メドラーク社製SLMの特徴とアプリケーション

フォトテクニカ株式会社

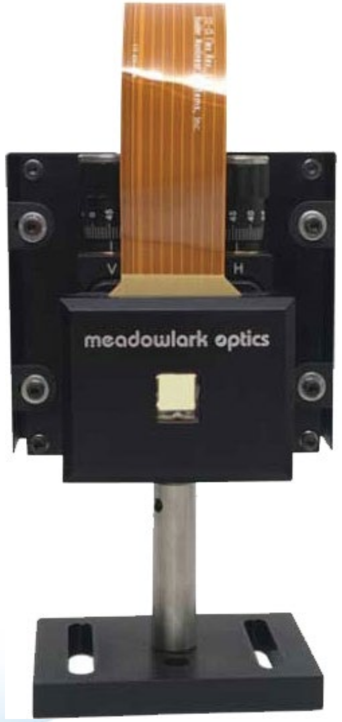
September 1, 2020

meadowlark optics
spatial light modulators

反射型・透過型、2D・リニア、豊富なラインナップからアプリケーションに最適なSLMを選択可能

- SLM1920x1152

- SLM512x512



- SLM1x12.288

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LCoS SLM高解像度2軸反射型1920x1152

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1920 x 1152 Analog Spatial Light Modulator

Resolution: 1920 x 1152
Array Size: 17.6 x 10.7 mm
Pixel Pitch: 9.2 x 9.2 µm

Fill Factor: 95.7%
Diffraction Efficiency*: 88%
Controller: HDMI 8/12-bit

Wavelength	Wavefront Distortion	Liquid Crystal Response Time	AR Coatings (Ravg <1%)
		Model P1920	
405 nm	λ/3	6 ms	400 – 800 nm
532 nm	λ/5	9 ms	400 – 800 nm
635 nm	λ/6	12 ms	400 – 800 nm
785 nm	λ/7	19 ms	600 – 1300 nm
1064 nm	λ/10	25 ms	600 – 1300 nm
1550 nm	λ/12	33 ms	850 – 1650 nm

*Diffraction efficiency of silicon backplane.
Performance varies as a function of wavelength and pixel value.

LCoS SLM 2軸反射型　512x512

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Small 512 x 512 Analog Spatial Light Modulator

Resolution: 512 x 512
Array Size: 7.68 x 7.68 mm
Pixel Pitch: 15 x 15 µm
Fill Factor: 83.4 - 100%
Diffraction Efficiency*: 61 - 95%
Controller: PCIe 8-bit, PCIe 16-bit, DVI 16-bit

Wavelength	Wavefront Distortion	Liquid Crystal Response Time (Standard Efficiency / High Efficiency)			AR Coatings (Ravg <1%)
		Model P512/PDM512	Model HSP512/HSPDM512	Model ODP512/ODPDM512	
405 nm	λ/5	25 ms / 33.3 ms	N/A	3 ms / 4 ms	TBD
532 nm	λ/7	33.3 ms / 45 ms	7 ms / 10 ms	3.5 ms / 4.5 ms	450 – 850 nm
635 nm	λ/8	33.3 ms / 45 ms	12 ms / 16.7 ms	4 ms / 5 ms	450 – 850 nm
785 nm	λ/10	55.5 / 80 ms	17.2 ms / 22.2 ms	4.5 ms / 5.5 ms	600 – 1300 nm
1064 nm	λ/10	66.7 / 100 ms	10 ms / 16.7 ms	5 ms / 6 ms	600 – 1300 nm
1550 nm	λ/12	100 / 130 ms	20 ms / 28.5 ms	6 ms / 7 ms	850 – 1650 nm

*Diffraction efficiency of silicon backplane.
Performance varies as a function of wavelength and pixel value.

LCoS SLM リニア透過型　1x12,288

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1 x 12,288 Analog Spatial Light Modulator

Resolution: 1 x 12,288
Array Size: 19.66 x 19.66 mm
Pixel Pitch: 1.6 µm x 19.66 mm
Fill Factor: 100%
Diffraction Efficiency*: 80 - 95%
Controller: PCIe 16-bit

Wavelength	Liquid Crystal Response Time	AR Coatings (Ravg <1%)
	Model HSP12K	
532 nm	4.5 ms	450 – 850 nm
635 nm	5 ms	450 – 850 nm
785 nm	8.5 ms	600 – 1300 nm
1064 nm	15 ms	600 – 1300 nm
1550 nm	30 ms	850 – 1650 nm

*Diffraction efficiency of silicon backplane.
Performance varies as a function of wavelength and pixel value.

Meadowlark社SLMの特長

シリコンに液晶をコーティングした（LCoS）型反射型SLM
は純粋な位相アプリケーション用のユニークな設計。
またそれと独立して常に新しいレートで直接アナログデータ
を届けるアナログドライブ技術により、リップルの殆どない安
定した位相安定性を得ることが可能。反射型アナログSLM
反射型LCoS 技術に基づき紫外～中赤外で対応可能。

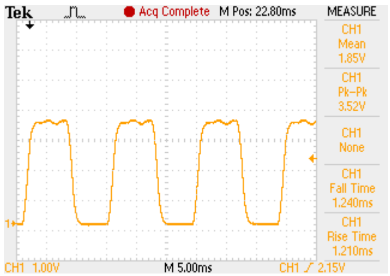
高速・高解像度・ハイパワー対応　1920 x 1152

High Resolution

1920 x 1152
Analog SLM

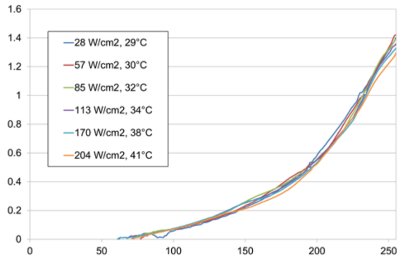
NEW

High Speed



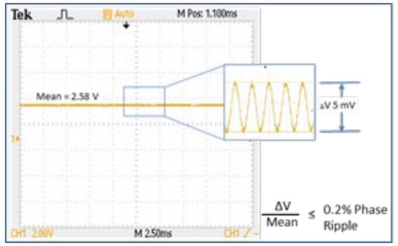
up to 714 Hz

High Power



up to 15 GW/cm²

Low Phase Ripple



as low as 0.2%

SLM1920 x 1152
高速応答>1.4ms

Unique Features:

- High resolution
- High speed
- Pure analog phase control
- High first order efficiency
- High reflectivity
- High power handling
- Compact design
- Wavelengths from 400 – 1650 nm

HDMI Controller

NEW

PCIe Controller to support high frame rates (up to 714 Hz)

各種のアプリケーションに対応

ビームステアリング

光ピンセット

2光子顕微鏡

PSFエンジニアリング

誘導放出抑制顕微鏡法・空間光干渉顕微鏡法

パルスシェーピング

1次元　2次元　3次元ビームステアリング

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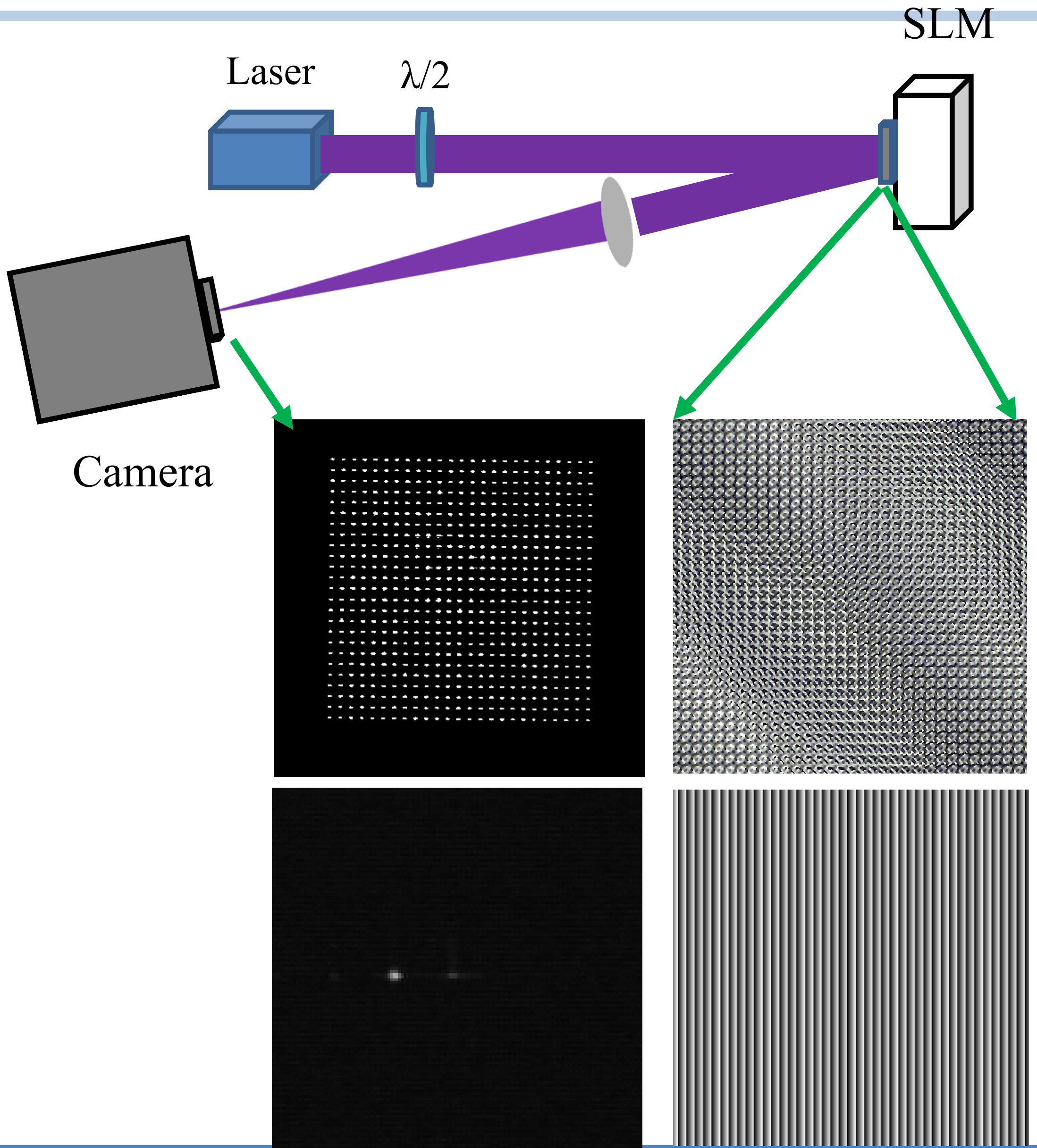
Modulate the phase of a wavefront for beamsteering

1D Beamsteering: essentially the SLM is a programmable prism (1x12288 pixel SLM)

2D & 3D Beamsteering: SLM can simultaneously create multiple foci in a 3D volume (1920x1152, 512x512 SLM)

Applications:
Laser communications
Optical Tweezing
Optogenetics



Real Time Optogenetics in 3D

Locate your Neurons in a 3D volume

↓

Meadowlark Software Computes Hologram →

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光　ピンセット

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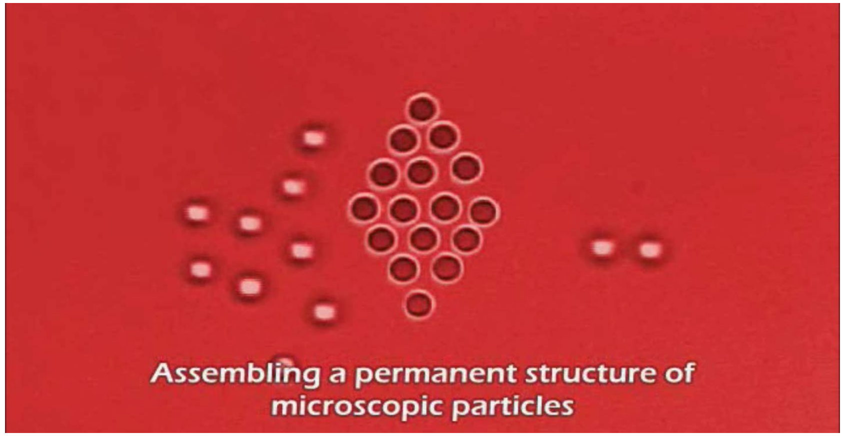
Key concept: Use light to pick up and manipulate objects 10’s of nm to 10’s microns in diameter

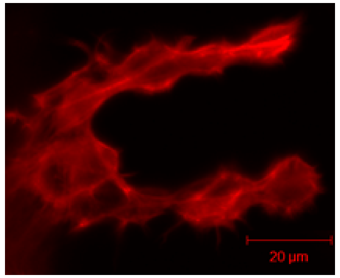
Biological Research

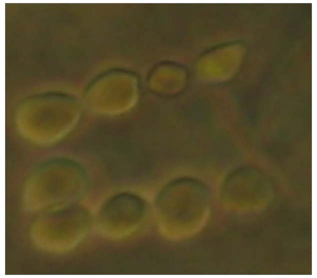
- Studies of Cell Properties
- Bacterial studies (biofilms)
- Tissue Engineering
- Cellular biochemical signaling

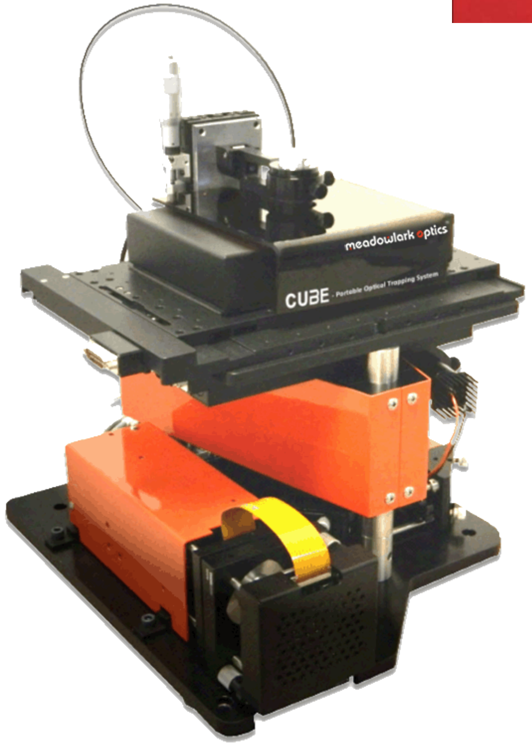
Fundamental Physics

Materials Engineering









光ピンセット光学系

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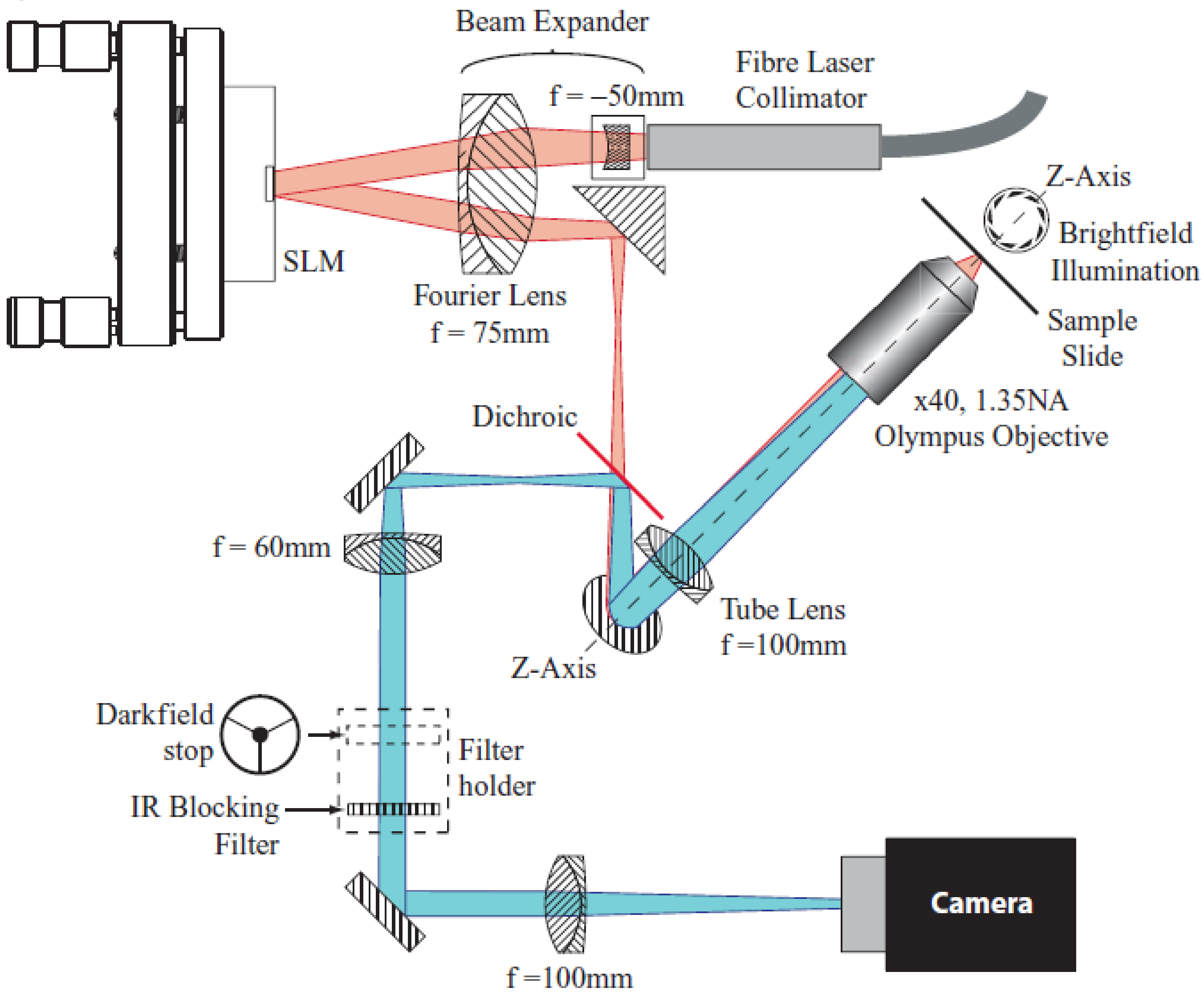


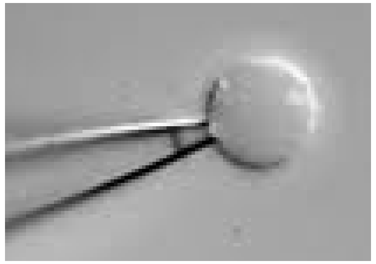
神経科学

- Daunting complexity limits progress
- No new therapeutics for psychiatric disorders since the 1970s
- Alzheimer's alone costs the nation
  - $203 billion (2013)
  - $1.2 trillion (2050)
- Perhaps a problem of tools for research

Patch Clamp

Pro: Signal to Noise

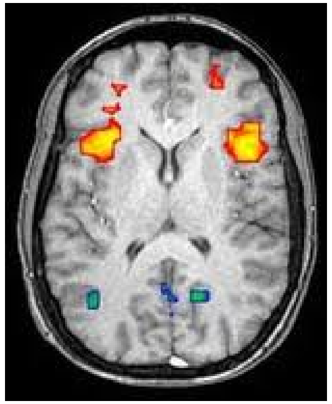
Con: invasive, long term studies impossible, challenging to map neural circuits

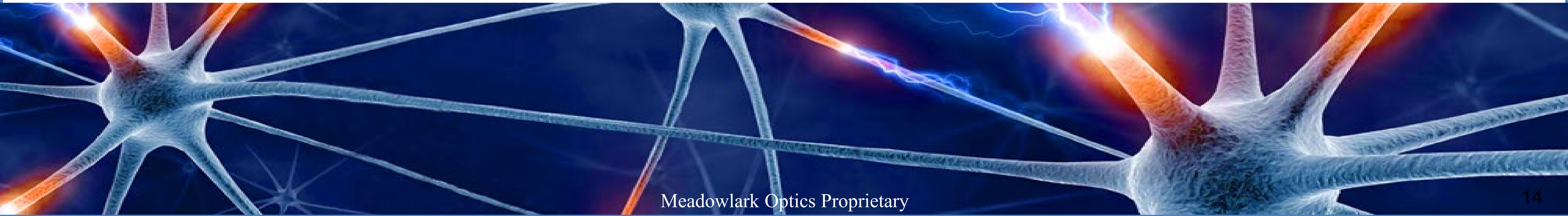


fMRI

Pro: non-invasive

Con: Resolution of few million neurons





カルシウムイメージングと光活性化

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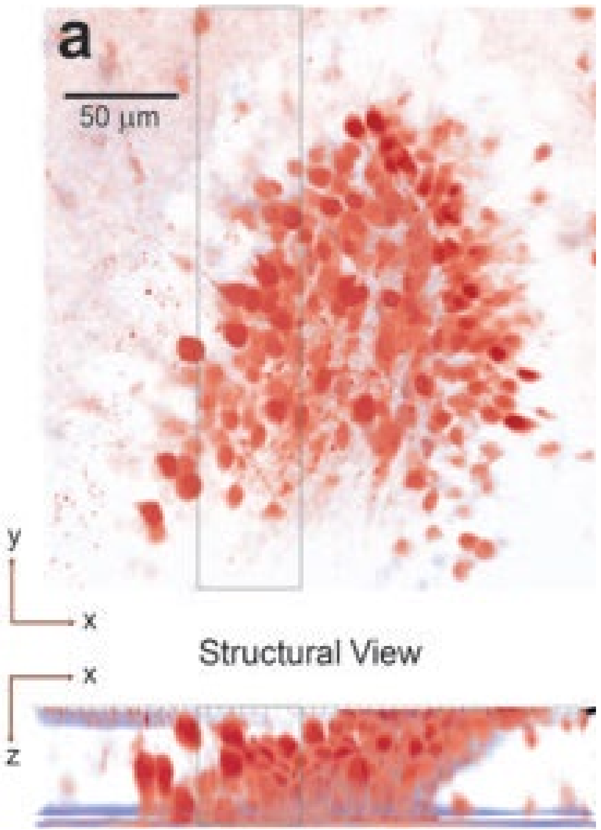
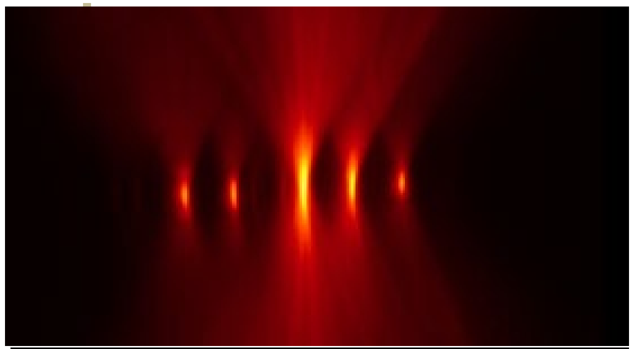
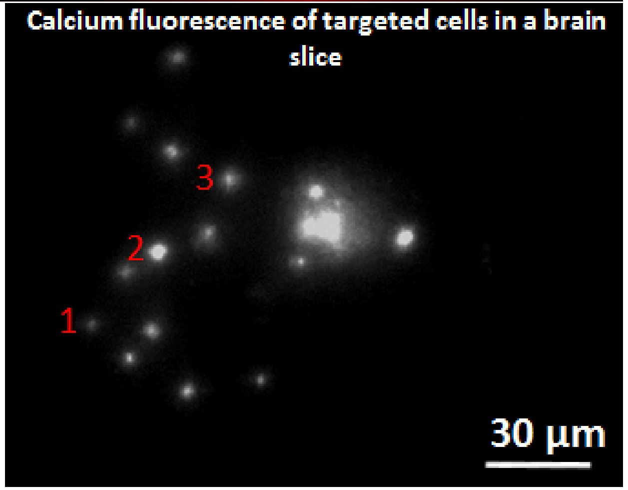
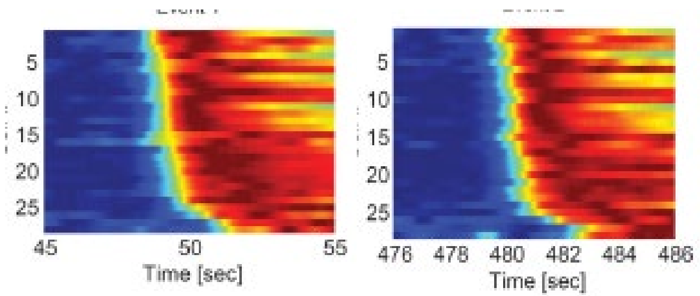
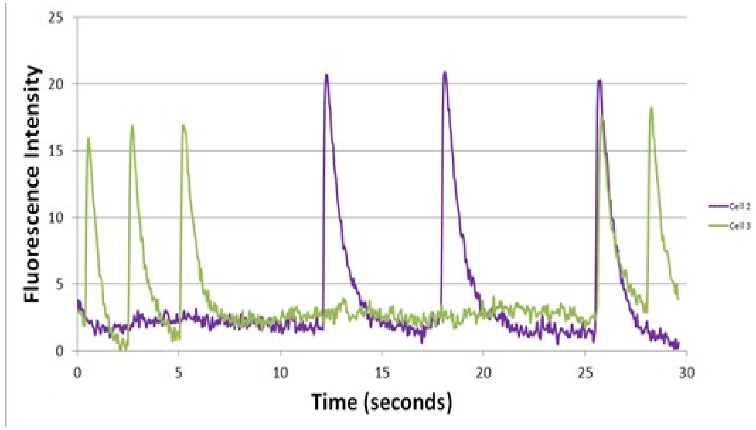








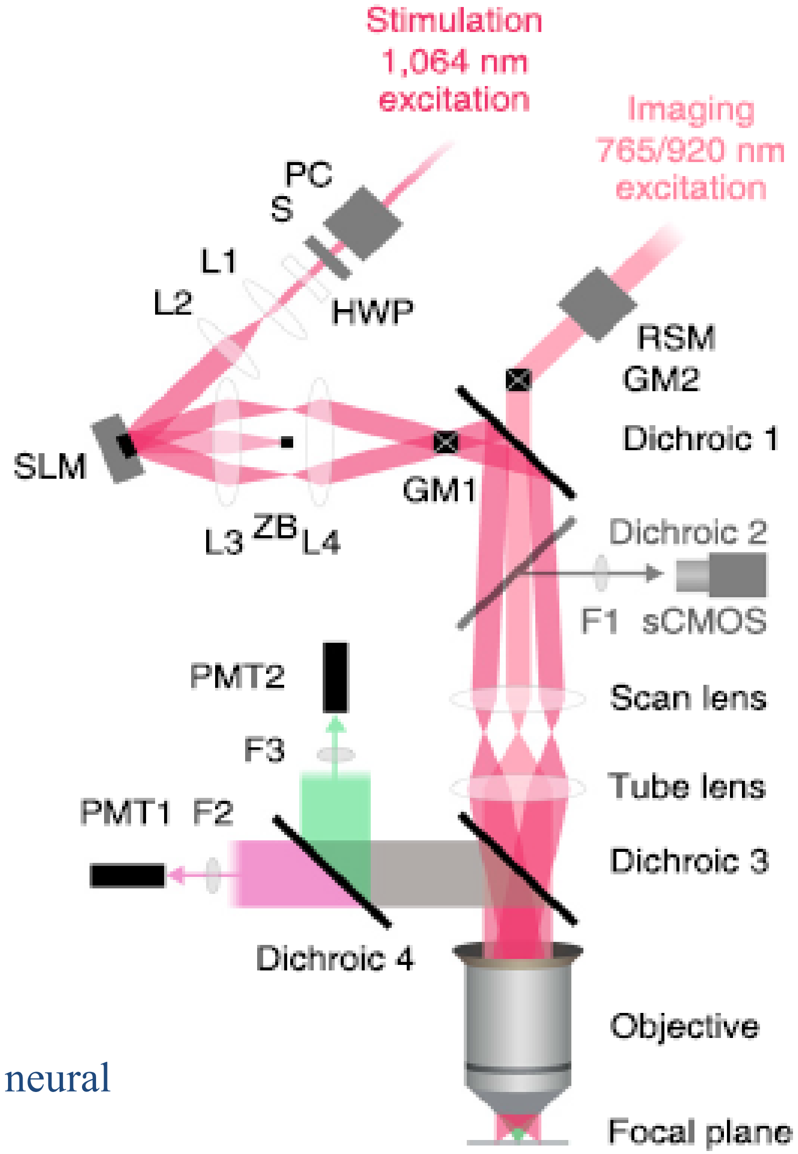
Temporal firing patterns of neural circuits



S. Quirin *et al.* 2014 Simultaneous imaging of neural activity in three dimensions
Linnenberger et al "The Pocketscope: a spatial light modulator based epi-fluorescence microscope for optogenetics"

2光子顕微鏡用SLM

SLM:
512x512 with ODP for speed, AP's at 1kHz
1920x1152 for excitation volume
Ideally you would have both



Packer, Adam M., et al. "Simultaneous all-optical manipulation and recording of neural circuit activity with cellular resolution in vivo." *Nature methods*

横励起: 512x512

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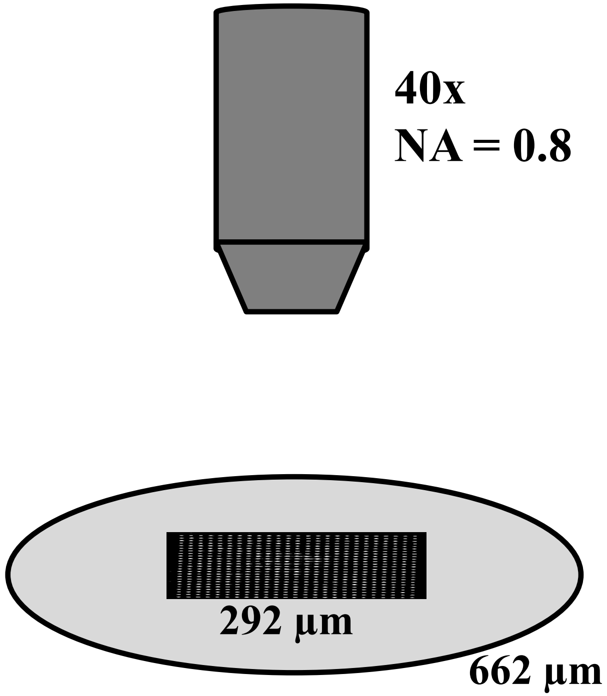
Take objective back aperture to be 7.6 mm in diameter

Objective:
FOV = Field Number/magnification = 26.5/40 = **662 µm**
f_{obj}= f_{tube}/mag = 180 mm / 40 = 4.5 mm

Excitation, 512x512 15 um pixel Pitch
Max steer angle: sin(θ) = mλ/d
λ=.488 µm, d = 15 µm, m = 1
θ = 1.86°
Max Displacement: d = tan(θ)*f **= ± 146 µm**
Excitation waist = 0.6 λ/NA = **0.366 µm**

512x512 spots within an area of 292 µm x 292 µm
Excite ~44% of the FOV
Diffraction Limited Foci



横励起: 512x512

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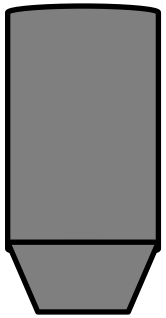
Under-fill the objective with the image of the SLM (reduce the Effective Pixel Pitch)
Sacrifice the Effective NA
L2/L1 = 0.4
Effective Pixel Pitch = 6 µm

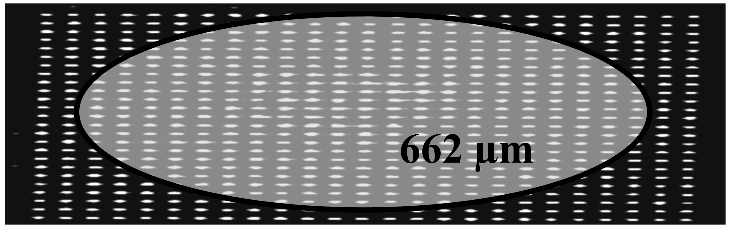
Excitation, 512x512 6 µm pixel Pitch
Max steer angle: $\sin(\theta) = m\lambda/d$
λ=.488 µm, d = 6 µm, m = 1
$\theta = 4.66°$
Max Displacement: d = tan(θ)*f **= ± 367 µm**
Excitation waist = 0.6 λ/NA = **0.915 µm**

512x512 spots within an area of 734 µm x 734 µm
Excite 100% of the FOV
Foci are 2.5x wider

Trade between excitation confinement, and FOV…
How can we do better?



40x
NA_{eff} = 0.32



734 µm

横励起高解像度 1920x1152

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1920x1152 pixel SLM, 9.2 um pixel pitch, 17.6 x 10.6 mm

6.7 µm effective pixel pitch for 7.6 mm back aperture

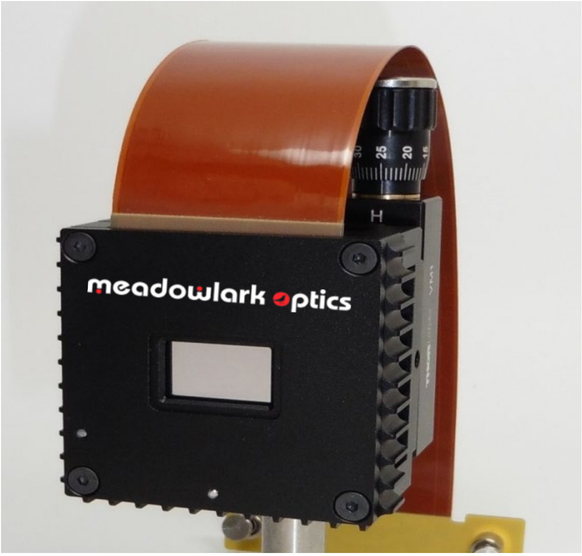
Max steer angle: θ = 4.17°

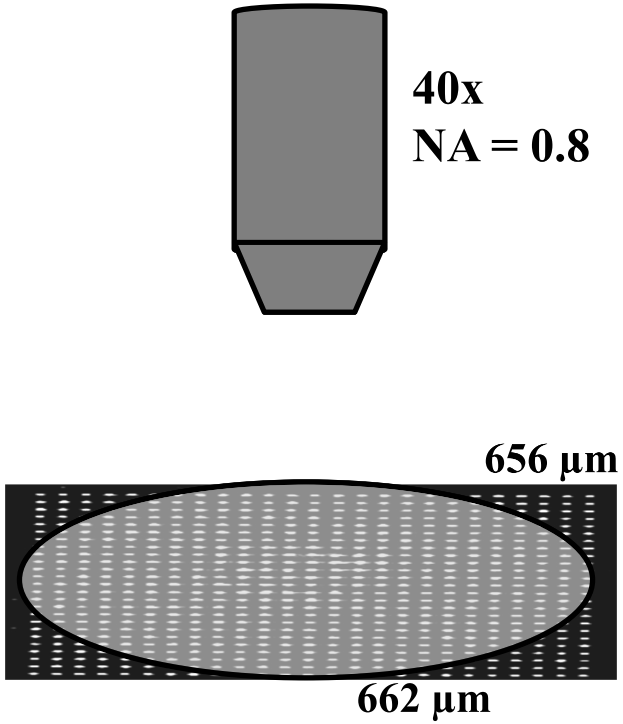
Max Excitation Displacement: d = ± **328 µm**

1152x1152 spots within an area of 656 µm x 656 µm

Excite ~99% of the FOV

Diffraction limited foci





理想的: ハイスピード, 高分解能 1920x1152

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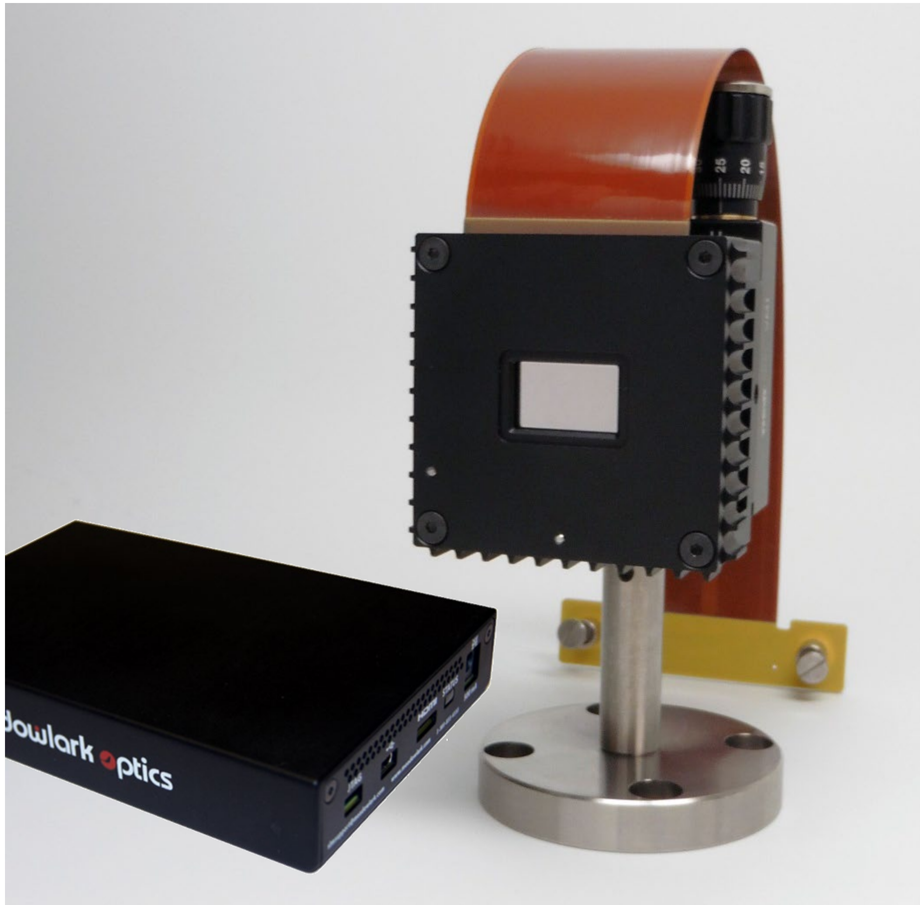
- 10 Volt pixels
- Refresh Rate: 845 Hz
- Response Time: 7 ms at 1064 nm

- Limited by 30 Hz HDMI Controller
- Replace with PCIe controller to enable high speed operation and Overdrive



PSF（点像分布関数）エンジニアリング

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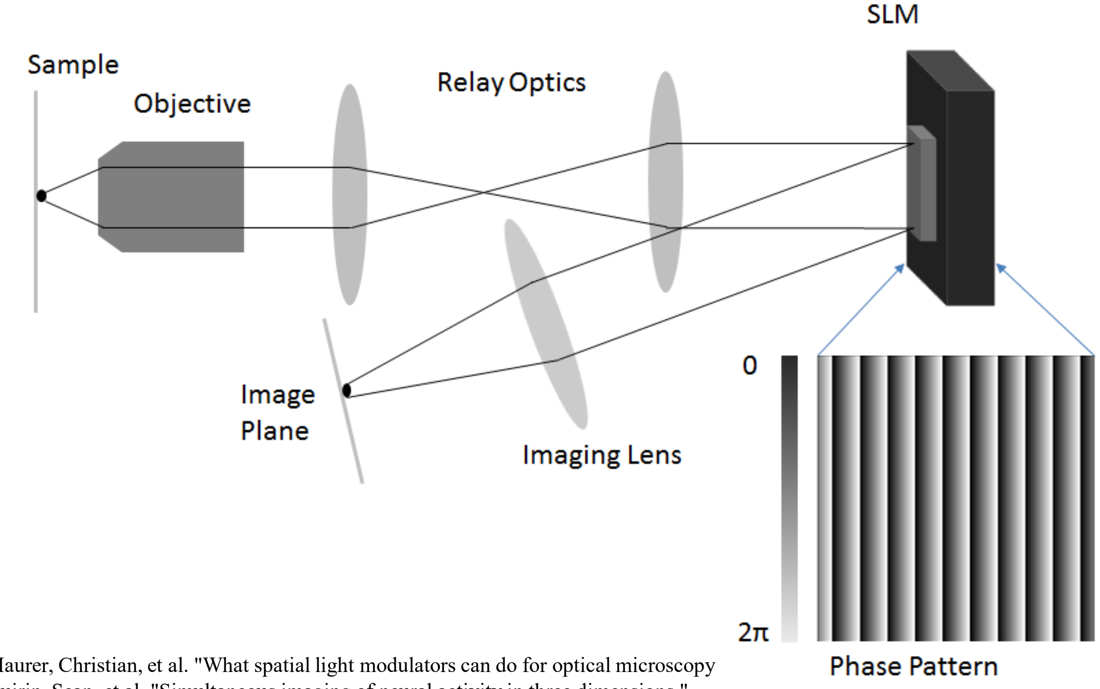
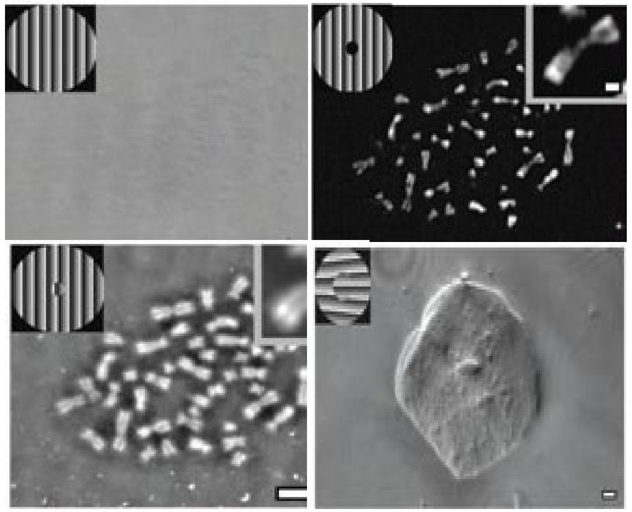
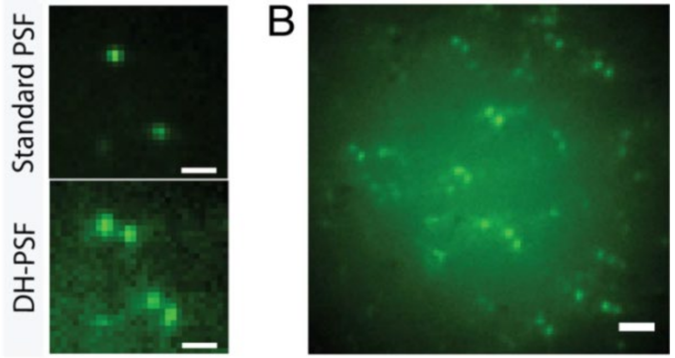
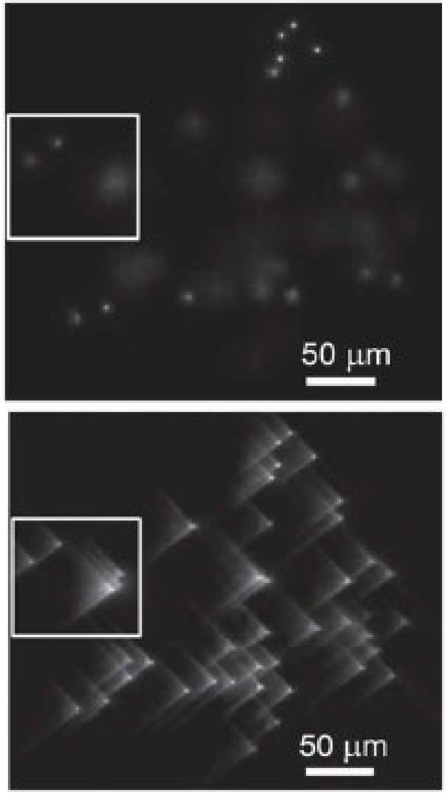
Modulate the phase of an image in a microscope for:
Enhanced contrast (Darkfield, phase contrast, spiral phase)
Super-resolution imaging (double helix)
Extended depth of field imaging

SLM:
512x512 pixel SLM Ideally Polarization Independent SLM









Maurer, Christian, et al. "What spatial light modulators can do for optical microscopy
Quirin, Sean, et al. "Simultaneous imaging of neural activity in three dimensions."
Pavani, et al. "Three-dimensional, single-molecule fluorescence imaging beyond the diffraction limit by using a double-helix point spread function."

PSF エンジニアリング:光学レイアウトの例

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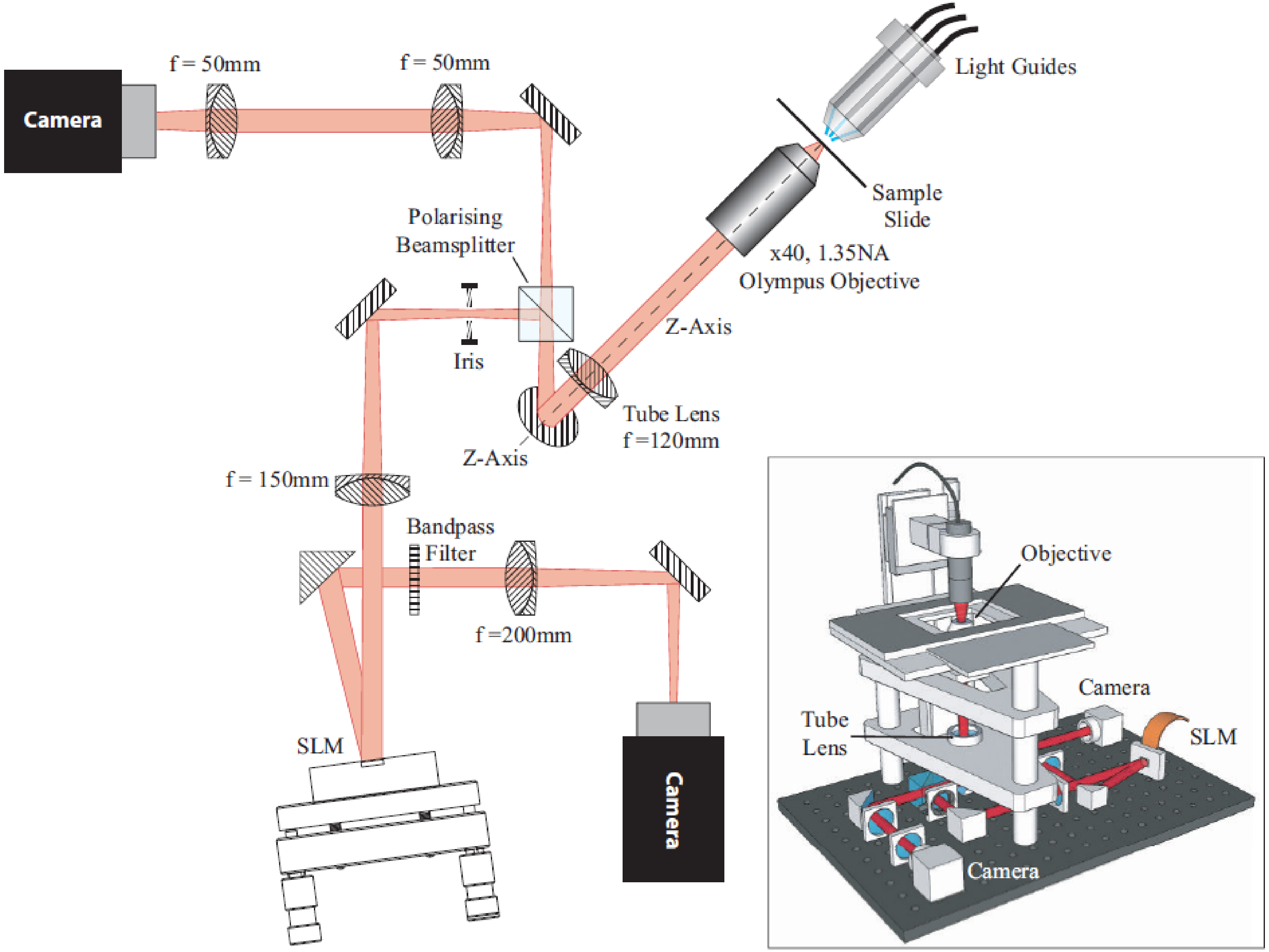

パルスシェービング

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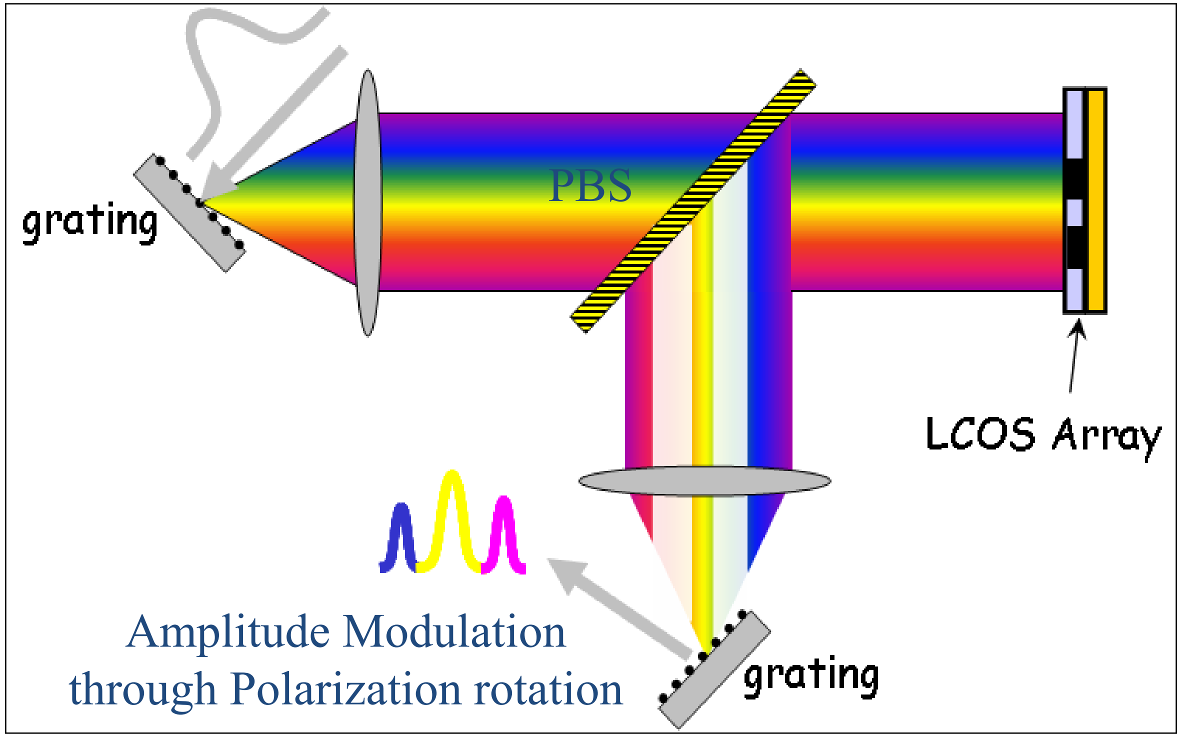
Modulate the phase and/or amplitude of spectral components

- *Use a Grating to spatially separate spectral components*
- *Use diffraction or polarization rotation to provide amplitude modulation*
- *Selectively phase modulate spectral components*

Applications:
Pulse compression (CARS Microscopy)
Scene Generators
Laser machining

SLM:
1x12,288 pixel SLM



誘導放出抑制顯微鏡法

Super-resolution Imaging

- *Use a Gaussian beam to excite fluorescence*
- *Use a Laguerre Gauss beam to suppress fluorescence*
- ***Generally don't need a SLM unless you are doing deep tissue imaging, then you need the SLM to maintain beam quality in the presence of aberrations.***

SLM:
512x512 pixel SLM
1920x1152 pixel SLM

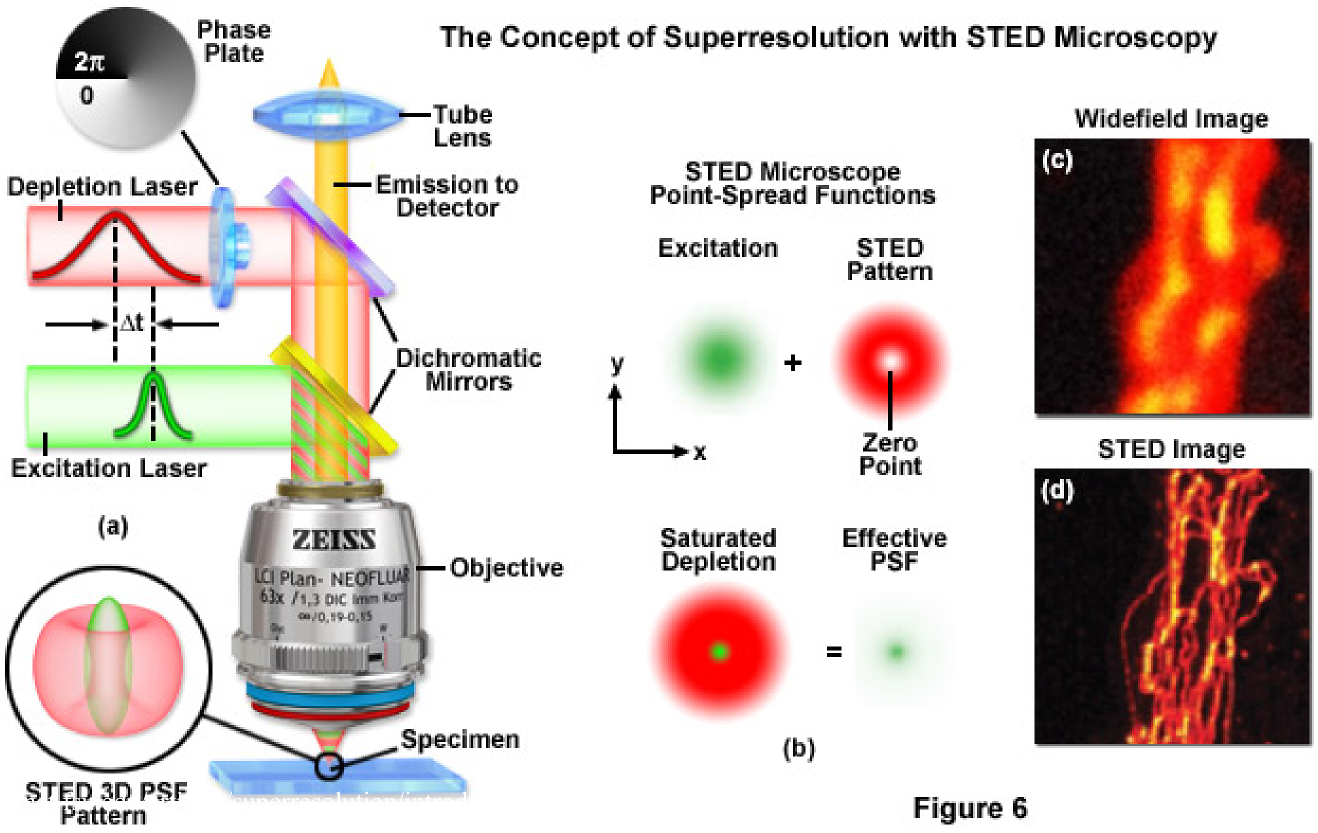


Figure 6

空間光干涉顯微鏡法

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Quantitative phase imaging

- *SLM is placed in the Fourier plane of the image of the sample*
- *The phase of the image is manipulated 4 times allowing for quantitative measurements of optical path difference in objects with weak differences in refractive index*

SLM:
512x512 SLM