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:YVO4, YVO4, 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 SiO2 as protective layer. For the YVO4 crystal after coating, the reflectivity at 1064 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 1064 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. OCIS codes: 310.1860, 310.4165, 310.6860.

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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:YVO4, have attracted much attention[1-4]. Nd:YVO4 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:YVO4 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 1064 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:YVO4 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:YVO4, YVO4, and KTP substrates are investigated.

In order to design high reflective and antireflective coatings on Nd:YVO4 and KTP substrates more accurately, it is necessary to precisely measure and calculate optical constants of Nd:YVO4 and KTP substrates. In our experiment, the transmittance spectra of Nd:YVO4 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 YVO4 crystals with normal incidence are shown in Fig. 1. The Optilayer thin films software is used to calculate optical constants of KTP and YVO4 crystals from transmissivity spectra data. The calculated refractive indexes curves of KTP and YVO4 crystals are shown in Fig. 2.

In order to satisfy the need of green solid-state lasers, two wide high reflective coatings at 1064 and 532 nm and one wide antireflective coating at 808 nm were

![Fig. 1. (Color online) Transmittance spectra curves.](image-url)
Fig. 2. (Color online) Calculated refractive indexes of KTP and YVO₄ crystals curves of KTP and YVO₄ crystals.

Fig. 3. Designed transmittance curves of multilayer optical coatings for (a) KTP and (b) YVO₄ crystals.

designed on YVO₄ and Nd:YVO₄ 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, Ta₂O₅ and SiO₂ are chosen as high (H) and low (L) refractive index coating materials. At the wavelength of 532 nm, the refractive indexes of KTP and YVO₄ are 2.056 and 1.847, respectively, and the refractive indexes of Ta₂O₅ and SiO₂ are 2.141 and 1.478, respectively. Choosing sub/(aL bH cL)m//air as the basic structures for multilayer optical coatings of KTP and YVO₄, a, b, c are the coefficients of the layer thickness. The designed transmittance curves of multilayer optical coatings for KTP and YVO₄ 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 YVO₄ at 808 nm is above 99.95%, and the reflectances for YVO₄ at 1 064 and 532 nm are above 99.95% and 99.99%, respectively. The designed results also satisfied the requirement.

Table 1. Parameters of Deposition

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameters</th>
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<tbody>
<tr>
<td></td>
<td>Film Material</td>
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<tr>
<td>Chamber</td>
<td>Base Pressure (Torr)</td>
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<tr>
<td></td>
<td>Temperature (°C)</td>
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<tr>
<td></td>
<td>O₂ Inlet (sccm)</td>
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<tr>
<td>16-cm RF Source</td>
<td>Beam Voltage (V)</td>
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<tr>
<td></td>
<td>Current (mA)</td>
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<td>Source Ar Inlet (sccm)</td>
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<td></td>
<td>RFN Ar Inlet (sccm)</td>
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<tr>
<td>Target</td>
<td>Material</td>
</tr>
<tr>
<td>Substrate</td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Dimensions (mm³)</td>
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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 1064 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 1064 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 1064 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 1064 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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References