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Blind mirror based on photonic crystal structures for diamond laser

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Abstract. A model of multilayer reflective coatings for the wavelength of diamond laser generation has been created. The results of the creation of reflective structures at the end of diamond samples are presented, the transmittance and photoluminescence spectra of the samples (before and after the application of mirrors) are presented.
Keywords: diamond, one-dimensional photonic crystal, laser resonator, numerical simulation.

1. Introduction

Diamond, due to its unique properties, is a promising semiconductor material for use in photonic and optical devices, including as a laser active element [1, 2]. In order to achieve a millijoule level of laser pulse energy, feedback formed by the polished ends of the active element is not enough, therefore it is necessary to use an optical resonator with the product of coefficients mirror reflections in the range 0.07–0.55 [3].

The use of classical resonators based on two external mirrors and their alignment is an extremely laborious procedure due to the small size of the diamond sample (units and tenths of millimeters). However, using one-dimensional photonic crystals, it is possible to create mirrors of a laser resonator with the ability to adjust to a certain wavelength and the necessary reflection coefficient. Such mirrors are applied directly to the ends of the active element, as a result of which there is no need to adjust them.

2. Results

1.1. Calculation of one-dimensional photonic crystals

In the presented work, the calculation of the photonic crystal structures was performed in the COMSOL Multiphysics program, the Wave Optics module. The calculations are based on the finite element method: after constructing the geometry of the model and assigning materials, it is divided into a grid, in each node of which the Maxwell equations are calculated. Titanium oxide (TiO_2) and aluminum oxide (Al_2O_3) were used as multilayer coating materials in the calculation. In addition, using such structures, it is possible to create antireflection coatings to enhance the optical pumping of diamond.

Fig. 1 shows a schematic representation of a laser active element with all the necessary structures. The numbers in the figure are indicate: 1 – Semitransparent mirror at 720 nm, 2 – 100% mirror at 720 nm, 3 – 100% mirror at 532 nm, 4 – Antireflection coating at 532 nm, 5 – Diamond active element.

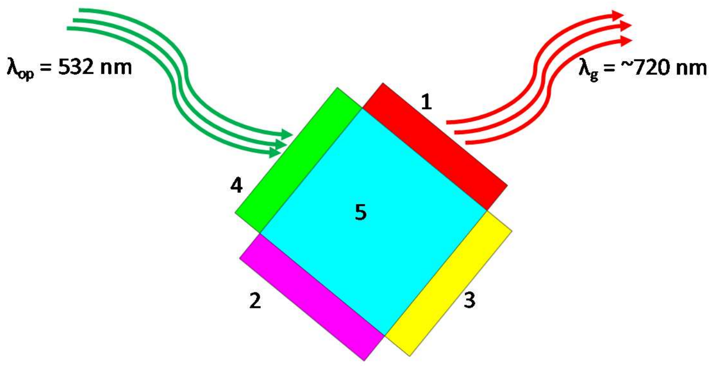

Fig. 1. Schematic representation of a laser active element with applied reflective and antireflection structures.

The calculation of the reflecting structures was carried out in order to achieve a minimum transmittance in the wavelength range of the diamond laser generation of 710–730 nm. The thicknesses of the layers used in the calculations are 75 nm for titanium oxide layers, 110 nm for aluminum oxide layers. Fig. 2 shows the geometry used and Fig. 3 shows the calculated transmittance spectrum of the resulting structure.

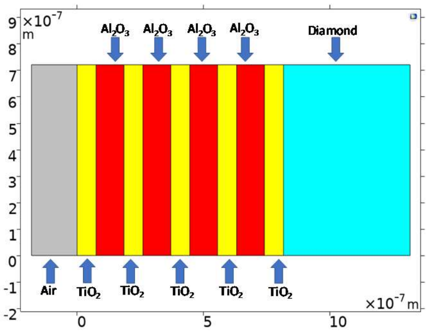

Fig. 2. The calculated geometry used.

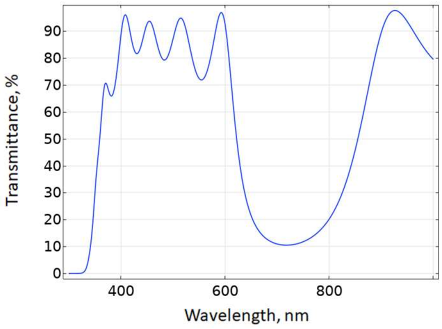

Fig. 3. The calculated transmittance spectrum for the geometry and materials presented.

1.2. The analysis of structures created on samples

To create a multilayer coating with the specified thicknesses (75 nm, 110 nm), the method of reactive magnetron sputtering was used. Spraying was performed on the end of the diamond sample, Fig. 4 and 5 shows photographs of the ends of the sample on which the reflective coating was applied.

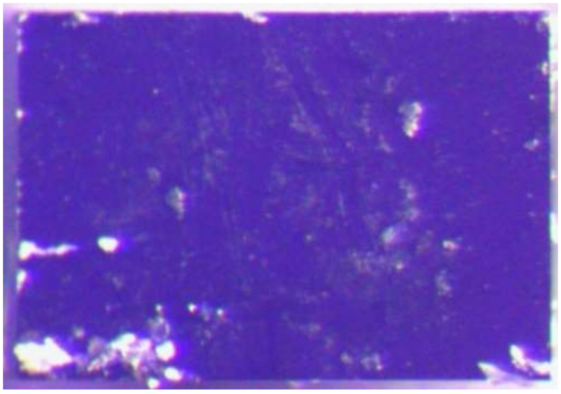

Fig. 4. Photographs of the ends of the sample before deposition of the calculated structure.

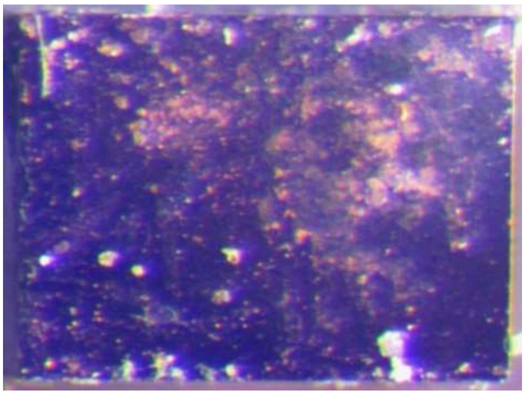

Fig. 5. Photographs of the ends of the sample after deposition of the calculated structure.

For the primary analysis of the obtained reflective structure, the transmittance and photoluminescence spectra of the sample were compared before and after the coating was created on it. Transmittance spectra were recorded "along" the sample to account for the created structure in the spectrum. Fig. 6 shows a comparison of the transmittance spectra before and after applying a reflective coating to one of the ends.

Based on the presented transmittance spectra, one can notice a sharp decrease in the transmittance coefficient in the red region of the spectrum, which confirms the presence and operability of the created mirror.

In addition, the photoluminescence spectra of the sample correspond to the obtained transmittance spectra. Photoluminescence was excited by a constant low-power green laser with a wavelength of 520 nm. Fig. 7 shows the results of recording the photoluminescence spectra of the given sample, as well as a comparison of the photoluminescence spectrum taking into account the mirror with the transmittance spectrum taking into account the mirror.

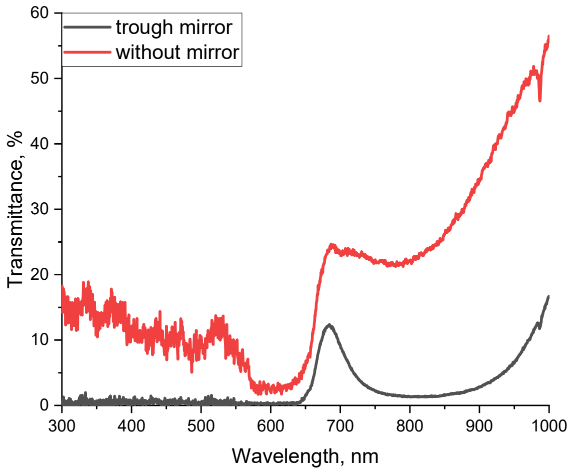

Fig. 6. Transmittance spectra before (red) and after (black) the creation of a reflective coating.

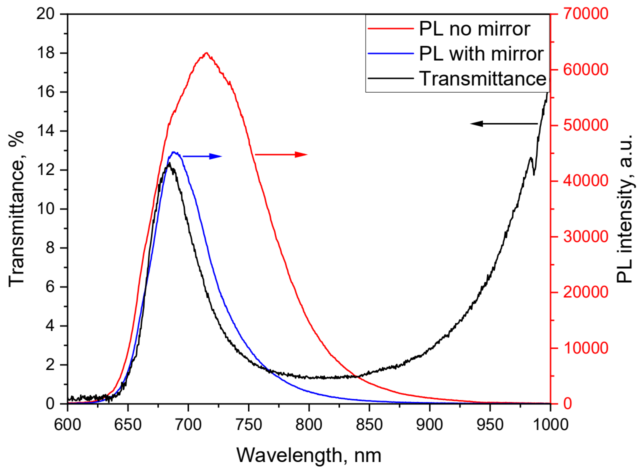

Fig. 7. Comparison of photoluminescence spectra (red, blue) and transmittance spectrum (black) of a sample with an applied mirror.

As can be seen from the presented figure, the photoluminescence spectrum, taking into account the mirror, behaves according to the obtained transmittance spectrum, taking into account the mirror. In this case, the maximum intensity of photoluminescence is shifted to the shortwave region in the region of the maximum transmittance of the mirror. In addition, generation was obtained on one of the samples after spraying the reflective structure onto the end, which also indicates the need to use reflective photonic crystal reflective structures as an optical resonator for a diamond laser. Fig. 8 shows the photoluminescence spectra of the sample.

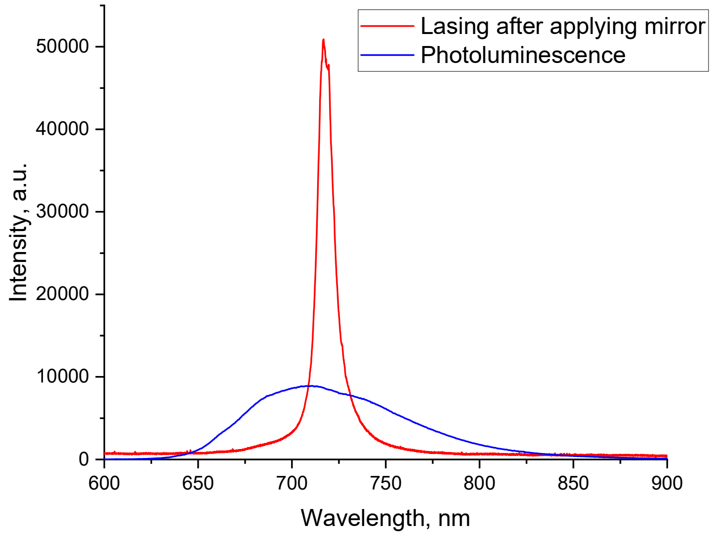

Fig. 8. Photoluminescence (laser generation) spectra of the sample when pumped with an intense pulsed green laser.

3. Conclusion

The presented work demonstrates the calculation of reflective one-dimensional photonic crystal structures to create an optical resonator directly at the ends of a diamond laser active element.

For the created reflective structure, the minimum transmittance is $T \sim 1.2\%$ (with a transmittance of $T \sim 20\%$ at the same wavelength for the sample without taking into account the structure). In addition, a narrow photoluminescence line was obtained on one of the samples after the creation of a reflective coating on the end, which may indicate the achievement of laser generation on this sample. At the same time, before the creation of the mirror, this sample did not show similar results.

Acknowledgement

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4. References

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