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INTERFERENCE COATING CALCULATION FOR DPSS LASER CAVITY END MIRROR

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The paper gives a basic idea of laser operation and its general classification. The interference coating calculation results for two sides of a DPSS pulsed solid-state laser with a passive Q-switching and extracavity frequency doubling cavity end mirror are also discussed. It is shown that the obtained calculation results satisfy the requirements for coatings of optical elements. The calculated interference coatings provide the necessary percent of radiation reflection and transmission at certain wavelengths. The necessity of such calculations lies in the fact that in order to achieve the required percent of radiation transmission at specific wavelengths, specific interference coatings are applied. Qualitative calculation implies the possibility of fabricating optical elements with a similar coating, that is the number of layers should not be too large, and their thickness should not be too small.

Key words: optical element, reflection, transmission, complex coating, thin films, resonator.

Lasers or optical quantum generators are sources of coherent radiation with a number of unique properties. When the first working laser was reported in 1960, it was described as «a solution looking for a problem» [1]. One of the most important properties of laser radiation is an extremely high degree of its monochromaticity, which is unattainable from natural sources. Lasers are widely used in materials processing technology, medicine, optical navigation, communication and location systems, in precision interference experiments, chemistry, everyday life, etc.

Optical quantum generators are classified according to many criteria:

- according to the operating mode: pulsed and continuously operated lasers;
- according to the active medium: liquid; gas; solid state; free electron lasers;
- according to the method of a laser active medium excitation (pumping): gas-discharge; gas-dynamic; diode; chemical; optically pumped; nuclear pumped; lasers with electron beam pumping (special types of semiconductor and gas lasers).

In order to understand the basics of laser operation, it is necessary to study more carefully the processes of photon absorption and emission. An atom can be in different energy states with energies E_1, E_2, etc. A stable state in which an atom can remain indefinitely in the absence of external disturbances is the state with the lowest energy. This state is called the ground state. All other states are unstable. An excited atom can remain in these states only for a very short time about 10^{-8} s, then it spontaneously passes into one of the lower states, emitting a quantum of light. Such radiation is called spontaneous emission. At some energy states, an atom can remain much longer – about 10^{-3} s. Such atom energy states are called metastable states [2].

An atom jump to a higher energy state can occur during resonant absorption of a photon, the energy of which is equal to the difference in the atom energy in the final and initial states. Atom jumps are not necessarily related to the photon absorption or emission. In 1916, A. Einstein predicted that the electron transition from the upper energy state to the lower one can occur under the external electromagnetic field influence, the frequency of which is equal to the natural transition frequency. The obtained radiation is called stimulated or induced emission. As a

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result of the interaction of an excited atom and a photon, an atom emits another photon of the same frequency, propagating in the same direction. That is, an atom emits an electromagnetic wave that has the same frequency, phase, polarization, and direction of propagation as the original wave. In the stimulated photon emission, the amplitude of the propagating wave in the medium increases. Due to the interaction of an excited atom with a photon, the frequency of whick is equal to the transition frequency, two completely identical photons appear. It is the induced emission of radiation that is the physical basis for lasers operation [2].

In order to amplify the wave passing through the layer of material, it is necessary to create a population inversion of states. Such a medium is thermodynamically nonequilibrium. The medium in which the population inversion of states is created is called active medium. It can be used as a resonant light signal amplifier. To start a light generation, it is necessary to use feed-back. To do this, the active medium must be placed between two mirrors that reflect light strictly back so that it passes through the active medium many times, causing an avalanche-type process of induced coherent photons emission. In this case, the population inversion of states must be maintained in the medium. This process is called pumping.

Under certain conditions, the start of an avalanche-type process in such a system can be caused by a random spontaneous act in which radiation directed along the system axis emerges. After some time, a steady-state regime occurs in such a system. This is the laser. Laser beam is coupled out through one of the mirrors, which has partial transparency [3]. To provide the necessary percent of reflection and transmission of mirrors between which the active medium is located, special interference coatings are applied.

The aim of this work is to calculate the antireflective and reflective interference coating for wavelengths of 808 nm and 1064 nm for two sides of a DPSS pulsed solid-state laser with a passive Q-switching and extracavity frequency doubling cavity end mirror.

1. The operation principle of DPSS pulsed solid-state laser with a passive Q-switching and extracavity frequency doubling

A Diode-pumped solid-state laser (DPSS) is a type of solid-state laser in which a laser diode (LD) is used for pumping [4]. DPSS lasers are highly efficient and compact in comparison with gas and other solid state lasers. In recent years, DPSS lasers have gained favor as radiation sources in laser pointers of green, yellow, and some other colors. In a typical DPSS laser scheme shown in fig. 1, the pump source is a powerful infrared LD (from 100 mW to several hundred watts) with a wavelength of 808 nm. This LD is optically coupled by means of transfer optics with the active medium of a solid-state laser. Let us assume that the active medium emits at a wavelength of 1064 nm. If a nonlinear optical crystal ($KTiOPO_4$, KTP) is attached to its output, then the initial radiation frequency doubles in it and the output beam has a wavelength of 532 nm. This corresponds to the green color of visible radiation. The efficiency of such a system is approximately 20 %. The main advantage of DPSS lasers in comparison with LD is the high radiation quality, both in terms of monochromaticity and in terms of focusing and beam divergence. DPSS lasers have a narrower wavelength range (less than 1 nm in comparison with 5–20 nm in case of diode lasers) and much smaller beam divergence [4].

2. Optical cavity

An optical cavity or resonator is a combination of several reflective optical elements, organizing an open resonator forming a standing light wave. Optical resonators provide positive feedback to ensure multiple pass of laser radiation through the active medium, which results in light flux amplification [3].

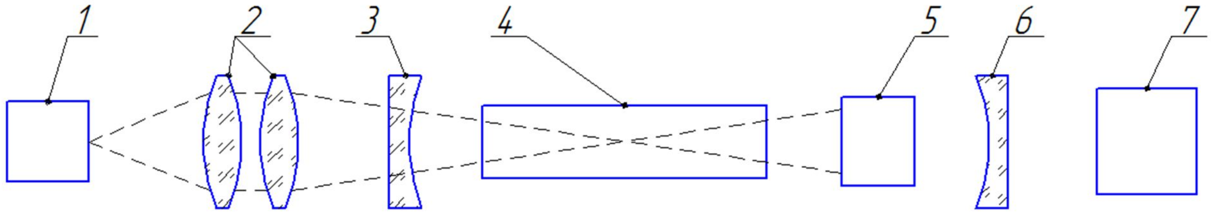

Fig. 1. Scheme of DPSS pulsed solid-state laser with a passive Q-switching and extracavity frequency doubling: 1 – pump radiation source, 2 – condenser, 3 – cavity end mirror, 4 – Nd: YAG crystal, 5 – passive Cr:YAG modulator, 6 – output mirror, 7 – KTP nonlinear crystal

Light is reflected many times, thereby forming standing waves with certain resonant frequencies. In general, optical cavities formed by two reflective elements are used. Resonators with spherical mirrors are most commonly used. The resonator geometric parameters are selected based on the requirements of stability and on such factors as, for example, the formation of the smallest beam waist.

The resonator is called unstable when an arbitrary beam, successively reflected from each of the mirrors, is removed at an unlimited distance from the cavity axis. Conversely, a resonator in which a beam remains within a limited region is called stable.

To ensure stability, the ratio of the mirrors curvature radii R_1, R_2 and the cavity optical length L must satisfy the following formula [3]:

$$0 \le \left(1-\frac{L}{R_1}\right)\left(1-\frac{L}{R_2}\right) \le 1$$

To ensure the necessary percent of reflection and transmission of mirrors in the laser resonator, special optical coatings in a form of thin films, are applied to these optical elements.

Thin films are thin layers of material, the thickness of which ranges from fractions of a nanometer (monoatomic layer) to several microns. They differ fundamentally from thick films by methods of deposition on a substrate. Solid thin films deposited on the surface of various objects are widely used.

Conditions and research methods

The MCalc software was used to calculate the antireflection and reflection interference coatings for the cavity end mirror. Titanium oxide was chosen as the coating material with a higher refractive index, and silicon oxide was chosen as the coating material with a lower refractive index. The number of layers was selected by reasons of the possibility of producing such a coating in practice, provided that the necessary percent of radiation transmission at specific wavelengths (808 nm and 1064 nm) was provided.

Results and discussion

Figure 2 shows a sketch of a cavity end mirror for which an interference coating was calculated. Coating was calculated for two sides of a cavity end mirror.

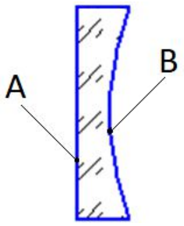

Fig. 2. Cavity end mirror

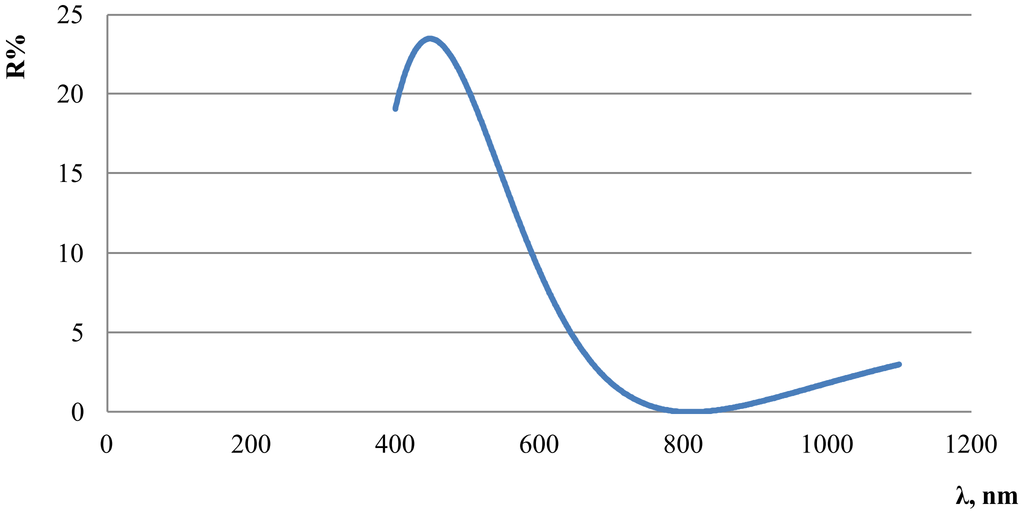

Fig. 3. Dependence of the reflection of a cavity end mirror side A with calculated antireflection coating on the incident beam wavelength

Table 1

Interference coating calculation results for side A

1.51/HL/ 1						
No	layer ID	Material	Refr. Indx	Opt. Thkn.	Phys. Thkn.	Monitoring Wl
1	H	TiO_2	2,320	0,244	21,272	808
2	L	SiO_2	1,428	1,323	187,228	808
Wavelength: 808 nm						

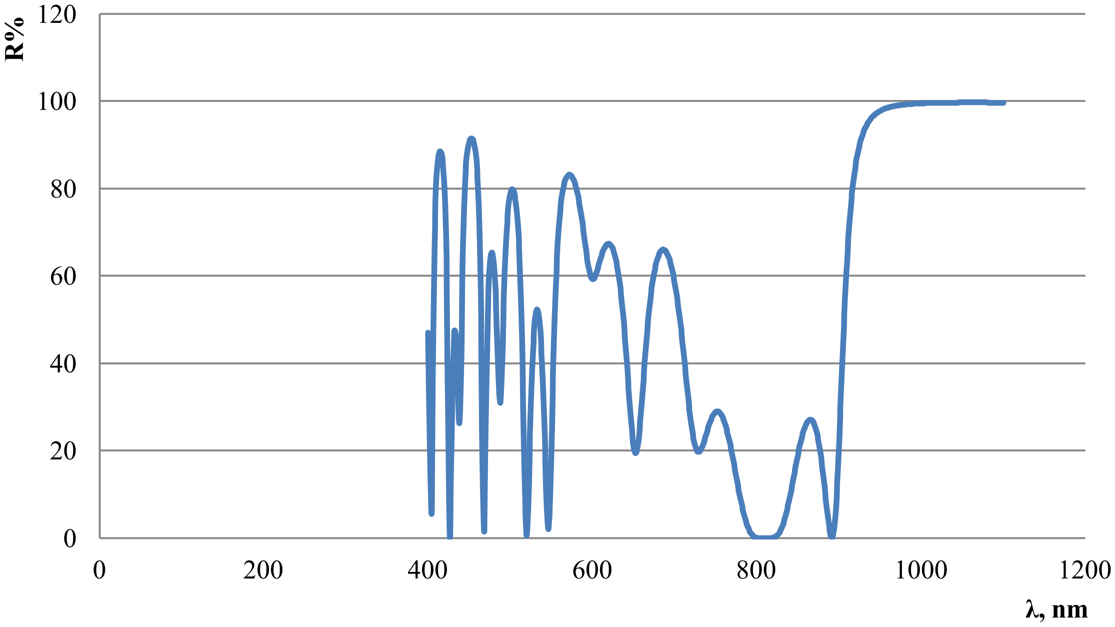

Fig. 4. Dependence of the reflection of a cavity end mirror side B with calculated antireflection and reflection coatings on the incident beam wavelength

For side A, it was necessary to obtain such a thin film that would allow radiation with a pump wavelength of 808 nm to completely pass into the resonator. As a result of the calculation, the dependence of reflection on the wavelength on side A was obtained, which is shown in fig. 3. At a wavelength of 808 nm, the reflection is 0.0005063826%, that is, all incident radiation with a given wavelength will completely pass into the cavity through the cavity end mirror. Table 1 shows the antireflection coating calculation results for side A. Here H is the coating layer with a bigger refractive index; L is the layer with a lower refractive index. To achieve the required antireflection degree at a wavelength of 808 nm, only two layers were needed – a layer of silicon oxide and titanium oxide.

For side B, it was necessary to obtain such a thin film that would transmit radiation with a wavelength of 808 nm into the cavity and reflect radiation with a laser wavelength of 1064 nm. As a result of calculation, the dependence of reflection on wavelength on side B was obtained, which is shown in fig. 4. At a wavelength of 808 nm, the reflection is 0.02409379%, that is, all incident radiation with a given wavelength will completely pass into the cavity through the cavity end mirror. At a wavelength of 1064 nm, the percentage of reflection is 99.7338%, which is permitted by the specified tolerance, that is, all incident radiation with a given wavelength will be reflected from the cavity end mirror inside the cavity.

Table 2 shows the coating calculation results for side B. To achieve the desired result, 15 layers of silicon oxide and titanium oxide were required.

Conclusion

As a result of this work, the fundamental principles of the laser operation were presented, and the interference coating was calculated for both sides of a DPSS pulsed solid-state laser with a passive Q-switching and extracavity frequency doubling cavity end mirror.

Table 2

Interference coating calculation results for side B

1,51/(HL)^7 H/1						
№	layer ID	Material	Refr. Indx	Opt. Thkn.	Phys. Thkn.	Monitoring Wl
1	H	TiO_2	2,320	1,210	138,782	1064
2	L	SiO_2	1,427	0,517	96,479	1064
3	H	TiO_2	2,320	1,451	166,366	1064
4	L	SiO_2	1,427	0,861	160,569	1064
5	H	TiO_2	2,320	0,780	89,428	1064
6	L	SiO_2	1,427	1,117	208,325	1064
7	H	TiO_2	2,320	0,883	101,257	1064
8	L	SiO_2	1,427	1,347	251,072	1064
9	H	TiO_2	2,320	0,704	80,677	1064
10	L	SiO_2	1,427	0,883	164,669	1064
11	H	TiO_2	2,320	1,263	144,803	1064
12	L	SiO_2	1,427	0,827	154,265	1064
13	H	TiO_2	2,320	0,947	108,560	1064
14	L	SiO_2	1,427	1,028	191,677	1064
15	H	TiO_2	2,320	1,226	140,533	1064
Wavelength: 1064 nm						

The calculated complex coatings provide the necessary fraction of radiation reflection and transmission at given wavelengths. The need for such calculations lies in the fact that in order to achieve the required percent of transmission at specific wavelengths, specific interference coatings are applied. Qualitative calculation implies the possibility of fabricating of optical elements with a similar coating, that is, the number of layers should not be too large, and their thickness should not be too small. It is shown that to achieve the necessary radiation transmission at a wavelength of 808 nm, a two-layer coating is required – a layer of silicon oxide and titanium oxide, and for simultaneous radiation transmission at a wavelength of 808 nm and radiation reflection at a wavelength of 1064 nm, 15 layers of silicon oxide and titanium oxide are required. Thus, the calculation performed fully satisfies the requirements outlined above, proving out the fact that this coating can be fabricated in practice.

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РАСЧЁТ ИНТЕРФЕРЕНЦИОННОГО ПОКРЫТИЯ ГЛУХОГО ЗЕРКАЛА ДЛЯ DPSS ЛАЗЕРА

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В данной статье даётся базовое представление о работе лазеров, их общая классификация, а также обсуждается проведённый расчёт интерференционного покрытия для двух сторон глухого зеркала импульсного твердотельного DPSS лазера с пассивной модуляцией добротности и внерезонаторным удвоением частоты. Показано, что полученные расчёты удовлетворяют требованиям, предъявляемым к покрытиям оптических элементов. Рассчитанные интерференционные покрытия обеспечивают необходимую долю отражения и пропускания излучения на заданных длинах волн. Необходимость подобных расчётов заключается в том, что для осуществления требуемой степени пропускания на конкретных длинах волн наносятся конкретные интерференционные покрытия. Качественный расчёт подразумевает возможность изготовления оптических элементов с подобным покрытием, то есть количество слоев не должно быть слишком большим, а их толщина – слишком маленькой.

Ключевые слова: оптический элемент, отражение, пропускание, сложное покрытие, тонкие пленки, резонатор.

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