Miniature, “eye-safe" solid-state lasers

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ABSTRACT

"Eye safe" lasers are very important for different applications in optical communication and lidar techniques. In this work we report the results of measurements of generation characteristics of Nd: GGG, Nd: YAG crystals for wavelength of 1.32 μm as well as Nd: YAP crystals generating radiation of 1.34 μm. Influence of UV radiation on the output characteristic of Nd: GGG laser is also reported.

Keywords: „eye safe" lasers, frequency conversion, giant-pulse lasers, passive Q-swiching, solid-state lasers,

1. INTRODUCTION

Eye hazards caused by laser radiation depends on the wavelength, laser power, exposition time and type of tissue. The figure 1 presents the eye transmission characteristic for the path to retina as well as absorption curve of retina. Excessive exposition of visible range radiation causes photochemical and thermal retina damage. Also infrared radiation (780-1400 nm) can penetrate the eye, causing cataract and retina blister. For the radiation above 1400 nm, only cornea is exposed on the injurious effects of radiation: bum, cataract and others.

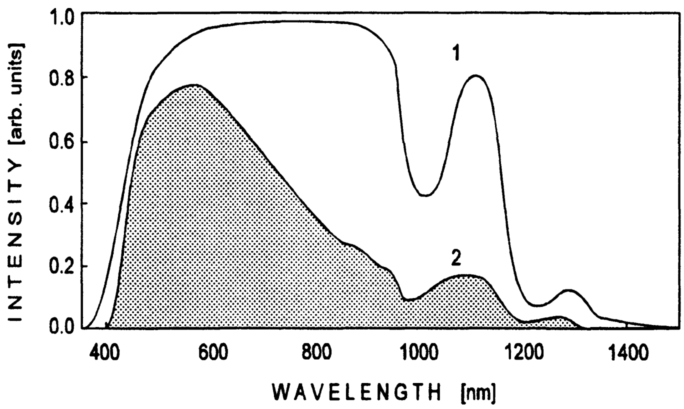

Fig.1. Penetration of radiation into the eye:
1 - eye transmission to the retina,
2 - radiation absorption in the retina.

The main eye threats are connected with retina damage by laser radiation of 400-1400 nm range, because the retina, lens, aqueous homuor and vitreous body transmit this range of radiation [1, 2]. Laser beam focused by eye lens on the retina, achieve high, dangerous power or energy densities. Radiation in the range of below 400 nm and above 1400 nm is strongly absorbed by tissues and doesn't penetrates the eye interior and therefore doesn't cause the damage of retina and eye lens.

According to the American standard ANSI Z136.1-1986, the wavelength of 1.5 μm is treated as safe for direct looking into the beam for energy densities 100 times larger than characteristic for 10.6 μm (CO_2 laser) and $2\text{-}10^5$ times larger than for 1.06 μm (Nd: YAG laser) (Fig. 2). According to the standards developed by International Electrotechnical Committee, the application of laser devices not performing the safety requirements will be soon considerably limited.

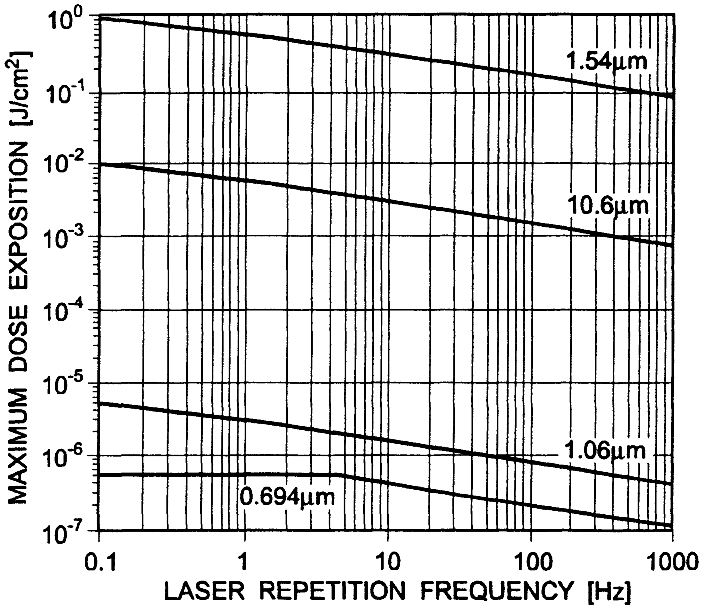

Fig.2.

Maximum dose of laser exposition

for different laser systems

There are two basic directions in the methods of eye protection against the laser radiation. One of them consists in the search of new materials and material engineering technologies to develop the anti-laser filters with proper optical parameters [3]. The second one is connected with the application of "eye-safe" lasers, generating radiation outside the spectral transmission region of eye, it means outside the region of 400-1400 nm [4-7]. The research work on the "eye-safe" lasers are conducted in the following directions:

a) lasers with Raman shifting of frequency in new mediums, so called Raman shifters,

b) application of new active mediums in the diode pumped and lamp pumped solid-state lasers (Er^{3+}: YAG, Cr^{4+} :YAG, Er^{3+} glass)

c) application of new mediums with nonlinear absorption for passive Q-switching of lasers, generating 1.5 μm radiation, (among others Nd^{2+}: SrF_2 U^{4+}: SrF_2, Er^{3+}:$Sr_5(V0_4)_3F$, garnets doped with Cr^{2+}, difluores of alkali metals and glass doped with U^{2+}).

Particularly perspective for applications seems to be Cr^{4+} doped YAG laser or Er (Er, Yb) doped glass lasers, passive Q-switch systems and systems with frequency conversion. These solutions, definitely exceeded lasers with gas, high-pressure Raman cell as well as erbium glass lasers with mechanical Q-switch resonator modulators, cause the possibility of wider application of „eye-safe" lasers into the military and commercial laser systems.

The high-pressure gas Raman chambers (methane, hydrogen, Cs-vapor) can be replaced by Raman shifters made of molecular crystals $Ba(NO_3)_2$. [10]. The dominating line in the stimulated Raman scattering of $Ba(N0_3)_2$ is 1047.8 cm^{-1}, that is, for Nd: YAG laser, generating radiation of 1064 nm interacting with this crystal, results in wavelengths of 1197 nm (I Stokes), 1369 nm (II Stokes) and 1598 (III Stokes). For the radiation of 1.32 μm, generated, among others, by Nd^{3+}: YAG and Nd^{3+}: GGG the result of Raman shift is the radiation of 1.53 μm. At the other side, in the case of Nd^{3+}: YAP crystal (λ_{gen} = 1.34 μm), the result of Raman shift is the wavelength of 1.56 μm.

Systems with frequency conversion based on $Ba(N0_3)_2$ need efficient 1.32 μm radiation source.

2. RESULTS OF INVESTIGATION

The work was devoted to the measurements of generation characteristics of Nd: GGG, Nd: YAG crystals for the wavelength of 1.32 μm as well as Nd: YAP crystals generating radiation of 1.34 μm. The resonator from miniature MGL laser head with spherical total reflective mirror of r=5m and flat output coupler with transmission of T=9% for λ=1.32 μm and T==7% for λ=1.34 μm has been applied. The elliptical chamber covered with gold as well as xenon discharge lamp with the diameter of 4 mm has been also utilized.

Investigated rods had dimensions of Φ=4 mm, 1=48 mm for Nd: GGG crystals, Φ=6 mm, 1=75 mm for Nd: YAG crystals and Φ=10 mm, 1=100 mm for Nd: YAP crystals (pumped by lamp with the diameter of 7 mm). The GGG crystals demonstrate high sensitive for UV radiation present in the lamp spectrum. Induced by lamp radiation color centers cause the decrease of generation efficiency. Special filters, cutting off UV radiation in the specified range, were used for determination of influence of UV radiation for generating characteristics. Fig. 3 presents the generation characteristics of Nd: GGG lasers with cut-off filters for the range of UV up to 480 nm (GG-5 filter) and up to 350 nm (sodium glass), placed in the resonator.

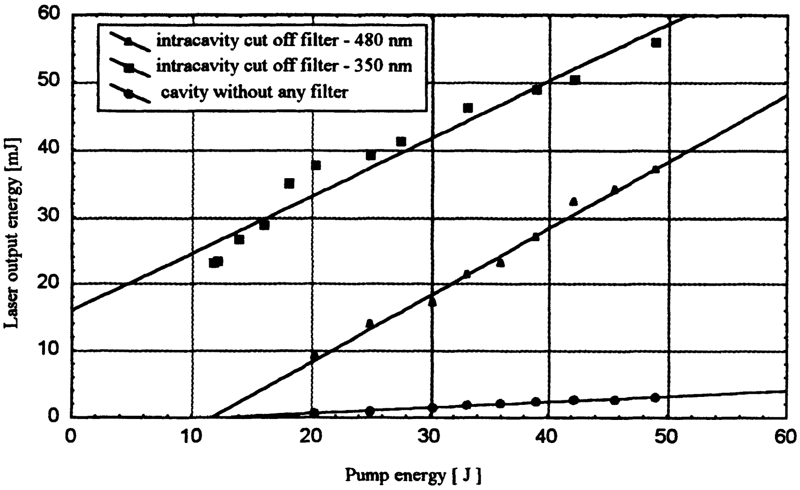

Fig. 3.
Nd: GGG 1.32 μm laser output energy as a function of the pump energy.

The highest efficiency has been obtained for the cut-off filters working in the range up to 350 nm. Nd: YAG crystals showed the decrease of efficiency for cut-off filters inserted into resonator (Fig.4). Low generation thresholds were accompanied by saturation for high pump intensities.

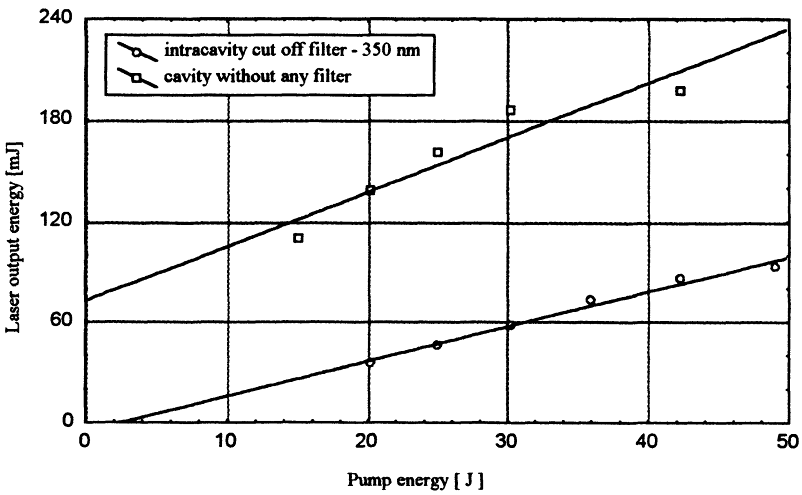

Fig. 4.
Nd: YAG 1.32 μm laser output energy as a function of the pump energy.

The highest output energies have been obtained for 1.34 µm Nd: YAP laser (Fig.5). Broadband interference filters with FWHM of 30 nm (Carl Zeiss Jena) were utilized in the detection systems of generated radiation. Taking into account conversion efficiencies from 1.32 µm to 1.54 µm, equal to about 45% [8], obtained for $Ba(N0_3)_2$ crystals, it allows to conduct further work with Nd: GGG and Nd: YAP lasers. Lower values of generation efficiency obtained in the experiments, as compared with the presented in the literature [9] are connected with not optimized conditions of generation. The change of output mirror transmission as well as type of reflector cover will significantly increase the generation frequency.

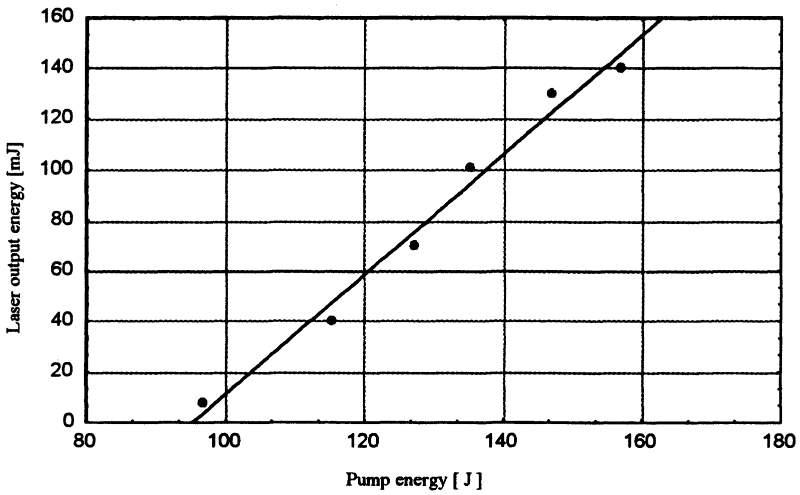

Fig. 5.
Nd: YAP 1.34 µm laser output energy as a function of the pump energy.

3. CONCLUSIONS

An intracavity solid state $Ba(NO_3)_2$ Raman shifter produces 1.535-1.556 µm radiation when pumped by laser operating at 1.318-1.338 µm can replace the high pressure gas Raman chambers. Such systems with frequency conversion need efficient 1.32 µm radiation source. Taking into account presented results, it allows us to conduct further work with Nd: GGG and Nd: YAP lasers.

4. REFERENCES

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