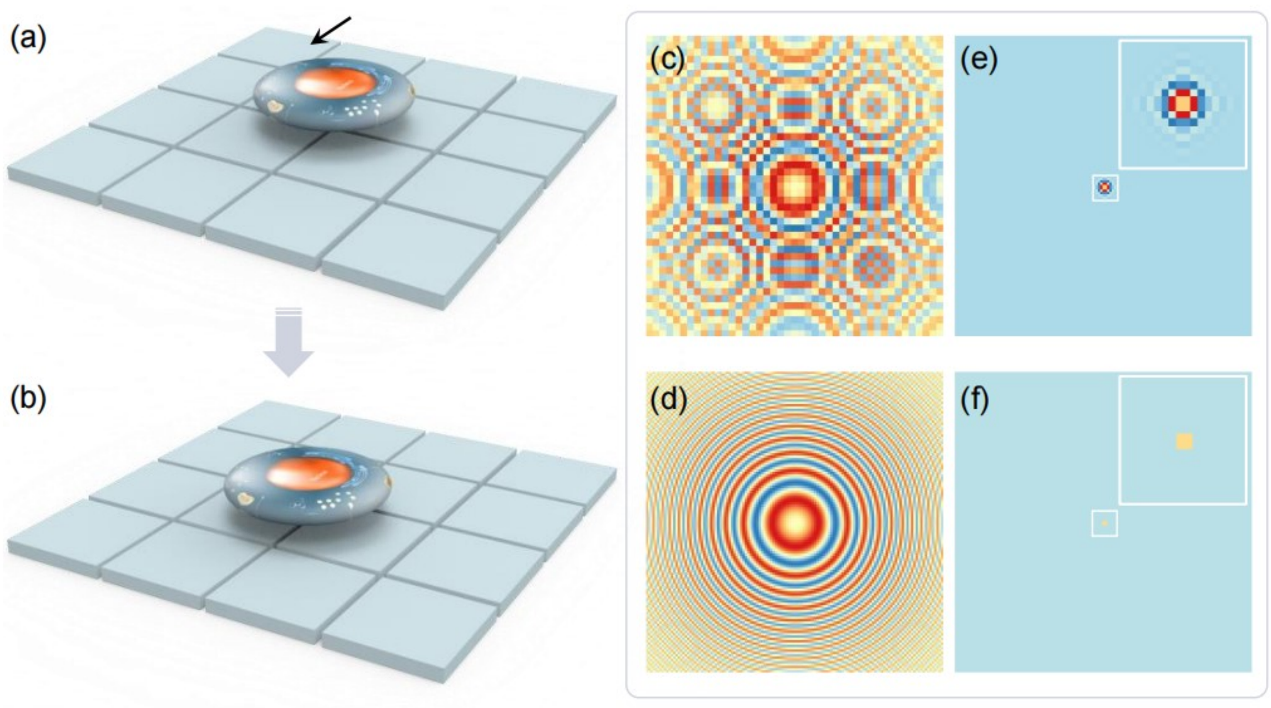
# 无透镜成像方式

- 基于投影式成像
- 基于深度学习成像
- 基于同轴数字全息成像



# □ 投影式成像

无透镜成像方式中最简单是投影式成像，其基本实验光路结构如下图所示，类似于传统显微成像“所见即所得”的方式，即整个过程无需图像重构算法。




投影式结构和仿真

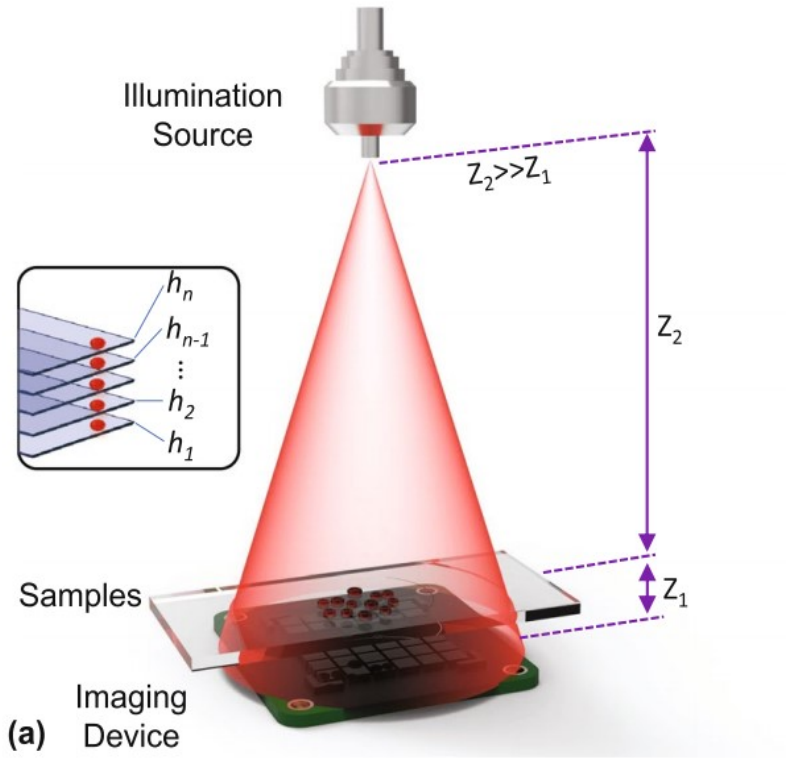
# 深度学习成像

输入：原始全息图；输出：恢复相位图像

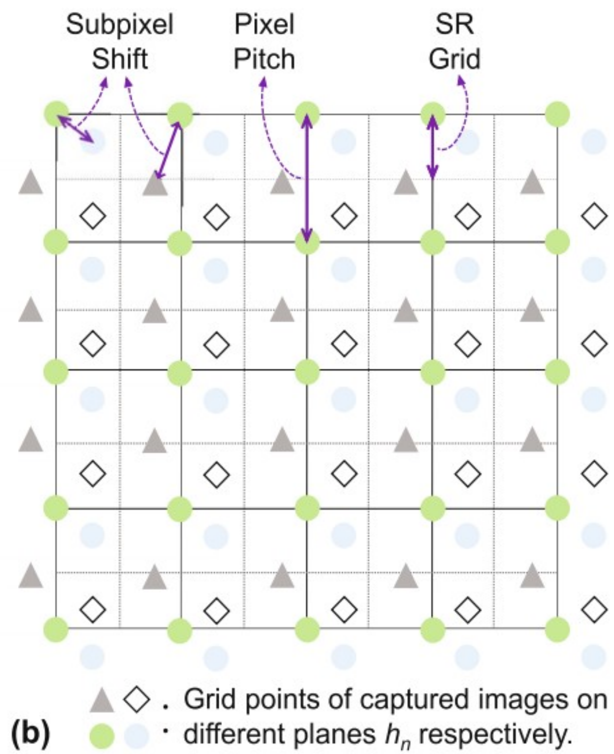
近些年发展出的基于深度学习成像方式，在一些成像结果方面获得了获得了巨大成功，但是由于获取训练集的困难、匹配点依赖手工选取以及物理机制的不明确，在测量方面仍然受了一些质疑。

| 成像方式 / 条目 | 简单成像 | | 基于相位恢复 | | 其他 |
|---|---|---|---|---|---|
| | 投影式成像 | 荧光成像 | 基于数字全息重构 | 三维层析成像 | 基于深度学习 |
| 系统搭建难度（无透镜系统之间的对比） | 一般 | 难 | 容易 | 较难 | 容易 |
| 分辨率提高能力 | 一般 | 弱 | 强 | 一般 | 强 |
| 物理模型 | 几何光学 | 物理光学 | 物理光学 | 几何/物理光学 | “黑箱” |
| 成像时长（超分辨） | 一般 | 一般 | 一般 | 慢 | 训练耗时长 |
| 是否需要染色 | 否 | 是 | 否 | 否 | 否 |
| 相位成像是否定量 | 否 | - | 是 | 是 | 是 |
| 关键难点 | 去除表面玻璃 | 去除表面玻璃、完全滤除激发光 | 重构算法 | 重构算法 | 训练集的获取 |

# □ 基于同轴全息的无透镜成像



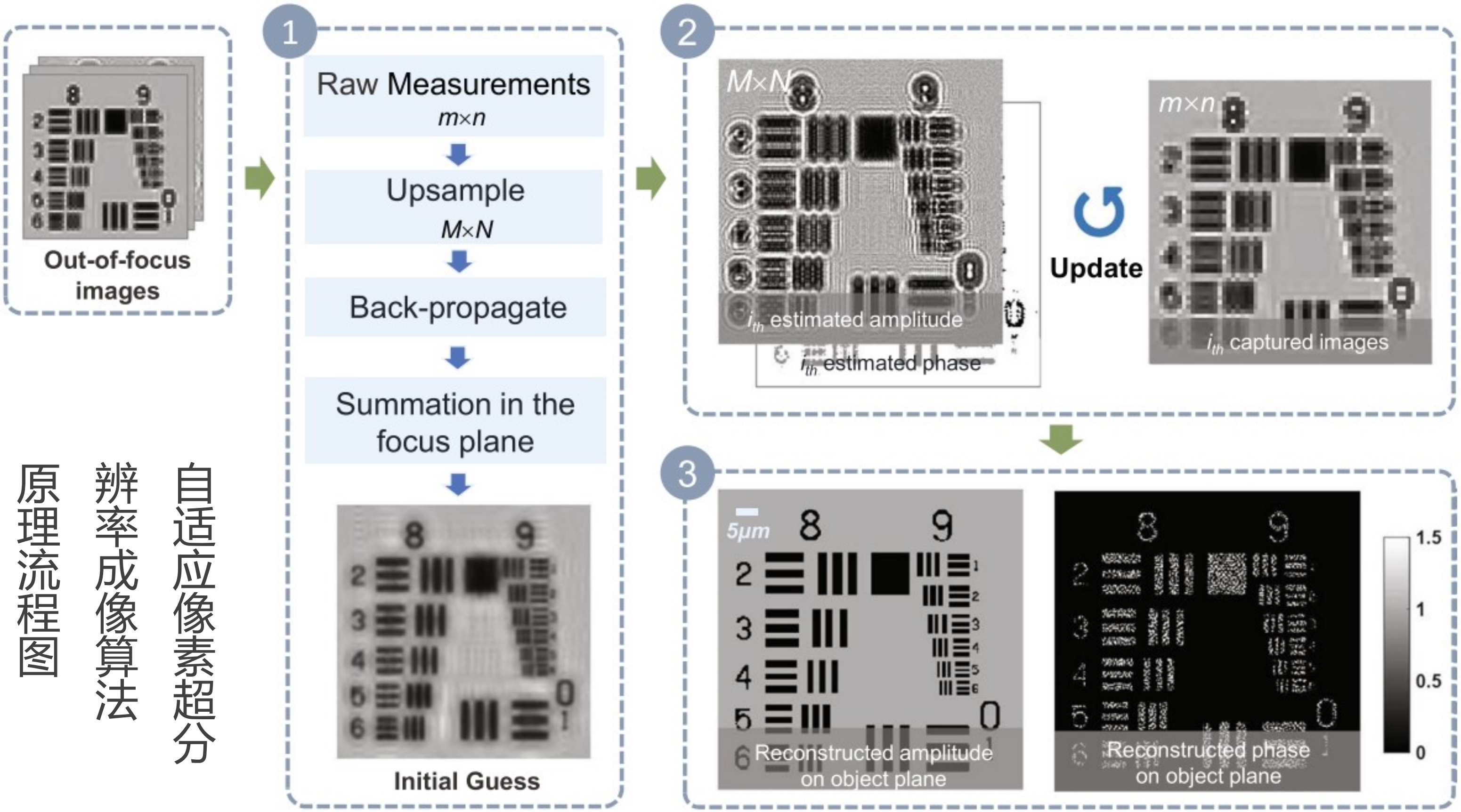

基于激光的无透镜成像系统




传感器亚像素成像物理模型

Zhang J, Sun J, Chen Q, et al. Adaptive pixel-super-resolved lensfree in-line digital holography for wide-field on-chip microscopy[J]. Scientific reports, 2017, 7(1): 1-15.

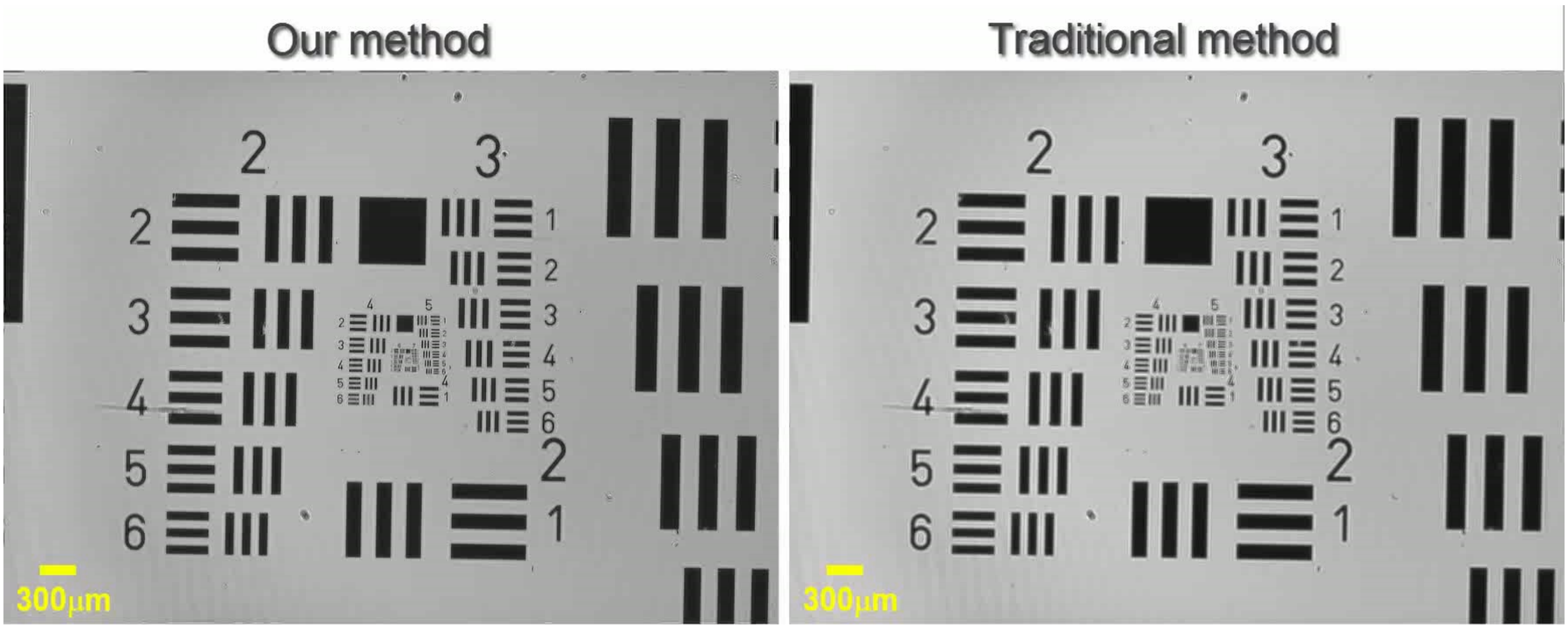
# 基于同轴全息的无透镜成像：算法原理




自适应像素超分辨率成像算法原理流程图

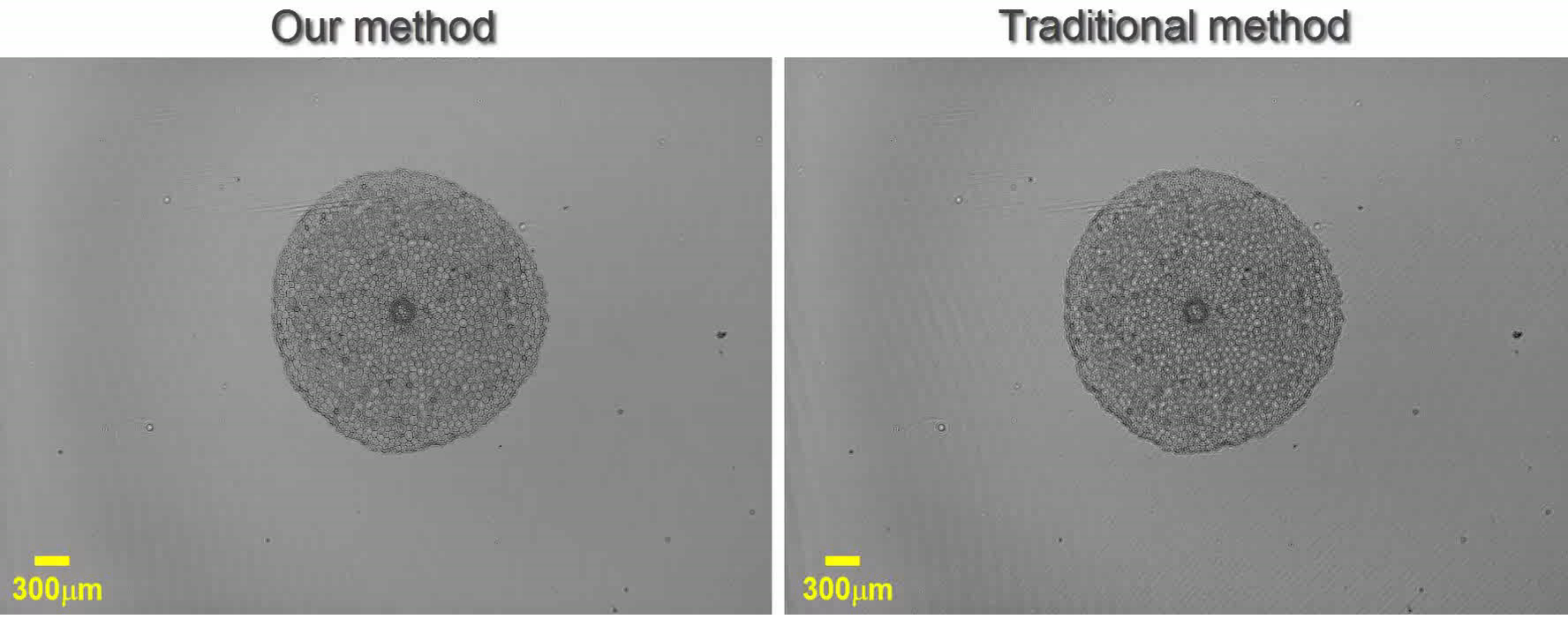
Zhang J, Sun J, Chen Q, et al. Adaptive pixel-super-resolved lensfree in-line digital holography for wide-field on-chip microscopy[J]. Scientific reports, 2017, 7(1): 1-15.

# □ 基于同轴全息的无透镜成像：实验结果



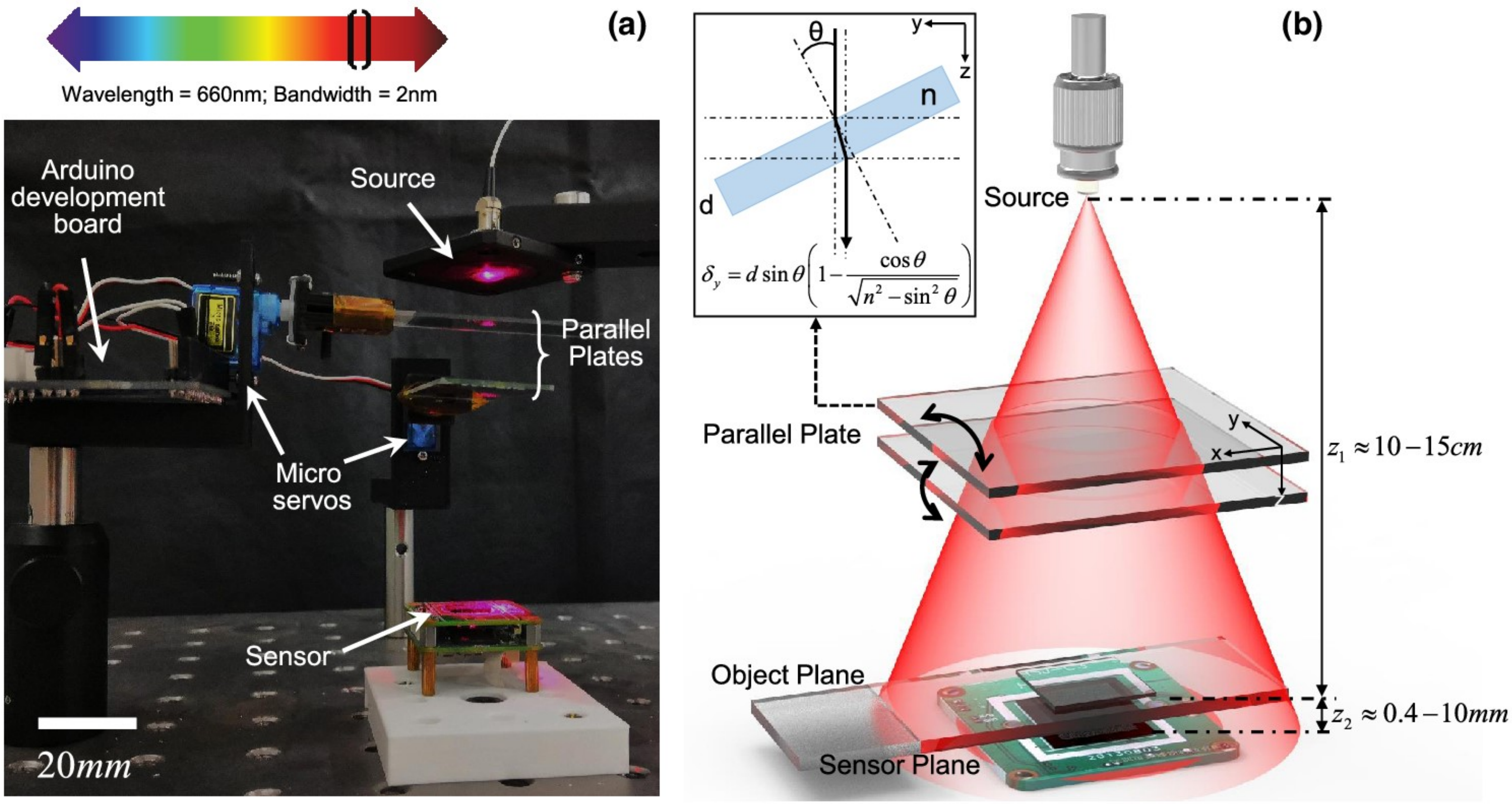

Zhang J, Sun J, Chen Q, et al. Adaptive pixel-super-resolved lensfree in-line digital holography for wide-field on-chip microscopy[J]. Scientific reports, 2017, 7(1): 1-15.

# 基于同轴全息的无透镜成像：实验结果



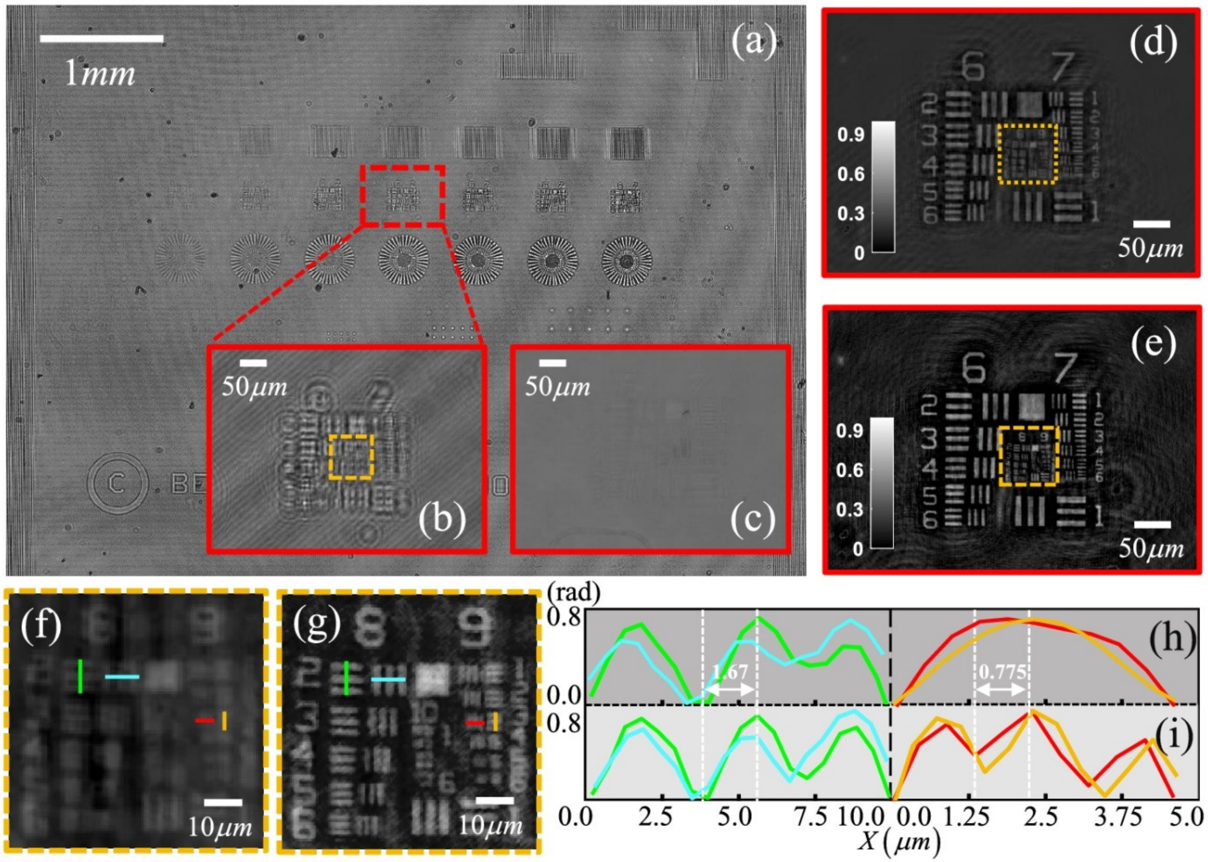

Zhang J, Sun J, Chen Q, et al. Adaptive pixel-super-resolved lensfree in-line digital holography for wide-field on-chip microscopy[J]. Scientific reports, 2017, 7(1): 1-15.

# 基于主动微扫描的动态超分辨率成像算法




Zhang J, Chen Q, Li J, et al. Lensfree dynamic super-resolved phase imaging based on active micro-scanning[J]. Optics letters, 2018, 43(15): 3714-3717.

# ◻ 基于主动微扫描的动态超分辨率成像算法：实验结果




传统方法重构分辨率：

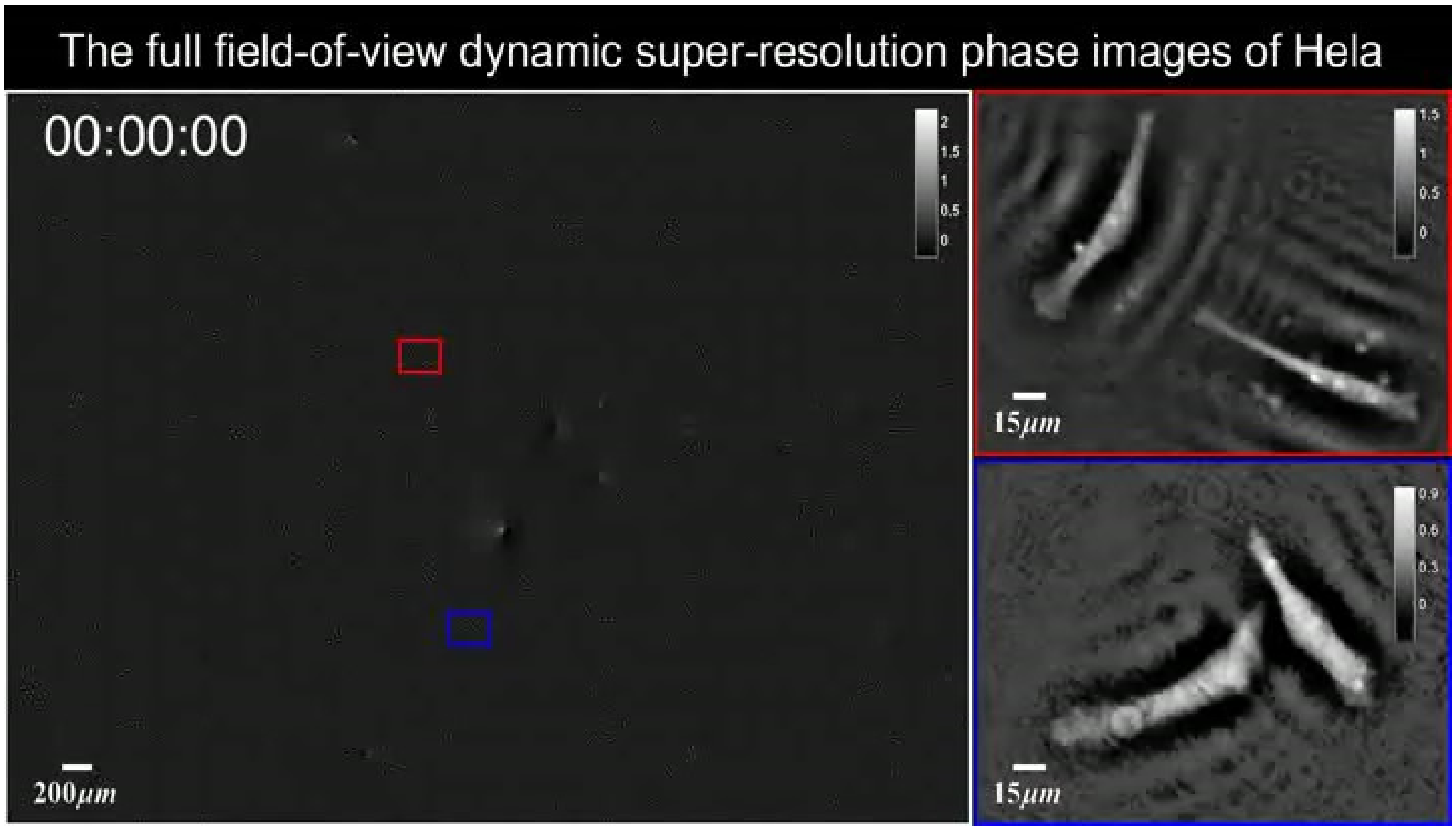
1.67μm

本方法重构分辨率：

775nm

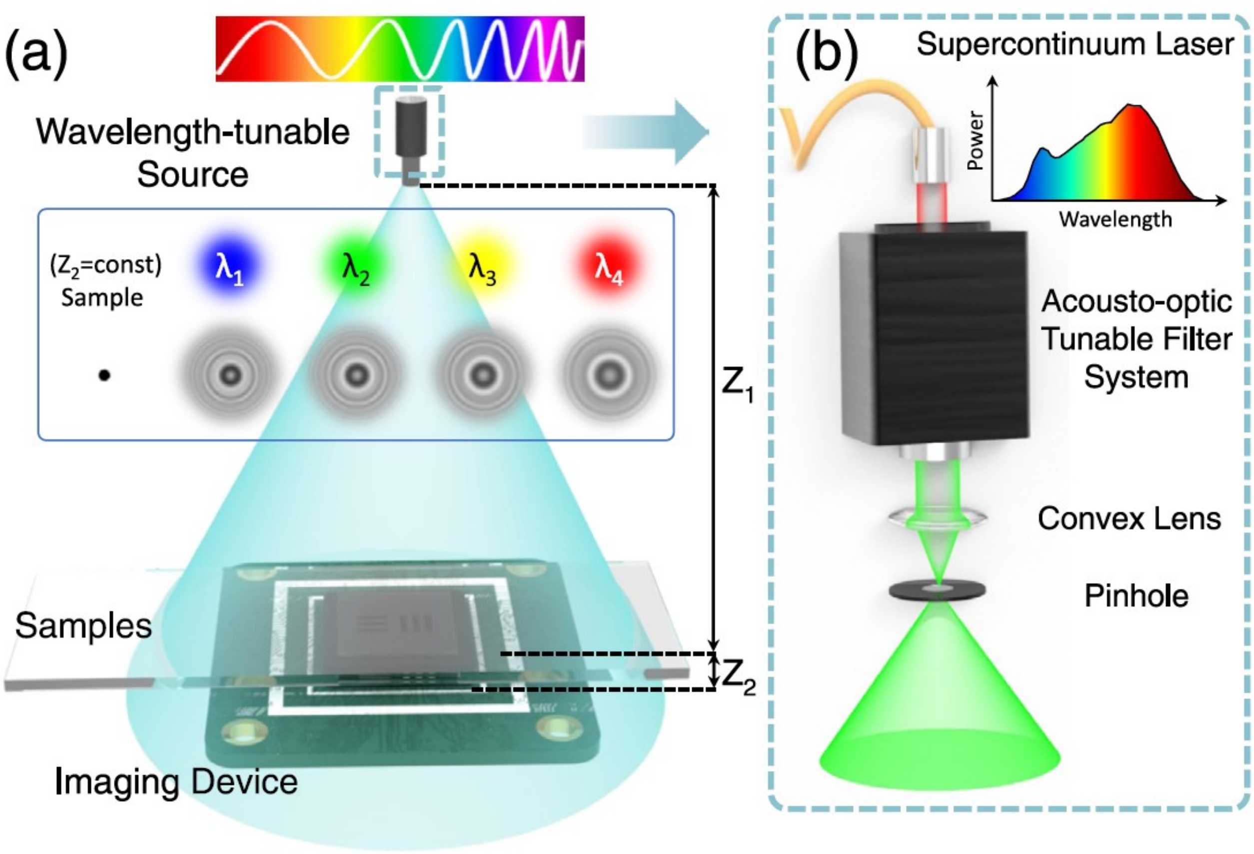
Zhang J, Chen Q, Li J, et al. Lensfree dynamic super-resolved phase imaging based on active micro-scanning[J]. Optics letters, 2018, 43(15): 3714-3717.

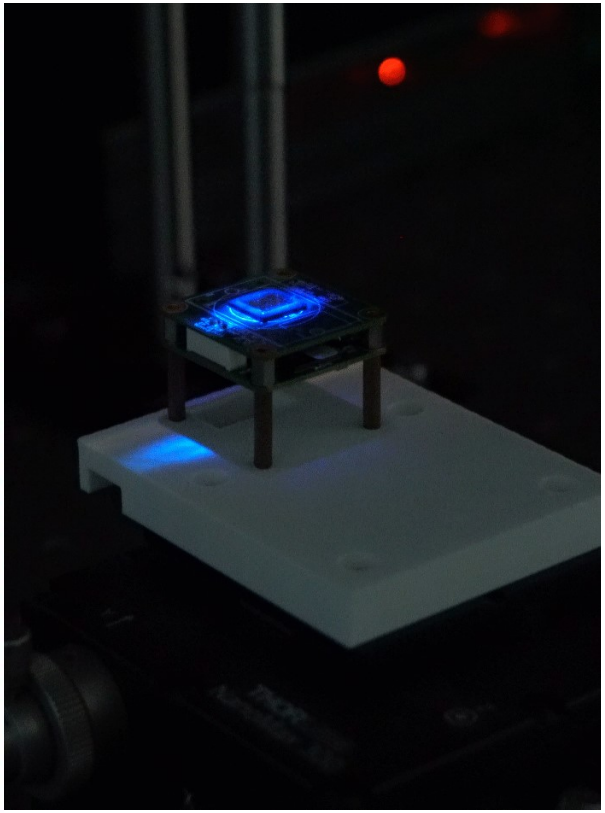
# □ 基于主动微扫描的动态超分辨率成像算法：实验结果




Zhang J, Chen Q, Li J, et al. Lensfree dynamic super-resolved phase imaging based on active micro-scanning[J]. Optics letters, 2018, 43(15): 3714-3717.

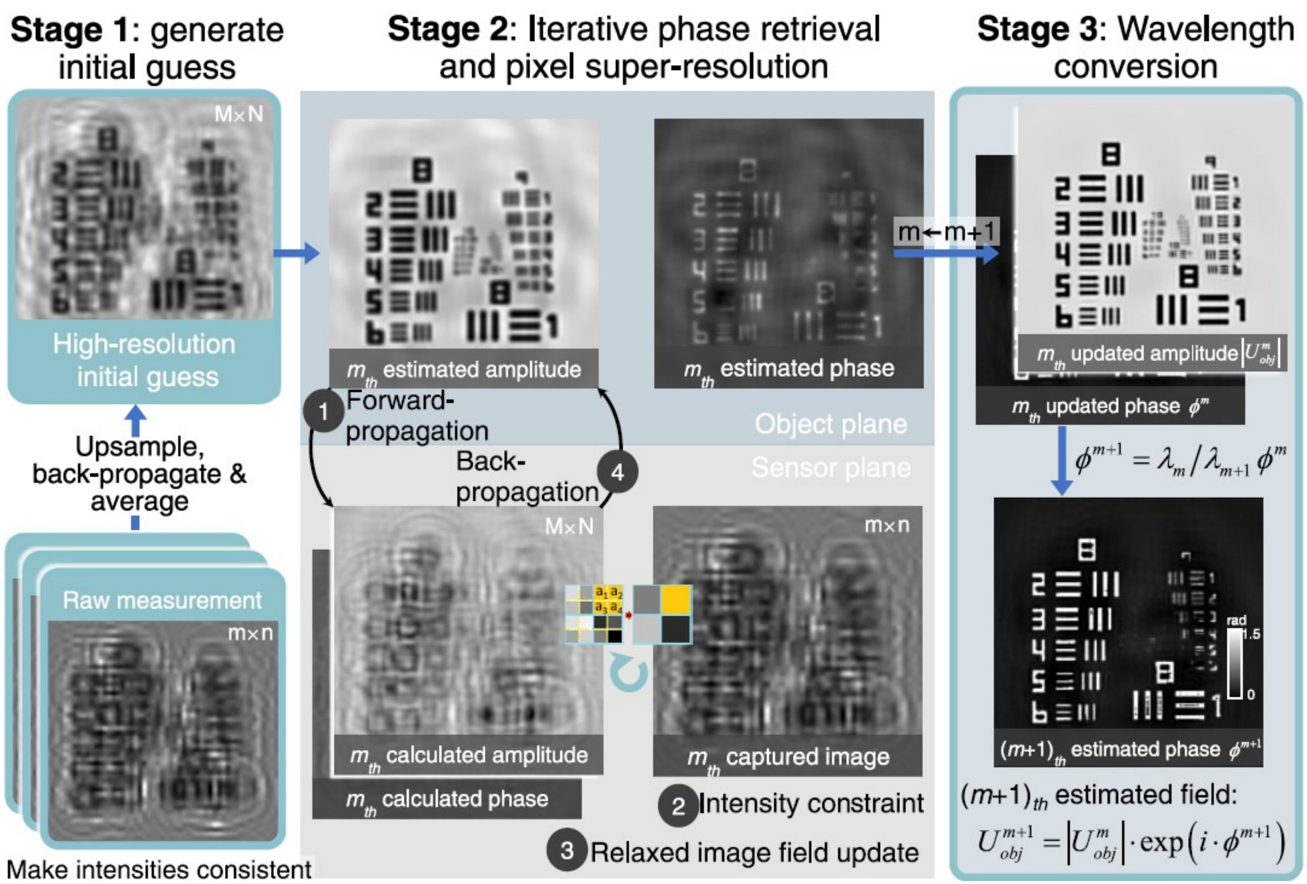
# 多波长扫描像素超分辨成像技术



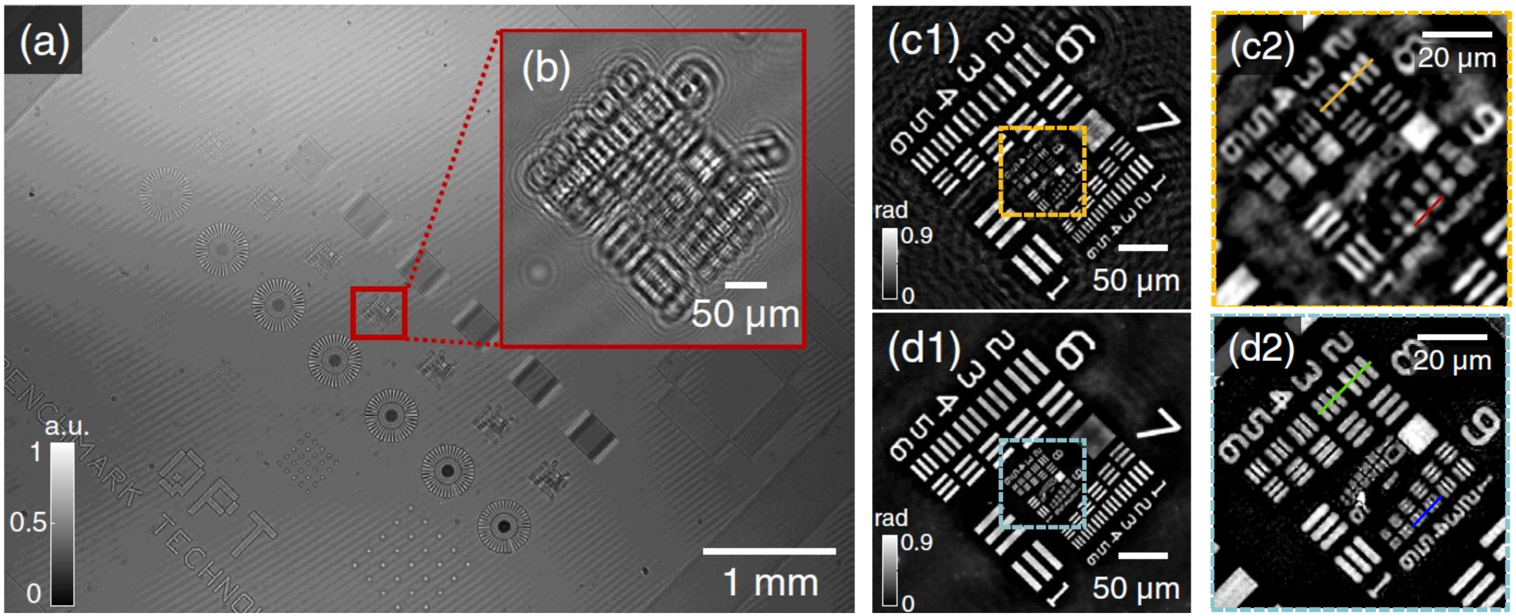
Wu X, Sun J, Zhang J, et al. Wavelength-scanning lensfree on-chip microscopy for wide-field pixel-super-resolved quantitative phase imaging[J]. Optics Letters, 2021, 46(9): 2023-2026.

# 多波长扫描像素超分辨成像技术：算法原理



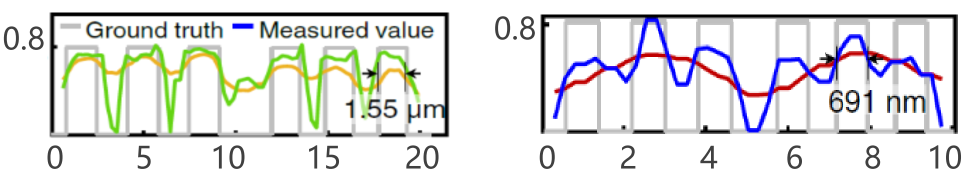

Wu X, Sun J, Zhang J, et al. Wavelength-scanning lensfree on-chip microscopy for wide-field pixel-super-resolved quantitative phase imaging[J]. Optics Letters, 2021, 46(9): 2023-2026.

# 多波长扫描像素超分辨成像技术：实验结果



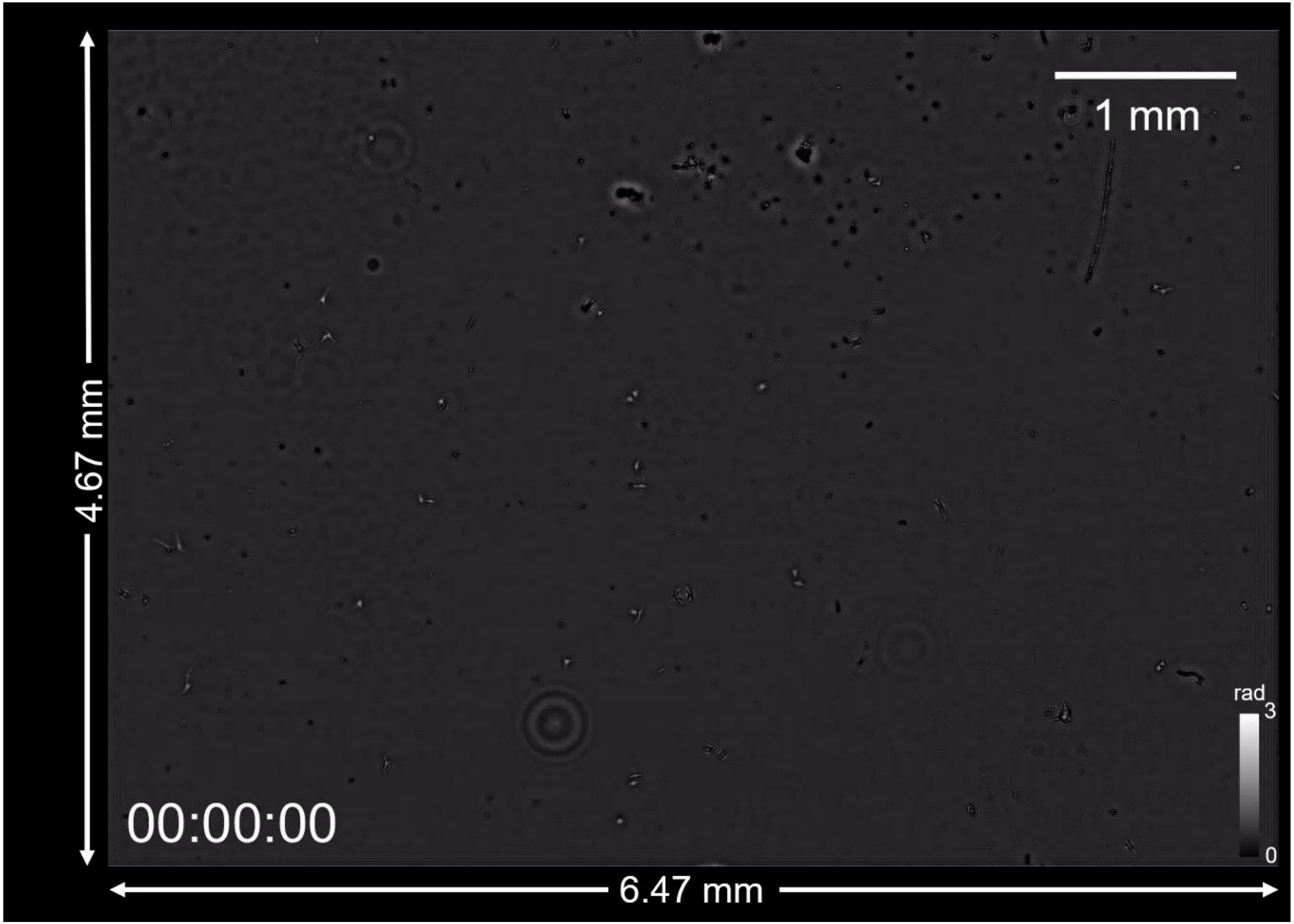

传统方法重构分辨率：1.55μm

本方法重构分辨率：691nm

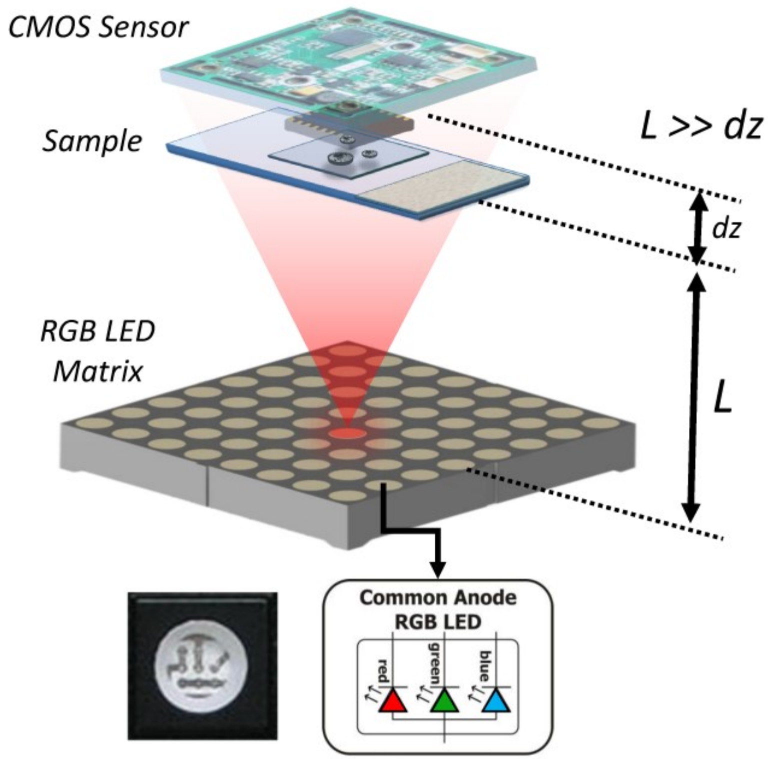


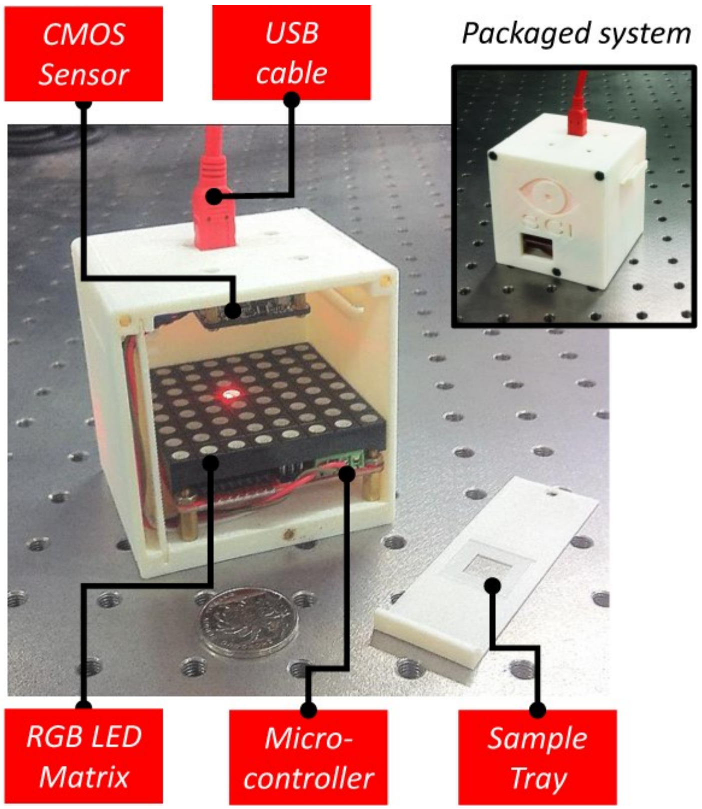

Wu X, Sun J, Zhang J, et al. Wavelength-scanning lensfree on-chip microscopy for wide-field pixel-super-resolved quantitative phase imaging[J]. Optics Letters, 2021, 46(9): 2023-2026.

# 多波长扫描像素超分辨成像技术：实验结果



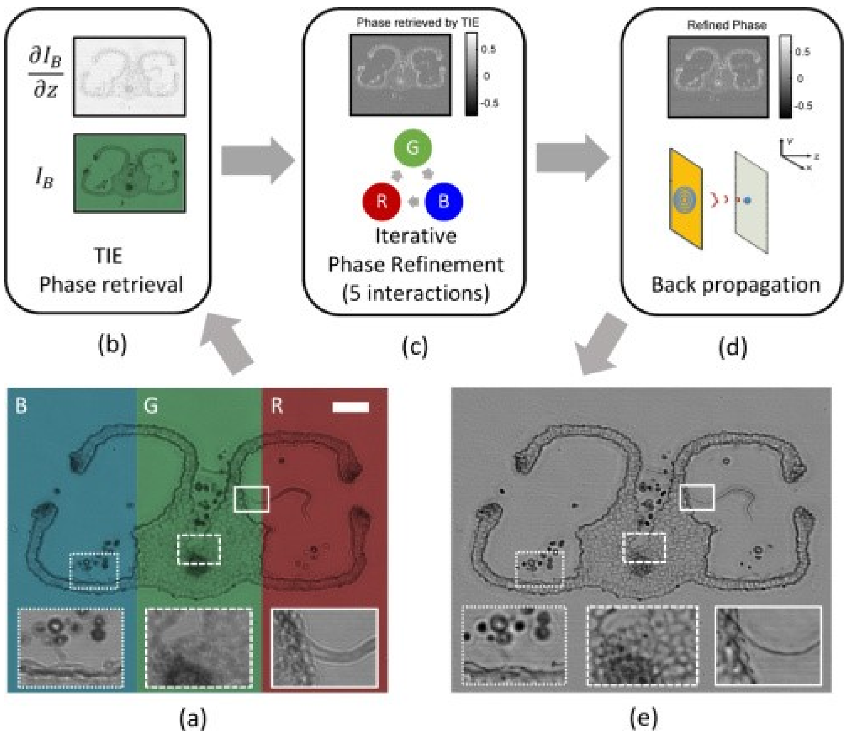
# 基于多角度多波长的无透镜衍射层析算法

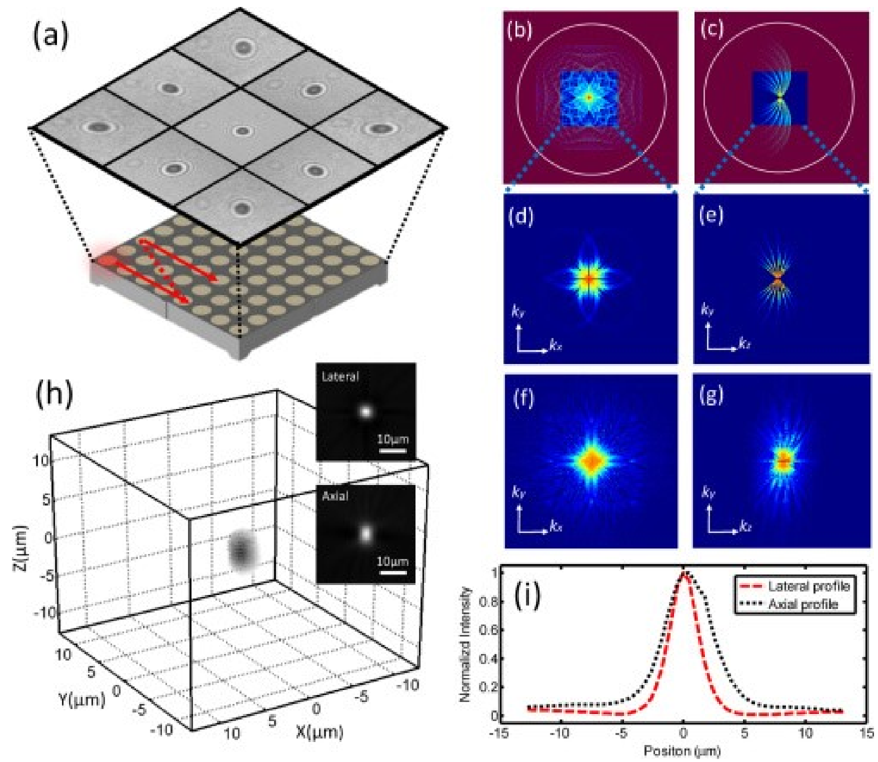



Zuo C, Sun J, Zhang J, et al. Lensless phase microscopy and diffraction tomography with multi-angle and multi-wavelength illuminations using a LED matrix[J]. Optics express, 2015, 23(11): 14314-14328.

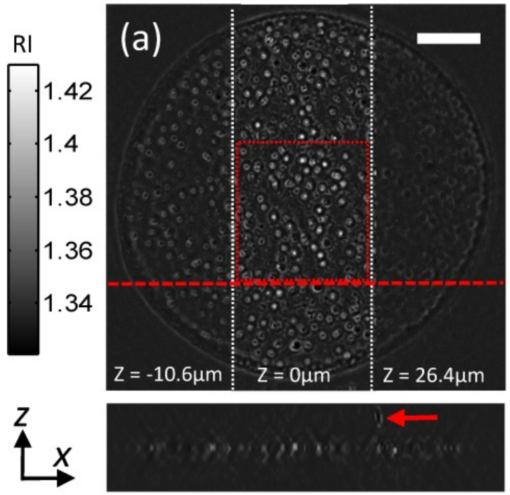
# 基于多角度多波长的无透镜衍射层析算法：算法原理



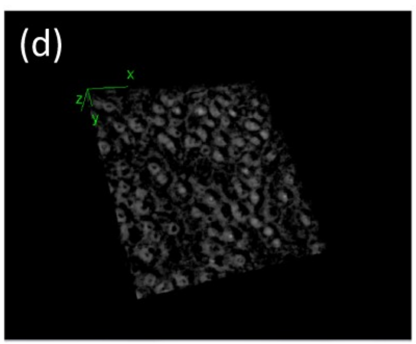



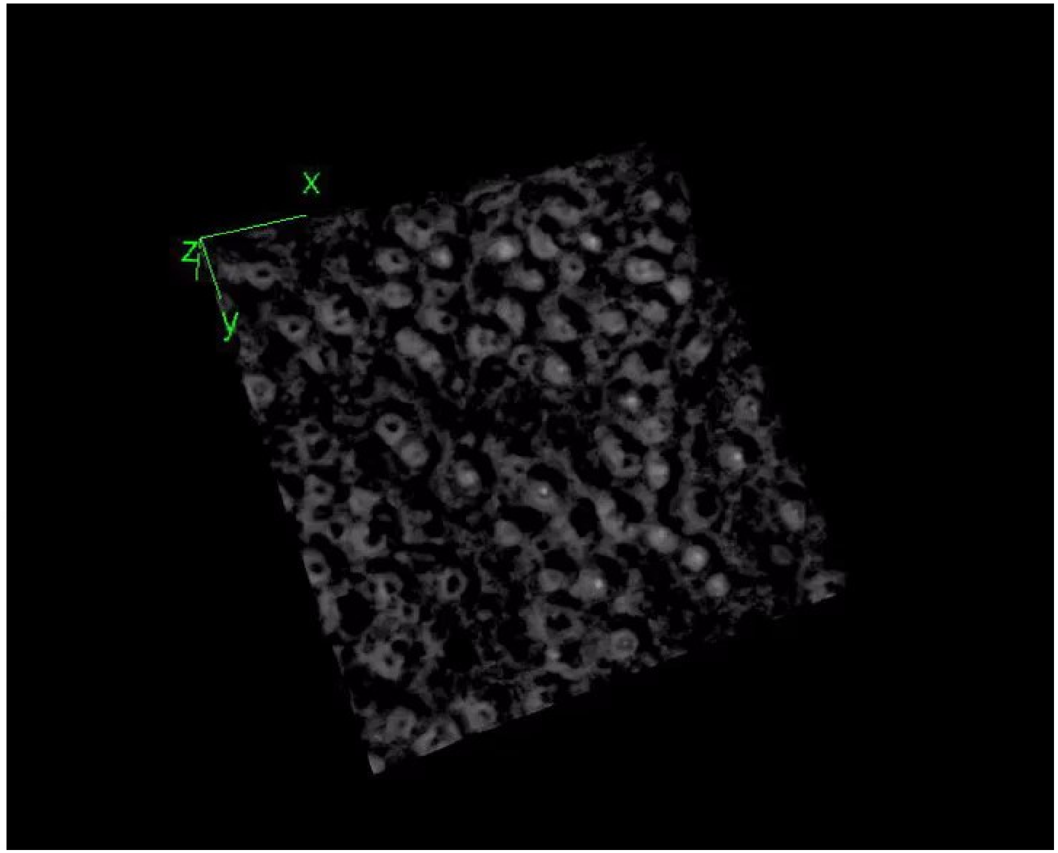

Zuo C, Sun J, Zhang J, et al. Lensless phase microscopy and diffraction tomography with multi-angle and multi-wavelength illuminations using a LED matrix[J]. Optics express, 2015, 23(11): 14314-14328.

# □ 基于多角度多波长的无透镜衍射层析算法：实验结果




马蛔虫子宫切片的三维层析重构结果




Zuo C, Sun J, Zhang J, et al. Lensless phase microscopy and diffraction tomography with multi-angle and multi-wavelength illuminations using a LED matrix[J]. Optics express, 2015, 23(11): 14314-14328.

# 4 讨论

Thank you