

LCOS-SLM

Applications and Features

(Laser processing/marking, etc.)



Laser
processing

Laser
marking

Aberration
correction

Highly efficient and precise spatial light modulation by reflective liquid crystal modulator with high power handling capability

● Structure

➤ Head

Parameter	Number of pixels	Pixel pitch (μm)	Effective area size (mm)	Fill factor (%)	Weight (g)
X13267 series	792 × 600	12.5	9.9 × 7.5	96	350
X13138 series	1272 × 1024		15.9 × 12.8		

➤ Controller

Parameter	Supply voltage AC (V)	Power supply frequency (Hz)	Weight		Input signal	DVI signal format (pixels)	Input signal level (levels)	DVI frame rate		Power consumption (VA)
			Main unit (g)	Including cable (g)				Typ. (Hz)	Max. (Hz)	
X13267 series	100 to 230	50/60	3300	4200	Digital Video interface (DVI-D)	800 × 600	256	60	120	50
X13138 series						1280 × 1024			-	

● Electrical and optical characteristics

Parameter		Readout light wavelength (nm)	Light utilization efficiency typ. (%)	Rise time* ¹ (ms)	Fall time* ¹ (ms)
X13267	-01	400 to 700	76 (633 nm)	5 (633 nm)	25 (633 nm)
	-02	800 ± 50	97 (785 nm)	30 (785 nm)	80 (785 nm)
	-03	1050 ± 50	97 (1064 nm)	20 (1064 nm)	80 (1064 nm)
	-04	510 ± 50	97 (532 nm)	10 (532 nm)	25 (532 nm)
	-05	410 ± 10	97 (405 nm)	10 (405 nm)	20 (405 nm)
	-06	650 ± 50	97 (633 nm)	10 (633 nm)	30 (633 nm)
	-07	620 to 1100	80 (1064 nm)	10 (1064 nm)	80 (1064 nm)
	-08	1000 to 1550	80 (1550 nm)	30 (1550 nm)	140 (1550 nm)
	-09	532 ± 1 1064 ± 5	96 (532 nm) 97 (1064 nm)	15 20	35 80
X13138	-01	400 to 700	76 (633 nm)	5 (633 nm)	25 (633 nm)
	-02	800 ± 50	97 (785 nm)	30 (785 nm)	80 (785 nm)
	-03	1050 ± 50	97 (1064 nm)	20 (1064 nm)	80 (1064 nm)
	-04	510 ± 50	97 (532 nm)	10 (532 nm)	25 (532 nm)
	-05	410 ± 10	97 (405 nm)	10 (405 nm)	20 (405 nm)
	-06	650 ± 50	97 (633 nm)	10 (633 nm)	30 (633 nm)
	-07	620 to 1100	80 (1064 nm)	10 (1064 nm)	80 (1064 nm)
	-08	1000 to 1550	80 (1550 nm)	30 (1550 nm)	140 (1550 nm)
	-09	532 ± 1 1064 ± 5	96 (532 nm) 97 (1064 nm)	15 20	35 80

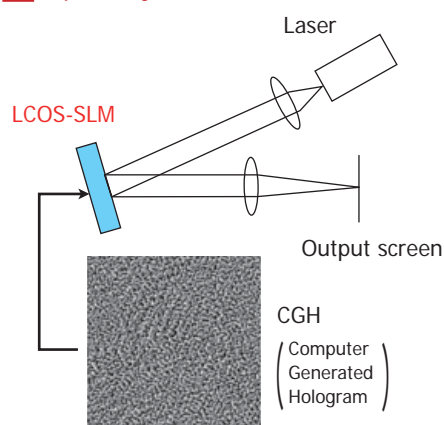
*1: Time required to change from 10% to 90% for 2π modulation (typical value)

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.

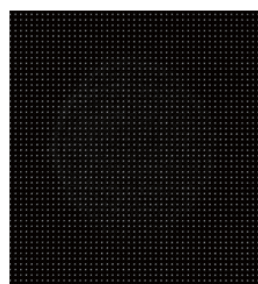
Optical system



High efficiency achieved through maskless design.



Clear reconstructed image of CGH (+ 1st order)



Multi-point generation (50x50) with 0th order suppression



Reconstruction of character set (+ 1st order)

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...

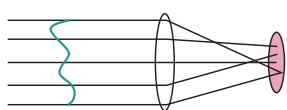


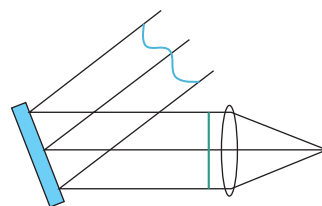
Image gets blurry since focusing spots are spread out.

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

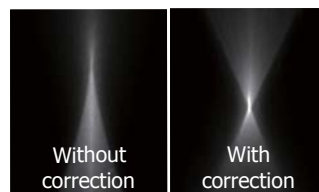
● Applications

Multi-point laser material processing

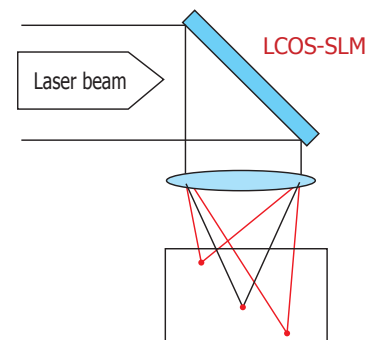
Simultaneous processing with holographic beam-shaping technology

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



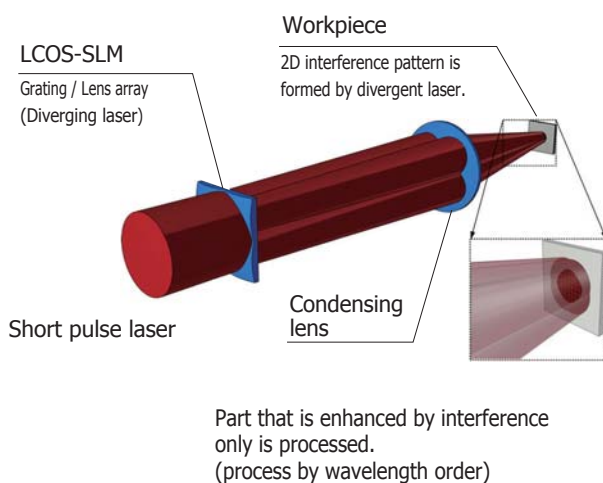
Lateral view of focusing beams



* Joint research with Kyoto University and New Glass Forum in NEDO project
"High efficiency processing technology for three-dimensional optical devices"

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

> Processing examples



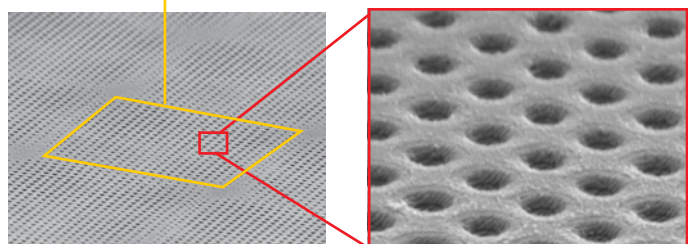
ITO layer removal

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



Processing area :
about 500 holes made

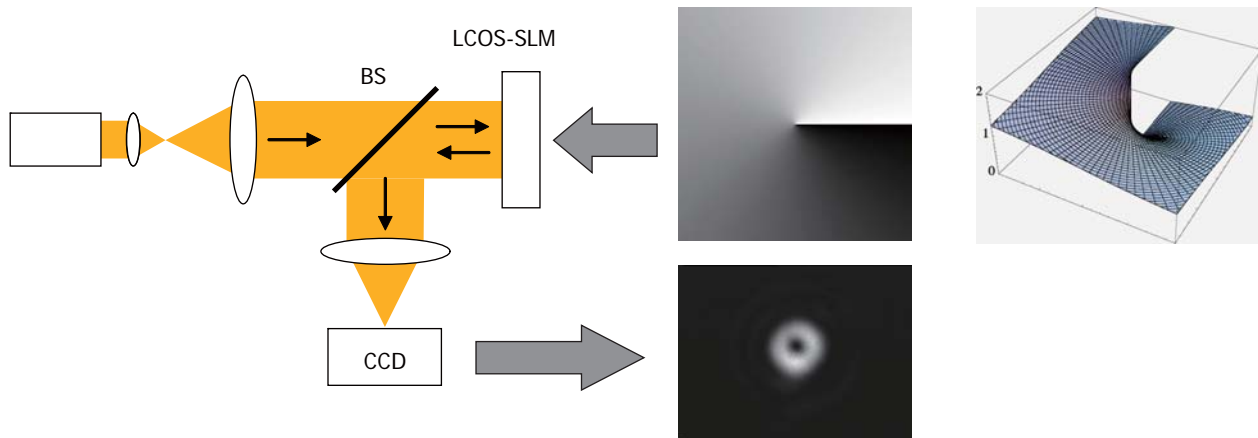
Hole size :
1.5 μ m max. in diameter



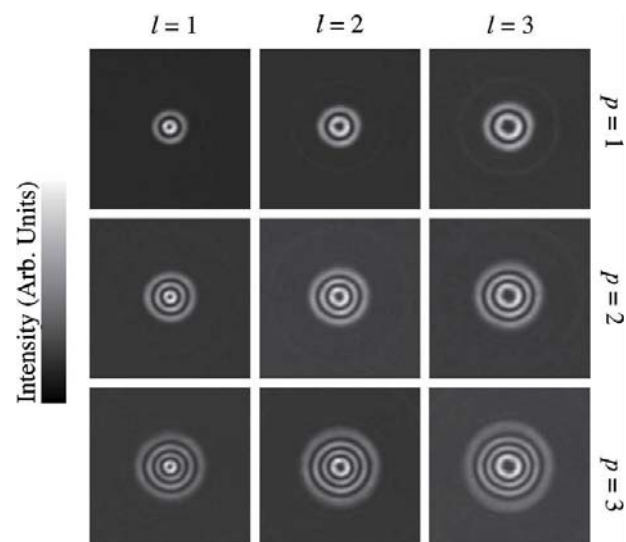
Optical vortex generation

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

Optical system



Result of high order beam generation

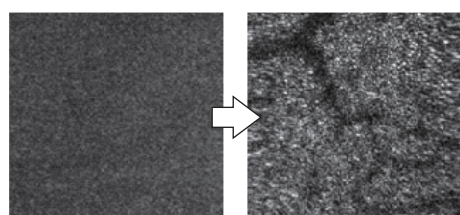


● Applications

Fundus imaging system using adaptive optics

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

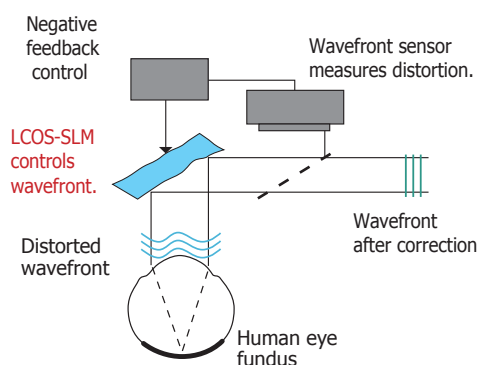
○ Visual cells can be discerned.



Fundus image
before correction

Fundus image
after correction

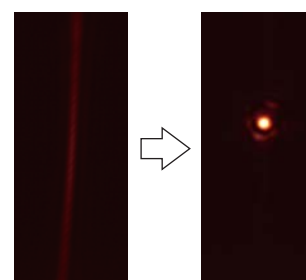
* Under joint development with NIDEK in NEDO project



▷ Experimental example of dynamic wavefront correction

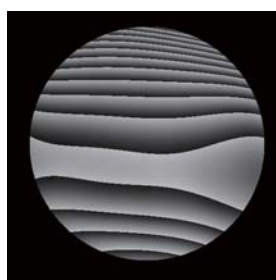
Improvement with adaptive optics

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

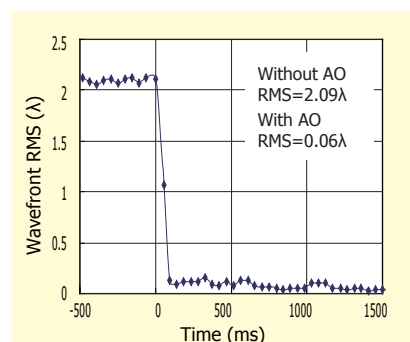


Wavefront
before correction

Wavefront
after correction



Aberration



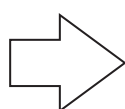
Optical manipulation (optical tweezers)

Wavefront control for efficient and precise manipulation

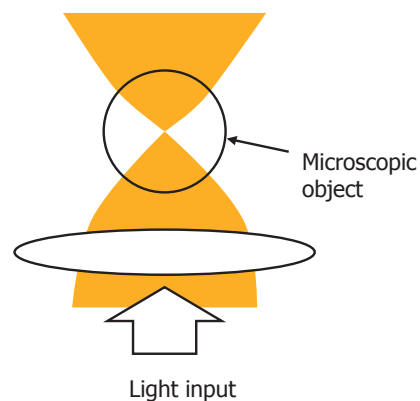
Technology for trapping microscopic objects by optical pressure

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



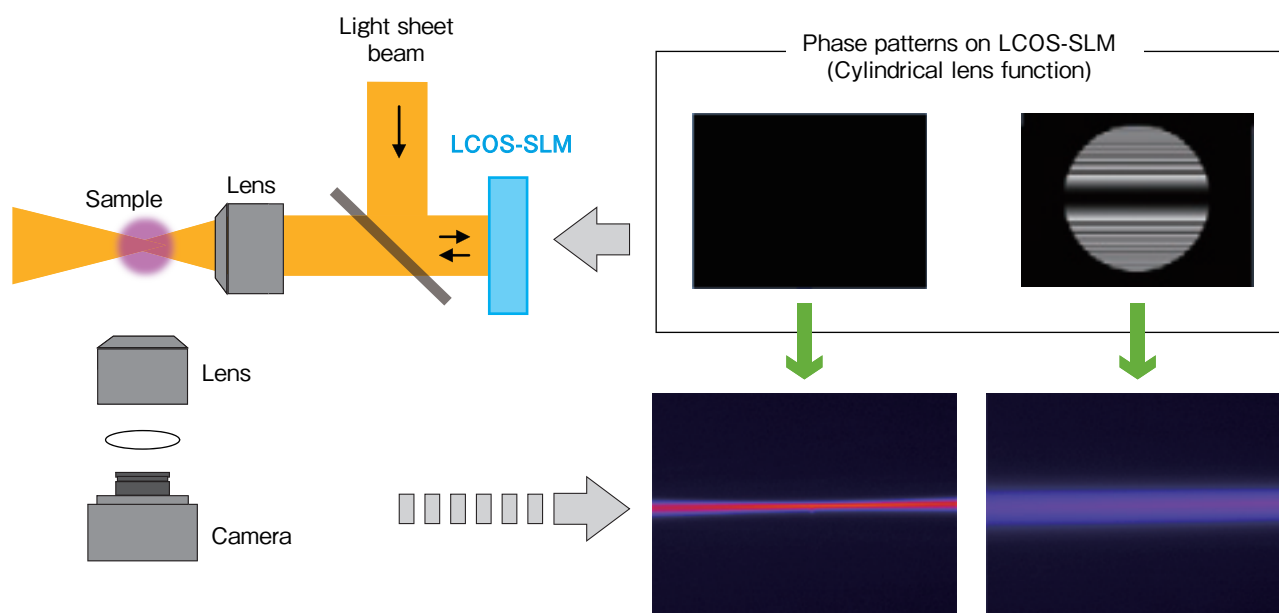
Optical manipulation
Micro-force measurement



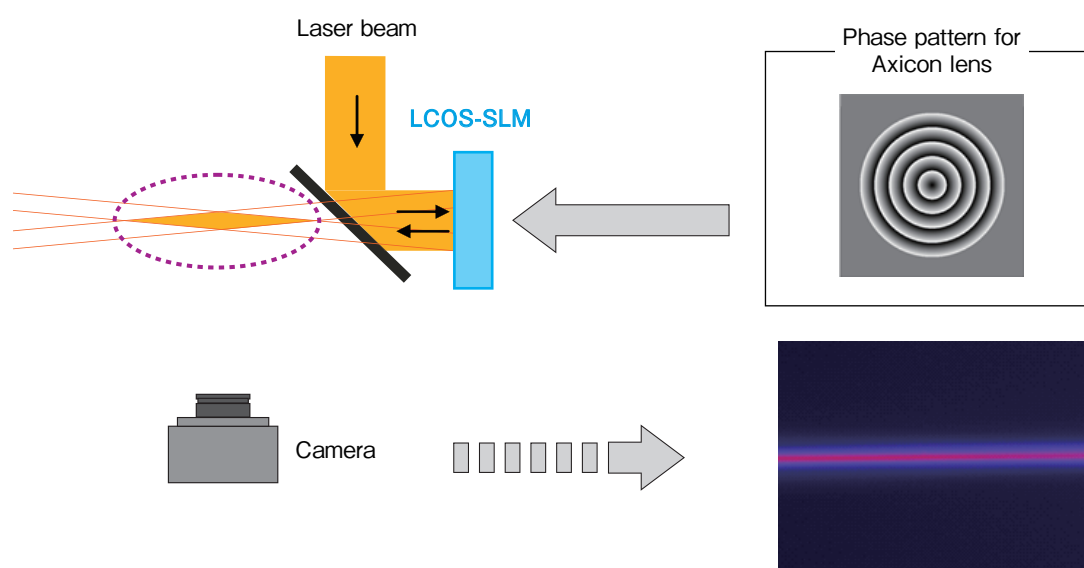
Beam control: lens function and non-diffractive beam generation

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 function

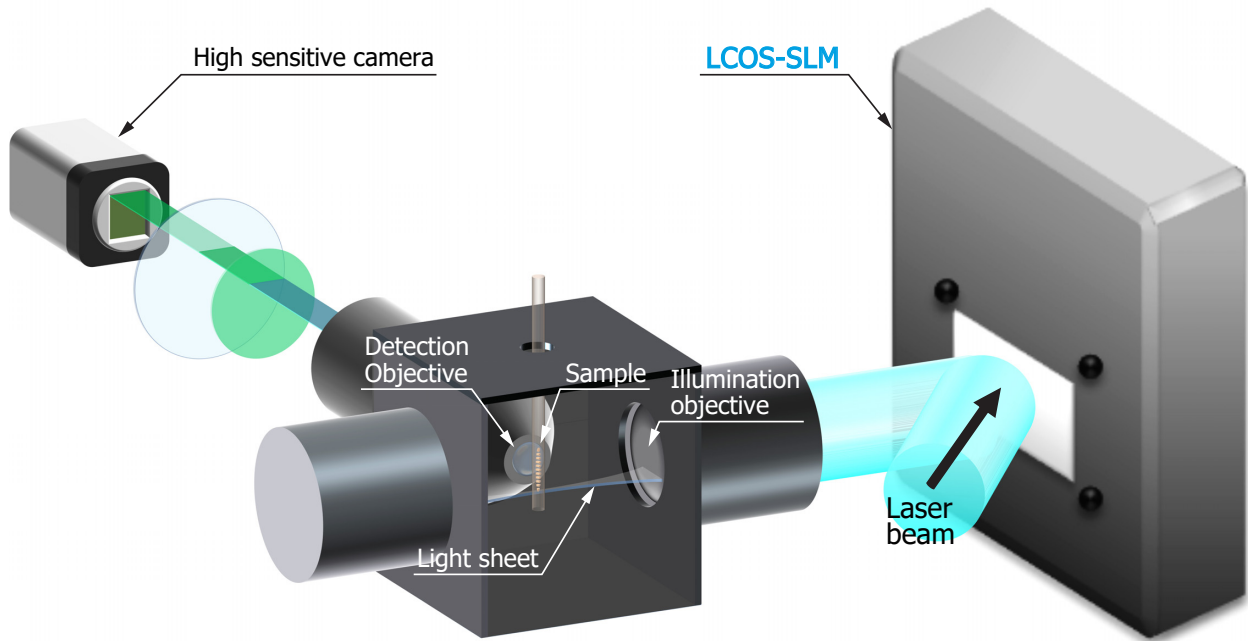


> Non-diffractive beam generation



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 processing 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
Optimum LCOS-SLM	X13267-04 X13138-04	X13267-04 X13138-04	X13267-02 X13138-02	X13267-03 X13138-03	X13267-03 X13138-03	X13267-03 X13138-03

● 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

Type	Light source			Beam size (mm) [at 1/e ²]	Irradiation time (hours)	Irradiation intensity		Peak power		Result	
	Wavelength (nm)	Pulse width	Repetition frequency (kHz)			Average output power (W)	Output power per area (W/cm ²)	Peak output power	Output power per area	Damage	Characteristic change
Ti:S laser (pulse)	800	50 fs	1	φ9	3	2.7	4.3	108 GW	170 GW/cm ²	Not seen	Seen
Ti:S laser (pulse)	800	50 fs	1	φ11	10	2.7	2.9	108 GW	114 GW/cm ²	Not seen	Not seen
Ti:S laser (pulse)	800	30 fs	0.01	φ18	6	0.05	0.02	333 GW	131 GW/cm ²	Not seen	Not seen

▷ Type-03

Type	Light source			Beam size (mm) [at 1/e ²]	Irradiation time (hours)	Irradiation intensity		Peak power		Result	
	Wavelength (nm)	Pulse width	Repetition frequency (kHz)			Average output power (W)	Output power per area (W/cm ²)	Peak output power	Output power per area	Damage	Characteristic change
YAG laser (CW)	1064	-	-	φ2.5	1	2.0	40.7	-	-	Not seen	Not seen
YAG laser (CW)	1064	-	-	φ2.5	Several minutes	3.5	71.3	-	-	Not seen	Seen
YAG laser (pulse)	1064	200 ns	80	φ2.5	1	2.0	40.7	0.25 kW	5.1 kW/cm ²	Not seen	Not seen
YAG laser (pulse)	1064	200 ns	80	φ2.5	Several minutes	3.5	71.3	0.44 kW	8.9 kW/cm ²	Not seen	Seen
Pulse laser	1030	670 fs	1	φ4.5	10	0.6	3.8	1.8 GW	11.3 GW/cm ²	Not seen	Not seen
Pulse laser	1030	1.37 ps	30	φ8.11	8	5.2	10.1	0.25 GW	0.49 GW/cm ²	Not seen	Not seen
Pulse laser	1030	11.4 ns	10	φ13	8	17.4	13.1	0.31 MW	0.23 MW/cm ²	Not seen	Not seen

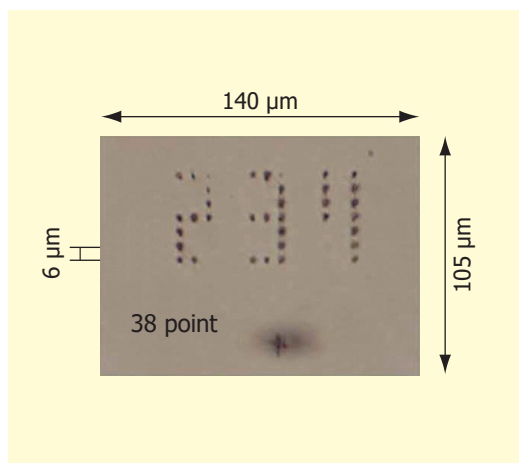
▷ Type-04

Type	Light source			Irradiation area (mm)	Irradiation time (hours)	Irradiation intensity		Peak power		Result	
	Wavelength (nm)	Pulse width	Repetition frequency (kHz)			Average output power (W)	Output power per area (W/cm ²)	Peak output power	Output power per area	Damage	Characteristic change
Pulse laser	515	0.91 ps	30	φ9.1	8	1.8	2.6	132 MW	203 MW/cm ²	Not seen	Not seen
Pulse laser	515	0.92 ps	30	φ9.5	8	3.2	4.9	234 MW	331 MW/cm ²	Not seen	Seen
Pulse laser	515	14.4 ns	10	φ12.8	8	4.3	3.3	25 kW	38 kW/cm ²	Not seen	Not seen

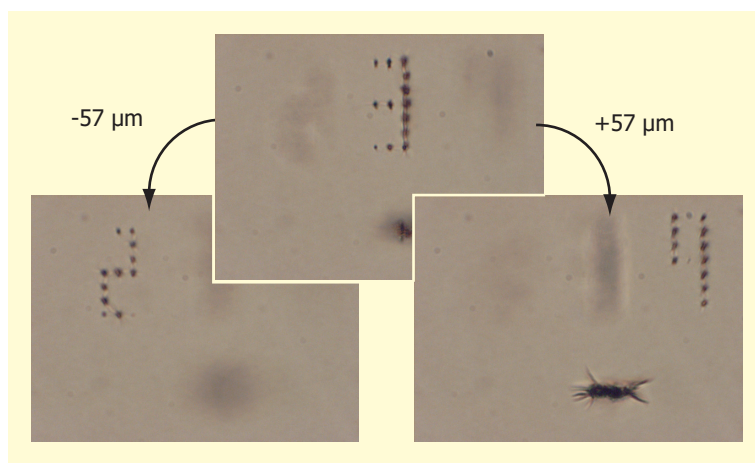
● Image gallery

Insite of glass is processed with CGH projection of fs laser

2D processing



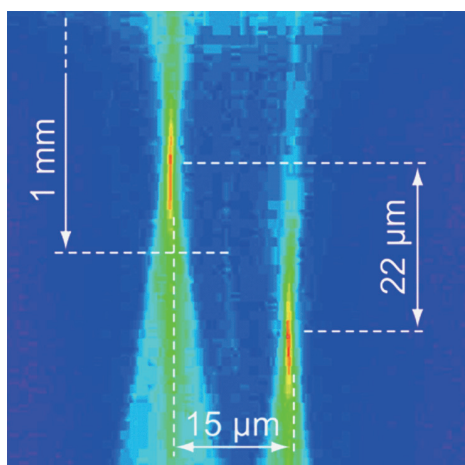
1-step 3D processing



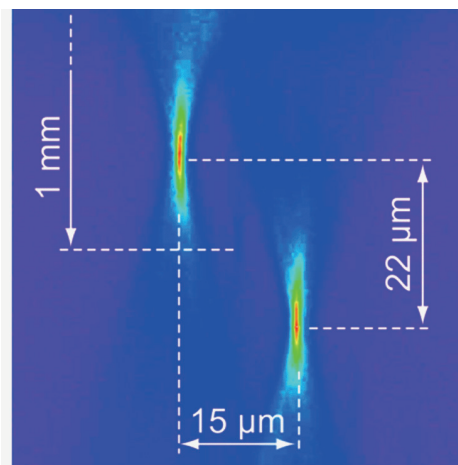
- Objective lens : NA=0.3 (Nikon)
- Irradiation intensity : 250 mW (ϕ 8 mm aperture)
- BK7

Laser beam condensation inside transparent material

Without aberration correction



With aberration correction



● Features

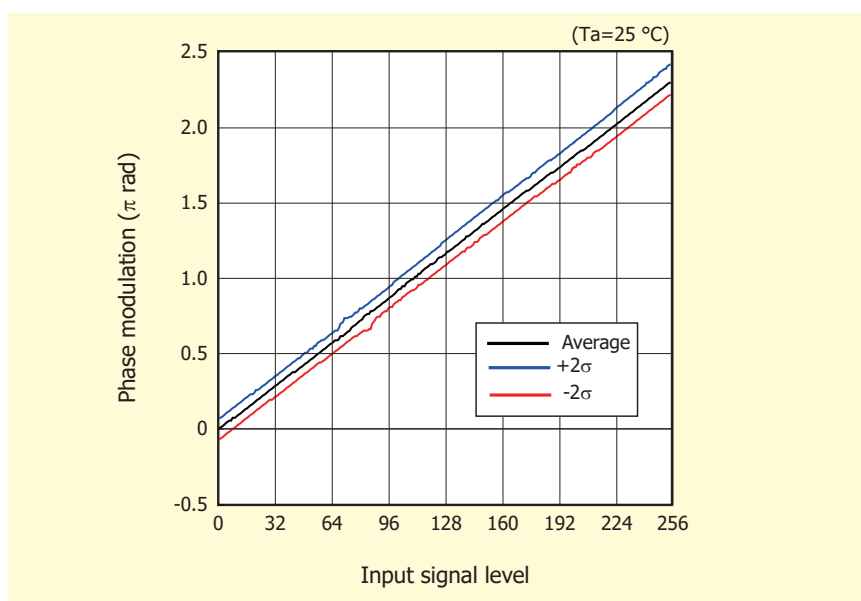
Feature 1 : Light utilization efficiency

The X13267/X13138 series have high light utilization efficiency, which is defined as 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/-04/-05/-06 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 efficiency compared to the ones with the dielectric mirror but have wide spectral response characteristics.

Feature 2 : Phase modulation

The X13267/X13138 series can achieve phase modulation of more than 2π radians over the 400-1550 nm readout wavelength range. The X13267/X13138 series comes pre-calibrated from the factory for a specified wavelength range to have more than 2π radians of phase modulation and its linear characteristics. The figure below shows typical phase modulation characteristics. A phase shift of 2π radians or more and a linear phase response are achieved. The phase modulation curves for 95% pixels lies within $\pm 2\sigma$.

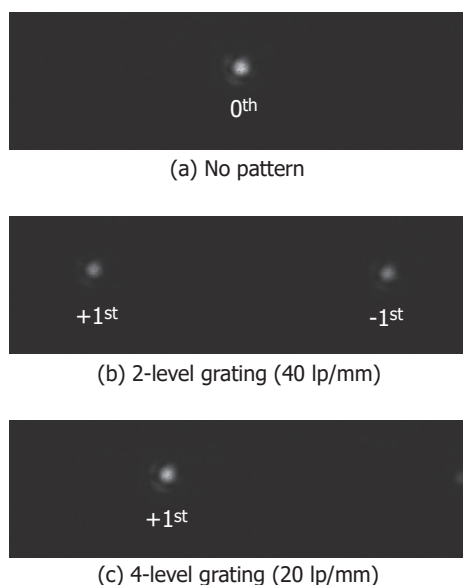
> Phase modulation



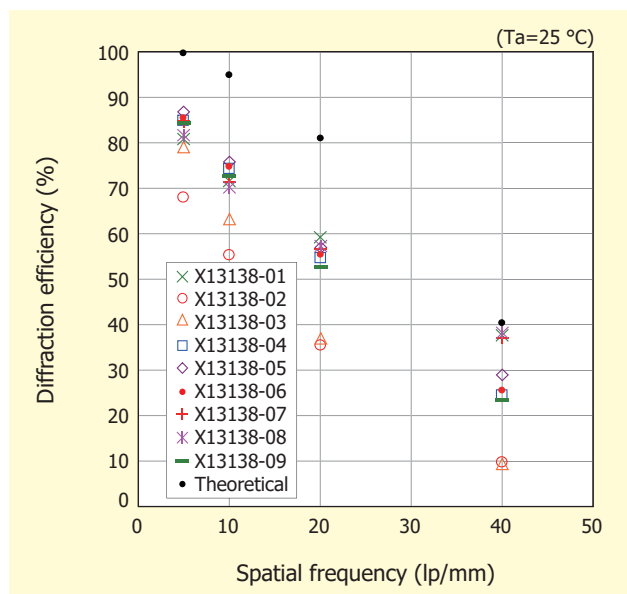
Feature 3 : Diffraction efficiency

The X13267/X13138 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 X13138 series and the right figure shows typical diffraction efficiency characteristics. Here, the diffraction efficiency is defined I_1/I_0 , I_1 is intensity of the 1st order diffraction spot, I_0 is the intensity of the 0th order light when no pattern is displayed.

> Diffracted spots images



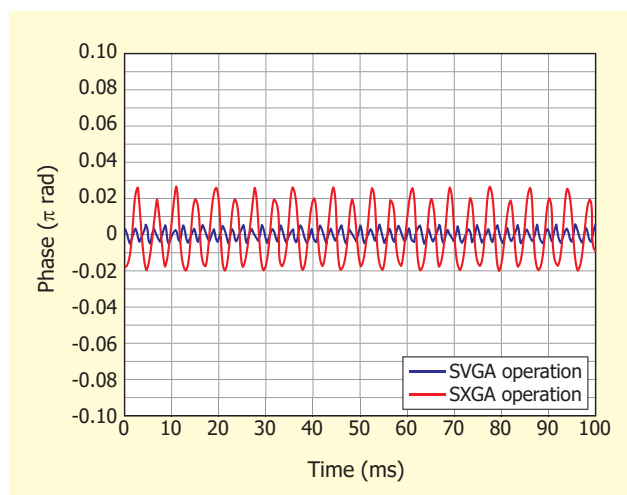
> Diffraction efficiency (typical example)



Feature 4 : High phase stability

The X13267/X13138 series shows small fluctuation of phase generated when the pattern displayed is not changed. The figure shows an example of the phase fluctuation for the -04 types. The drive frequency is 120 Hz for SXGA operation (X13138-04) and 240 Hz for SVGA operation (X13267-04). In SXGA operation, which operates at low frequency, the phase fluctuation is about four times greater than that in SVGA operation.

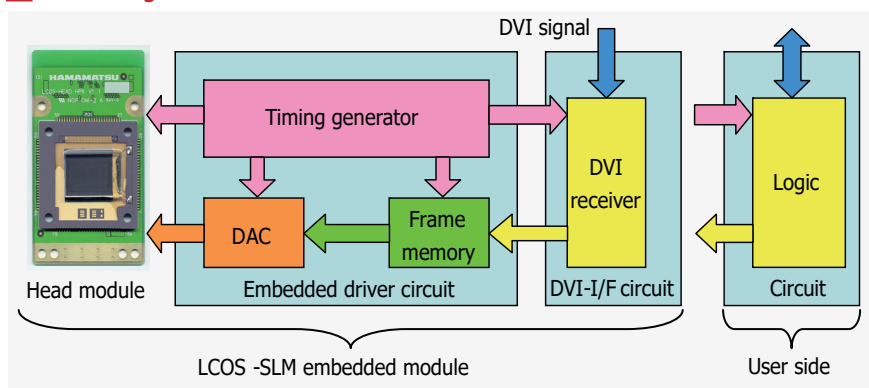
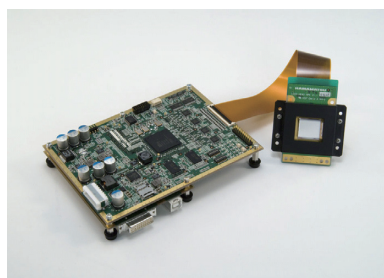
> Phase stability



● LCOS-SLM embedded module X13268/X13139 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 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 is the light utilization efficiency of the LCOS-SLM X13138 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/-04/-05/-06 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 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 theses / Technical materials

■ Laser processing

- Modified Alvarez lens for high-speed focusing.
Optics Express 25 (24): 29847-29855 (2017)
- Massively parallel femtosecond laser processing
Optics Express 24 (16): 18513-18524 (2016)
- Three-dimensional vector recording in polarization sensitive liquid crystal composites by using axisymmetrically polarized beam.
Optics Letters 41 (3): 642-645 (2016)
- Abruptly autofocusing beams enable advanced multiscale photo-polymerization.
Optica 3 (5): 525-530 (2016)
- Laser material processing with tightly focused cylindrical vector beams.
Applied Physics Letters 108 (22): 221107 (2016)

■ Adaptive optics

- Adaptive optics scanning laser ophthalmoscope using liquid crystal on silicon spatial light modulator : performance study with involuntary eye movement
Jpn. J. Appl. Phys. 56, 09NB02 (2017).

■ Beam shaping/Pulse shaping

- 9-kW peak power and 150-fs duration blue-violet optical pulses generated by GaInN master oscillator power amplifier.
Optics Express 25 (13): 14926-14934 (2017)
- Sub-diffraction-limited fluorescent patterns by tightly focusing polarized femtosecond vortex beams in silver-containing glass.
Optics Express 25 (9): 10565-10573 (2017)
- Creating a nondiffracting beam with sub-diffraction size by a phase spatial light modulator.
Optics Express 25 (6): 6274-6282 (2017)
- Vortex-free phase profiles for uniform patterning with computer-generated holography.
Optics Express 25 (11): 12640-12652, 2017
- Realization of multiform time derivatives of pulses using a Fourier pulse shaping system.
Optics Express 25 (4): 4038-4045 (2017)
- Diffractive fan-out elements for wavelength-multiplexing subdiffraction-limit spot generation in three dimensions
Applied Optics 55 (23): 6371-6380 (2016)
- Fluid flow vorticity measurement using laser beams with orbital angular momentum.
Optics Express 24 (11): 11762-11767 (2016)
- Comparison of beam generation techniques using a phase only spatial light modulator.
Optics Express 24 (6): 6249-6264 (2016)
- Mode crosstalk matrix measurement of a 1 km elliptical core few-mode optical fiber.
Optics Letters 41 (12): 2755-2758 (2016)
- Arbitrary shaping of on-axis amplitude of femtosecond Bessel beams with a single phase-only spatial light modulator.
Optics Express 24 (11): 11495-11504 (2016)

- Mitigating self-action processes with chirp or binary phase shaping.
Optics Letters 41 (1): 131-134 (2016)
- High-quality generation of a multispot pattern using a spatial light modulator with adaptive
Optics Letters 37, 3135 (2012)

■ Microscopy applications

- Raman imaging through a single multimode fiber.
Optics Express 25 (12): 13782-13798 (2017)
- Transmission-matrix-based point-spread-function engineering through a complex medium
Optica 4 (1): 54-59 (2017)
- Three-dimensional spatiotemporal focusing of holographic patterns.
Nature Communications 7: 11928 (2016)
- Colored point spread function engineering for parallel confocal microscopy.
Optics Express 24 (24): 27395-27402 (2016)
- Three-dimensional STED microscopy of aberrating tissue using dual adaptive optics.
Optics Express 24 (8): 8862-8876 (2016)
- A VO core neuronal circuit for inspiration.
Nature Communications 8 (1): 544 (2017)
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[A list of the other related theses is on the following website.]
<http://www.hamamatsu.com/jp/en/community/lcos/publications/index.html>

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