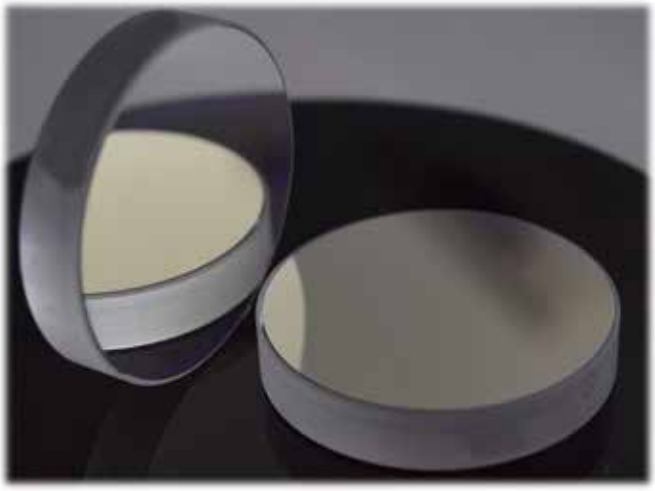
High Performance Laser Mirrors

- Chirped Mirror
- Low Dispersion Mirror
- High Power Laser Mirror
- Ultra Broad Band Mirror
- Ultra High Reflectance Mirror



TOKAI OPTICAL CO.,LTD.

Going toward future with the most advanced optical thin-film technology for the innovative laser application.

Since TOKAI OPTICAL located at Okazaki-city in Japan was founded in 1939, our increasing experience and technological capabilities have enabled us to continually move forward as a manufacturer of specialized ophthalmic lenses and industrial optical products. In October 2000, we obtained ISO 9001 and 14001 certification so that TOKAI OPTICAL engineers can produce reliable products for the world wide customers from the advanced facilities.

Optical thin-film made of dielectric multi-layer has been used for ophthalmic lenses, optical equipment, measuring devices, and analysis equipment. It blocks reflection in optical parts, optical filters, and polarized films, and in electronics it plays an important role in light interfaces.

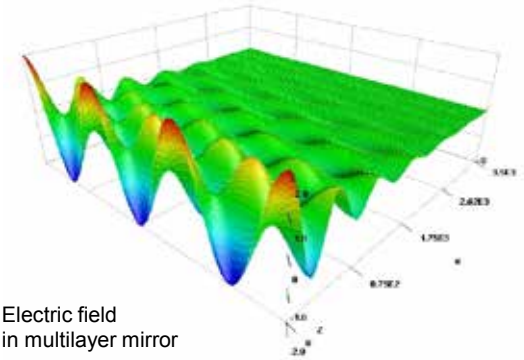
Nowadays, TOKAI OPTICAL has expanded this technology more for laser application which has been getting important for high-end medical, bioengineering and nano fabrication instruments. With over 75 years experience for this technology and well educated researchers, TOKAI OPTICAL is developing the most advanced laser optical components such as high performance laser mirrors which are introduced in this brochure.

Dielectric multilayer mirror

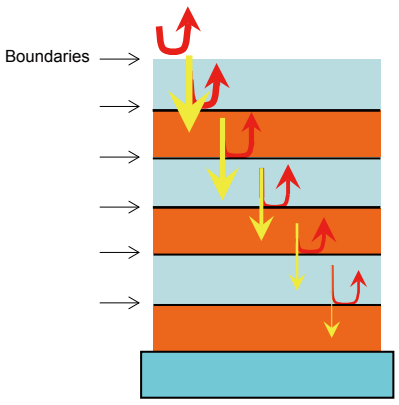
High Reflectance and Low Loss

Most laser mirrors are constructed by dielectric materials since their optical absorption is very low, which allows high performance for high power laser beams. The high specular reflectance is due to the constructive interference of reflected lights from respective boundaries between high and low index materials (shown in the upper right figure). The asymptotic value for normal incidence (angle of incidence (AOI) = 0°) , R, is written as follows: $R \cong 1-4(n_m/n_H{}^2)(n_L/n_H)^{2p}$, for the case $(n_L/n_H)^p<<1$, where n_H, n_L ($<n_H$) and n_m are the refractive index of high index film material, low index film material and the substrate, respectively. The design is "Glass | $(H\ L)^p$ | Air". The symbols H and L denote the quarter-wave optical thickness for high and low index materials, respectively. You can see that we have almost perfect reflectance in principle : $R \to 1$ when $p \to \infty$. Here, we note the quality of boundaries, specifically it's roughness, which is a detriment for actually obtaining its high reflectance, since the roughness causes optical loss due to scattering.

We have been producing multilayer mirrors by using ion-assisted deposition and ion beam sputtering methods, which are state-of-art processes to coat dense film with smooth surfaces and boundaries. The films are also free from spectral shift problems caused by humidity fluctuations.



Electric field
in multilayer mirror



Schematic of multilayer mirror

Multi Function

In multilayer mirror design, there are many choices for degrees of freedom, i.e., materials, layer thicknesses and number of layers. So, other functions can be added to the conventional mirror by modifying the regular alternating design, $(H\ L)^p$. We propose mirrors with multiple functions by combining basic design concepts, analytical calculations and powerful optimization methods from the latest software.

In applications for ultrafast laser systems, phase property is also important for wide spectral range. We produce multilayer mirrors used for dispersion compensation, the so called chirped mirror, which has typically negative group delay dispersion (GDD), $-\partial^2\varphi/\partial\omega^2$, where φ is the reflected phase of the mirror and ω is the angular frequency. Complex design technique and precise thickness control in the coating process are required.

Electric field (EF) in a multilayer mirror is also important in applications for high power laser systems, since strong EF intensity breaks down the mirror itself. In design, EF distribution is adjusted to resist high power laser beam through choice of the layers' thickness.

Please see our products listed in the following pages.

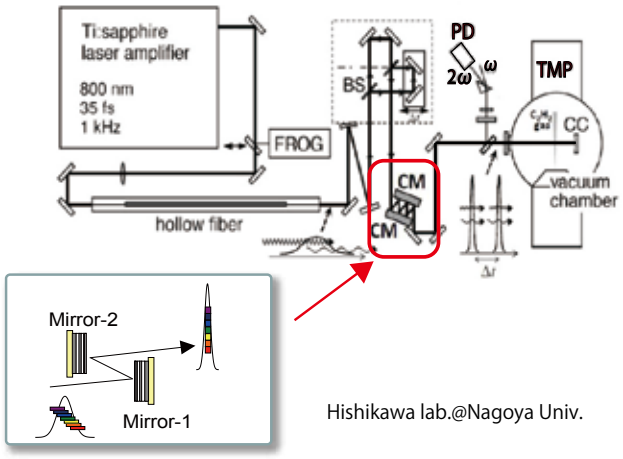
Broad Band Chirped Mirror with Negative GDD

Application : Pulse compensation of femtosecond laser beam

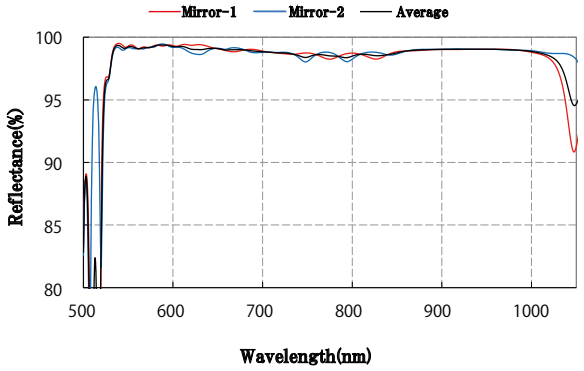
Feature : Wide band, Dispersion,Flat GDD (<0)

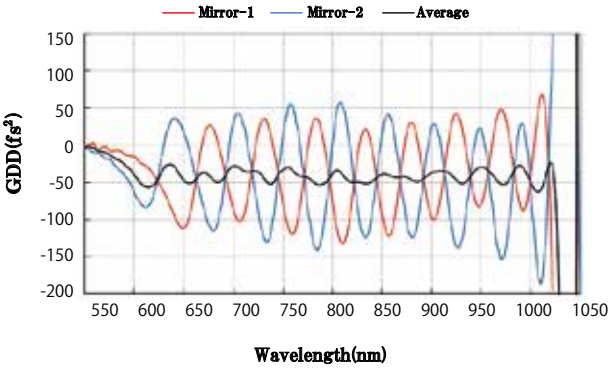
Dispersion compensation in wide wavelength is an important technology for obtaining an ultrashort pulse with the pulse width less than 10fs. Dielectric multilayer mirrors can be applied for this purpose, if its reflective phase,φ, is properly adjusted to the intended systems. For up-chirped pulse, negative group delay dispersion (GDD), $-\partial^2\varphi/\partial\omega^2$, is required. We have designed two kinds of chirped mirrors, which cancel each other oscillation of GDD in order to obtain a nearly flat negative GDD as a function of wavelength. Some features of the mirrors are a constant negative GDD and high reflectance for wavelengths between 600nm-1000nm.

Example



Hishikawa lab.@Nagoya Univ.





Wavelength	AOI	Reflectance	GDD	Size	Part number
600-1000nm	0° ~ 5°	≧98%	-40fs^2	φ25.4 x 5t	CGS-002505-10
				φ30 x 5t	CGS-003005-10
				φ50 x 5t	CGS-005005-10

*custom products are also available

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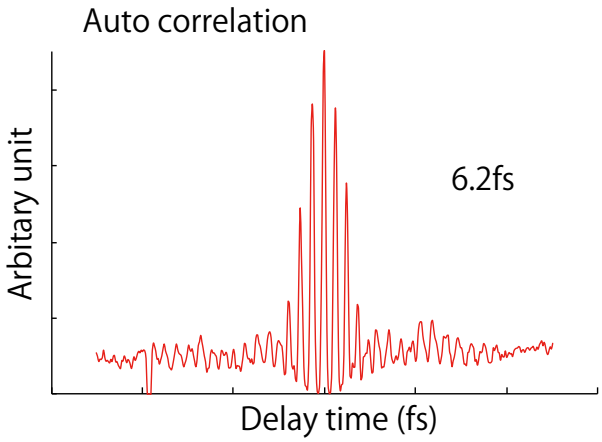
Broad Band Chirped Mirror with Negative GDD and TOD

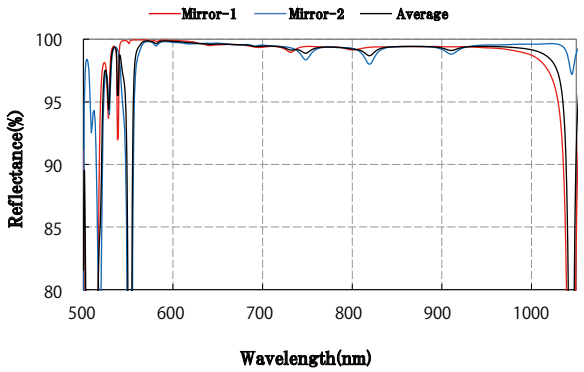
Application : Pulse compensation of femtosecond laser beam

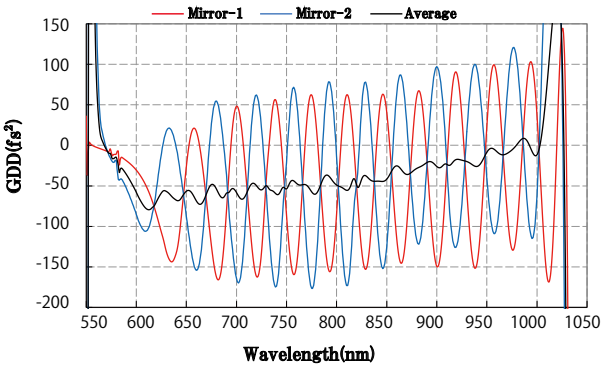
Feature : Wide band, Dispersion compensation up to 3rd order

For the sake of precise control of pulse shape, higher order dispersion compensation is required. Since, in general, group velocity dispersion (GVD) of mediums is large in shorter wavelength, larger negative GDD is expected for chirped mirrors. This chirped mirror has been designed to compensate for GVD up to the 3rd order dispersion (TOD), $-\partial^3\varphi/\partial\omega^3$, where GDD<0 and TOD<0. By using these mirrors in combination with the mirrors listed in P4, pulses with wide spectral width broaden by self phase modulation are compressed to 6.2fs (almost Fourier transformation limit). Measured auto correlation is shown in the right graph.



Hishikawa lab.@Nagoya Univ.





Wavelength	AOI	Reflectance	GDD	Size	Part number
600-1000nm	0° ~ 5°	≧98%	-75fs^2(600nm) ~ -0fs^2(1000nm) TOD=-127fs^3(800nm)	φ25.4 x 5t	CTS-002505-10
				φ30 x 5t	CTS-003005-10
				φ50 x 5t	CTS-005005-10

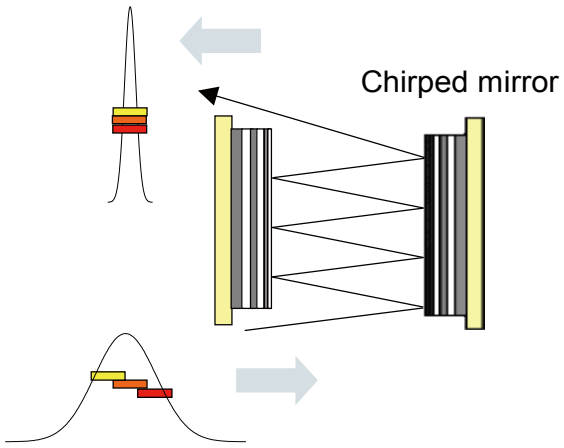
*custom products are also available

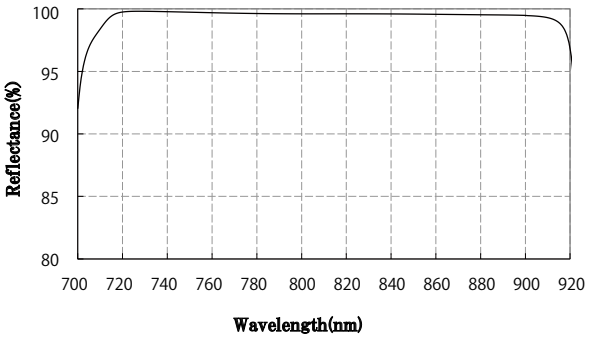
Chirped Mirror for 800nm
- The fundamental of Ti-sapphire laser -

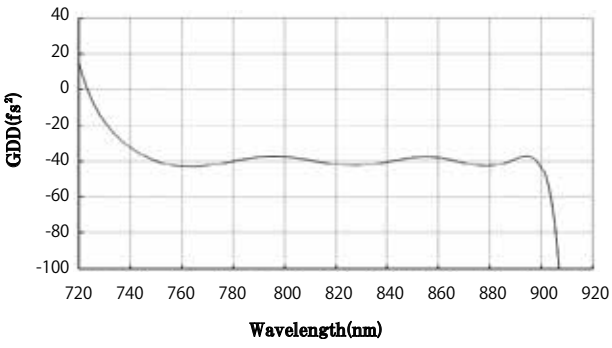
Application : Pulse compensation of femtosecond laser beam

Feature : High reflectance

This chirped mirror is design for the dispersion compensation of up-chirped pulses with wavelengths around 800nm. Some features of this mirror are a constant negative GDD and high reflectance for wavelengths between 750nm-850nm. The mirror coated on the rectangular substrate is also listed, which will be helpful to obtain large amount of GDD by multiple reflections between two opposite mirrors.







Wavelength	AOI	Reflectance	GDD	Size	Part number
750-850nm	0° ~ 5°	≧99.5%	-40fs^2	φ25.4 x 5t	CTF-002505-10
				φ30 x 5t	CTF-003005-10
				φ50 x 5t	CTF-005005-10
				□20 x 40 x 5t	CTF-204005-10

*custom products are also available

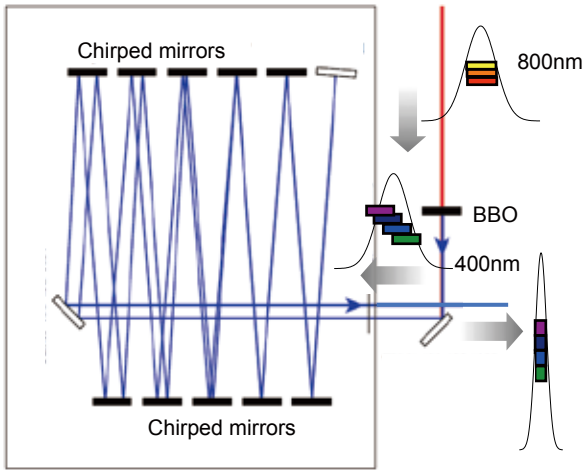
Chirped Mirror for UV

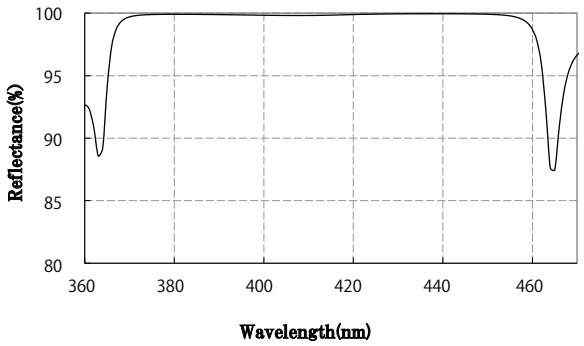
- The second harmonics of Ti-sapphire laser -

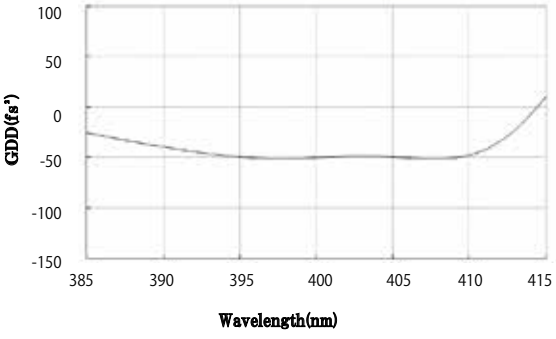
Application : Pulse compensation of UV femtosecond laser beam

Feature : High reflectance and dispersion compensation in UV region

Dispersion compensation is an important technology in the Ti-Sapphire laser systems. In the molecular science, there are many cases where the second harmonics of the ultrashort pulses are used. In these cases, careful attention is required for larger dispersion of the group velocity of medium in the ultraviolet (UV) region. With this in mind and through the collaboration with Hishikawa lab. of Nagoya University, this chirped mirror has been developed for the sake of the dispersion compensation in the UV region.







Wavelength	AOI	Reflectance	GDD	Size	Part number
395-405nm	0° ~ 5°	≧99.5%	-50fs^2	φ25.4 x 5t	CUV-002505-10
				φ30 x 5t	CUV-003005-10
				φ50 x 5t	CUV-005005-10
				□20 x 40 x 5t	CUV-204005-10

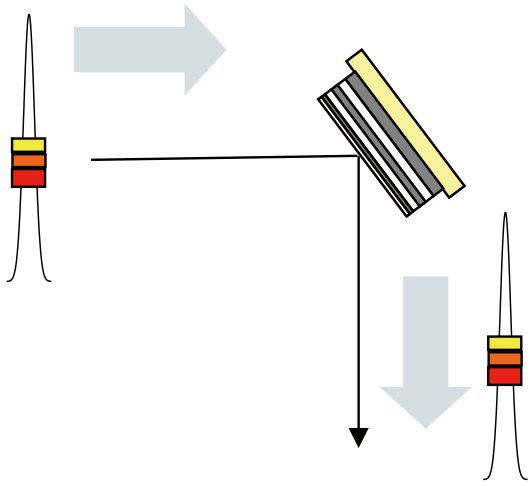
*custom products are also available

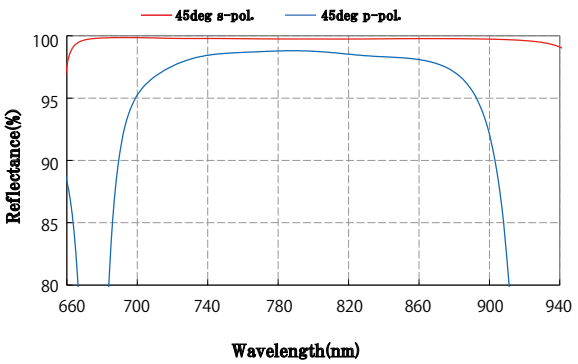
Low Dispersion Mirror

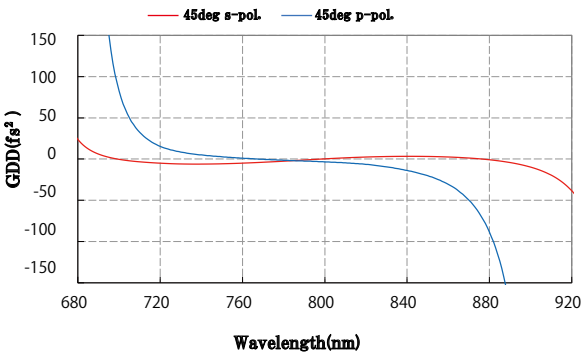
Application : Turning mirror for ultra short pulses

Feature : Low dispersion and high reflectance

Femtosecond pulses are easily broadened and lose their high intensity peak when they propagate in mediums or are reflected by standard multilayer mirrors. This leads to difficulty with utilizing the femtosecond pulses' high peak during use. This mirror is designed to reduce changes in pulse shape through reflection. The result is shown in the image to the right. The short pulse sustains the sharpness even after changing its propagating direction from this mirror. Energy loss can be reduced compared to that of metal mirrors.







Wavelength	AOI	Reflectance	GDD	Size	Part number
700-900nm(s-pol.) 750-850nm(p-pol.)	45°	≧99%(s-pol.) ≧97%(p-pol.)	≦-50fs²	φ25.4 x 5t	LDF-002505-10
				φ30 x 5t	LDF-003005-10
				φ50 x 5t	LDF-005005-10

*custom products are also available

High Power Laser Mirror

Application : High power laser systems

Feature : High laser induced damage threshold

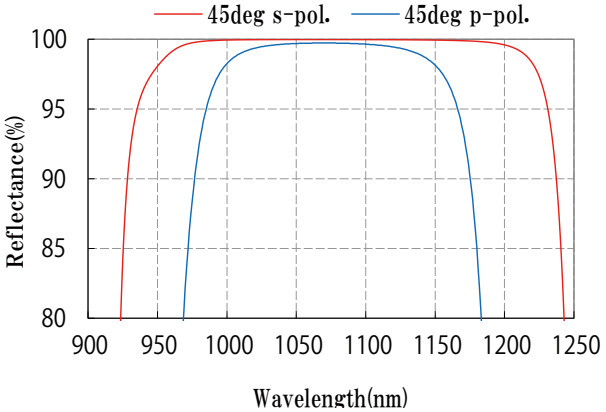
In high power laser systems, multilayer mirrors are required to have high laser induced damage threshold (LIDT), since damage to the mirrors prevents increasing the output energy of the system. To make a mirror's LIDT high, our mirrors are designed by taking into account the distribution of the electric field (EF) formed by incident laser beams in the mirrors.

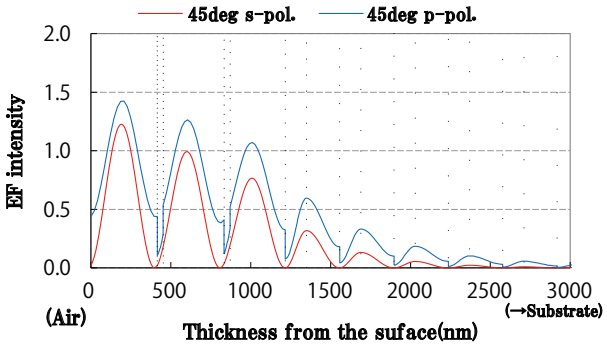
The right figure shows standing waves of EF in a mirror for 1064nm. The intensities are normalized by the intensity of incident waves. The standing waves originate in the interference between propagating waves and reflected waves from respective boundaries, where waves in orthogonal polarization states are independent of each other. In general, the intensities became large near the incident medium. It had been pointed out that if the strong intensity peaks are located at boundaries, the mirror is easily broken down by high powered laser beams[1,2].

For the sake of application for high power laser systems, our mirrors are optimized to shift the EF intensity peaks from boundaries (shown by vertical dotted line), keeping high reflectance for the wave.

[1] B.E. Newman, S.R. Folty, L.J. Jolin and C.K. Carniglia, "Laser Induced Damage in Optical Materials:1981", NBS Spec. Publ.638, p.3 63

[2] Y. Sato, M. Kobiyama, S. Kimura and S. Tamura: daikoshi kiho, 39-4, p156 (1988) (in Japanese)





Wavelength	AOI	Reflectance	LIDT#(p-pol.)	Size	Part number
1064nm	45°	≧99%(s and p-pol.)	134 J/cm²	φ25.4 x 5t φ30 x 5t φ50 x 5t	Listed on P14
532nm		≧99%(s and p-pol.)	121 J/cm²		
355nm		≧99%(s and p-pol.)	47 J/cm²		
248nm		≧99%(s and p-pol.)	5.8 J/cm²		

*custom products are also available

Evaluation method: 1-on-1, pulse width: 8~10ns

The LIDT's listed in the table are typical values (not guaranteed).

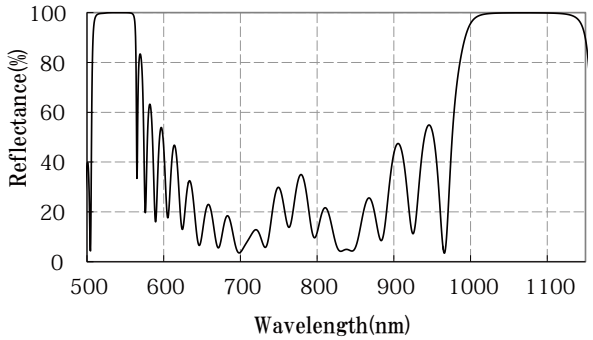
Dual Wavelength Mirror for High Power Lasers

Application : Second harmonic generation, High power laser systems

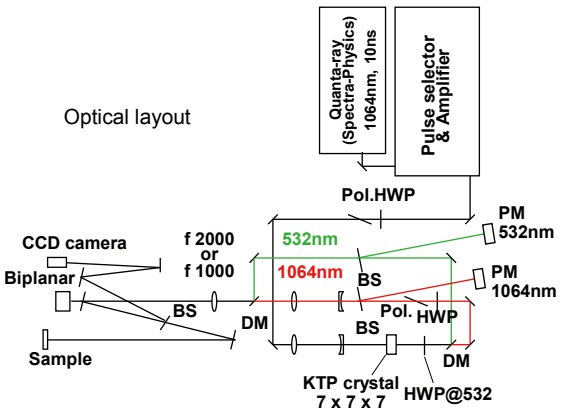
Feature : High laser induced damage threshold for 1064nm and 532nm

Recently, two high-power laser beams with different wavelength are often used simultaneously in an optical system. For example, the laser beams are Nd:YAG fundamental wave (1064nm) and its second harmonic wave (532nm) generated by the wavelength conversion technique. The optics used in the system, such as multilayer mirrors and optical thin film filters, are expected to have complex spectral reflectance and/or transmittance as well as the resistance for high powered laser beams.

We propose dual wavelength mirror with high laser induced damage thresholds (LIDT) for both 1064nm and 532nm, where this mirror is designed by extending the conventional design method. The high LIDTs of this mirror have been confirmed experimentally by the Institute of Laser Technology.



LIDT evaluation



[Institute for Laser Technology]

Conditions (1-on-1)

Samples	This mirror		Standard mirror *	
Wave length	1064nm	532nm	1064nm	532nm
Pulse length	11.8ns	8.2ns	11.8ns	8.2ns
Spot size x	208μm	202μm	316μm	438μm
Spot size y	373μm	276μm	430μm	695μm
AOI	0 deg			

LIDT

	This mirror	Standard mirror *
1064nm	112 J/cm^2	67 J/cm^2
532nm	>180 J/cm^2	46 J/cm^2

* The "Standard mirror" 's data are shown to compare the LIDT to this mirror's LIDT. The both mirrors have been coated by the same coating process using same layer materials.

Wavelength	AOI	Reflectance	LIDT*	Size	Part number
532nm / 1064nm	0°	≧99% (1064nm) ≧99% (532nm)	112 J/cm^2 (1064nm) > 180 J/cm^2 (532nm)	φ25.4 x 5t	HPD-002505-10
				φ30 x 5t	HPD-003005-10
				φ50 x 5t	HPD-005005-10

* The LIDT' s listed in the table are typical values (not guranteed).

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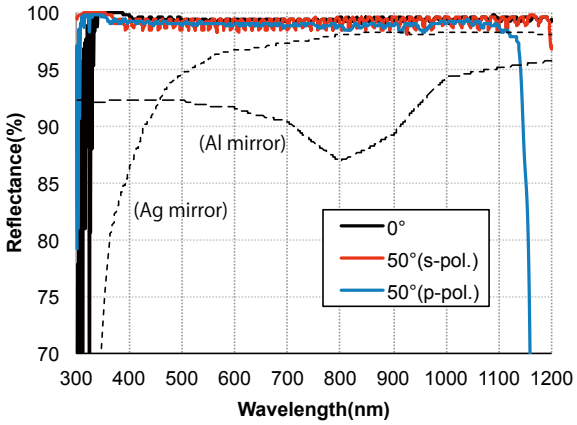
Ultra Broad Band Mirror

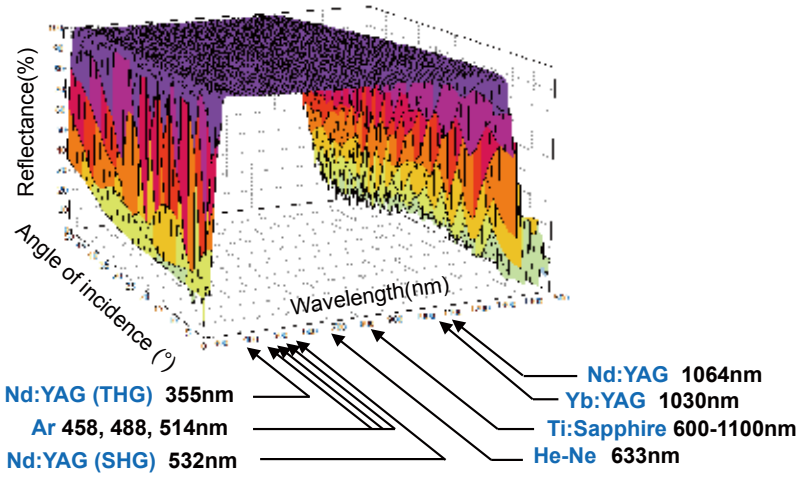
Application : Harmonics of Nd:YAG laser, gas laser, etc.,

Feature : High reflectance at wide AOI in wide wavelength

This mirror is constructed by dielectric materials with over 200 layers. Since the film quality is very high as a result of applying ion beam sputtering to the coating process, the optical loss is very low regardless of the film's high thickness. The main feature of this mirror is to have high reflectance for wide wavelengths and a wide angle of incidence regardless of the polarization. This mirror will allow greater flexibility when constructing laser systems.

For reference, the spectral reflectance is compared to that of an Ag mirror and Al mirror in the right graph.





Wavelength	AOI	Reflectance	Size	Part number
350-1100nm	0° ~ 50°	≧98%	φ25.4 x 5t	BBM-002505-10
			φ30 x 5t	BBM-003005-10
			φ50 x 5t	BBM-005005-10

Ultra High Reflectance Mirror

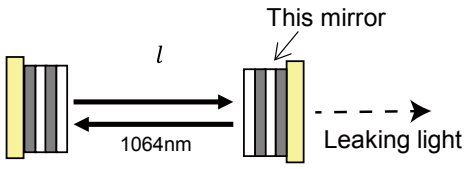
Application : : Cavity ring down spectroscopy

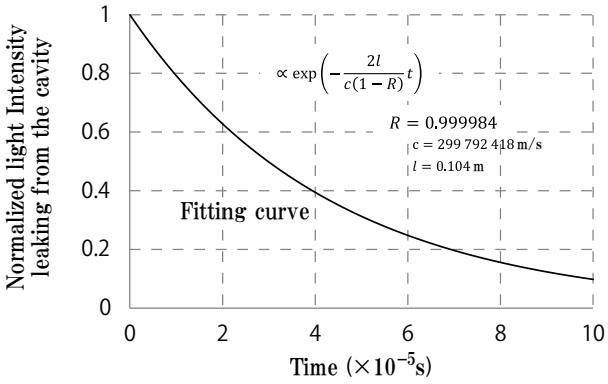
Feature : : High reflectance over 99.99%

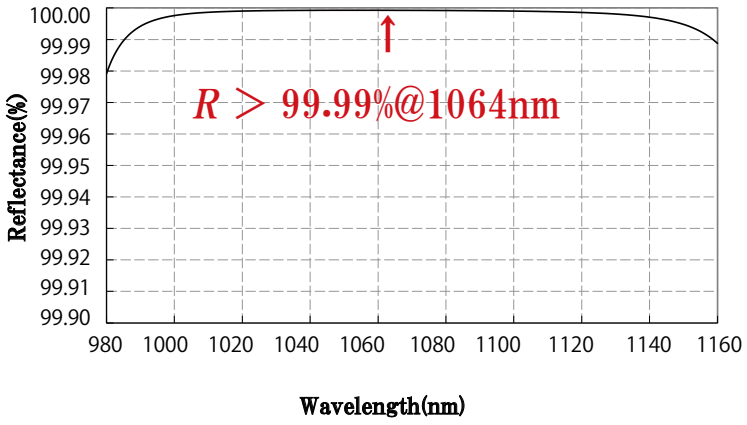
This mirror has an extremely high reflectance of over 99.99% at 1064nm. Although a high reflectance of nearly 100% is possible theoretically, it is difficult to actually coat such mirrors. Special attention should be paid to the quality of coating materials and the substrate as well as the coating process.

We produce this mirror by using the ion beam sputtering method in the coating process. The right graph is an evaluation of the mirror by the cavity ring down method. From the fittings of light intensity leaking from the cavity constructed by these mirrors with plano and 1m concave surface, the geometric mean of the respective mirror's reflectance is evaluated as R>99.99%.

Cavity ring down measurement







Wavelength	AOI	Reflectance	Size	Part number
1064 nm	0°	≧99.99%	φ25. x 5t(Plano)	UHR-002505-10
1064 nm	0°	≧99.99%	φ25.4 x 5t(1m concave)	UHR-002505-20

Products list

Classification	Name		Part number	Type	Size(mm)	Wavelength	AOI	Reflectance	GDD
For ultrafast lasers	Chirped Mirror	Broad Band Chirped Mirror with negative GDD	CGS-002505-10	2 pair	φ25.4×5t	600-1000nm	0° ～ 5°	≧98%	-40fs^2
			CGS-003005-10		φ30×5t				
			CGS-005005-10		φ50×5t				
			CGS-204005-10		□20×40×5t				
		Broad Band Chirped Mirror with Negative GDD and TOD	CTS-002505-10	2 pair	φ25.4×5t	600-1000nm	0° ～ 5°	≧98%	-75fs^2(600nm)～ 0fs^2(1000nm), TOD=-127fs^3 (800nm)
			CTS-003005-10		φ30×5t				
			CTS-005005-10		φ50×5t				
			CTS-204005-10		□20×40×5t				
		Chirped Mirror for 800nm	CTF-002505-10	1 piece	φ25.4×5t	750-850nm	0° ～ 5°	≧99.5%	-40fs^2
			CTF-003005-10		φ30×5t				
			CTF-005005-10		φ50×5t				
			CTF-204005-10		□20×40×5t				
		Chirped Mirror for UV	CUV-002505-10	1 piece	φ25.4×5t	395-405nm	0° ～ 5°	≧99.5%	-50fs^2
			CUV-003005-10		φ30×5t				
			CUV-005005-10		φ50×5t				
			CUV-204005-10		□20×40×5t				
	Low Dispersion Mirror		LDF-002505-10	1 piece	φ25.4×5t	700-900nm (s-pol.) 750-850nm (p-pol.)	45°	≧99% (s-pol.) ≧97% (p-pol.)	≦-50fs^2
			LDF-003005-10		φ30×5t				
			LDF-005005-10		φ50×5t				
For high power lasers	High Power Laser Mirror		HPF-002505-10	1 piece	φ25.4×5t	1064nm	45°	≧99%	-
			HPF-003005-10		φ30×5t				
			HPF-005005-10		φ50×5t				
			HPS-002505-10	1 piece	φ25.4×5t	532nm	45°	≧99%	-
			HPS-003005-10		φ30×5t				
			HPS-005005-10		φ50×5t				
			HPT-002505-10	1 piece	φ25.4×5t	355nm	45°	≧99%	-
			HPT-003005-10		φ30×5t				
			HPT-005005-10		φ50×5t				
			HPF-002505-10	1 piece	φ25.4×5t	266nm	45°	≧99%	-
			HPF-003005-10		φ30×5t				
			HPF-005005-10		φ50×5t				
			HPK-002505-10	1 piece	φ25.4×5t	248nm	45°	≧99%	-
			HPK-003005-10		φ30×5t				
			HPK-005005-10		φ50×5t				
	Dual Wavelength Mirror for High Power Lasers		HPD-002505-10	1 piece	φ25.4×5t	1064nm (R) 532nm (R)	0°	≧99% (1064nm) ≧99% (532nm)	-
			HPD-003005-10		φ30×5t				
			HPD-005005-10		φ50×5t				
	Beam Splitter		BSF-002505-10	1 piece	φ25.4×5t	1064nm(T)/ 532nm(R)	45°	≧99% @1064nm ≦0.5% @532nm	-
			BSF-003005-10		φ30×5t				
			BSF-005005-10		φ50×5t				
			BSS-002505-10	1 piece	φ25.4×5t	532nm(T)/ 355nm(R)	45°	≧99% @532nm ≦0.5% @355nm	-
			BSS-003005-10		φ30×5t				
			BSS-005005-10		φ50×5t				
For special applications	Ultra Broad Band Mirror		BBM-002505-10	1 piece	φ25.4×5t	350nm-1100nm	0° -50°	≧98% (s and p-pol)	-
			BBM-003005-10		φ30×5t				
			BBM-005005-10		φ50×5t				
	Ultra High Reflectance Mirror		UHR-002505-10	1 piece	φ25.4×5t Plano	1064nm	0°	≧99.99%	-
			UHR-002505-20	1 piece	φ25.4×5t 1m concave	1064nm	0°	≧99.99%	-

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