Design and preparation of multilayer optical coatings for laser crystal Nd:YVO4 and KTP

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Design and preparation of multilayer optical coatings are investigated on laser crystal Nd:YVO_4, YVO_4, and frequency doubling crystal KTP substrate. Multilayer optical coatings are deposited on one surface of the crystals using the ion beam sputtering technique, and the other surface is coated with a single SiO_2 as protective layer. For the YVO_4 crystal after coating, the reflectivity at 1 064 and 532 nm are greater than 99.9% and 99.8%, respectively, and the transmissivity at 808 nm is greater than 91.5%. For the KTP crystal after coating, the reflectivity at 1 064 nm is greater than 99.95%, and the transmissivity at 532 nm is greater than 99.5%. After thermal annealing, the transmissivity can be improved. The obtained coated crystals can be used in high power solid-state lasers.

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During the past few years, laser diode pumped solid-state lasers (DPSSLs) have become one of the most actively researched devices in laser physics. Specifically, lasers based on intra-cavity frequency doubling of a diode-pumped Nd-doped material, such as Nd:YAG and Nd:YVO_4, have attracted much attention[1−4]. Nd:YVO_4 crystal is grown almost 40 years ago[5] and has been widely used as one of laser host materials because of its excellent features such as low lasing threshold, large stimulated emission cross section, high absorption over a wide pumping wavelength bandwidth, and well mechanical and physical characteristics. It has been reported to be one of the most efficient laser crystals for DPSSLs[6−9].

KTP is the most commonly used material for frequency doubling of Nd lasers to obtain green/red laser outputs, particularly for the low or medium level power density. KTP has provided the basis for the construction of compact green solid state laser systems in industry applications, such as diode-pumped Nd:YVO_4 lasers. When a nonlinear KTP crystal is used as the active element for generating the second harmonic, antireflection and high-reflection coatings are required at two wavelengths of 532 and 1 064 nm[10].

To improve the efficiency of solid-state laser systems, many high reflective coatings and antireflective coatings are intended to deposit on the laser crystals and frequency doubling crystals which are expected to have wide high reflective coatings and high antireflective coatings. This letter proposes antireflection and high-reflection coatings for KTP and Nd:YVO_4 crystals, and a method for designing multilayer optical coatings. The effects of thermal annealing on optical properties of multilayer optical coatings for laser crystal Nd:YVO_4, YVO_4, and KTP substrates are investigated.

In order to design high reflective and antireflective coatings on Nd:YVO_4 and KTP substrates more accurately, it is necessary to precisely measure and calculate optical constants of Nd:YVO_4 and KTP substrates. In our experiment, the transmittance spectra of Nd:YVO_4 and KTP substrates were recorded using a Lambda-900 dual beam spectrophotometer covering the near-ultraviolet (UV), visible, and near-infrared (IR) wavelength ranges (190–2 600 nm). The measured transmissivity spectra curves of KTP and YVO_4 crystals with normal incidence are shown in Fig. 1. The Optilayer thin films software is used to calculate optical constants of KTP and YVO_4 crystals from transmissivity spectra data. The calculated refractive indexes curves of KTP and YVO_4 crystals are shown in Fig. 2.

In order to satisfy the need of green solid-state lasers, two wide high reflective coatings at 1 064 and 532 nm and one wide antireflective coating at 808 nm were

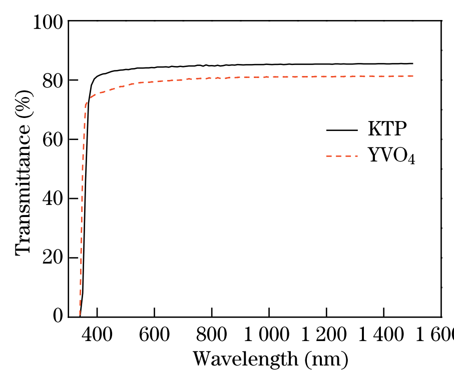

Fig. 1. (Color online) Transmittance spectra curves.

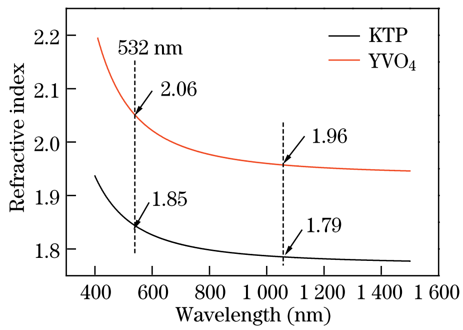

Fig. 2. (Color online) Calculated refractive indexes of KTP and YVO_4 crystals curves of KTP and YVO_4 crystals.

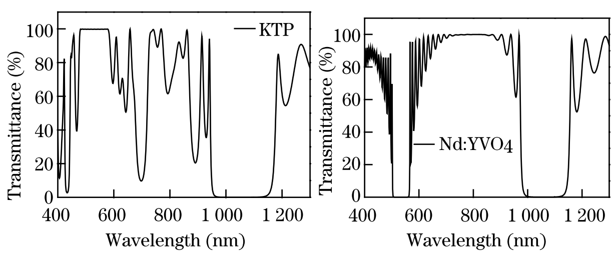

Fig. 3. Designed transmittance curves of multilayer optical coatings for (a) KTP and (b) YVO_4 crystals.

designed on YVO_4 and Nd:YVO_4 substrates, and wide high reflective coatings at 1 064 nm and antireflective coatings at 532 nm were designed on KTP substrate. In the design of multilayer optical coatings, Ta_2O_5 and SiO_2 are chosen as high (H) and low (L) refractive index coating materials. At the wavelength of 532 nm, the refractive indexes of KTP and YVO_4 are 2.056 and 1.847, respectively, and the refractive indexes of Ta_2O_5 and SiO_2 are 2.141 and 1.478, respectively. Choosing sub//$(a\text{L}\ b\text{H}\ c\text{L})^m$//air as the basic structures for multilayer optical coatings of KTP and YVO_4, a, b, c are the coefficients of the layer thickness. The designed transmittance curves of multilayer optical coatings for KTP and YVO_4 crystals are shown in Fig. 3. It can be seen that the transmittance for KTP at 532 nm is above 99.9% and the reflectance for KTP at 1 064 nm is above 99.99%. The transmittance for YVO_4 at 808 nm is above 99.95%, and the reflectances for YVO_4 at 1 064 and 532 nm are above 99.95% and 99.99%, respectively. The designed results also satisfied the requirement.

KTP crystals with the dimension of 10×10×2 (mm) and YVO_4 crystals with the dimension of 10×10×1 (mm) are used as the substrates. The surfaces of substrates are ultrasonic cleaned by the mixture of acetone and ethanol, and dried by centrifugal machine. The purity of SiO_2 and Ta target is greater than 99.99% and they are used as multilayer optical coatings forming materials. Single SiO_2 films layer were deposited on one of the surfaces of crystal substrates by an ion beam sputtering technique and its film physical thickness is about 50 nm. Multilayer optical coatings were deposited on the other surface of crystal substrates by ion beam sputtering technique. Detail parameters of deposition can be seen in Table 1. After coating for crystals, the samples are thermal annealed at the temperature of 300 °C for a fixed time of 24 h.

Figure 4 shows the measured transmittance curves of multilayer optical coatings for KTP crystal after coating and annealing. It can be seen that the transmittance for KTP at 532 and 1 064 nm before annealing are above 98.1% and below 0.05%, respectively. After thermal annealing at the temperature of 300° for a fixed time of 24 h, the transmittance spectra exhibit a red shift. At the wavelength of 1 064 nm, the quantity of red shift is about 10 nm. The transmittance can be also increased due to thermal annealing. The transmittance for KTP at 532 nm reaches 99.5%.

The measured transmittance curves of multilayer optical coatings for YVO_4 crystal after coating and annealing are shown in Fig. 5. It can be seen that the transmittance for YVO_4 at 532 and 1 064 nm are below 0.2% and 0.1%, respectively. At the wavelength of 808 nm, the transmittance reaches 90.4%. After thermal annealing at the temperature of 300 °C for a fixed time of 24 h, the transmittance spectra exhibit a red shift. At the wavelength of 1 064 nm, the quantity of red shift is also about 10 nm. Due to thermal annealing, the transmittance at 808 nm can be also increased and reaches 91.5%.

Figure 6 shows the measured transmittance spectra curves of multilayer optical coatings for Nd:YVO_4 crystal before and after annealing. It can be seen that optical coatings for Nd:YVO_4 have very little transmittance at 532 and 1 064 nm and have intense absorption at 808 nm. The obtained results indicate that Nd:YVO_4 with optical coating is proper to be used as laser crystals for DPSSLs.

Table 1. Parameters of Deposition

Item	Parameters			
	Film Material		Ta_2O_5	SiO_2
Chamber	Base Pressure (Torr)		$\leqslant 8 \times 10^{-6}$	
	Temperature (°C)		80	
	O_2 Inlet (sccm)		30	
16-cm RF Source	Beam	Voltage (V)	1250	
		Current (mA)	600	
	Source Ar Inlet (sccm)		18	
	RFN Ar Inlet (sccm)		5	
Target	Material		Ta	SiO_2
Substrate	Material		KTP / Nd:YVO_4	
	Dimensions (mm^3)		10×10×2/10×10×1	

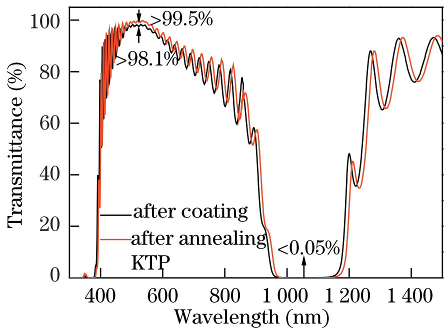

Fig. 4. (Color online) Measured transmittance curves of multilayer optical coatings for KTP crystal.

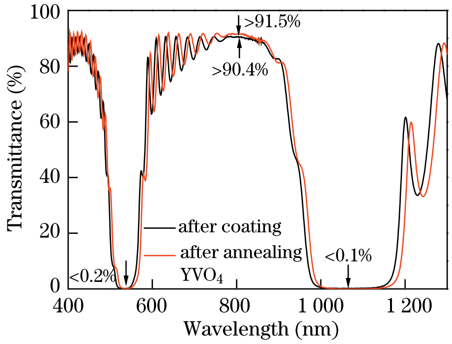

Fig. 5. (Color online) Measured transmittance curves of multilayer optical coatings for YVO_4 crystal.

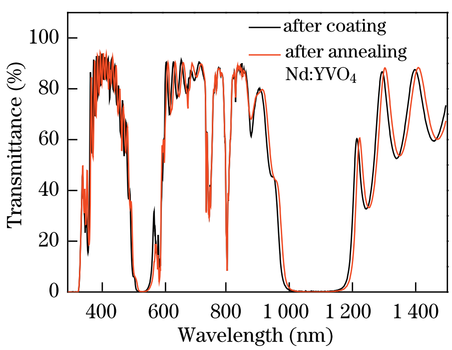

Fig. 6. (Color online) Measured transmittance curves of multilayer optical coatings for Nd:YVO_4 crystal.

In conclusion, the refractive index of YVO_4 and KTP crystal substrates are accurately calculated from the transmittance spectra. Two wide high reflective coatings at 1 064 and 532 nm and one wide antireflective coating at 808 nm are designed on YVO_4 and Nd:YVO_4 substrates, and wide high reflective coatings at 1 064 nm and antireflective coatings at 532 nm are designed on KTP substrate. Multilayer optical coatings are deposited on one surface of the crystals using the ion beam sputtering technique, and the other surface is coated with a single SiO_2 as protective layer. For the YVO_4 crystal after coating and thermal annealing, the reflectivity at 1 064 and 532 nm are less than 0.1% and 0.2%, respectively, and the transmissivity at 808 nm is greater than 91.5%. For the KTP crystal after coating and thermal annealing, the reflectivity at 1 064 nm is greater than 99.95%, and the reflectivity at 532 nm is less than 0.05%. The obtained coated crystals can be used in high power solid-state lasers.

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