HAMAMATSU

PHOTON IS OUR BUSINESS

Spatial Light Modulators

LCOS-SLM

Applications and Features

(Laser processing / marking, etc.)

CONTENTS

July 2020

Structure / Specifications

The LCOS-SLM X15213 series is a reflective liquid crystal device that can control the wavefront of light with high efficiency and high precision by phase modulation.
It consists of a head and a controller connected by a flexible cable.

Structure

Head

Type No.	Number of pixels	Pixel pitch (μm)	Effective area size (mm)	Fill factor (%)	Weight (g)
X15213 series	1272 × 1024	12.5	15.9 × 12.8	96	150 (Water cooled type: 550)

Controller

Type No.	Supply voltage AC (V)	Power supply frequency (Hz)	Weight		Input signal	DVI signal format (pixels)	Input signal level (levels)	DVI frame rate (Hz)	Power consumption (W)
			Main unit (g)	Including cable (g)					
X15213 series	100 to 230	50/60	910	1350	DVI-D/ USB-B (2.0 High-speed)	1280 × 1024	256	60	15

▪ X15213 series

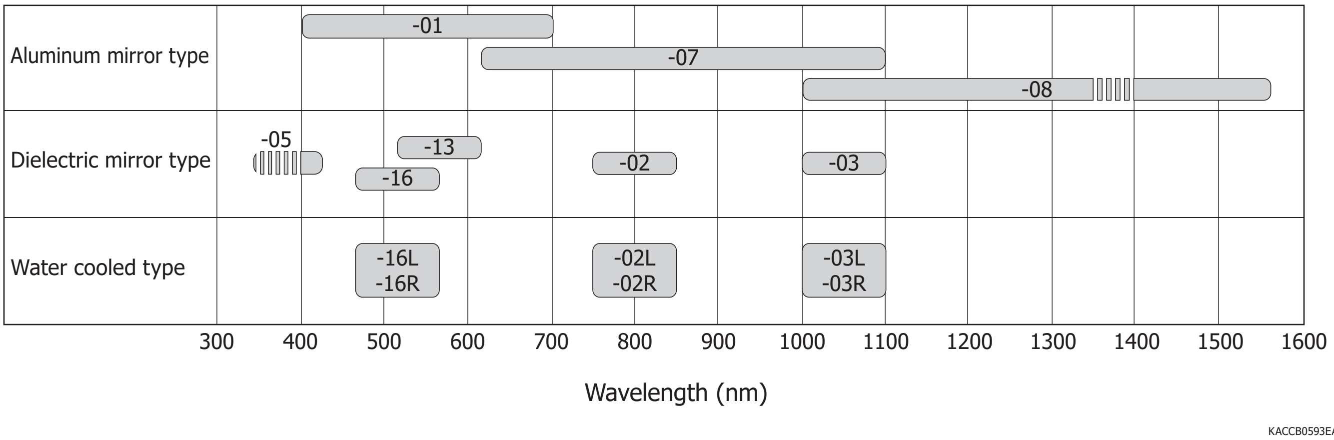
Head

Controller

Selection guide

There are eight types in the X15213 series, which cover different wavelengths of light sources. They can be grouped into dielectric mirror types (-02/-03/-05/-13/-16) and aluminum mirror types (-01/-07/-08). To enhance the reflectivity of the device, dielectric mirror types have dielectric mirrors corresponding to different wavelengths of laser light source. [-02: titanium sapphire laser (800 nm band), -03: YAG laser (1064 nm), -05: LD (405 nm), -13: YAG laser 2nd harmonic (532 nm)/He-Ne laser (633 nm), -16: YAG laser 2nd harmonic (532 nm)]. The increased reflectivity achieved by the dielectric mirror decreases the internal absorption rate. This allows accommodation for high powered lasers, but the covered wavelength range is narrowed. Aluminum mirror types use reflections from the aluminum electrodes on the CMOS chip. The reflectivity is inferior to that of the former, but the reflection wavelength range is wider, covering a range of 400 nm to 1550 nm with just three types. For the wavelength band between 1350 and 1400 nm on the -08 type, the reflectance degrades about 5% due to the absorption by the glass substrate. Dielectric mirror types for the 532 nm band are available in - 13 and -16. The -16 is designed to be more light-resistant to short-pulse lasers than the -13.

Spectral response



Electric and optical characteristics

Type No.	Reasout light wavelength (nm)	Light utilization effidiency typ. (%)	Rise time* (ms)	Fall time* (ms)
X15213-01	400 to 700	79 (633 nm)	5 (633 nm)	25 (633 nm)
X15213-02	800 ± 50	97 (785 nm)	30 (785 nm)	80 (785 nm)
X15213-02L				
X15213-02R				
X15213-03	1050 ± 50	97 (1064 nm)	25 (1064 nm)	80 (1064 nm)
X15213-03L				
X15213-03R				
X15213-05	410 ± 10	97 (405 nm)	10 (405 nm)	20 (405 nm)
X15213-07	620 to 1100	82 (1064 nm)	10 (1064 nm)	80 (1064 nm)
X15213-08	1000 to 1550	82 (1064 nm)	30 (1064 nm)	140 (1064 nm)
X15213-13	530 to 635	97 (532 nm)	10 (532 nm)	25 (532 nm)
X15213-16	510 ± 50	97 (532 nm)	11 (532 nm)	34 (532 nm)
X15213-16L				
X15213-16R				

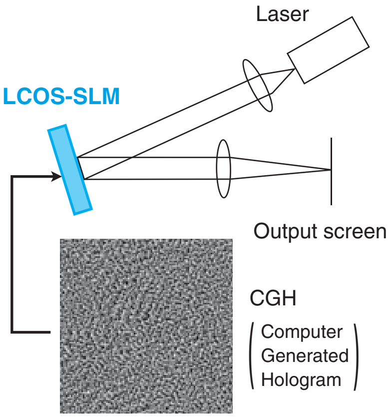
* Time required to change from 10% to 90% for 2π modulation (typical value)

Technologies

Optical beam shaping technology

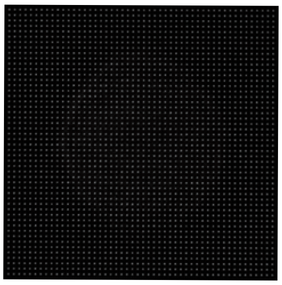
Unlike conventional intensity modulation techniques using masks to block out light to form a desired optical pattern, the LCOS-SLM redistributes the light to generate light patterns efficiently by using phase type holograms.

Optical system

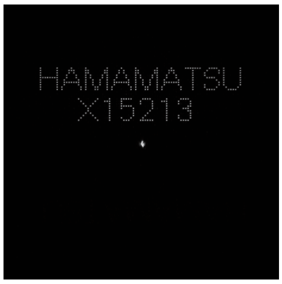


✓ High efficiency achieved through maskless design.

2D code reconstructed image with 0th order light suppression



Multi-point generation (50×50) with 0th order light suppression



Example of character reconstruction

Aberration correction technology

Imaging performance is degraded largely by aberrations that are wavefront distortions on any kind of optical system. In a microscope, the aberrations cause lower resolution and contrast, and in laser processing, they cause lower processing quality and efficiency, for example. An optimum optical system can be achieved by controlling the wavefront to cancel its distortion.

When aberrations remain

△ Aberrations (wavefront distortions) affect imaging performance.

- Decreased resolution and contrast during microscope observation
- Decreased processing quality and efficiency

When aberrations on the wavefront remain...

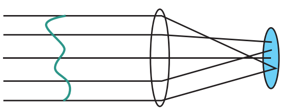
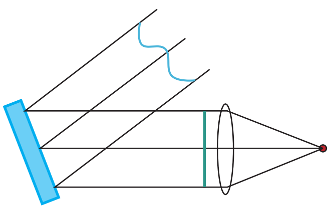


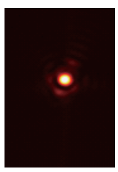
Image gets blurry since focusing spots are spread out.

When aberrations are corrected by LCOS-SLM

✓ An optical system is optimized by controlling the wavefront to correct aberrations.

Correction of distortion in the wavefront





Focusing close to diffraction limit can be achieved.

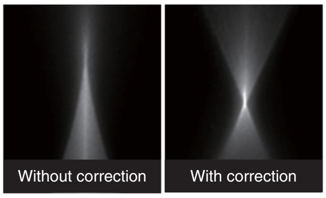
Applications

Multi-point laser material processing

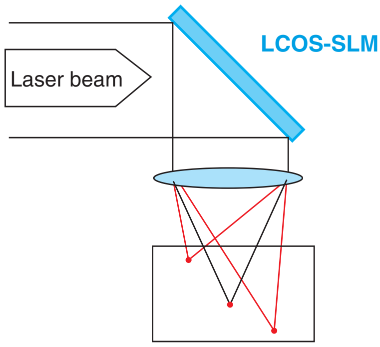
Simultaneous processing with holographic beam-shaping technology

Optical pattern forming technology allows generating multiple laser beams, so high throughput can be achieved by simultaneous multi-point processing. Furthermore, an unprecedented laser processing can be realized by controlling the 3D space including the depth rather than just the 2D plane.

- ✓ High speed by multi-point processing
- ✓ Depth controllable
- ✓ Simultaneous aberration correction

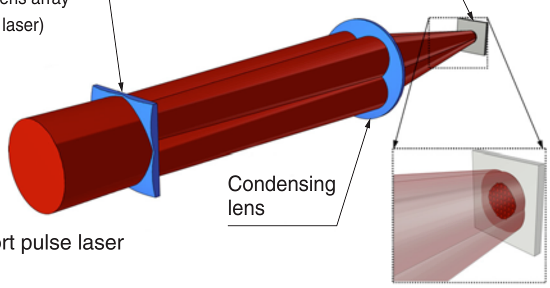


Lateral view of focusing beams



* Joint research with Kyoto University and New Glass Forum in NEDO project

Super-fine multi-point simultaneous laser processing with multiple beam interferometer



Part that is enhanced by interference only is processed.
(process by wavelength order)

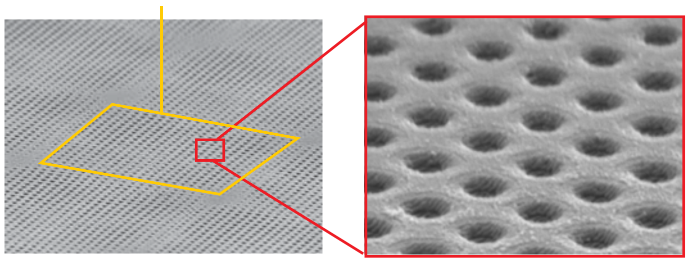
■ Processing examples

ITO layer removal

Laser : Manufactured by Hamamatsu
Ultra-short pulse laser
MOIL-ps L11590
SHG 515 nm

Processing area : about 500 holes made

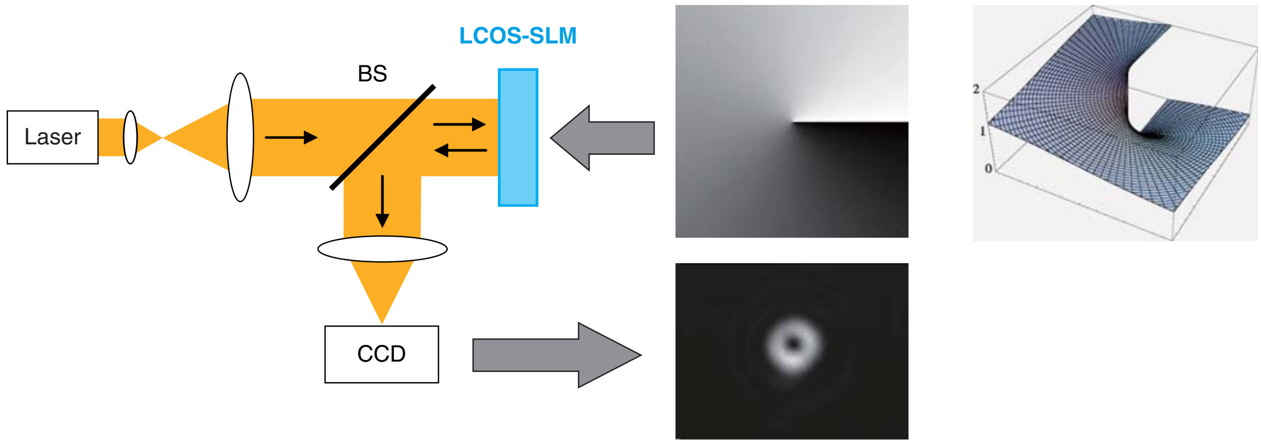
Hole size : 1.5 μm max. in diameter



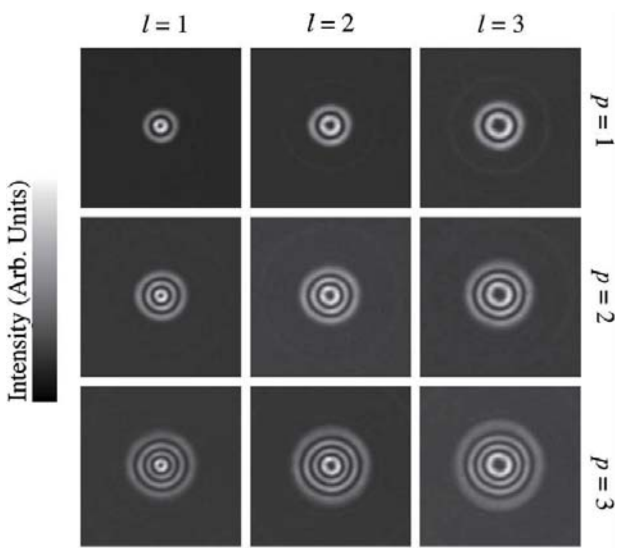
Optical vortex generation

Optical vortex can be generated with a spiral phase distribution modulated by an LCOS-SLM.

Optical system



Result of high order beam generation



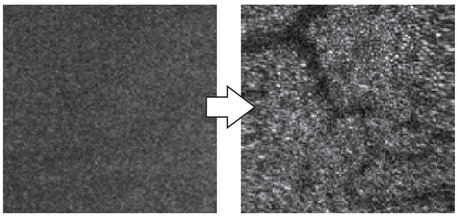
Related thesis

- Structure of optical singularities in coaxial superpositions of Laguerre-Gaussian modes
  Journal of the Optical Society of America A
  Vol. 20 No. 2 (2013)133-138

Fundus imaging system using adaptive optics

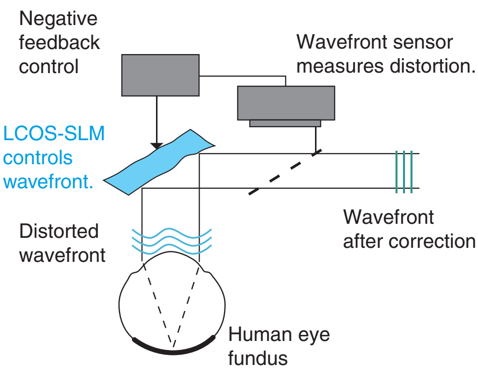
Dynamically eliminates human eye aberrations for high-resolution ocular fundus imaging.

✓ Visual cells can be discerned



Fundus image before correction | Fundus image after correction

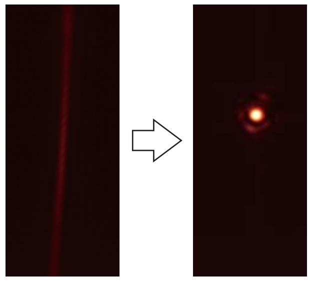
* Under joint development with NIDEK in NEDO project



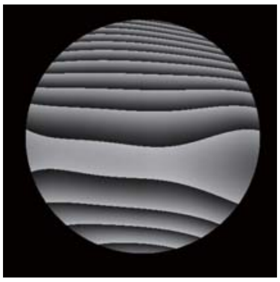
Experiemental example of dinamic wavefront correction

Improvement with adaptive optics

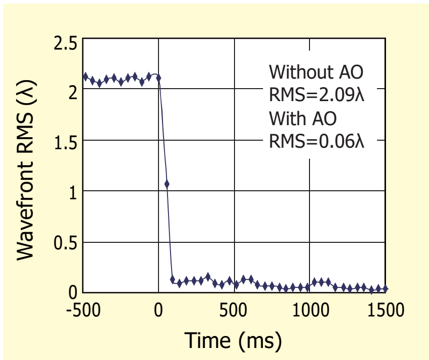
· Beam size	< 1/25
· Peak intensity	> 12 times
· PV value (Peak to Valley)	> 10 λ



Wavefront before correction | Wavefront after correction



Aberration



Optical manipulation (optical tweezers)

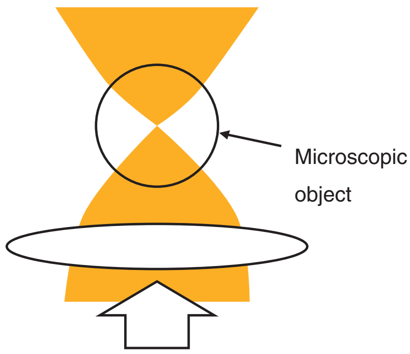
Wavefront control for efficient and precise manipulation

Technology for trapping microscopic objects by optical pressure

Biology and science fields need equipment able to handle microscopic objects in large quantities with high precision.

- **Multi-point control**
- **3D control**
- **Beam shape control**

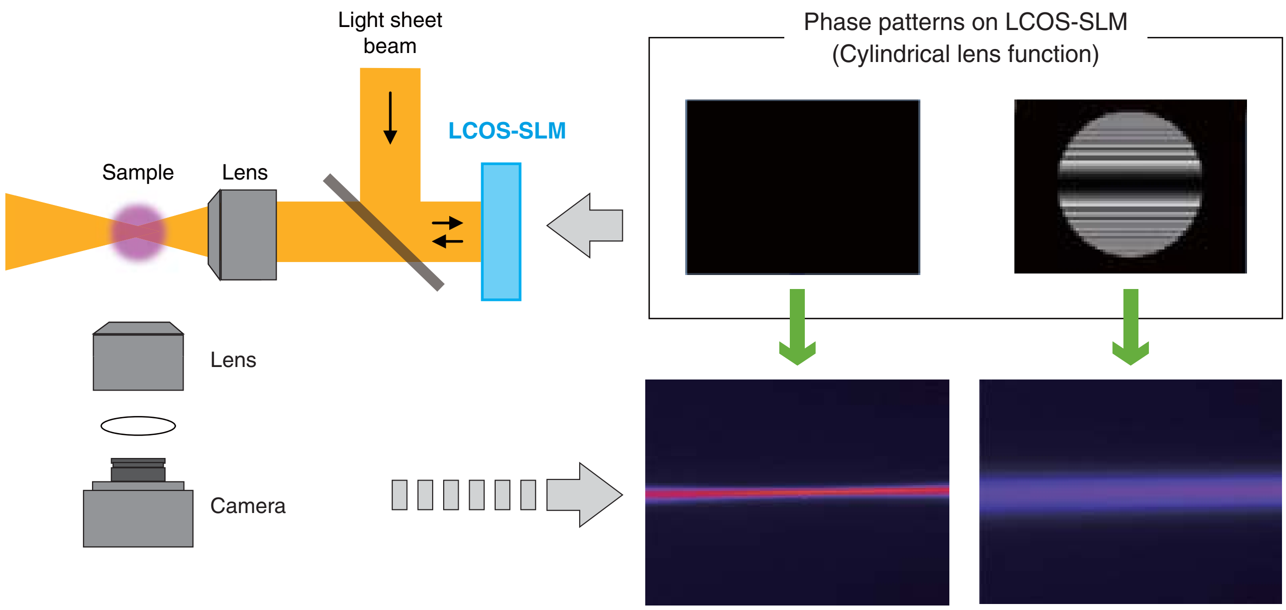
→ Optical manipulation
Micro-force measurement



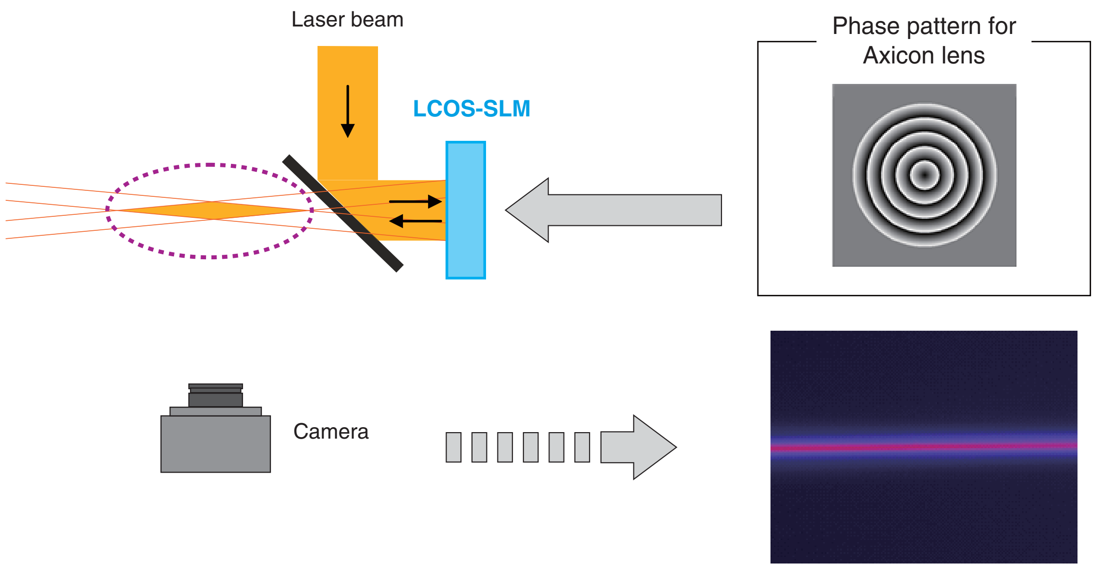
Beam control: lens function and non-diffractive beam generation

Various beams can be generated and controlled by displaying phase images for lens functions, Bessel beam generation, etc. in the LCOS-SLM, which is expected to be applied to cutting-edge applications such as light sheet microscope, etc.

Cylindrical lens functions

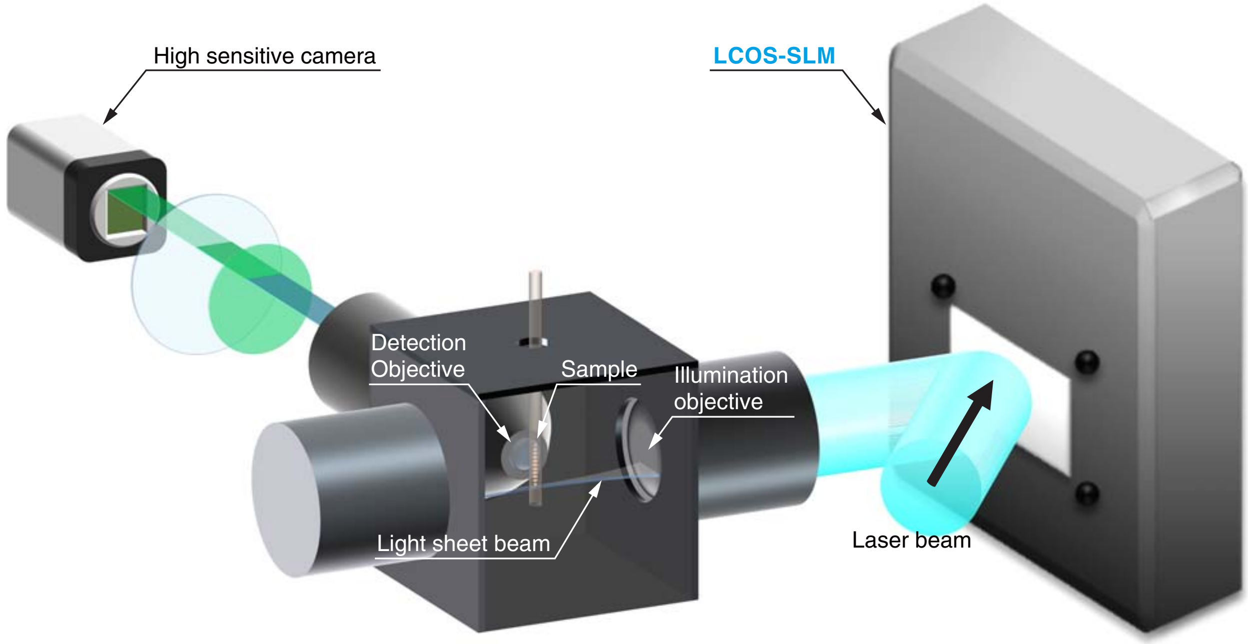


Non-diffractive beam generation



Light sheet microscopy

Light sheet microscopy is one of fluorescent microscopic techniques used for bio-imaging, which can make dramatic reduction of photo toxicity and photo bleaching possible by illuminating a focal plane of a sample only. A lot of beams are being developed as illumination light sources, and a high sensitive camera is used for detection.



LCOS-SLM for material proccessing laser

An optimum LCOS-SLM corresponding to each laser for material processing is indicated in the table below.
Unprecedented laser processing can be realized by controlling 3D spaces including depth direction rather than just the processing points on a 2D plane.

Laser type	Yb:YAG, Yb:Fiber	Nd:YAG	Ti:S	Nd:YAG	Nd:YVO4	Yb:YAG, Yb:Fiber
Wavelength (nm)	515	532	800	1064	1064	1030
Optinum LCOS-SLM	X15213-16	X15213-13 X15213-16	X15213-02	X15213-03	X15213-03	X15213-03

Damage type

Damages to LCOS-SLM can be categorized into the 3 types below.

① Thermal damage to liquid crystal layer
② Erosive damage to dielectric mirror or aluminum mirror
③ Optical damage to liquid crystal material

Thermal damage occurs from excessive input power, and the likely phenomena are described in order as below:

① Optical absorption at each constituent material of LCOS-SLM
② Temperature increase caused by absorption of light energy
③ Degradation of birefringence caused by temperature increase of liquid crystal
④ Disappearance of birefringence when liquid crystal temperature reaches phase transition temperature
⑤ Irreversible deterioration caused by liquid crystal boiling when temperature increase reaches the limit

The above mentioned thermal damages can be prevented by monitoring the characteristic of birefringence.
Erosive damage occurs from excessive peak input power that is beyond a threshold level, and the damage cannot be reversed.

Power handling capability

LCOS-SLM might be damaged by high-power lasers even though it has high reliability in general. The measurement examples of laser irradiation are indicated in the tables below.

Type-02

Light source				Beam size [at 1/e ²]	Irradiation time	Irradiation intensity		Peak power		Result	
Type	Wavelength	Pulse width	Repetition frequency			Average output power	Output power per area	Peak output power	Output power per area	Damage	Characteristic change
Ti:S laser (pulse)	800 nm	50 fs	1 kHz	Φ9 mm	3 hours	2.7 W	4.3 W/cm²	108 GW	170 GW/cm²	None	Seen
Ti:S laser (pulse)	800 nm	50 fs	1 kHz	Φ11 mm	10 hours	2.7 W	2.9 W/cm²	108 GW	114 GW/cm²	None	None
Ti:S laser (pulse)	800 nm	30 fs	0.01 kHz	Φ18 mm	6 hours	0.05 W	0.02 W/cm²	333 GW	131 GW/cm²	None	None

Type-03

Light source				Beam size [at 1/e ²]	Irradiation time	Irradiation intensity		Peak power		Result	
Type	Wavelength	Pulse width	Repetition frequency			Average output power	Output power per area	Peak output power	Output power per area	Damage	Characteristic change
YAG laser (CW)	1064 nm	-	-	Φ2.5 mm	1 hour	2.0 W	40.7 W/cm²	-	-	None	None
YAG laser (CW)	1064 nm	-	-	Φ2.5 mm	Several minuits	3.5 W	71.3 W/cm²	-	-	None	Seen
YAG laser (pulse)	1064 nm	200 ns	80 kHz	Φ2.5 mm	1 hour	2.0 W	40.7 W/cm²	0.25 KW	5.1 KW/cm²	None	None
YAG laser (pulse)	1064 nm	200 ns	80 kHz	Φ2.5 mm	Several minuits	3.5 W	71.3 W/cm²	0.44 KW	8.9 KW/cm²	None	Seen
Pulse laser	1030 nm	670 fs	1 kHz	Φ4.5 mm	10 hours	0.6 W	3.8 W/cm²	1.8 GW	11.3 GW/cm²	None	None
Pulse laser	1030 nm	1.37 ps	30 kHz	Φ8.11 mm	8 hours	5.2 W	10.1 W/cm²	0.25 GW	0.49 GW/cm²	None	None
Pulse laser	1030 nm	11.4 ns	10 kHz	Φ13 mm	8 hours	17.4 W	13.1 W/cm²	0.31 MW	0.23 MW/cm²	None	None

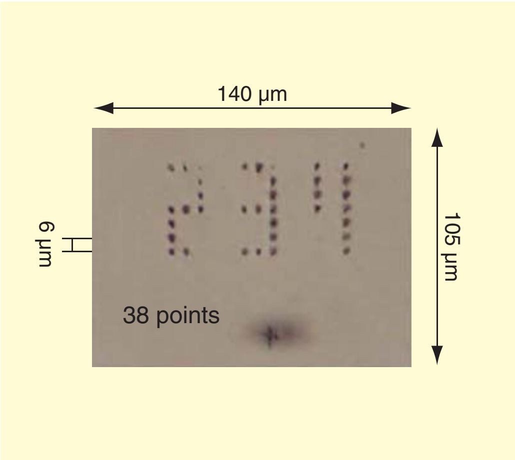
Type-13

Light source				Beam size [at 1/e ²]	Irradiation time	Irradiation intensity		Peak power		Result	
Type	Wavelength	Pulse width	Repetition frequency			Average output power	Output power per area	Peak output power	Output power per area	Damage	Characteristic change
Pulse laser	515 nm	0.91 ps	30 kHz	Φ9.1 mm	8 hours	1.8 W	2.6 W/cm²	132 MW	203 MW/cm²	None	None
Pulse laser	515 nm	0.92 ps	30 kHz	Φ9.5 mm	8 hours	3.2 W	4.9 W/cm²	234 MW	331 MW/cm²	None	Seen
Pulse laser	515 nm	14.4 ns	10 kHz	Φ12.8 mm	8 hours	4.3 W	3.3 W/cm²	25 KW	38 KW/cm²	None	None

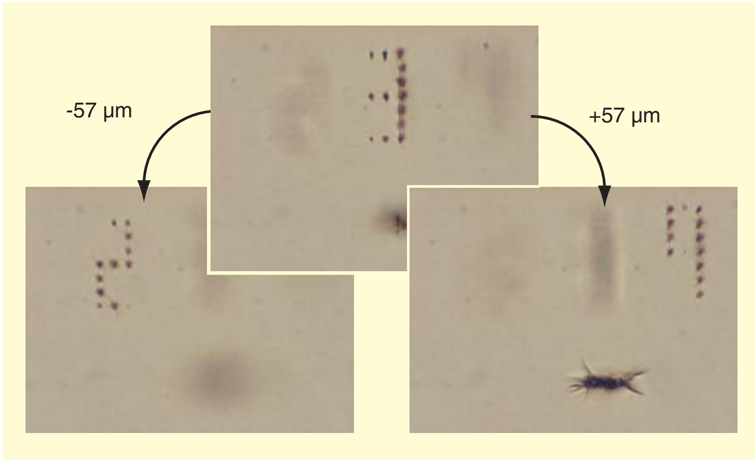
Image gallary

Insite of glass is processed with CGH projection of fs laser

2D processing



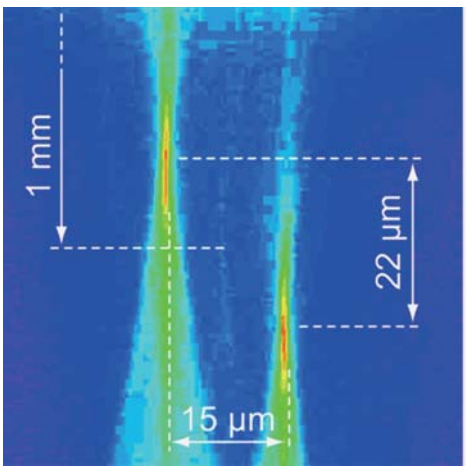
1-step 3D processing



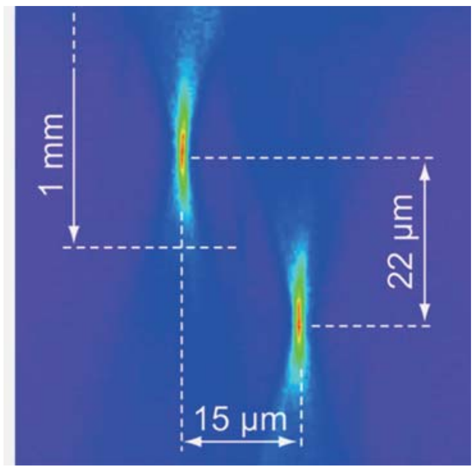
- Objective lens : NA=0.3 (Nikon)
- Irradiation intensity : 250 mW (ϕ8 mm aperture)
- BK7

Laser beam condensation inside transparent material

Without aberration correction



With aberration correction



Features

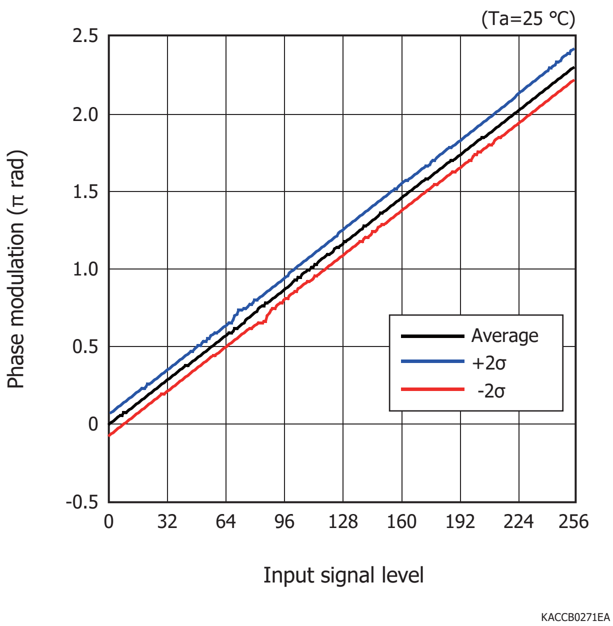
Feature 1 **High light utilization efficiency**

The X15213 series have high light utilization efficiency, which is defined a ratio of the 0th order diffraction light level to the input light level. The high light utilization efficiency mainly depends on reflectivity, and the amount of diffraction loss caused by the pixel structure. We adopted advanced CMOS technology to make the diffraction loss smaller. As a result, the diffraction loss is less than 5%. The -02/-03/-05/-13/-16 types have a dielectric mirror which has high reflectivity. Therefore, these types have very high light utilization efficiency. The -01/-07/-08 types have relatively low light utilization effi ciency compared to the ones with the dielectric mirror but have wide spectral response characteristics.

Feature 2 **Pure, linear and precise phase control**

The X15213 series can achieve phase modulation of more than 2 π radians over the 400-1550 nm readout wavelength range. The X15213 series comes pre-calibrated from the factory for a specified wavelength range to have more than 2 π radians of phase modulation and its linear characteristics. The figure below shows typical phase modulation characteristics. A phase shift of 2 π radians or more and a linear phase response are achieved. The phase modulation curves for 95% pixels lies within +/- 2 σ.

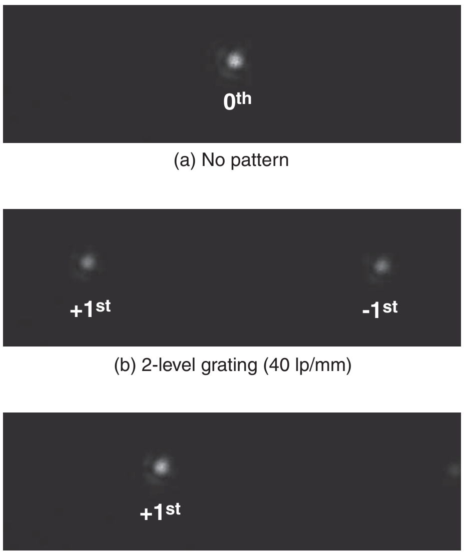
■ **Phase modulation**



Feature 3 High diffraction efficiency

The X15213 series is a pure phase SLM with high precision phase control; therefore, it has high diffraction efficiency close to the theoretical values. The left figure shows images of diffracted spots, when a multi-level phase grating is formed in the X15213 series. The right figure shows typical diffraction efficiency characteristics. The diffraction efficiency here is the ratio of the 1st order diffraction intensity to the 0th order intensity of light without modulation (no pattern).

■ Diffracted spots images

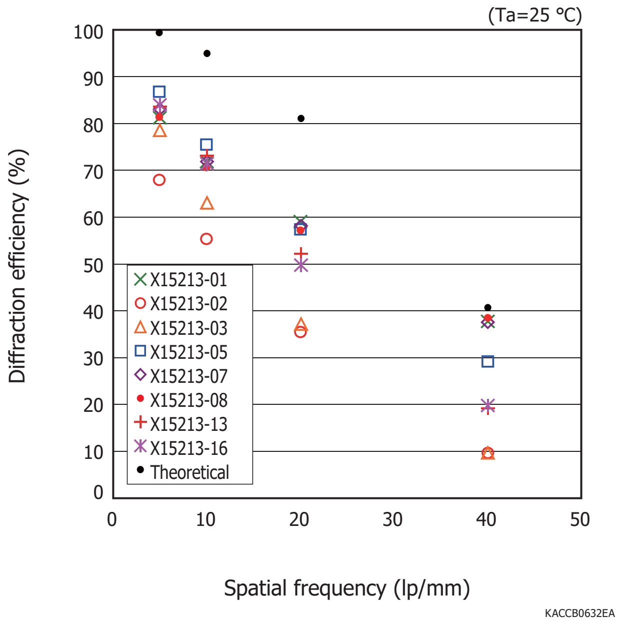


(a) No pattern

(b) 2-level grating (40 lp/mm)

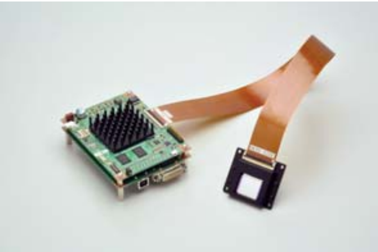
(c) 4-level grating (20 lp/mm)

■ Diffraction efficiency (typical example)

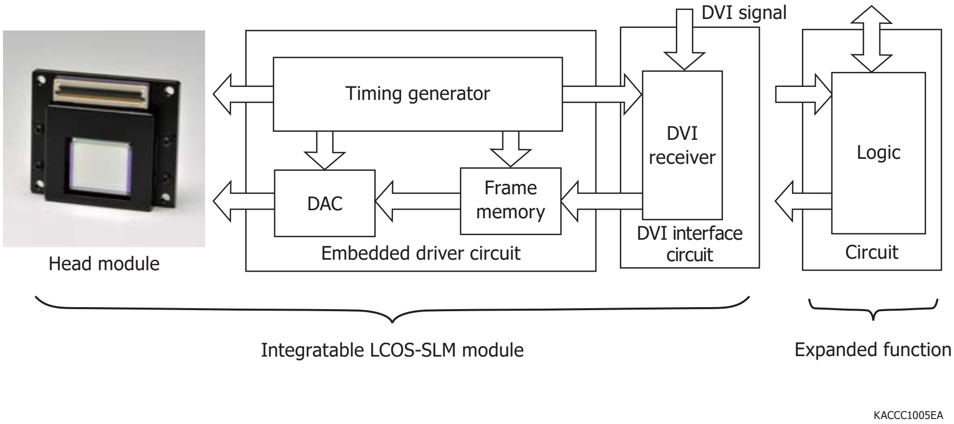


Related product "LCOS-SLM embedded module X15223 series"

A compact and low cost driver circuit is connected to a compact head module with a flexible cable. A phase only spatial light modulator can be integrated easily for industrial applications.



■ Block diagram



FAQ

Q: Do you develop the LCOS-SLM system and the LCOS chip itself in-house?

A: Yes, the whole system including the CMOS backplane and optical thin film is designed and manufactured in-house by HAMAMATSU. This means that the LCOS-SLM is individually optimized to the readout laser and the specific application.

Q: Can you offer custom LCOS-SLM?

A: Yes, as mentioned above, all parts of the LCOS-SLM are designed in-house at the HAMAMATSU factory, meaning that there is a higher degree of flexibility with regard to providing customized LCOS-SLM. Please contact us with your exact requirements, and we'll see what we can do.

Q: Do we need to make baseline measurements for correcting the device characteristic and flatness?

A: No, all LCOS-SLMs are delivered with a linear phase characteristic data, and an individual flatness correction data is provided.

Q: Does your LCOS-SLM show phase fluctuations/flickering?

A: We use carefully designed control electronics to electrically drive the LCOS chip. Consequently, the phase fluctuations and flickering are negligible. For further information, please consult us and we can provide further details.

Q: What is the light utilization efficiency of the LCOS-SLM X15213 series?

A: The total light utilization efficiency is related to the reflectivity and the diffraction loss of the pixel structure. The reflectivity is determined by the “mirror” characteristics of either an aluminum mirror or the highly reflective dielectric mirror with up to 97% reflectivity. Also the pixel fill factor is relevant to minimizing diffraction losses due to the pixel structure (the higher fill factor the better). The diffraction loss is dependent on several factors of the LCOS-SLM design like pixel size, fill factor and LC material.

Q: Is there a special interface needed to control the LCOS-SLM?

A: No, all you need is to use a standard graphics card with a DVI-D output, ideally a card with two DVI-D ports to connect to a monitor and to the LCOS-SLM.

Q: What is the laser damage threshold?

A: It depends if you use the -01/-07/-08 with an aluminum mirror or the -02/-03/-05/-13/-16 with the dielectric mirror. The latter can withstand much higher CW and pulsed laser powers. We tested several lasers, and you can find the results in the LCOS-SLM “Technical Information” (ask us for a copy). If your special laser parameters are not listed, please ask us and we are happy to help ensure you use the LCOS-SLM safely.

Q: What wavelengths does LCOS-SLM operate at?

A: We have a range of LCOS-SLM to cover wavelengths between 400 nm and 1550 nm.

Q: What kind of LCOS-SLM do you manufacture?

A: Our LCOS-SLM uses parallel-aligned, nematic liquid crystals and a CMOS backplane for the addressing. They are reflective devices.

Q: Do you offer demo loans?

A: Yes, we can provide you with a demo system. You can then use the LCOS-SLM in your lab and test its performance directly within your setup. Please contact us to discuss your experiment and arrange the schedule. This demo loan is free of charge for you. We kindly ask you to send it back to our office and summarize your findings on completion of the loan.

Q: Do you got a price list for the SLM?

A: The LCOS-SLM is individually optimized for the user’s application and readout laser, so please call or e-mail us to determine which LCOS-SLM will be optimal for your application and we’ll provide quotations right away.

Q: What is the delivery time of the LCOS-SLM?

A: The standard delivery time will depend on the manufacturing cycle. The typical lead time is six to eight weeks from receipt of order though sometimes deliveries can be shorter than this, and we do hold some LCOS-SLM in loan stock should something be urgently required.

Q: What is your standard warranty?

A: The standard warranty is 12 months from receipt of product.

Related thesis / Technical materials

Laser processing

- Modified Alvarez lens for high-speed focusing.
  Optics Express 25 (24): 29847-29855 (2017)

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